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14 - 16 July 2014
Glenburn Lodge, Muldersdrift

SOUTHERN AFRICAN INSTITUTE FOR
INDUSTRIAL
ENGINEERING

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PREFACE

The Southern African Institute for Industrial Engineering's (SAIIE) annual conference has become a popular choice for industry, academics and researchers in Industrial Engineering and related disciplines. I am excited and honoured to be the editor again for this proceedings. This year's editorial process was administrated by two very capable individuals: Pieter Conradie and Francois Conradie, both postgraduate students from Stellenbosch University, who acted as track directors. Thank you for your professional hard work to put the proceedings together and making the editorial process so effortless!

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

- Presentations submitted for the ***"Abstract and Presentation"*** track were approved on submission of the abstract only.
- Submissions for the "***Research Paper"*** or ***"Applied Engineering or Industry paper"*** tracks were provisionally approved on the basis of an abstract, where-after the authors were invited to submit a full-length academic paper, which was reviewed by a double blind peer review refereeing process.

Close to 160 submissions were received of which 42 peer-reviewed papers made it through the review process, with another approximately 30 non-peer-reviewed submissions.

The review process was managed through an on-line conference system, allowing referees to provide on-line feedback, and to ensure that a fully traceable record exists for all editorial decisions taken during the process. Papers were allocated at least two reviewers, often teaming up an experienced academic, with a less experienced author, so as to follow a true **peer**-review process and also to serve as a learning experience for the less experienced reviewer, without sacrificing the credibility of the peer review process. Reviewers allocated to papers were usually from another institution than the author to avoid possible conflicts of interest. When the reviewers recommended minor improvements, the final checks were performed by the editors and track directors of the programme committee, otherwise the improved paper was sent back to at least one of the reviewers to confirm that it had been sufficiently improved. Only papers that passed this peer reviewed process are published in the conference proceedings.

This conference has therefore two outputs:

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

We trust that you will enjoy the 26th Annual SAIIE Conference, and that this publication will serve as a first step for exposing the work of authors to the world!

Prof Corné Schutte
Editor
July 2014

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AN EMPIRICAL ANALYSIS OF OPERATIONAL DISTURBANCES AND THEIR IMPACT ON BUSINESS PERFORMANCE IN MANUFACTURING FIRMS: CASE TOOLING INDUSTRY SOUTH AFRICA

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ABSTRACT

Globalization has managed to break trade barriers and the manufacturing environment has become more competitive. Market share is now determined by quality of goods and services irrespective of location. Today's business environment for manufacturers requires flexible, responsive and robust systems, which produce a variety of products at competitive prices. To gain a competitive edge, the paradigms of e-manufacturing and distributed manufacturing have been recently advocated by researchers as potential solutions. However, irrespective of these technological advancements, manufacturing firms in the tool and die sector are still struggling to perform efficiently in the face of recurring operational disturbances. The paper identifies the most prevalent operational disturbances which occur in South Africa's manufacturing firms in the tooling industry and their impact on business performance. A field study was conducted on a number of organizations which form an industrial cluster in the Western Cape manufacturing sector and seven typical disturbances were evaluated together with their root causes. The results gathered portrayed the correlation between identified disturbances and their corresponding consequences. The findings of the study were recommended to be used to develop models and computerized systems to solve the pending pandemic.

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1 INTRODUCTION

The business world has become a global market. Customers are now able to get their needs met with aid of e-commerce and mobile technologies. With the rapid growth in manufacturing technologies and the internet, most manufacturing firms are now adopting agile manufacturing to improve their productivity, responsiveness and customer service. Production units that have not evolved their manufacturing strategies to adopt best practises are now facing vigorous competition with respect to quality, cost and time to market.

To cope in such a competitve environment, manufacturing firms need to build reactive, scalable and flexible manufacturing systems which are capable of adapting to dynamic market and shop-floor conditions. With these characteristics, firms position themselves competitvely and grow their market share. In an effort to achieve these goals, a lot of research is being conducted on the possibility of South African manufacturing firms in the Tool, Die and Mould-making industry (TDM) implementing e-manufacturing systems. These systems promise to facilitate the sharing of information and resources among manufacturing firms over a collaborative network. An e-manufacturing system model which facilitates enterprise integration, knowledge transfer and resource sharing among manufacturing firms in the Western Cape Province was proposed by Nyanga [1]. However, the efficient and smooth running of TDM organizations remains a major problem irrespective of the human and technological resources they may have at their disposal. This is mainly because these firms continually face internal and external unwanted setbacks during their day to day operations. These operational disturbances compromise the business performance thus upsetting the achievement of set targets and goals.

This paper presents a set of operational disturbances which firms in the South African TDM industry face more frequently. The organization of the paper is as follows: we first discuss the current state of the TDM industry in South Africa, we then discuss different operational disturbances and lastly we present the identified disturbances with their corresponding impact on business performance.

2 CURRENT STATE OF THE SOUTH AFRICAN TDM SECTOR

Tool, Die and Mould manufacturing has long been considered a key industrial sector. It is the sole supplier of basic production equipment for all manufacturing firms. According to Canis [2], tools, dies, and moulds are pivotal to durable-goods manufacturing. Tools are used to cut and form metal and other materials, while dies are metal forms used to shape metal in stamping and forging operations. Moulds are metalic implements used to shape plastics, ceramics, and composite materials.

The Tool, Die and Mould Making industry plays an important role in terms of employment creation and the economic growth in South Africa. Captains in industry and researchers have developed keen interest in developing strategies and methods to improve this sector. The main reasons for this interest in the industry are:

1. Records as highlighted by Geyer and Bruwer [3] reveal that 90% of the South African tooling industry companies comprise of Small, Medium or Micro Enterprises (SMMEs). According to Malherbe [4], SMMEs are the economic backbone of developing economies and account for approximately 60% of all employment in South Africa, with a contribution of 40% to the South African Gross Domestic Product (GDP). In addition, the SMMEs are often the vehicle by which entrepreneurs from all socio-economic levels gain access to economic opportunities [4].
2. The value adding of tooling in the economy is high (estimated 1:19). For every R 1 million invested in TDM equipment and technology, over 250 million components could be manufactured making the industry an important value-added catalyst in the South African economy [3].

The Tool, Die and Mould-making (TDM) industry in South Africa is a critical support industry to the broader manufacturing industry bridging the gap between product development and production. The sector supports different production units with the automotive and packaging industries being its biggest clients [3]. This makes the TDM industry a high value-adding constituent of the supply of manufactured products by being the heart of component manufacturing and by forming the backbone of the manufacturing sector.

Due to its importance to the economy and manufacturing sector, the South African Government initiated the National Tooling Initiative Programme (NTIP) in March 2002. The NTIP under the Department of Trade and Industry, was mandated to formulate strategies to revive the TDM sector. Two key programmes namely the Skills Development Programme and the Enterprise Development programme were launced by the NTIP so as to improve the sector's competitiveness.As part of the work, the NTIP in collaboration with academic institutions of higher learning conducted a benchmarking programme for the TDM industry so as to establish the status of the sector before strategic interventions could be designed and implemented [4]. As revealed in an Engineering Artisan article [5], the current benchmarking report on the South African TDM Industry indicates that without interventions, many local companies benchmarked will not survive global competition and will eventually struggle.

Results of the benchmarking study conducted indicated that besides producing quality tools, dies and moulds, another key success factor for firms doing well in the TDM sector globally is product time-to-market. Some South African firms are still struggling to deliver customer orders on time or faster than their European and Asian competitors who have altered their businesses to design, manufacture and deliver products fatser and reliably to customers. The work done to date has addressed the aspect of improving quality, minimizing cost of products and the optimal utilization of tool room resources with little emphasis on improving production speed.

In his study, Islam[6] revealed that inorder to meet customer due dates or improve delivery speed to market, high levels of overall system reliability need to be maintained. However, almost all manufacturing organizations face undesirable and unwanted setbacks in their day to day operations. These setbacks, referred to as "operational disturbances" in this paper have the potential to negatively impact business performance. In work done by Mitala [7], Monostori [8] and Monica [9], it was observed that events like the late delivery of raw materials and rush orders can lead to operational disturabnces which render the shop-floor system unavailable, unreliable and delay the production of orders.

To deal with these operational disturbances effectively, companies in the TDM sector need a systematic way to identify and manage these setbacks. The paper focuses on the first step of identifying the main operational disturbances firms in the TDM sector in South Africa have suffered and their possible causes and consequences. Firms in the Western Cape Province forming an industrial cluster were used for this analysis.

3 OPERATIONAL DISTURBANCES

A manufacturing entity is a complex system which includes many functional areas which are mutually dependent on each other from procurement of raw materials to finished products dispatch. The failure of one function can greatly impact other functions. At times, system failure results from operational disturbances. These internal and external disturbances alter the state of the system at any given time rendering it unreliable thus compromising production goals. Islam [10] defined an operational disturbance as:

> "*An undesirable or unplanned event that causes the deviation of system performance in such a way that it incurs a loss*"

In other studies, he used the terms setbacks, disruptions, errors, failures, production risks determinants [11] and unwanted events [12] interchangeably to refer to these disturbances. The consequences of operational disturbances may be experienced through wastage of time and raw materials resulting in high production costs, longer lead times and poor product quality.

3.1 Disturbance mapping

Every operational disturbance, regardless of size is caused by some event and results in a consequence which negatively affects business performance, flow of operations and worker health and safety (Figure 1). Events leading to operational disturbances may be triggered from external factors emanating from a firm's suppliers and customers or from internal factors resulting from incorrect production practices on the shop-floor.

The work discussed in this paper will focus mainly on the impact of identified operational disturbances on the business performance of firms in the TDM sector.

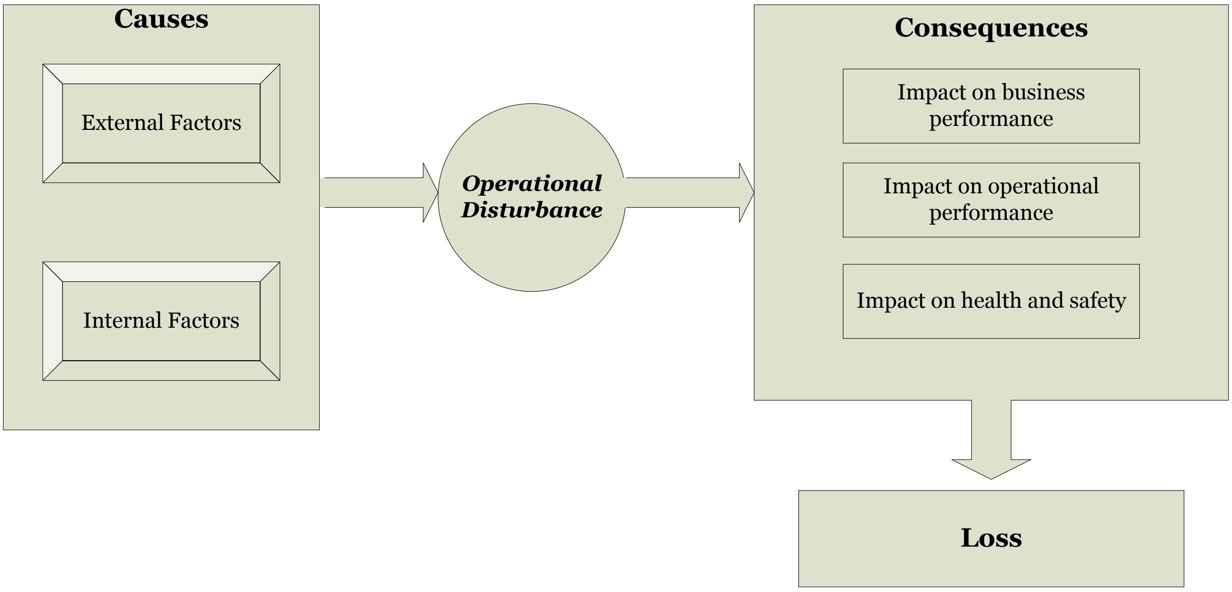

Figure 1: Operational Disturbance mapping Diagram [13]

3.2 Classification of operational disturbances

Scholars have used different methods of classifying operational disturbances. According to De Jong [14], operational disturbances can be resource-related, task-related, supplier-related or job-related. Resource-related setbacks include machine breakdown and worker absenteeism. Cowling and Johansson [15] discussed on job-related disturbances which include work-in-process increase due to sudden demand changes and rush orders. Supplier-related operational disturbances include shortage of raw materials which can result from the late delivery of a required raw material while task-related disturbances include tool malfunction or equipment damage during an operation.

In other studies, Islam and Tedford [12] classified the disturbances are either as internal or external where the former are related to the setbacks which are initiated within the production system while the later disturbances encompass those caused by customers and suppliers. However, Frezzile et al. [16] employed a supply chain approach to classify possible causes of operational disturbances according to their position of occurrence. In his analysis, causes were classified as either coming from upstream events, internal events or downstream events. All approaches are related and help describe the dynamics of operational disturbances in terms of their relation to a manufacturing set-up. In this study, De Jong's approach of classifying operational disturbances is used since it relates a disturbance to different parts of the manufacturing system (customer orders - jobs, suppliers, resources and tasks).

3.3 Types of operational disturbances

The entire supply chain needs to be monitored and managed well to prepare for the occurrence of disruptions, which can be caused by sudden changes in events within a system. This section outlines different types of operational disturbances other researchers have identified in previous studies. The presented set was then used for further analysis in the identification of the most prevalent setbacks the TDM sector in South Africa is experiencing.

3.3.1 Resource-related operational disturbances

Bereiter [17] and Nauro et al. [18] identified machine breakdown as a major setback most manufacturing set-ups encounter. Malfunctions may result from inadequate maintenance procedures or the adoption of a wrong operation during manufacturing. Operator absenteeism is another operational disturbance which can be expensive to any production system. When a worker is absent, the shop-floor is deprived of certain skills and this may delay production or compromise the quality of outputs produced. Possible causes of worker absenteeism include unsafe working conditions, poor motivation, industrial action or untimely family events. When system resources fail to function well, production is slowed down.

3.3.2 Task-related operational disturbances

The damage of tools or equipment during production is a common task-related operational disturbance which can temporarily hinder progress. Wear and tear occurs during use of tool resulting in them becoming obsolete. Tool damage may result from poor procedures during fabrication. Nauro et al. [18] also identified defective raw materials as another task-related setback which may result from receipt of defective parts from suppliers or the use of poor storage and material handling techniques. Occupational accidents are task-related disturbances which can also result from the resources being used.

3.3.3 Supplier-related operational disturbances

Upstream problems or changes can lead to shop-floor disruptions. Shortage of raw materials which may result from delayed supply or unavailability of the resources from suppliers can affect the smooth flowing of operations. In other cases, the firm may be adopting a poor inventory control system hence resulting in untimely stock outs. An erratic supply of power or water is another supplier-related production setback which has the potential to negatively affect performance. Power cuts render the entire system unavailable since most elements in the production system; machinery, equipment and computers depend on a supply of electricity.

3.3.4 Job-related operational disturbances

Downstream changes by customers can result in job-related operational disturbances. These changes include changes in volumes, cancellation of orders, rush orders or changes in due dates. Such events result in work-in-progress increase, which is a major production setback. Table 1 summarizes the operational disturbances identified from the literature.

Table 1: Types of operational disturbances

Category	Operational Disturbance
Supplier-related	• Erratic power supply • Erractic water supply • Shortage of raw materials
Job-related	• Work-in-progress increase • Defective products
Resource-related	• Worker absenteeism • Machine breakdown • Software failure • Machine malfunction • Stalemate due to labour strike
Task-related	• Equipment damage • Tool failure • Material handling disruption • Line blockage

4 RESEARCH METHODS AND MATERIALS

An empirical investigation was selected as the appropriate methodology. Pettigrew et al. [19] and Luis et al. [20] agreed on the fact that empirical studies place special emphasis on affiliated research leading to framework establishment for improvement of an entity's strategies. As such, structured interviews and questionnaires were used as a means for data collection. The purpose of the interviews was to establish the frequently experienced operational disturbances in the tool and die industry in South Africa. The tooling industry in South Africa serves the Packaging, Food, Automotive, Mining and Plastic Forming industries. The Delphi or Expert Opinion methodology was used to select the appropriate respondents who were captains of industry in the South African tooling sector. Five firms were randomly selected for the interviews and all accepted to participate. A set of similar structured questions based on the operational disturbances shown in Table 1 were asked.

The purpose of the questionnaire survey was for further analysis of the identified operational disturbances in terms of their frequency of occurrence and their relationship with the suggested causes and consequences. The questionnaire was developed in two stages which included a pilot study to test and refine the data collection instrument and a formal study to collect the required information.

In the questionnaire survey, a targeted population size of 150 tool rooms forming an industrial cluster in the Western Cape region of South Africa were selected for investigation. Of these, 102 firms agreed to take part in the study making them the sample size for analysis. A total number of 102 questionnaires were sent out to the organizations participating. A follow up on receipt of the questionnaires was done via telephone calls and emails. Of the 102 questionnaires, 71 were returned; hence the response rate was 70%, which is acceptable. Among the 71 returned for analysis, only 58 were in an acceptable format (13 were spoiled or inadequately filled).

The variables in the questionnaire study were the identified operational disturbances (established from the structured-interviews), a set of events that might have caused them and a set of consequences which would result from them. Other questions included tool room specific data like product range, order qualifying and order winning factors. Each operational disturbance and possible consequence was questioned as a closed-ended question requiring responses on a five-point Likert scale proposed by John [21]. This was done so as to determine the frequency of occurrence for the variables in question. A ranking scale of Never = 1, rarely = 2, sometimes =3, often = 4 and always =5 was employed. An open ended question was included at the end of each section for respondents to include additional information they deemed relevant to the study. To establish the relationship between the identified operational disturbances and their consequences, a correlation analysis based on the Pearson correlation analysis was also conducted in SPSS.

5 RESEARCH FINDINGS

5.1 Structured interview results

After the structured interviews, seven operational disturbances affecting the South African tooling industry were established. The possible causes of the identified operational disturbances and their consequences on business performance were also outlined. Table 2 summarises the operational disturbances identified. These results were used for the design of the questionnaire used for further analysis.

Table 2: Summary of identified operational disturbances

Operational Disturbance	Category
Work-In-Process increase	Job-related/Task Related
Shortage of raw materials	Supplier-related
Defective raw materials	Supplier and Task-related
Equipment damage	Task-related
Machine break down	Resource-related
Worker absenteeism	Resource-related
Accidents	Resource/Task-related

5.2 Key Competitive Performance Objectives

Statistical Package for Social Sciences (SPSS – version 21.0) was employed as an engineering tool for data analysis of the questionnaires collected. According to Dewa et al. [22], offering good service to customers involves many different relations between a firm and its customers. These factors, also known as Competitive Performance Objectives (CPOs) determine whether a firm wins market share or remains uncompetitive. According to the results illustrated in Figure 2, 43% of respondents (industrial captains in the TDM sector) believed that product quality was the most important CPO that Tool Room products should possess to win market share. Due date conformance (16%), Product cost (13%) and Speed to Market (12%) was also deemed as critical success factors for firms doing well in the sector.

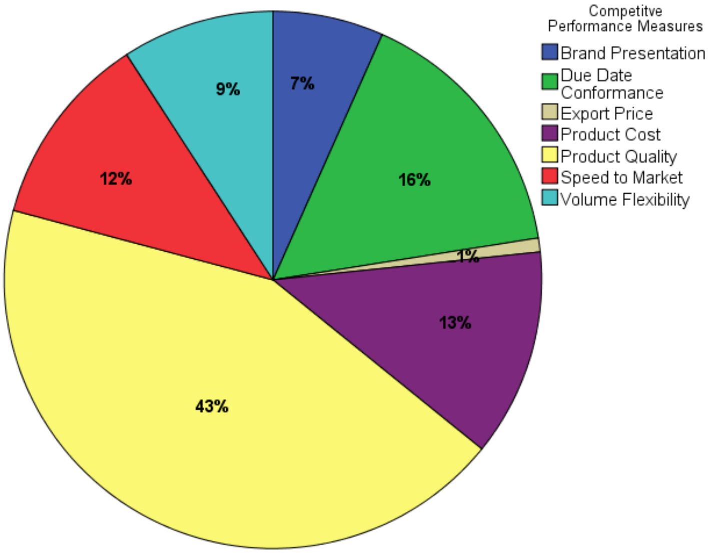

Figure 2: Key Competitive Performance Measures

5.3 Key Operational Disturbances

The seven types of operational disturbances shown in Table 2 were examined in terms of their frequency of occurrence in the studied companies. All organizations (100%) were found to encounter one major disturbance namely machine breakdown and 91% of the firms reported to have experienced equipment damage and raw material shortage. The percentage of investigated firms experiencing each operational disturbance data is presented in Figure 3.

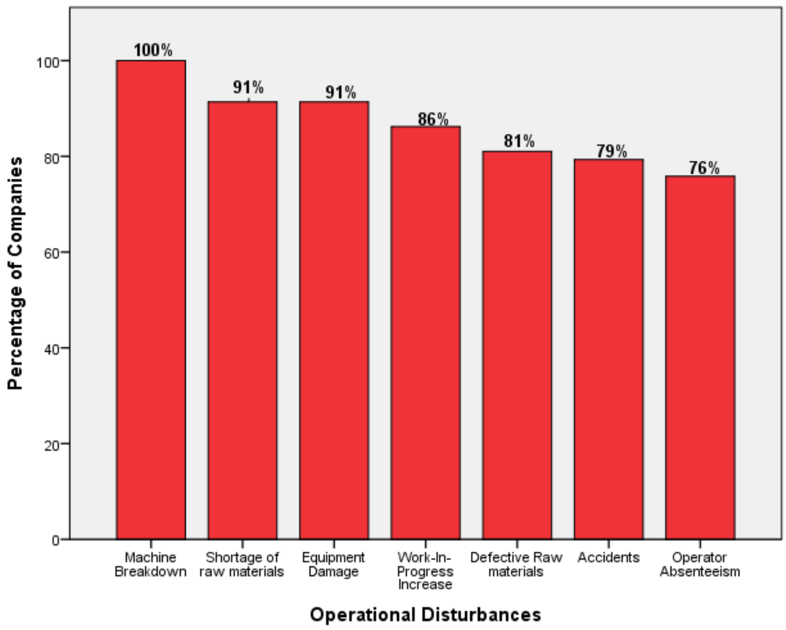

Figure 3: Prevalent operational disturbances

To establish the most prevalent operational disturbances experienced by the TDM sector in South Africa, mean values for each disturbance based on descriptive statistics in SPSS was used to rank the operational disturbances with the disturbance having the highest mean being ranked first. These results are displayed in Table 3.

Table 3: Descriptive Statistics for Operational Disturbances

	Raw Material Shortage	Defective Raw Materials	Work In Process Increase	Machine Breakdown	Equipment Damage	Accident Occurrence	Operator Absenteeism
Sample Size	58	58	58	58	58	58	58
Mean	2.93	2.33	2.61	3.33	2.53	1.96	2.20
Std. Deviation	0.953	0.893	1.013	0.632	0.847	0.660	0.840
Rank	2	5	3	1	4	7	6

Results of the calculated means of each operational disturbance based on the frequency levels gathered from the analysis are displayed in Table 3. The disturbances were ranked according to these means with the highest rank (1) assigned to the setback with the highest mean value and the lowest rank (7) assigned to the lowest mean value. According to the information shown in Figures 3 and Table 3 the most significant operational disturbances experienced by firms in the TDM sector are:

- Machine breakdown
- Shortage of raw materials
- Work build-up
- Equipment damage

Of the four identified operational disturbances, machine breakdown was the most common in terms of frequency.

5.4 Possible Causes of Operational Disturbances

Seventeen possible root causes of the operational disturbances were examined in terms of their frequency of occurrence in the studied firms. The results presented in Figure 4 show that 63% of the firms investigated attributed late delivery of raw materials from suppliers as the major cause of some of the disturbances experienced. Lack of worker motivation, poor machine maintenance and supplier production, quality and transportation challenges were also cited as key causative factors to the experienced setbacks by the participating respondents.

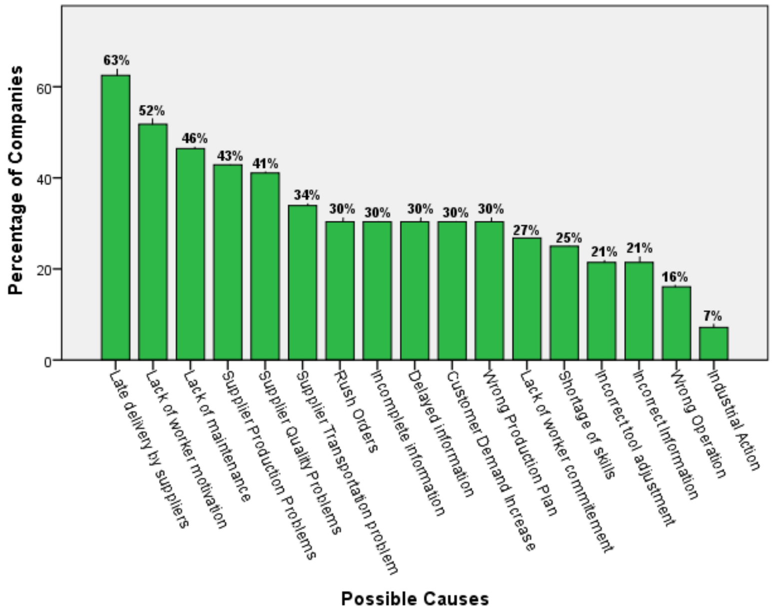

Figure 4: Root causes of operational disturbances

The relationships existing between the operational disturbances and the causes were also established. Results of the correlation analysis illustrate these relationships and are displayed in Table 4.

Table 4: Operational Disturbances and causes correlation

Causes / Disturbance	Late delivery by suppliers	Supplier Production Problems	Supplier Quality Problems	Supplier Transportation problem	Shortage of skills	Industrial Action	Lack of worker commitment	Lack of worker motivation	Wrong Operation	Incorrect tool adjustment	Lack of maintenance	Rush Orders	Customer Demand Increase	Incorrect Information	Incomplete information	Delayed information	Wrong Production Plan
Shortage of raw materials	.380**	-.047	-.002	-.116	.030	.084	-.128	-.184	-.072	.005	-.217	-.376**	.063	.157	.067	-.072	.063
Defective Raw materials	.147	.139	.212	.150	.067	.132	.085	-.044	-.276*	.139	-.006	.118	.215	-.079	-.070	-.075	.022
WIP Increase	.187	.336**	.120	.066	.226	.109	.122	.200	.036	.204	.059	.148	-.072	.081	.153	.148	.038
Machine Breakdown	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.380**	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]
Equipment Damage	-.123	-.116	-.128	-.047	.030	-.159	.041	.184	-.069	.005	.153**	.063	-.207	.157	-.069	-.072	.063
Accidents	-.240	.170	.240	-.369**	.089	-.029	.204	.085	.090	.054	.118	-.232	-.045	.051	.027	-.045	-.045
Operator Absenteeism	-.045	.228	.128	.136	.318*	.154	-.035	.242	.121	.010	.184	.186	.009	.288*	.105	.098	.363**

**correlation is significant at the 0.01 level (2 tailed). *correlation is significant at the 0.05 level (2 tailed)

5.5 Impact of disturbances on business performance

Sixteen experienced consequences due to the operational disturbances were examined in terms of their frequency of occurrence in the studied companies. The results presented in Figure 5 show that 91% of the firms investigated experienced long downtime as the major result of some of the disturbances experienced. This is possibly due to machine breakdowns experiences which stop production and slow down operations. Eventually, orders are delivered late to customers while maintenance, inventory and production cost are increased. Upstream quality related problems result in the production of defective products thus resulting in waste of time and materials.

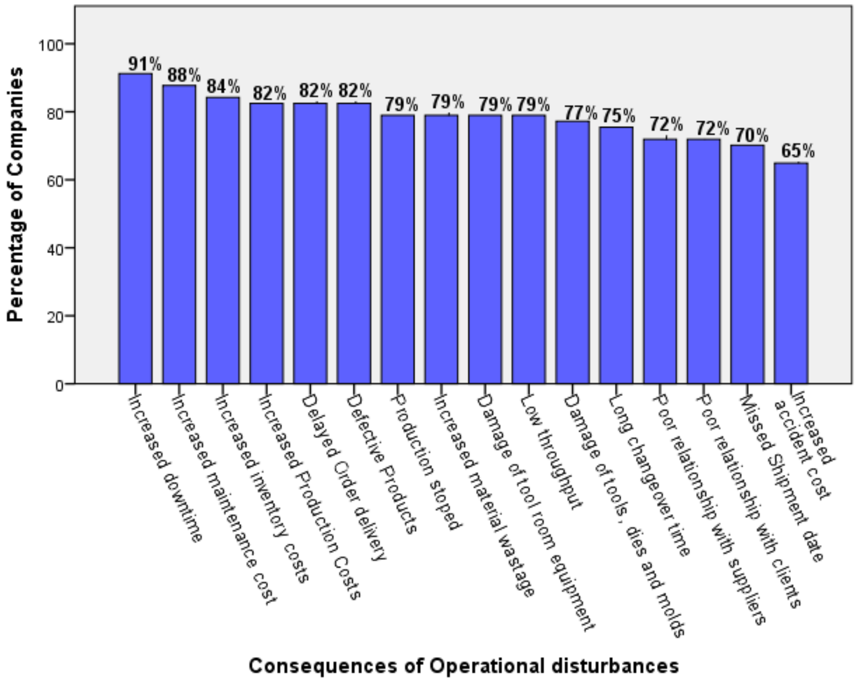

Figure 5: Consequences of operational disturbances

The mean values of each operational consequence were also determined and the results of the ranks are presented in Table 5. Increased downtime, increased inventory cost, increased production cost, late delivery of orders, increased maintenance cost and increased production cost were identified as the main consequences experienced in the sector.

Table 5: Descriptive Statistics for Consequences

Consequences	Sample Size	Mean	Std. Deviation	Rank
Defective Products	58	2.43	0.920	7
Low throughput	58	2.52	0.978	5
Delayed Order delivery	58	2.50	0.996	6
Long changeover time	58	2.36	1.038	8
Increased downtime	58	2.90	1.038	1
Missed Shipment date	58	2.12	0.900	13
Production stopped	58	2.10	0.912	14
Increased Production Costs	58	2.59	0.992	3
Increased material wastage	58	2.21	0.932	11
Increased accident cost	58	1.84	0.745	16
Increased maintenance cost	58	2.77	1.000	2
Increased inventory costs	58	2.53	1.037	4
Operator Absenteeism	58	.83	0.566	17
Poor relationship with clients	58	2.00	0.926	15
Poor relationship with suppliers	58	2.14	1.043	12
Damage of tools, dies and moulds	58	2.23	0.945	10
Damage of tool room equipment	58	2.35	0.973	9

The identified relationships existing between the operational disturbances and the consequences were also established. Results of the correlation analysis illustrate these relationships and are displayed in Table 6.

Table 6: Correlation between disturbances and Consequences

	Defective Products	Low throughput	Delayed Order delivery	Long changeover	Increased downtime	Missed Shipment date	Production stopped	Increased Production Costs	Increased material wastage	Increased accident cost	Increased maintenance cost	Increased inventory costs	Poor relationship with clients	Poor relationship with suppliers	Damage of tools, dies and moulds	Damage of tool room equipment
Raw material shortage	.014	-.066	-.067	-.168	-.185	-.032	.015	-.011	-.018	-.147	-.166	-.062	.049	-.068	-.110	-.229
Defective Raw materials	.416* .	.196	.324*	.161	.220	.164	.254	.133	.201	-.096	.173	.236	.302*	.286*	.211	.072
Work-In-Progress Increase	-.208	.066	.067	-.047	-.115	-.166	-.162	-.214	-.173	.028	-.104	-.198	-.146	-.147	-.175	.090
Equipment Breakdown	-.052	.130	.042	.110	-.049	-.129	-.037	-.077	-.072	-.074	-.188	-.235	.000	.006	-.036	.062
Accidents	-.120	.128	.118	.051	.141	-.154	.053	.119	.188	.374**	.247	.012	.170	.139	.239	.333*
Operator Absenteeism	.179	.417**	.156	-.041	.089	-.027	.273*	.121	.135	-.023	-.009	.068	.135	.162	.109	.145
Machine Breakdown	1	.177	.354**	.367**	.562**	-.043	.239	.295*	.488**	-.080	.313*	.310*	.510**	.535**	.522**	.341**

**correlation is significant at the 0.01 level (2 tailed). *correlation is significant at the 0.05 level (2tailed).

As illustrated in Table 6, it was noted that the production of defective products is strongly correlated to defective raw materials. Machine breakdowns are strongly correlated to delayed order delivery, increased downtime, wastage of raw materials, and damage of equipment resulting in poor relationships with clients. Figure 7 summarizes the relationships established from the correlation analysis.

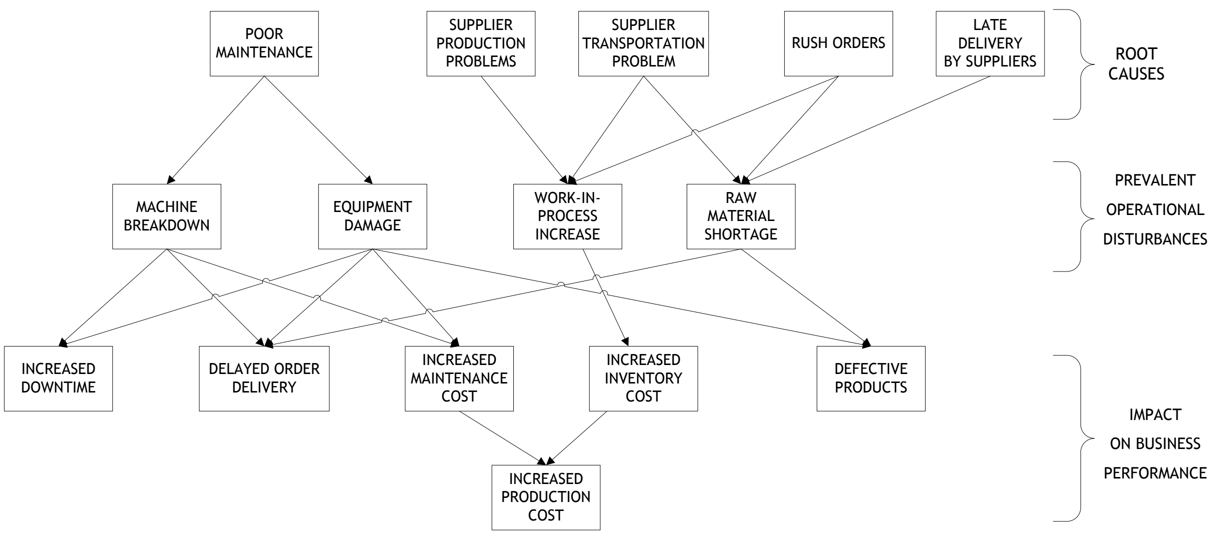

Figure 6: Cause-disturbance-consequence mapping

6 CONCLUSION AND RECOMMENDATIONS

The purpose of the study was to identify a set of common operational disturbances experienced by the Tool, Die and Mould making industry in South Africa's Western Cape Province. Due to the increased frequency of disturbances in manufacturing systems, techniques to minimize the impact of changes and disturbances on the manufacturing system performance are being developed. Most recently, researchers have proposed the design of holonic manufacturing and control systems (Bal and Hashemipour, [23]) to be a viable solution to the problem. Zhao et al. [24] confirmed the notion by mentioning that holonic systems are computerized models which provide a flexible and decentralized manufacturing environment to accommodate changes dynamically. The findings of this study are a key step to realising the goal of developing holonic systems.

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AN OVERVIEW OF PRIVACY SCHEME IN CLOUD COMPUTING

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ABSTRACT

Cloud computing provides a virtualized pool of computing resources. Cloud computing is categorized in three different broad service models: Software as a Service (SaaS); Platform as a Service (PaaS); Infrastructure as a Service (IaaS).An example is the accessing of services from remote databases through the use of Internet. This means users cannot physically or directly access data from the cloud server, without a client's knowledge. Therefore, there is no need for users to know the exact location of the server; but there is a need for securing the data and information especially in public cloud computing. The aim of this study was to investigate the security challenges or vulnerabilities of cloud computing and propose a conceptual solution. In this regard, a systematic literature search was conducted. Descriptive statistics was used to analyse the data. The researcher found that there are a lot of research issues within the area of security in cloud computing. Furthermore, through this overview study the researcher found that most policies of cloud computing providers allow them to modify or delete data which is not used or that occupy a chunk of the storage space without consulting the clients. This is another security vulnerability issue which creates a research platform.

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1 INTRODUCTION

Some of the major assets in every organisation include its data files that contain important client and business information. Therefore, privacy and compliancy issues should not be ignored. Nowadays, cloud computing turn's the organisations' utility computer services into a reality. For example, a mobile service technician can access and save data (that could be needed for a meeting) using online storage which is accessible by the employer. Therefore, organizations may only pay for what they are currently using. Furthermore, organisations can benefit from computing power, storage capacity as well as in electricity and other utilities.

These advantages are perfect motivations for organizations to migrate their data to cloud computing, in particular public cloud services. However, issues of privacy and compliance are still a matter of concern in cloud computing solutions especially for public cloud services [4].

In this regard, the aim of this paper was to investigate the security challenges or vulnerabilities of cloud computing and propose a conceptual solution. The rest of this paper is divided into brief description on the origins of cloud computing; some methods used to conduct the study; results of the study; proposed scheme; conclusion and future work.

2 CLOUD COMPUTING: THE ORIGINS

The advent of contemporary computer networking happened in the mid-1970s, no talk of anything remotely emulating a concept like "cloud computing" came about, until about a decade later in 1984 when John Gage of Sun Microsystems coined the memorable slogan, "The network is the computer" - to describe the then-emerging world of distributed computing [11].

Cloud computing is an extension of this paradigm wherein the capabilities of business applications are exposed as sophisticated services that can be accessed over a network [7]. These services are accessible on demand and can be billed on a pay-per-use basis.

The power of communication networks has been made possible by the application of Metcalfe's law, which is "The value (or importance) of telecommunications network is proportional to the square of the number of communications devices connected to it" [12]. This has been demonstrated through the growth of the Internet.

In mid-2006, Sun Microsystems launched Amazon Web Services (AWS), in which they sold computing power to clients, and other large well-known technology companies with computing resources such as Google, Microsoft, Sales Force, VMware, etc., joined the game and heralded the present day technologies such as "Cloud Computing" [11].

3 BRIEF BENEFITS AND CHALLENGES OF CLOUD COMPUTING

Cloud technology is paid incrementally meaning the client pays only for their needs as specified by them. Cloud services are usually elastic, and cloud computing thus has an advantage of reducing the organisation's cost [13]. The other advantage of cloud computing is that it is capable of increasing organisation's data storage as the organisation's data could be stored on private remote computer systems [13].

There are more benefits that could be obtained from cloud computing, such as mobility, highly automated services, etc. As much as there are benefits there are also some challenges with cloud computing. For example, in cloud computing there are different malicious attacks such as on-line, off-line, dictionary, insider-assisted, man-in-the-middle and replay attacks. In this paper, a conceptual framework is proposed as work in progress solution to deal with such attacks.

4 SYSTEMATIC LITERATURE SEARCH

The initial step in this study was to conduct a desktop literature search. In this regard, the following online research databases and magazines (as tabulated below) were consulted for articles relevant and relating to security challenges and opportunities in cloud computing.

Table 1: Visited online research databases

Source	URL	No. of articles
Scielo	http://www.scielo.cl/	2
Science direct	http://www.sciencedirect.com/	6
IEEE	http://ieeexplore.ieee.org	3
ACM	dl.acm.org	2
Google Scholar	Scholar.google.co.za	3
InfoWorld	http://www.infoworld.com	1

A total of 17 articles were sourced from the databases. Figure 1 shows that most of the articles that the researcher read where talking of cloud computing security followed by those in cloud computing policy. This was aligned to the aim of this paper. Of the 11 security papers only six were related to privacy and authentication, while the rest spoke about encryption techniques.

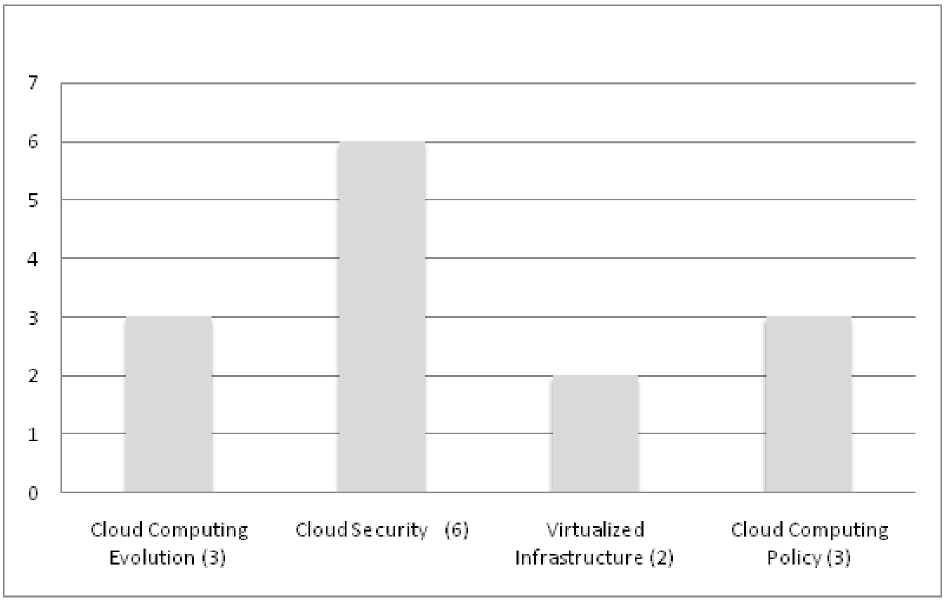

Figure 1: Areas and No. Of articles read

5 RESULTS OF THE LITERATURE SEARCH

Cloud computing is not a new technology; more over it is a new way of delivering technology. Providers deliver it in the form of services, and in computing field security lies the main concern which blocks the tremendous growth of Cloud computing and became a huge debate area worldwide, due to security breach of user's valuable information.

The literature search that we conducted also revealed that a lot of research embarked on enhancing security of the cloud computing systems [3, 4, 5, 6, 14, 16], simply meaning security is still an issue.

In a cloud computing environment all services are available to the users via internet connection. It is therefore a matter of concern for the users and providers to worry about security issues. According to Loganayagi & Sujatha [4] security is the most significant need for every client in a public cloud computing environment.

Chandra Mohan, et. al. [15] focus on privacy mitigation methodology by proposing a privacy preserving algorithmic approach to congregate the privacy issue and preserve users' confidential data stored in the cloud. They achieved that by firstly identifying that most cloud providers are weak in maintaining and preserving users' secrecy and failed to deliver on a universal service level agreement (SLA).

In the Integrating Signature Apriori based network intrusion Detection system, Chirag & Modi [5] reported that existing vulnerabilities in cloud computing affects the confidentiality, availability and integrity of cloud resource and offered service [5].

Loganayagi & Sujatha [4] argued that their method can reduce risk of data by combining authentication and authorization techniques along with service monitoring policy. The short-come of their method is that it only reduces the risk while public cloud needs a full protection.

Pearson & Charles [3] noted that Cloud sharing makes image transfer faster in health care application, often streamlining and improving patient care. Hence they developed a cloud computing based medical image exchange system. They report that their biggest stumbling block to widespread use is still fear and unease about security issues on this technology. Secondly, temporary or permanent, partial or complete disruption to cloud service (known as downtime) happens frequently with their system. Pearson and Charles [3] argue that the primary cause of downtime includes Internet bandwidth, equipment and software malfunction, and natural disasters. In this study the gap that we propose to close is that our proposed scheme will do automatic updates every five seconds for users whose sessions have elapsed.

A user stores his/her personal files in the cloud, and retrieves them wherever and whenever he/she wants, as long as there is connectivity. For the sake of protecting the privacy of user data and user queries, a user should store personal files in an encrypted form in a cloud, and then send queries in the form of encrypted keywords. However, a simple encryption scheme may not work well when a user wants to retrieve only files containing certain keywords using a thin client. Therefore, [14] proposed an efficient privacy preserving keyword search scheme in cloud computing. It allows a service provider to participate in partial decipherment to reduce a client's computational overhead, and enables the service provider to search the keywords on encrypted files to protect the user data privacy and the user queries privacy efficiently. Although, the proposed scheme by Qin, Guojun & Jie [14] is similar to our proposed scheme the only difference is that our system will create a privacy mechanism at an authentication stage.

To keep the user's data confidential against untrusted cloud service providers or outsiders, the normal way is to apply cryptographic primitives by giving the secret keys only to approved users. In this paper we propose a resourceful, secure and privacy preserving keyword search scheme which supports multiple users with low calculation cost and flexible key management. Our proposed scheme uses a management key, however, differs from RemyaRajan [16] as it will be sent via cell phone, email and will need some de-encryption before the user access the cloud services.

The obfuscation and data retrieval in an Agent-based Security Model Using Obfuscation [6] takes place through a key chosen by the agent and not revealed to cloud service providers. This means that an application in the cloud cannot de-obfuscate the data. According to Popov, Debray & Andrews [17] obfuscation is not 100% secured, someone can get access to the cloud and steal the confidential data. In our proposed scheme this technique will be adapted, however, our scheme will have a key code for authentication (general log-in which will not be sent to users) and will have an encryption key that will be sent only to an authenticated user qualifying for access.

6 PROPOSED CONCEPTUAL SECURITY SCHEME

The researcher proposes a conceptual scheme (Figure 2) to ensure that sensitive data from the user is not misused by malicious cloud computing providers or hackers. It is envisaged that the proposed scheme will enhance security which generates random security codes for users.

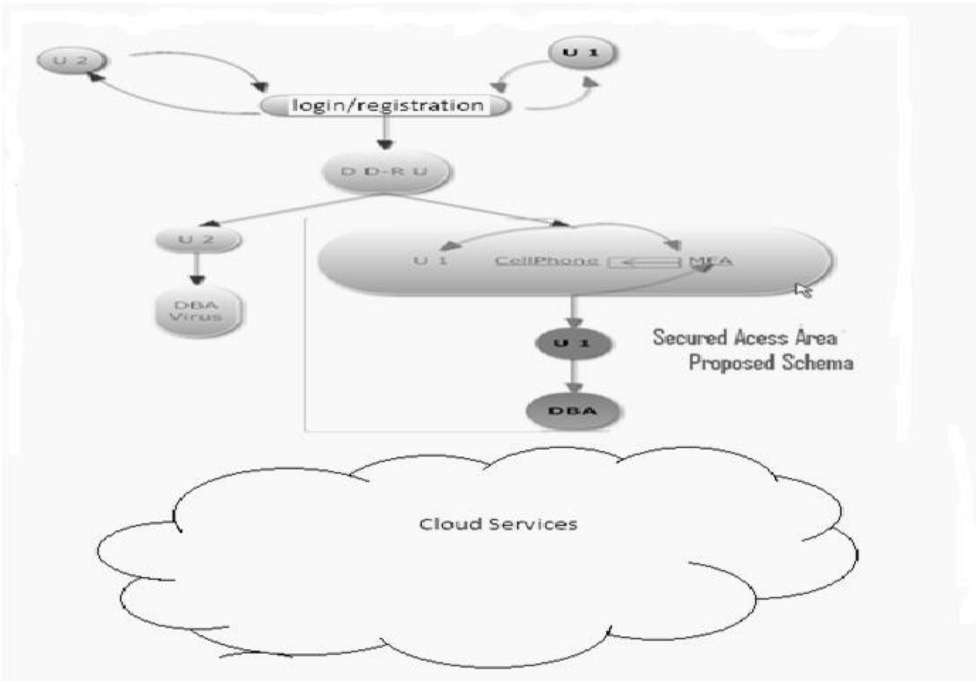

Figure 2: Proposed security scheme for accessing cloud computing services

Figure 2 indicates the proposed conceptual scheme for cell phone and email users in the cloud computing environment. This scheme is aimed at ensuring security for achieving privacy in a cloud computing environment.

In this scheme, any cloud computing user will have to register before enjoying any cloud services. In this regard, during the registration process users will be required to create a unique username and password, and then a random security code will be sent to their cell phones or emails. They need to use that security code to confirm their registration. The registration will be authorised from the dummy database registering users (DD-RU) by issuing digital authority certificate to be saved anywhere in their systems. or virus database.

Virus database (DDA-Virus)

Function of virus database is to communicate with unauthorised users to ensure that system is accessed by right customer's only, sending warning message to the hackers two times before it can execute virus step.

To secure the user, the proposed scheme will use a multi-factor authentication (MFA). A two-factor authentication is commonly found in electronic computer authentication, where basic authentication is the process of a requesting entity presenting some evidence of its identity to a second entity.

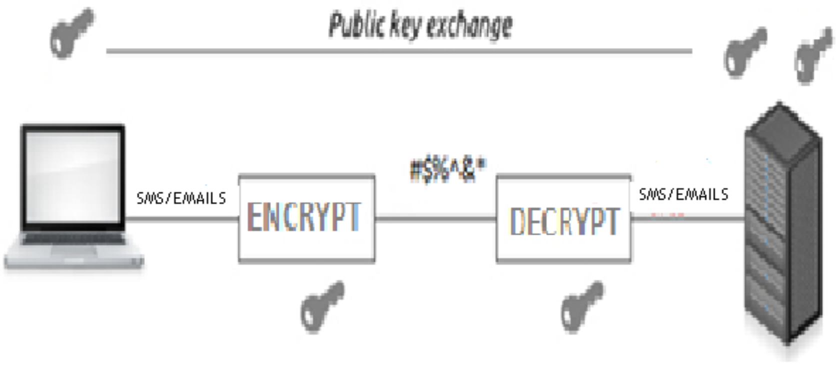

Figure 3: Encryption key and codes send out mechanism

Dummy database registering users (DD-RU)

The DD-RU is supported by encryption techniques. In case, many users are attempting to log-on to access cloud services, then the DD-RU will have to schedule the authentication priorities, and the virus database will be on stand-by. If the user comply with registration policies, terms and conditions, the second authentication step will be begin and summaries in Box 1.

Box 1: Algorithm for secured access

How a secure access is achieved? Refer to figure 2:

Algorithm:

Step 1: Registration checked

- ***User 1, accesses the system.***
- ***The DD-RU confirms the authentication based on its policies.***

Step 2: Cloud services requested

- **User 1 uploads/downloads data from the cloud.**
- ***Multi-factor authentication (MFA) is initiated.***
- ***MFA checks if user 1 qualifies for receiving a key code.***
    - ***If user 1 qualifies, then MFA sends encryption key code to cell phone or email (even if the user uses a computer to access the system). User1 confirms key code (insert it) and then MFA decrypt the key code***
        - ***if same key, then user 1 gains access to cloud services,***
        - ***otherwise user 1 is denied access (error messaged sent via cell phone) and step 1 is initiated; AND***
    - ***If user 1 does not qualify (even if user has been authenticated), then the system will send error message to cell phone and e-mail address. The system will log-off user 1 from step 2, and let user 1 to start with step 1 and rectify the sent error code.***

If, the user does not comply with registration policies or terms and conditions, an automatically generated alert advising the user that access will be at their own risk: will be sent. If many incorrect passwords are submitted or access attempts are made, then the system will treat that user as a hacker and send a warning message: "Your system will crash your computer and block you permanently from accessing the cloud service". In this regard, once the user ignores the warning message and further attempts to access system, then the virus database will release a virus and send it to the user.

In the proposed scheme, since cloud computing infrastructure operates 24/7, when the user tries to access the system, the administrator will be notified through a short-messages-service (sms) or e-mail approach. This is known as automatic monitoring that will be done by Information Technology Service Management (ITSM). The ITSM will log a ticket and send it to the IT administrator to monitor the system, alerts will be received via cell phone and email when hackers try to hack the system or when the system is down.

In this proposed scheme, the systems cannot be hacked since access provided through authentication and the multi-factor authentication (MFA) system via a cell phone and email. In case, the hacker tries to redirect code virus will be sent to their system.

7 FUTURE WORK

Since this paper was drafted from a continuing Masters Study future work will entail the use of CloudSim to build and test the proposed scheme for privacy, authentication and monitoring.

CloudSim is a new, generalized and extensible simulation toolkit and application which enables seamless modelling, simulation, and experimentation of emerging cloud computing systems, infrastructures and application environments for single and internetworked clouds [10]. CloudSim is not a framework as it does not provide a ready to use environment for execution of a complete scenario with a specific input. Instead, in CloudSim a cloud scenario needs to be developed by providing the input parameters; such parameters will be evaluated then the required output will provided.

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QUALITY MANAGEMENT SYSTEMS FOR MANUFACTURING INCUBATORS IN CLUSTERS

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ABSTRACT

In the current competitive economic environment, start-up companies struggle to accomplish production tasks alone. As part of the national supplier and enterprise development programs, corporations are discovering innovative ways to enable start-ups to compete within established value streams. Although manufacturing clusters can support collaboration and cooperation among incubation partners, its evolving quality management systems remains an issue. The quality of the products produced and service delivery of these manufacturing clusters are a concern. Still these clusters have not been able to develop a coordinated approach to quality management. Total quality management systems within these clusters can assist to optimize the quality costs and improve the cluster's overall competitive position within the market. In this research study several cluster case studies were evaluated and incubation clusters within South Africa were visited to understand the quality issues, challenges and opportunities within clusters. A quality management framework was proposed to assist start-up companies to grow into established value streams from these incubation clusters.

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1 BACKGROUND AND MOTIVATION

Manufacturing of products and goods is probably the most important economic activity in the world that exists to create value. As it becomes more difficult to understand and control values of products and services, the concept of *sustainable value* has emerged to target not only ecological sustainability, but also social and economic values [1]. Having a strong manufacturing base is important to any society or community, because it stimulates all the other sectors of the economy [2] to be productive. Manufacturing deserves strong and continuous endeavor of all actors in a modern society to ensure prosperity, better life and sustainable development [3].

This highlights the need to understand the issues, challenges and opportunities better to help simplify the complexities of incubation clusters. Complexity is a term to describe a characteristic which is not yet possible to quantify precisely. Yet the complexity of production systems is the critical cause of many management problems [4]. Figure 1 illustrates the drivers and enablers for complexity that should be managed in any production system to stay competitive [5].

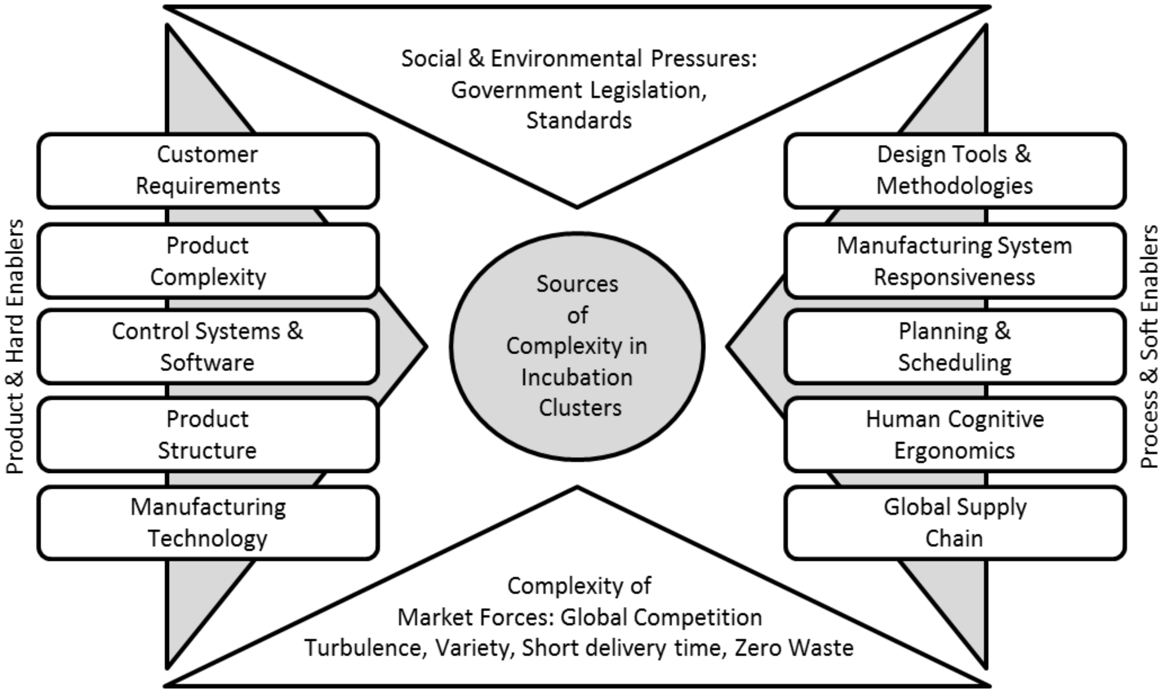

Figure 1: Drivers of manufacturing complexity in incubation clusters (Adapted from [5])

The name *incubator* originates from a chicken processing company that was one of the first tenants in a successful model of promoting small and medium sized enterprises (SMME) development when a very large industry closed down in New York [6].

The United Nations industrial development organization also adopted this incubator model in order to create a support environment for entrepreneurship to expand SMME's in developing countries [7]. The universal idea is that a company located within a business cluster, experiences better chances of survival and stronger growth than a company located in isolation. It should be considered as a mutual support network for manufacturing.

Small and medium sized enterprises (SMME) suffer from the shortage in skills (know-how), appropriate technology and the lack of a collective support system. This leads to inefficient value creation, a high degree of energy (resources) wasted in production processes and frightening pollution. The failure rate of these SMME's in the first two years was reported to be over 60 % in Africa and other developing countries [8].

The lifecycle for SMME's to evolve into mature organisations include the growth phases through creativity, direction, delegation co-ordination, collaboration and alliances [9]. In a favourable ecosystem, innovative enterprises can flourish by interacting with different innovation actors and across sectorial boundaries [3]. In order to meet customer demand, production organisations develop rapidly more products, which lead to an increase in the number of variants of assemblies and parts [5]. Thus, the coordination of activities can increase significantly.

Clustered support systems offer the benefit that production engineers can have physical access to the manufacturing floor to keep track of progress, while entrepreneurs are able to meet like-minded individuals to explore new ideas. Clusters can evolve from the hero (entrepreneurship) phase through a mature economics of scale phase, growing into a further renaissance or decline into a museum state [10].

The type and degree of regional specialisation and thus the potential for regional development depends on path-dependent processes influenced by regional characteristics of factors such as available resources, level of education and existing industrial structures. Collaboration in a cluster needs to be facilitated in order to tap the cluster's full potential [11, 12].

The establishment of international cluster policy collaboration bodies and benchmarking of cluster organisations and programmes helped to develop these policies significantly [12]. Although scientific methods (e.g. agent theory, neural network, genetic algorithms, fuzzy logic [13, 14]) for managing complexity exist, the management and control of complexity in clustering remains a challenge. Key phases for implementation of a clustered based framework and a better understanding of the complex change management are also still needed.

In this research study several cluster case studies were evaluated and incubation clusters within South Africa were visited to understand the quality issues, challenges and opportunities within clusters. This work is a continuation of previous research [11] on industrial clusters. A quality management framework was proposed to assist start-up companies to grow into established value streams from these incubation clusters.

2 INCUBATION CLUSTERS

"*An industrial cluster is an entity characterized by a social community of people and a population of economic agents localized in close proximity in a specific geographic region. Within an industrial cluster, a significant part of both the social community and the economic agents work together in economically linked activities, sharing and nurturing a common stock of product, technology and organizational knowledge in order to generate superior products and services in the marketplace*" [15].

This definition stresses the geographic proximity of cluster partners which, perhaps, is the main distinction between a cluster and a network. In other words, a cluster is a regional network. The collaboration of SMME's with each other and the research and development institutions can be seen as an opportunity to renew the economy and the society [12].

Clusters are geographic concentrations of interconnected companies and institutions in a particular field that compete and collaborate at the same time [16]. These clusters also reflect the specialisations of regions in activities, within which companies can gain higher productivity through accessing external economies of scale or other comparative advantages. Business clusters refers to an area that is home to many companies or organizations working within the same industry to gain an edge by concentrating their resources in one area [13]. This support model gains competitive strength because of its better access to trained and experienced employees, suppliers, specialized information and public goods, as well as from the motivating forces of local competition and customer demand [21].

The ability to identify opportunities co-creatively and bring innovative products to market effectively in an efficient way will enhance a manufacturing cluster's competitiveness. Therefore, as shown in figure 2, desired products should be brought to market on the right time at the desired quality level.

Manufacturing cluster management naturally look first inside their own business entities for creative sparks as it is easier to understand what is available. The bigger sparks, they discover, are ignited when fragments of ideas come together – specifically, when entities across the cluster brainstorm or when business entities can tap external partners for ideas [17].

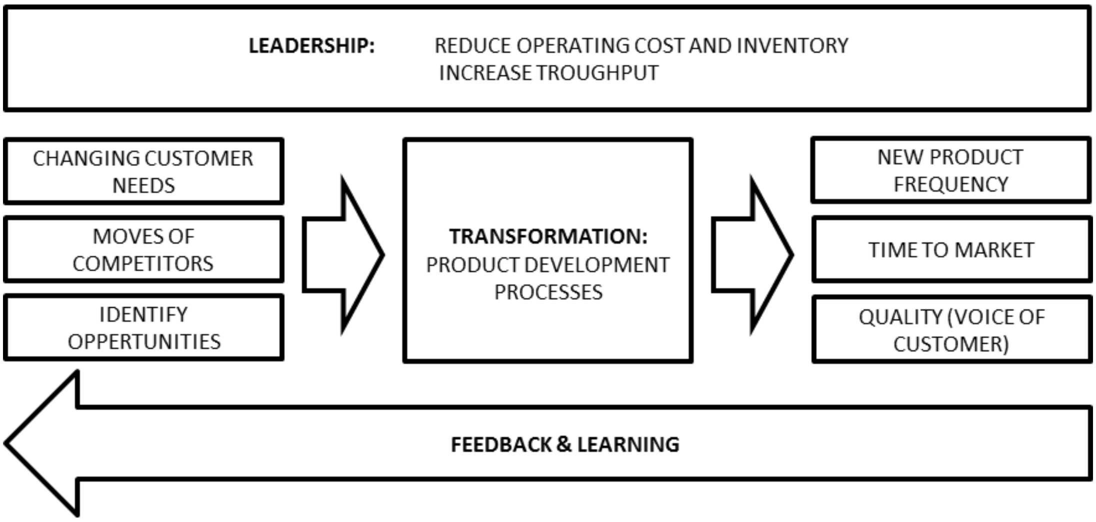

Figure 2: Measures of product development success in clusters (Adapted from [13])

Measures of product development success can be categorized into those that relate to the speed and frequency of bringing new products to market, to the productivity of the equal development process, and to the quality of the actual products introduced [18]. The time, quality and productivity define the performance of development. In combination with other activities like sales, manufacturing, advertising, and customer service the transformation process determine the market impact and its profitability [18]. When entities within a cluster decide to collaborate in open innovation, the level of governance and level of participation should be decided [19].

Industrial clusters can support this type of collaboration and cooperation among partners [20]. Clusters provide a sound basis for competitiveness, innovativeness, agility and adaptiveness by enabling the interconnected partners to (1) form long-term business coalitions, (2) share information, knowledge, resources, competencies and risks, (3) develop mutual understanding and trust, (4) jointly react to business opportunities, and (5) gain synergetic effects by collaboration and cooperation. Thus, they combine good characteristics of large companies with the advantages of SMME's and introduce new possibilities and potentials for innovation. Innovation is usually one of the strongest motivation factors for establishment of a cluster.

In South Africa the petrochemical cluster around Sasol near Witbank supports various industries and downstream linkages were created. Around East London and Uitenhage, the motor vehicle industry cluster that exists produced around 40% of the country's vehicle output [21]. Other evolving clusters within South Africa exist within the automotive, chemical, clothing, textile, footwear, leather, agro-processing, forestry and agro-processing industries. Qualitatively new areas of intervention include the green energy, mineral beneficiation, upstream oil and gas services and equipment and boatbuilding industries. Long term advanced capabilities include the nuclear, advanced materials, aerospace and defence and electro-technical industries [22].

Incubators, or more specifically business incubators, are programs which support entrepreneurial or start-up companies via various business support resources and services. There are currently approximately 60 privately- and publicly-funded incubators in South Africa. The Department of Trade and Industry (the dti) currently supports publicly-funded incubators via the Small Enterprise Development Agency's Technology Programme, and also has very ambitious plans to establish an additional 250 incubators directly by 2015 under its recently-launched Incubator Support Programme (ISP) [22].

Incubation clusters have proven to be an effective way of fostering sustainable business growth and stimulating entrepreneurship. However, establishing a business incubator is a challenging task. The United States National Business Incubation Association (NBIA) [23] defines these incubation clusters as a dynamic system of business enterprise development. Its main task is to support development of supported small and medium-sized enterprises (SMME's), by providing the right resources at the right time. Establishing and maintaining quality management systems within these evolving incubation clusters remains a challenge.

3 QUALITY MANAGEMENT SYSTEMS IN MANUFACTURING CLUSTERS

Quality refers to those features of a product which meet customer needs, that is, freedom from deficiencies [24]. Quality also does not pertain to a single aspect of a product, but a number of different dimensions [25]. These dimensions of quality include performance, special features, conformance, reliability, durability, and service after sale [26]. The cost of quality analyses are used in most industries and even constitute one of the primary functions of a quality control department.

The basic assumptions that justify an analysis of the costs of quality include failures are caused, prevention is cheaper and performance can be measured. Deming [24] taught that by adopting appropriate principles of management, organisations can increase quality and simultaneously reduce costs. The costs of quality are generally classified into appraisal, prevention, internal (e.g. unnecessary meetings) failure and external (e.g. distribution problems) failure costs [25]. The standardization in SMME's will thus help to manage risk, achieve process consistency, to compete better in the market place and to optimize the utilization of resources.

The International Organization for Standardization (ISO) was established as a United Nations Agency in 1947 and is made up of representatives from more than 90 countries and includes the British Standards Institution for the United Kingdom and the American National Standards Institution for the United States [27]. The ISO 9000 series identifies the basic disciplines of a quality management system that can be used by manufacturers, suppliers, distributors and end users. The series specifies the national, regional and international accepted procedures and criteria that are required to ensure that products and services meet the customers' requirements [27].

The series is divided into a number of different parts which provide details of all the essential requirements for quality assurance during the design, manufacture and acceptance stages of a product. ISO 9001, 9002 and 9003 are the standards by which a company can be certified, if they so desire [27]. According to Tricker [27], since the introduction of ISO, there have been a growing number of bodies to give accreditation to companies that have a quality system in place, which includes the South African Bureau of Standards (SABS).

4 RESEARCH METHODOLOGY

The objective of this research was to understand the quality issues, challenges and opportunities within clusters better. This research was divided into different phases as illustrated in Figure 3. The first step constituted of a thorough literature study incubation clusters and quality management systems. Several case studies were studied in order to understand dynamics of clusters and the issues and opportunities of implementing quality management systems within these clusters.

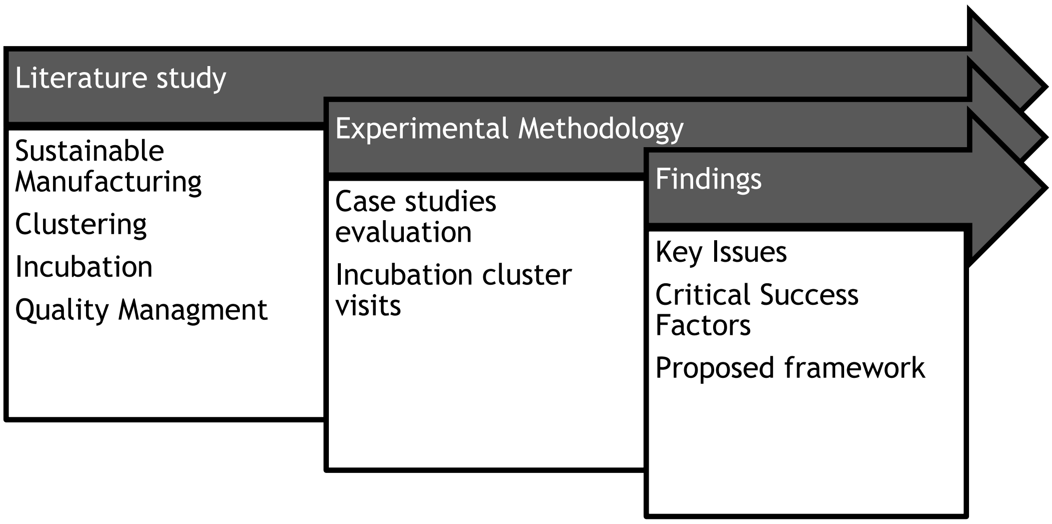

Figure 3: Experimental approach followed to understand the quality issues, challenges and opportunities within clusters better

Thereafter, several incubation clusters within South Africa were visited between August to December 2013, followed with a short questionnaire. The reasons behind the current incubation and clustering practises were studied and evaluated as input to a proposed quality management framework that can assist start-up companies to grow into established value streams from these incubation clusters.

5 FINDINGS AND PROPOSED FRAMEWORK

Several case studies were studied in order to understand dynamics of clusters and the issues and opportunities of implementing quality management systems within these clusters. The value creation processes in these success stories were also studied. Although Africa is still seen as a developing continent, it holds pockets of vital economic activity of which many are clusters scattered across the continent's countries and industries.

5.1 The Suame manufacturing cluster in Ghana

The Suame cluster is one of the biggest in Africa and evolved from a sustained attempt to provide public support for small business development [28]. The role of formal and informal associations has been important to the sustainability of the cluster [29]. The incubated SMME's filled the gap by producing spare parts that had been previously imported and delivering a repair service. The basic technologies and relatively complex machinery (e.g. tool- and die making equipment) has increased the competitiveness of this incubation cluster.

There is a development from recent studies that the trade in engineering materials and spare parts was more profitable than manufacture and repair work [29]. The market of the Suame cluster currently includes the government, private companies and individuals. The market for vehicle repair benefits from the cluster's location on the main road as it is linking two capital cities, Accra (Ghana) and Abidjan (Cote d'Ivoire) [29].

5.2 The Kamukunji metalwork cluster in Kenya

The Kamukunji cluster occupies about 10 hectares to the east of Nairobi's central district, known as the Eastlands [29]. This cluster enjoys an advantage with its location, but the role of the Kenyan government in this cluster has been minimal. It has a population of 5,000 artisans. Kenya's colonial government designated the area as a business centre for native

Africans, so it evolved under the colonial urban policy that segregated space on the basis of race. Business activities carried out in the cluster were restricted to SMME's that catered to African consumption patterns. Trade licenses were issued to businesses engaged in the sale of indigenous foods, repairs and artisan manufacturing. The products produced included cooking pans and hand tools to meet local household demands. The cluster also served the needs of customers and traders from rural areas, as it was the bus station where busses arrived in Nairobi from the countryside [29].

5.3 The Nnewi automotive components cluster in Nigeria

The Nnewi automotive components cluster is made up of four villages - Otolo, Umudim, Uruagu, and Nnewichi. This cluster obtained its Intellectual property from Taiwan [30]. Each hosts a number of automotive spare parts manufacturing firms. Large and medium-size firms are generally located away from residential areas, while small enterprises are located in homes, apartment buildings, backyards, market stalls, and the federal government's Technology Incubation Centre. Consequently, the automotive industry serves as a stimulus for the development of other industries (e.g. machine tool production, iron and steel, and transportation). The automotive industry in Nigeria has a capacity to produce 102,000 cars, 55,000 commercial vehicles, 500,000 motorcycles, and 650,000 bicycles annually [30].

5.4 Handicraft and furniture clusters in Tanzania

The furniture and handicraft sectors in Tanzania comprise a predominant number of small-scale enterprises and a few large firms utilizing simple technologies; the workforces of both have relatively low skill levels compared with internationally competitive enterprises. Major challenges include low productivity, lack of capital accumulation, and labour-intensive (though capital-saving) production [28]. The Tanzanian government tried different economic development models since the country's independence (1961), as recognized the potential socio-economic development of SMME's [28]. This cluster is still part weak, fragmented, and uncoordinated. The sector also lacks clear policy guidance from government authorities. Despite these challenges, the SMME's survived and evolved over time and produced relatively good-quality products despite intensified competition following import liberalization [29].

5.5 The Lake Victoria fishing cluster in Uganda

Fish processing and the exporting of it are important to the Ugandian economy [31]. In 1997, the European Union (EU) applied to Ugandan fish exports a set quality standards that led to a conditional ban on one of the country's most important exports. When the country's fish processors and exporters were unable to meet the quality standards, the industry was plunged into a severe export crisis. Fish processors were locked out of their largest and most lucrative market for three long years. The industry had no choice but to become compliant with the EU standards. This case study proved to be an interesting example of a technologically weak cluster in Africa that overcame a serious challenge through networking, linkages, learning, and upgrading [31].

5.6 The Textile and clothing cluster in Mauritius

The textile and clothing cluster formed a key strategy by the government to shift the economy's dependence away from a sugar based production economy. In 2001, the textile and clothing sector accounted for around 82% of its total manufactured exports, but this sector was at risk [32]. From a study [33] the export competitiveness of the Mauritian economy was found to be exceptionally vulnerable. This was due to its dependence on the textile and clothing sector. In order to become more competitive the garment quality and its total production quality systems had to be upgraded and standardised [33].

5.7 The Wine Cluster in South Africa

This wine cluster has been effective at innovation in product and production, by introducing new varieties and by improving the quality of its products [34]. An under resourced, but relatively effective network of technical support and research that closely aligned the industry needs has aided with these quality systems.

5.8 The Film Production cluster in Nigeria

Nigeria is the third-largest film producer in the world, after the United States and India and this film cluster is dominated by SMME's [35]. The lack of an organized industry, inadequate skills and quality systems are some of the challenges experienced by this cluster.

5.9 Issues and Opportunities from incubation cluster visits

Several incubation clusters within South Africa were visited between August to December 2013, followed with a short questionnaire. The reasons behind the current incubation and clustering practises were studied and evaluated as input to a proposed quality management framework that can assist start-up companies to grow into established value streams from these incubation clusters.

None of the visited clusters were found to be practicing any formal quality management system which makes the development of cluster-focused public procurement and local purchasing agreements very difficult. Also, none of these incubation clusters were certified with any ISO standards. These clusters also faced well-known challenges which include product traceability, poor factory layout and poor safety management systems. The clusters have no broker agencies to jointly market their products and then start inter-trading with each other to build on synergies.

These incubation clusters are also very isolated from research and development institutions and have very little cluster specific information available to external parties that would like to join the network. Together with any form total quality management system it is also very difficult for these clusters to develop cluster related marketing material. Therefore, it is not easy for institutions to identify and develop demand-led specific skills and education programmes for these incubation clusters.

Most of these incubation clusters were built on the unique strengths of its region and all agreed that the cluster's competitive strengths require an on-going conversation with the organisations and other economic actors in the incubation cluster. It was also evident that each cluster has a different strategy according to its needs and that government should rather promote and maintain the economic conditions that enable the evolution, than wishing to develop the cluster's strategy.

5.10 Proposed framework

A dynamic cluster can't be isolated and in order for an incubation cluster to prosper it needs an inflow of people with different skills, social development grants, innovative materials, technologies and products and; constant progress of quality management systems.

The early period of an incubation cluster is often identified with a few people, termed the heroes of a cluster as illustrated in figure 4. As the cluster grows through creativity, direction and delegation phases the identifiable cluster begins to emerge.

As the cluster matures in the growth through delegation and co-ordination phases, the cluster matures and certain production strategies will be structured. As economics of scale starts to play an increasing role the quality management systems become standardised according to the external environment.

Ultimately, the incubation cluster goes into decline, finally reaching the museum state or alternatively leapfrogs onto a cycle of renaissance based on the development of innovative intellectual property.

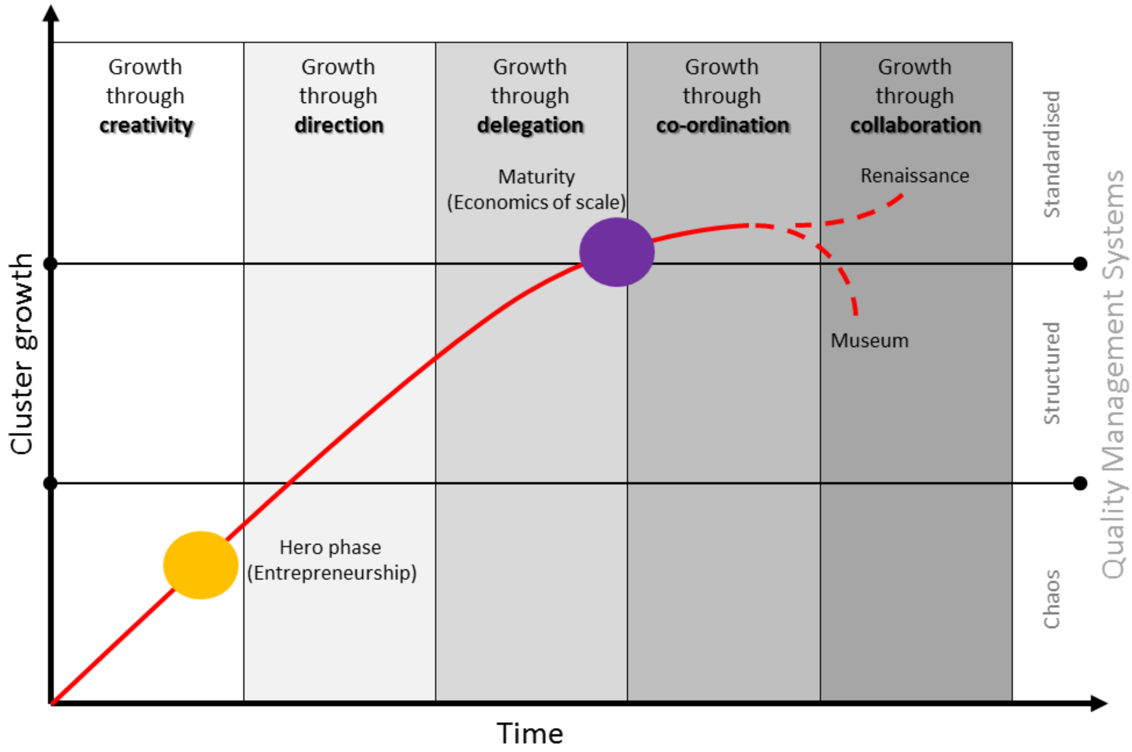

Figure 4: Proposed quality management framework for incubation clusters

Once the incubation cluster reaches critical mass and starts to grow, there is often a strong cumulative process that locks the cluster. In order for these clusters to grow and prosper from the hero (entrepreneurship) phase through a mature economics of scale phase the quality management systems also need to evolve from a chaotic state to a standardised quality management system. This needs to be balanced with factors like demand sophistication, factor upgrading and specialisation and emerging strategies from competition. In addition to this the emergence of new entrants, cluster and quality management system development involves continuous collaboration and emerging social capital.

6 CONCLUSION

Several cluster case studies were evaluated and incubation clusters within South Africa were visited to understand the quality issues, challenges and opportunities within clusters. Incubation clusters vary from location to location and needs a multidimensional approach with a combination of quantitative and qualitative methods to assist SMME's to develop into global value streams. A quality management framework was proposed to assist start-up companies to grow into established value streams from these incubation clusters.

7 ACKNOWLEDGEMENT

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THE EVALUATION OF THE INVOLVEMENT OF EMPLOYEES IN QUALITY PROJECTS AT LOCALLY BASED COMPANIES

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ABSTRACT

The fields of employee involvement and quality are constantly evolving and repositioning themselves in direct relation to a more competitive business environment. The benefits associated with the holistic involvement of employees for the duration of quality projects is an often debated issue. In light of this, deriving the true benefit (if any), of unreservedly involving employees in quality initiatives becomes an interesting proposition that may provide new information from a local perspective. Review of the associated literature provided the study with the grounding of several theories that provide a consensus for employee involvement in quality as a necessity for business excellence. However, employee involvement in quality is still not prevalent in many local companies. Two separate locally based multinational firms were selected as participants in this study so as to gain a better perspective and understanding of the current status of employee involvement in quality efforts. The results of the investigation indicate a positive interrelation between the involvement of employees in quality projects and the subsequent success of these projects. The positive benefits were applicable to both company and employees alike. The investigation highlights the universality of involving employees in quality as a key success factor among local industries.

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1 INTRODUCTION

The broad field of quality has advanced significantly and continues to reinvent itself and the way it is viewed and adapted in industry. Despite its common prevalence in a variety of literature sources, application techniques and practices, it remains a much debated topic in that several contrasting theories and techniques are practiced by various industries in pursuit of providing a quality product or service. Every business year, companies around the world strategically plan their quality endeavours and begin their annual pilgrimage journey into the vast abyss of quality, some uncovering hidden strategies quickly succeeding and rising to the top of their markets, whilst others fade away in their journey toward quality excellence. One aspect of quality remains fundamental i.e. rising competition, customer expectations, and a greater emphasis on continual business improvement. With this in mind, companies are having to regularly rethink strategies for attaining success in quality projects.

As the advent of employee involvement gains momentum, there has been a paradigm shift of thinking in industry today. The fundamentals of employee involvement, which calls for the holistic participation of employees across the vertical and horizontal structures of the organisation, provides a basis for untapped prospects of organisational success. Correctly managed staff who are well motivated, properly ultilised, and given the necessary delegation of authority can often yield quite surprising results, which may be equally applicable to quality projects.

An interesting proposition surmounts when combining the distinct fields of employee involvement and quality, both of which serve as powerful components to an organisation. Varying levels of speculation exist with regards to the feasibility of involving staff in quality endeavours. On the one side of the spectrum, theories propose the use of employee involvement as a key factor to reaching quality excellence [1], whilst adversely others tend to adopt the general practice of soliciting quality specialists or the quality department in the undertaking of quality projects [2]. The results from case studies when integrating employee involvement in quality projects will provide more light on whether the combination of these two factors surmount to an explosive advantage in quality results, or conversely, on whether the two components fail to complement each other, hampering quality projects from reaching their desired results.

One of the confounding aspects in favour of the prescription of employee involvement in quality is that proponents of employee participation in quality observed this combination from a variety of international settings. The differences in cultural backgrounds, management styles, traditional deployment and the centre’s of power within industries in South Africa will differ vastly from other international locations such as Japan or the United States for instance. This study aims to evaluate and assess employee involvement in quality based projects from a local context i.e. multinational firms based within the Durban Metropolitan area. Company A: a fast moving consumer goods manufacturer and Company B: an automotive manufacturer. Both these companies collectively share the same ideology of employee involvement in their quality based projects, and to this end, will provide the study with an interesting view into the topic.

The objective of this study is then to evaluate the aspect of involving employees in quality based projects at these two Durban based companies. In researching the objective of the study, the project will aim to look at the effectiveness of a sample of quality based projects exhibiting employee participation from both companies and will collect the perceptions of employees regarding their participation in these quality based projects. From the study, it was also the researchers’ intention to unearth possible recommendations for refining and/or enhancing the local implementation of employee participation in quality based projects from the data collected.

2 LITERATURE REVIEW

In the coverage of developmental aspects surrounding employee involvement, it becomes important to note the aspects of scientific management as proposed by Frederick W. Taylor [3]. This is further reinforced through the use of a popular example of the Ford Motor Company [4] where the implementation of mass assembly line production demanded high focus on achieving efficiency. However some may argue that whilst efficiencies may have been achieved, scientific management came at a cost namely its failure to address certain human aspects of work.

It is the human relations movement that started looking into the human factor as an important aspect in job design. The likes of Frank B. Gilbreth and his wife Lillian M. Gilbreth, performed extensive studies and research into the psychological implications of work, together covering and drawing early attention to aspects such as worker motion, fatigue and ergonomics amongst several other human-factor related aspects [5] .

The Hawthorne studies conducted on worker behavior and motivation by George E. Mayo contributed immensely to the establishment of Human relations management with the discovery that encouragement, teamwork and morale played an integral role in achieving results leading to productivity improvement [4].

The resultant formation of Human relations management opposed much of Taylor's traditional scientific management systems by viewing it as inadequate treatment and utilisation of human assets. In other words, the use of scientific management in companies was specified for high efficiency regardless of worker emotion, culture, fulfillment and development towards work.

Quality pioneer William E. Deming noted that the use of work measurement systems set expectations without much due consideration for workers as individuals. Individuals with needs, talents and the longing to express their contributions in the work that they performed [1].

Ultimately, Mayo, along with the other pioneers discussed above, believed in a simple yet unequivocal statement in that if workers were motivated, involved and supported, their performances could surpass what was established using the traditional scientific management methodology.

Silos [6] and Sun, et al [7] state that employee involvement is a process designed to empower members in an organisation to make decisions and solve problems. The involvement of all employees makes the drive towards achieving the objective much smoother and more efficient. If employees are equipped with the necessary skill to accomplish tasks they are able to further enhance the quality achieved by the organisation. According to Yan and Zhang [8], to successfully implement a strategy on quality, it is essential to get the holistic involvement of the workforce.

According to Besterfield, et al [9], Stevenson [4] and Sun, et al [7]; T.Q.M. (Total Quality management) is a philosophy used to involve everyone in the company in a continual effort to improve quality and achieve customer satisfaction. To this end, T.Q.M. can be viewed as the art of managing the whole to achieve brilliance requiring a disciplined approach, fundamental management techniques, existing improvement efforts and technical tools [10].

Three highlighted obstacles to the implementation of T.Q.M. according to Suganthi and Samuel [11], Stevenson [4] and Kelemen [12] are; (a) Lack of employee involvement, (b) Lack of workforce motivation and (c) Lack of leadership.

From denoting obstacles (a-c) above, it becomes evident that the lack of employee involvement serves as one of the underlying obstacles to T.Q.M. success. It is further noted that management serves as one of the key initiators of T.Q.M.; as management must lead and provide the necessary motivation to employees, which may occur through soliciting a higher degree of their involvement.

Quality circles promote making small improvements in the performance of an element of the production system [13]. It is further noted according to Rich [13], that the word circle represents a team. In Japan the concept involved 5 to 10 employees meeting regularly to solve problems within the same working area. He further goes on to state that quality circles;

- offer job satisfaction through respect for people;
- contribute to the development of the organisation; and
- aids in fully realising and utilising employees skills and potential capabilities.

Silos [6] and Sun, et al [7], in agreement with Rich, state that forming quality circles is the first step in implementing employee involvement as the advent of a team makes a significantly positive difference in the process of improvement. The contribution of a team with a unified goal would provide greater momentum as compared to an individual effort or the effort of management alone since employees are directly involved in the process and could provide greater insight into the problem and greater effort towards its solution.

According to Tang, et al [14], in an instance, over 90% of the Fortune 500 companies were estimated to have had Quality Circle programs in the mid 1980s and over two hundred thousand U.S. workers have had Quality Circle experience during that period. However he goes on further to state that Quality Circle programs in the United States have failed in more than 60-75% of the companies whom had implemented them. This points to the fact that implementation of quality involvement programs (in this case Quality Circles) are not as straightforward and elementary as may seem. The principles underlying these philosophies may be beyond dispute; however implementation and failure of these programs is an ever present danger faced by many companies as is evidenced through above statistics within the fortune 500 companies.

The act of employee involvement embodies itself in several commonly utilised programs adopted in industry today such as kaizen (continuous improvement), employee suggestion schemes, employee empowerment, teamwork initiatives and quality control circles. Despite the name of the program or the package implemented within a company, almost all programs of improvement consist of and call for the involvement and participation of employees in decision making and problem solving [6]. With employee involvement attributed to being the baseline of emphasis within industry programs in their various forms, taking cognisance of the importance of employee involvement in isolation becomes an important factor.

3 METHOD

The methodological design for achieving the objectives of this investigative project is characterised by the following:

a) On site observations & interviews to determine the effectiveness of quality based projects encompassing employee involvement
b) The use of questionnaires to analyse the perceptions of employees regarding their participation in quality based projects.

As mentioned earlier data were collected from two separate locally based multinational manufacturing companies i.e. Company A and Company B. Using the concept of triangulation [15], which seeks to support or enhance the internal validity of an investigative project, data were collected using two distinct research methods mentioned above. These methods are further discussed individually below;

3.1 Methodology: On-site observation/Interviews

To determine the effectiveness of quality based projects encompassing employee involvement; three quality based projects were selected and observed from each of the two companies under study. Criteria selections for the projects were as follows;

- projects should encompass holistic employee participation (employees are active members of the project team from point of problem identification through to solution implementation);
- projects would have to have been undertaken between years 2011 to 2013;
- adequate amounts of data from these projects as well as its active integration in the factory should be prevalent during the on-site observation visit/interview; and
- projects should exhibit a compact number of employees (5-10) in order to collect data within the time frame allocation and to promote uniformity in project scope.

The projects were then inspected and verified on-site at each company by a member of the project team. Data on each project, in the form of Key Performance Indicators (KPI's) were collected through direct observation, consultation and from company information databases.

3.2 Methodology: Questionnaire

The perceptions of employees regarding the aspects surrounding their participation in quality based projects were solicited through the use of a closed loop questionnaire. The questionnaire will serve to provide a firsthand perspective and understanding of the dynamics and current state surrounding employee involvement in quality projects at these local companies. The formulated questionnaire consisted of 15 statements, each of which was designed to test a specific outcome as is illustrated in table 1. The questionnaire adopted a three point Likert scale with options of agree, neutral and disagree. All questionnaires were submitted during the on-site observation visits and members of the project team remained on site during its completion to provide any necessary support that may be required by the respondents.

Table 1: Statements in questionnaire and their distinct link to an outcome

No.	Statement	Outcome
1	I have been or am involved in a quality project	Outcome 1:To ascertain primarily, if the companies within this study adopt employee involvement strategies in quality projects
2	I think I can be more involved in quality projects	
3	My company emphasises staff involvement in quality projects	
4	Shop floor staff are involved in most quality projects	
5	I feel responsible for the success of the project	Outcome 2:To determine the success or failure of quality projects with holistic of employee involvement
6	All the quality projects that I am involved in complete their objective	
7	The projects completed were made possible largely due to people involvement	
8	My manager/team leader is the only reason the project ultimately succeeds	Outcome 3:To determine the employees perception of quality involvement
9	People should not be involved in quality projects as it is the job of the quality department	
10	I want to be involved in as many quality projects as is available	

No.	Statement	Outcome
11	From my view, being involved in a quality project was a value adding experience	
12	I am involved but my ideas/opinion are not always taken into account	
13	I get a significant amount of time to address quality projects	Outcome 4:To assess the broader culture of employee involvement in quality projects and management styles adopted
14	I receive adequate recognition for my efforts within quality projects	
15	I am aware of other quality projects plant wide	

4 ANALYISIS OF DATA

4.1 Quality based projects encompassing holistic employee involvement

In order to determine the effectiveness of quality based projects encompassing holistic employee involvement, a total of six quality based projects with holistic employee involvement were selected (three from each company) and studied through the onsite observation/interviewing methods discussed above. A short synopsis of each of the individual projects along with their results is presented in table 2.

Table 2: Individual project synopsis

Project 1: Downtime reduction

Company:	A
Project outline:	Reduce downtime on machine through root cause analysis and team implementation of solution
Condition before project:	22.4 hours per month of downtime
Project target:	Reduce downtime to 11.2 hours per month
Value to reduce by:	11.2 hours of downtime per month
Actually achieved:	10 hours per month

Project 2: Defective carton reductions

Company:	A
Project outline:	Reduce number of defective cartons through a team based implementation and training
Condition before project:	128 defective cartons per annum

Project 2: Defective carton reductions (continued)

Project target:	Reduce to 0 defective cartons per annum
Value to reduce by:	128 defective cartons
Actually achieved:	24 defective cartons per annum

Project 3: Reduction of carton waste

Company:	A
Project outline:	Reduce number of cartons scrapped for negligible reasons through team brainstorming exercise and implementation of standardised procedure for discarding of cartons
Condition before project:	42.19kg waste per week
Project target:	Reduce to 20 kg waste per week
Value to reduce by:	22.19kg
Actually achieved:	14.3 kg waste per week

Project 4: Reduction of costs associated with de-rusting of parts

Company:	B
Project outline:	Team to implement FIFO system to reduce rusting of parts and hence cost associated with process of de-rusting parts prior to production
Condition before project:	R6825.60 de-rusting cost per month
Project target:	Reduce to R2000 per month
Value to reduce by:	R4825.60
Actually achieved:	R138.08 de-rusting cost per month

Project 5: Reduction of defective components

Company:	B
Project outline:	Reduce scratch defects on components due to internal causes through team based planning, implementation and department wide training
Condition before project:	15 defects per month
Project target:	Reduce to 0 defects per month
Value to reduce by:	15 defects
Actually achieved:	3 defects per month

Project 6: Reduction of downtime for line process

Company:	B
Project outline:	Reduce downtime on engine pipe process through team observation, analysis and collective implementation of proposal
Condition before project:	95.7 minutes per month
Project target:	Reduce to 10 minutes per month
Value to reduce by:	85.7 minutes
Actually achieved:	10 minutes per month

Whilst it can be established from the table above that Projects 1, 3, 4 and 6 meet and exceed their proposed target value; projects 2 and 5 approximate towards their target values showing levels of improvement.

The effectiveness for each of the projects will be computed by providing a simple percentage of the actual achieved result versus the target value set and will be computed using either of the below adapted formulae (1 or 2);

If actually achieved results do not exceed the project target;

$$effectiveness\ of\ project = \left(\frac{actually\ achieved}{project\ target}\right) \times 100 \qquad \textbf{(1)}$$

Alternatively, if actually achieved result exceeds the project target;

$$effectiveness\ of\ project = 100 + \left[\left(\frac{project\ target - actually\ achieved}{value\ to\ reduce\ by}\right) \times 100\right] \qquad \textbf{(2)}$$

The effectiveness for each of the six quality based projects encompassing holistic employee involvement are presented graphically in figure 1 below.

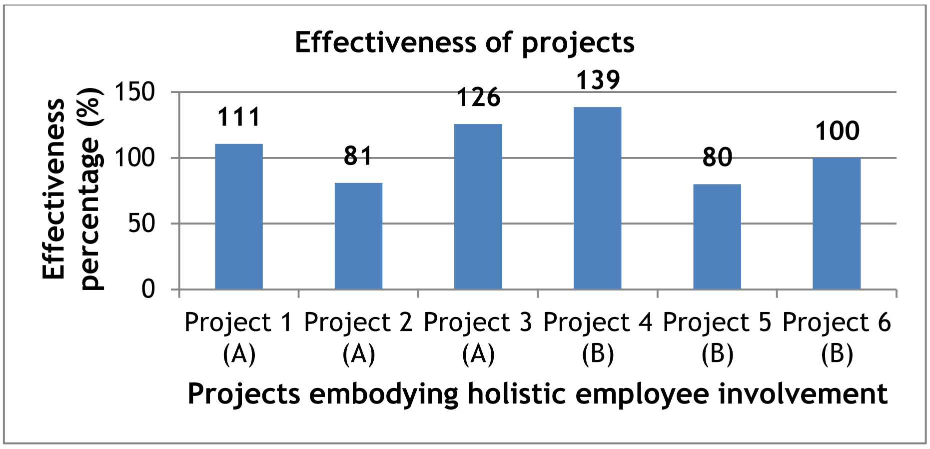

Figure 1: Effectiveness of projects with holistic employee participation at both companies

By referring to figure 1, the point which becomes evident through the collective analysis of the effectiveness for all six projects involving employees; is that both companies on average, display similar levels of overall success in their projects, although operating in vastly differing industries, conditions and cultures. The universality of success seen from the projects covered in this study (emphasising employee involvement) is noted.

Although all six projects indicate a positive trend of effectiveness through involving employees, it cannot be established thus far to what level this involvement has manifested or if shortcomings in the policy of involving employees could have impeded greater potential improvements in these projects or others.

The following analysis on the perceptions that the employees involved in these projects have on the concepts surrounding their involvement in quality based projects provides the study with a first-hand consensus in understanding and evaluating the current state of employee involvement in quality projects at the companies.

The following section will analyse data collected from responses to the questionnaire. The questionnaire itself consists of four individual sections (refer Table 1), testing different aspects regarding employee involvement in quality projects at the companies. The collective responses under each section (outcome) of the questionnaire will provide a more in-depth picture of the current state and aspects regarding the employee involvement policies in quality projects studied.

4.2 Responses to questionnaires testing aspects surrounding employee involvement in quality projects at the companies

Figure 2 presents a graphical representation of the responses testing outcome 1(To ascertain primarily, if the companies within this study adopt employee involvement strategies in quality projects) for statements 1-4 of the questionnaire;

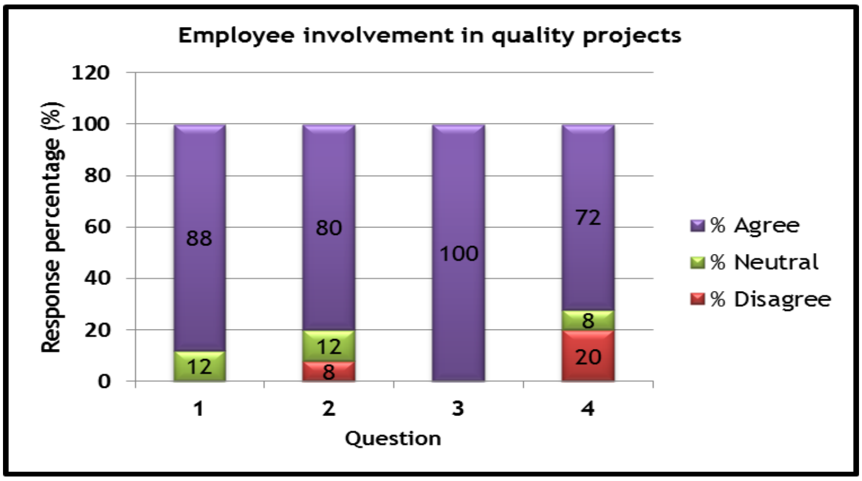

Figure 2: Outcome 1- Employee involvement in quality projects

From figure 2, it becomes quite evident that there is a strong tendency towards agreement with all four of the statements. With a percentage range from 72 to 100 for statements (1-4), it can be verified and confirmed that the involvement of employees is being adopted by both companies in their drive towards improvement.

A 100% agreement noted from the respondents with respect to statement 3(My company emphasises staff involvement in quality projects), indicates that the quality aspect is encouraged amongst employees, which augurs well since emphasis from the company on employee participation forms the basic ingredients for capturing the potential that the employee base possesses. The 72% and 80 % agreement to statement 2(I think I can be more involved in quality projects) and 4(Shop floor staff are involved in most quality projects) respectively, does indicate room for improvement in involving employees in quality endeavours.

Figure 3 presents a graphical representation of the responses testing outcome 2(To determine the success or failure of quality projects with holistic of employee involvement) for statements 5-7 of the questionnaire;

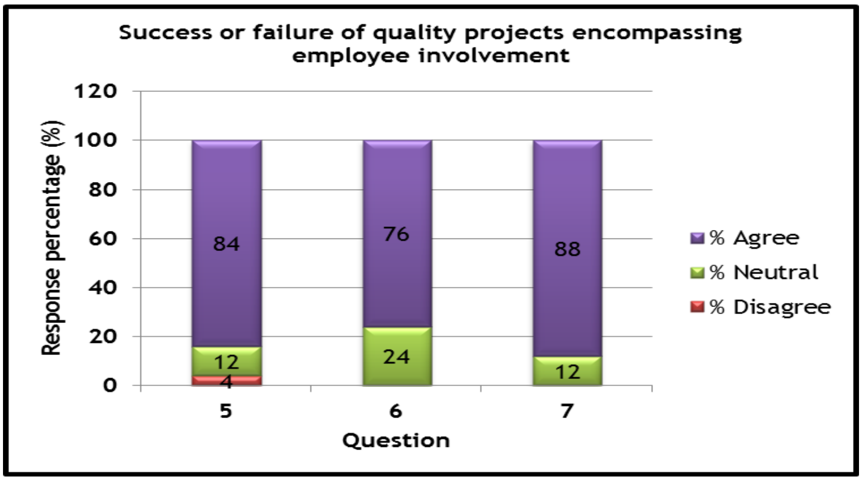

Figure 3: Outcome 2- Performance of quality projects with holistic employee involvement

From Figure 3, it is evident that all 3 statement responses depict a significant agreement to the aspects associated with the success of quality projects encompassing their (staff) involvement.

With respect to statement 5(I feel responsible for the success of the project) and 7(The projects completed were made possible largely due to people involvement), an 84% and 88% agreement toward these statements were noted respectively. This indicates that the employees have a strong sense that their involvement within quality projects is vital and their contributions are important factors in determining final project completion and success. This also indicates favourably to employee involvement being one of the critical success factors responsible for the high levels of effectiveness seen within the six projects.

A 24% disagreement in statement 6(All the quality projects that I am involved in complete their objective) does indicate that although employee involvement is evident in quality projects, it may not be completely integrated in a manner that ensures all projects completely meet their objective. A further consideration to this response is that employee involvement in isolation does not guarantee a project will succeed or meet its objective. There are several contributing factors key to the success of a quality project such as; strong leadership, teamwork, power sharing and morale, these must function as a framework alongside employee involvement in order to reach success.

Figure 4 presents a graphical representation of the responses testing outcome 3(To determine the employees perception regarding their participation in quality based projects) for statements 8-12 of the questionnaire;

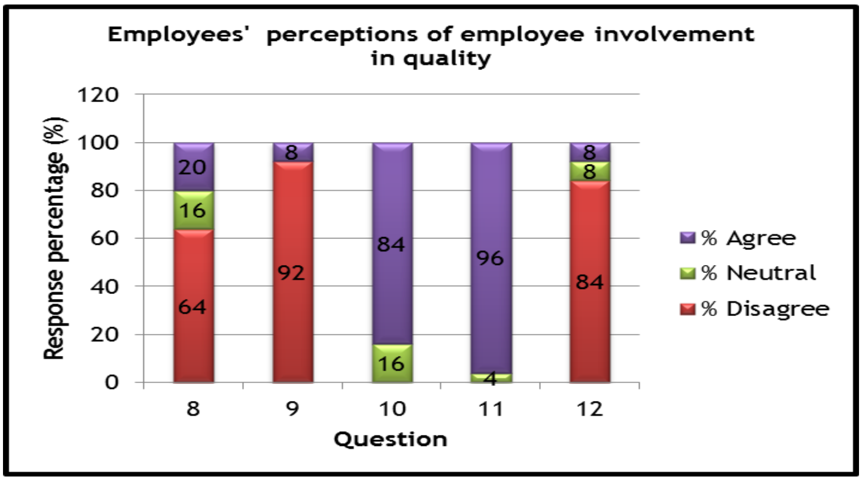

Figure 4: Outcome 3- Employee's perception of their involvement in quality

From figure 4, statement 8 incurs the most spread out distribution of responses whilst the responses for statements 9, 10, 11 and 12 lean towards a particular view. The 20% in agreement and 16% neutral response evident in statement 8(My manager/team leader is the only reason the project ultimately succeeds), suggests that some employee's feel that ultimately a project involving employees will only succeed because of their team leader or manager and not due to their own input. This proves an interesting proposition as several quality theories [1] require that management provide the necessary freedom for employees to express themselves through projects and feel the sense of accomplishment which they should attribute to their own efforts without the reluctance or mental model of wanting to equate the success of a project to a senior member of management.

In direct contradiction to the negative response to statement 8, a more positive response consensus from statements 9-12 is noted. The high percentages of disagreement obtained for statements 9(People should not be involved in quality projects as it is the job of the quality department),the agreement to statement 10(I want to be involved in as many quality projects as is available),the strong agreement to statement 11(From my view, being involved in a quality project was a value adding experience) and lastly the disagreement to statement 12(I am involved but my ideas/opinion are not always taken into account) collectively indicate that employees possess strong awareness of their input in quality and a willingness to express their commitment to quality projects.

Thus, it can be ascertained that employees have grown to become extremely knowledgeable concerning their contribution in quality and view the aspect with a willing and a positive demeanour when involved. Ultimately, this provides important information as, although both companies operate in differing environments, structures and cultures, the same willingness and affirmative reactions are seen when analysing the collective stance on the aspect of employee involvement in quality projects.

Figure 5 presents a graphical representation of the responses testing outcome 4(To assess the broader culture of employee involvement in quality projects and management styles adopted) for statements 13-15 of the questionnaire;

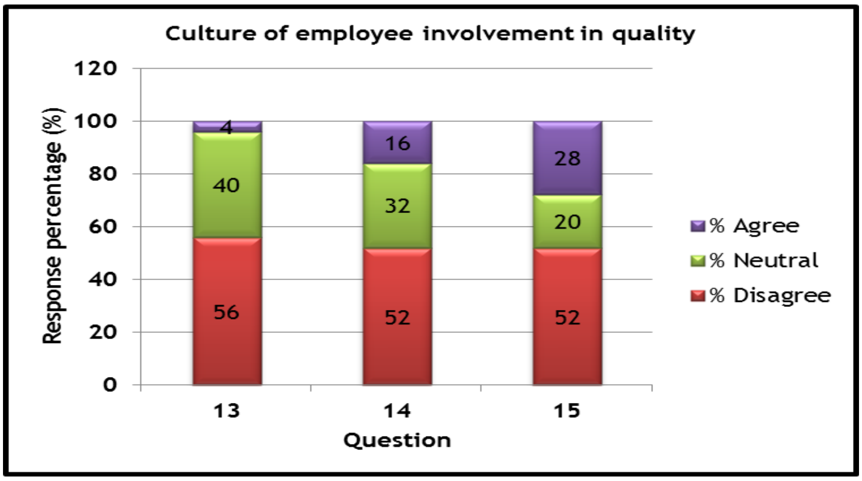

Figure 5: Outcome 4- Culture of employee involvement in quality and management styles

From figure 5, there is a widely distributed view held by employees which is indicated by the percentage contribution to all three statements of response. The particularly negative response to statement 13(I get a significant amount of time to address quality projects), indicate that management may not wholly or in its entirety provide the resources necessary to enable the completion of quality tasks. One aspect key to employee involvement is that management provide the necessary avenues to support the endeavour. Employees perceive that not enough time is provided for the completion of quality projects. Whilst an employee involvement policy is commendable, providing inadequate support to enrich and develop such a policy may prove to be detrimental in future.

Furthermore, employees' negative responses to statement 14(I receive adequate recognition for my efforts within quality projects), indicate that inadequate amounts of recognition for efforts are obtained. Whilst it cannot be assumed that there is no recognition in place at companies (as is indicative of the 16% of respondents indicating favourably to being recognised), undertaking employee involvement policies require that it become centrally and constantly reinforced and to this end, maintaining and developing new methods of rewarding and recognising employees for their contributions are warranted. Finally, the negative response to statement 15(I am aware of other quality projects plant wide), is indicative of management not adequately initiating a platform from which all quality projects may be displayed and understood. Immersing the entire organisation in learning and awareness may lead to a breeding ground for new ideas and inevitably a culture of ever improving quality.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

From the above analysis the following conclusions can be drawn:

- Quality based projects that encompass holistic employee participation generally attain due levels of success.
- Companies within this study are making a concerted effort to involve employees' on a more holistic level. Employees respond to this effort by acknowledging that they would like to be more involved in quality projects - the underlying message is clear in this regard; employees whom have been involved in quality projects and having experienced success and accomplishment beyond their regular functions have a motivation to want to be further engaged.
- Employee involvement has positively influenced the chance of success for the quality projects under study although, it is dually noted that employee involvement in isolation will not achieve optimal results, a complementary framework of other principles must be integrated within employee participation in order to reach further success.
- Employees from a local context are growing in their knowledge of quality aspects. It becomes a feasible proposition for companies to tap into this array of hidden skills and attributes that employees possess beyond their regular activities.
- Employees involved in the projects agree that the aspect surrounding their involvement has been a fulfilling and value adding experience to their own growth and development.
- The culture surrounding the sound implementation of holistic employee involvement in quality is still shown to be a developing aspect in local industry and aspects such as time allocation, recognition, awareness and strategic emphasis requires continued support.
- Two industry organisations that differ culturally, operationally and functionally have been shown to reach levels of success in the sample of projects studied from adopting policies of employee participation in quality.

5.2 Recommendations

From the study and the analysis the following recommendations can be made:

- Locally based companies whom do not possess employee involvement strategies in quality based initiatives should explore such avenues, as projects involving employees have been shown to achieve levels of success.
- Management must ensure that the resources to sustain such a program are available to cultivate and sustain the growth of employee involvement (aspects such as structured planned project timetables, adequate time allocation, team meetings and consultation, necessary training and support as well as budget allocations must be made available to the endeavour, since an ad hoc policy of employee involvement without due commitment and support will be fraught with failure.
- In adopting a policy of employee involvement in quality endeavours, certain barriers of power must be relinquished to the workforce. This ensures freedom for employees to express their skills and abilities, thus providing a sense of accomplishment, growth and learning to the employee.
- Rewards and recognition (in forms that are feasible to the company) should be allotted to employees in recognition of success or completion of an objective; this sustains the morale and enthusiasm for continual improvement and involvement.

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1129-14

HOLONIC CONTROL SYSTEM: A PROPOSED SOLUTION FOR MANAGING DYNAMIC EVENTS IN A DISTRIBUTED MANUFACTURING ENVIRONMENT

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ABSTRACT

Due to globalization, manufacturing of products is no longer a local activity done by a single company but rather a distributed venture as more firms are realizing the need to improve their flexibility and agility. The paradigm of e-manufacturing is gaining popularity among researchers and manufacturers who aim to improve their market share and shop floor visibility by belonging to larger collaborative networks. However, real-time events which lead to operational disturbances in a plant remain a challenge most manufacturers face since they result in deviation from initially prepared process plans and schedules, rendering them invalid before they can be launched on to the shop floor for implementation. The paper presents a Holonic Control System (HCS) as a proposed solution to managing this pandemic. The research focused on manufacturing firms in the Western Cape of South Africa which belong to the tooling industry. Cited in this paper are holonic architecture together with the success factors and barriers to implementing holonic control systems in South Africa. Results of the proposed system were generated by a simulation model and revealed that delivery time and resource utilization were improved by adopting the system.

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1 INTRODUCTION

Customers make the business world go round. It is common knowledge in the business world today that customers are the life blood of organisations. Lack of customers or depletion of customer base has seen businesses fold up at an alarmingly fast rate. The question that remains for sustained survival in the cutthroat business environment is; what needs to be in place to ensure that customers stay? The answer that has been heralded of late from a manufacturing perspective is the design and installation of e-manufacturing systems. Nyanga et al. [1] proposed the installation of an e-manufacturing system as a viable solution for facilitating manufacturers in South Africa to form collborative networks. These systems are expected to facilitate enterprise integration, cooperation among organizations and distributed manufacturing via the internet thus ensuring customer needs are met with improved shop-floor visibility.

E-manufacturing systems can also aid in generating optimal process plans and schedules for manufacturing goods in response to customer demand through the use of Multi Agent Systems (MAS) [2]. However, during tool room operations, events rarely go as expected as scheduled orders may get cancelled while new jobs are inserted. In addition, certain machinery for production may become unavailable due to breakdowns or scheduled maintenance, while newly purchased resources can be introduced. In some cases, scheduled tasks may take longer than anticipated. Other uncertainties like operator absence, unavailability of tools and depletion of raw materials are possibilities. These unforeseen dynamic events on the shop-floor can render an optimal process plan and schedule generated earlier after considerable effort unacceptable. If this happens, a new schedule must be generated to restore system performance and maintain achievement of business goals competitvely. A possible solution to this challenge is the design and installation of Holonic Control Systems (HCS). According to Wyns [3], these applications promise benefits that a holonic organizations provide to living organisms and societies; stability in the face of disturbances, adaptability and flexibility in the face of change, and the efficient use of available resources.

The paper presents a proposed Holonic Control System for the South African Tool, Die and Mould-making (TDM) sector in the Western Cape Province which enables real-time process planning and dynamic rescheduling in a distributed manufacturing environment. The organisation of the paper is as follows: firstly the concept of holonic manufacturing is discussed, then the proposed Holonic Control System architecure is presented together with the success factors and barriers for its implementation and lastly there is a presentation of the system's simulation results to support system efficacy.

2 THE HOLONIC CONCEPT

In a quest to describe how social and biological systems evolve, Koestler [5] initiated the concept of a Holon. In his study, he observed that living and organizational systems are made up of entities where almost every discernible element can be simultaneously perceived as a whole (an essential autonomous body) and a part (a cooperative integrated section of a larger more capable body). These systems were observed to adapt to new environments by evolving through self-reorganization and growing by extending themselves in an effort to satisfy internal and external changing conditions. This evolution resulted in stable, self-resilient and more capable systems than the ones that initially existed.

With these findings, Koestler [5] proposed the term "holon" which is a combination of Greek prefix "holos" meaning whole and Greek suffix "on" meaning part to describe such autonomous and cooperative elements of a system. Decades later, a Japanese scientist, Suda [6], indicated that such properties would be very essential for a manufacturing operation or system subject to increasing demands and rapidly changing conditions. He redefined a Holon in the manufacturing context as a building block of a manufacturing system for designing and operating elements [7].

2.1 Holonic Manufacturing System

Based on the findings of Suda's preliminary work, researchers have been motivated to translate the holonic concept to a manufacturing set-up. In 1994, a Holonic Manufacturing System Consortium (under the Intelligent Manufacturing Systems project) was formulated which constituted of research institutes, universities and industrial partners from Europe, America and parts of Asia. The purpose of this consortium was to conduct research by creating test-beds, prototypes and applications which employ holonic systems properties in a manufacturing set-up so as to see the benefits before industrial adoption. During these studies, a set of definitions were proposed for the holonic concept in a manufacturing perspective [8]. These key terms are defined in Table 1.

Table 1: Holonic Manufacturing Systems terms

Term	**Definition**
Holon	*An autonomous and cooperative building block of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects. The Holon consists of an information processing part often a physical processing part (Figure 1).*
Autonomy	*The capability of an entity to create and control the execution of its own plans and strategies.*
Cooperation	*A process whereby a set of entities develop mutually acceptable plans and executes those plans.*
Holarchy	*A system of holons that can cooperate to achieve a goal or objective. The holarchy defines the basic rules of the cooperation of the holons and thereby limits their autonomy.*
Holonic Manufacturing System	*A holarchy that integrates the entire range of manufacturing activities from order booking through design, production and marketing to realize the agile manufacturing enterprise.*

2.2 Holon structure and properties

Wyns and Langer [9] proposed a generic structure of a Holon as illustrated in Figure 1. A Holon can interact with its environment which may consist of human operators, machinery and other holons via specific communication protocols. Humans communicate with the Holon via the human interface while other holons communicate with the Holon via the inter-holon interface. Physical components and machinery can be controlled via the Holon's physical part. Hence, Holons are computerized entities capable of doing specific tasks within a manufacturing environment on behalf of their users.

When holons cooperate with each other to achieve a goal, they are said to form a holarchy. Holarchies can be created or dissolved dynamically depending on the current needs of a manufacturing process. This key feature makes Holonic Manufacturing Systems possess the following essential properties:

- Self-organization: Holons enable manufacturing units to collect and arrange themselves in order to achieve a production goal.
- Reconfigurability: a manufacturing unit's function can be altered in a timely and cost effective manner in response to sudden changes or new demands.

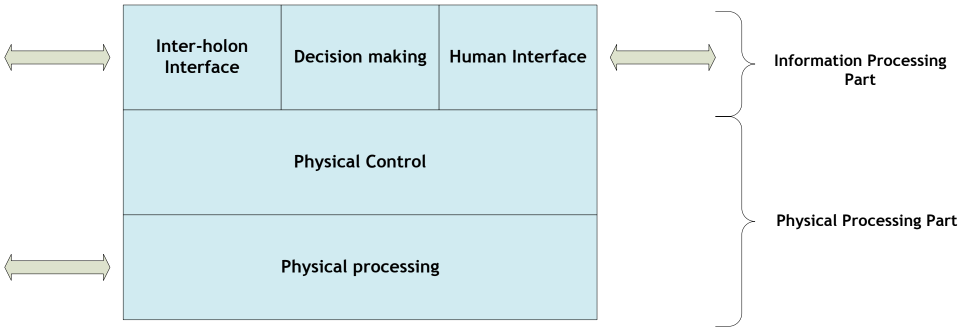


Figure 1: General Structure of a Holon [9]

2.3 Reference architecture

The first Holonic Manufacturing System architecture was proposed by Wyns [3], [4], during his studies at Katholieke University of Leuven. The architecture, referred to as PROSA (Product Resource Order Staff Architecture) consists of three basic Holons and an optional staff Holon as key components defining a manufacturing system. The identified basic Holons were defined as:

- Product Holon (PH): carries all the information about the products in a manufacturing system. The data includes bill of materials, process plans, levels of quality and product lifetime.
- Resource Holon (RH): represents the value addition part of the system which identifies the machinery, equipment, operators and transporters in a manufacturing system.
- Order Holon (OH): represent the customer requirements which are translated to system tasks.

These basic holons exchange production system information in a timely manner as shown by the architecture illustrated in Figure 2. Staff Holons (SH) representing human functions in a system can be added to supply expert knowledge to other Holons. These Staff Holons represent tasks that a competent person can do in a manufacturing facility.

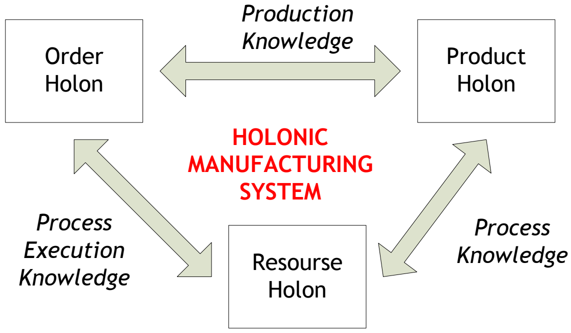


Figure 2: HMS Reference Architecture [4]

This architecture attracted many researchers and scholars who used it to build holonic control systems for different manufacturing settings.

2.4 Holonic Control System prototypes and applications

Extensive work and developed prototypes addressing control in planning and scheduling of manufacturing systems using the holonic manufacturing system approach exist. Chirn and McFarlane [10] built a holonic control system for a robotic assembly cell so as to enable it to cope with increased requirements of production change. In an effort to improve material handling operations, Babiceanu [11] developed a holonic based control system for generating a feasible schedule for the material handling resources given real-time constraints. A holonic control system was also developed by Roulet-Dubonnet and Ystgaard [12] for a flexible reconfigurable assembly cell. The study was conducted to solve the problem of frequent changes in the product spectrum and size. In other studies, holonic scheduling was successfully implemented in a die casting flow-line manufacturing system by Bal and Hashemipour [13]. Results of all these studies portrayed that uptime efficiency and the production rate of the manufacturing systems were significantly improved by the approach. It was observed in the studies done that the Holons utilized in the systems helped to improve the reaction of the systems to changing market or business requirements, the production of products more efficiently and better utilization of available resources.

2.5 Holonic Control System for South Africa TDM sector

Most firms in the South African tooling industry have been failing to compete with companies in Asia and Europe who have adapted to a modern manufacturing environment and embraced 21st century manufacturing principles and technologies that allow them to be competitive in a global arena. An Engineering Artisan Article [14] revealed that one of the key success factors for firms doing well in the tooling industry is product-time-to-market. However, according to Geyer and Bruwer [15], a majority of South African manufacturers in the tooling industry are uncompetitive with lead times and due date reliability resulting in them losing market share to firms in more developed nations who are adopting industry best practices. The main reason for this challenge is that operational disturbances resulting from late delivery of raw materials, machine failure, rush orders and market changes affect the smooth running of operations. The currently adopted planning and scheduling systems in South African tool, die and mould making organizations fail to handle such dynamic changes. This leads to compromising of system availability which results in late order deliveries.

The problem creates a need for the adoption of new computerized planning and scheduling systems which facilitate system reconfigurability, self-organization and real-time response to changes in the business environment, a gap holonic control systems can fill.

3 METHODS AND MATERIALS

Giret and Botti [16]'s proposed methodology for analysis and design of a Holonic Manufacturing System was used in the study. It involves establishment of the system requirements and design of the Holonic Control System architecture. The flow diagram for the procedure is presented in Figure 3.

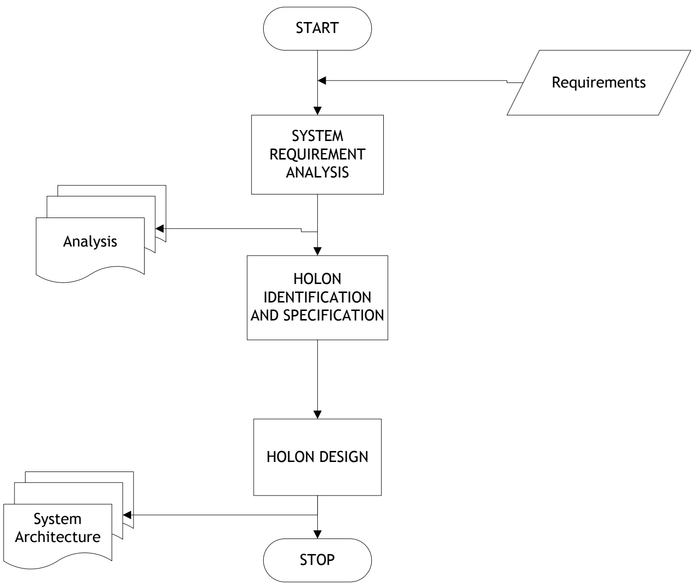


Figure 3: HMS Analysis and design stages [14]

To establish the requirements for the system, in-person, structured interviews were conducted. This method was specifically chosen because according to Sullivan et al. [17], interviews allow researchers to obtain large amounts of data and perform in-depth probing. The method helped to get information for model or system building. The purpose of the interviews was to establish frequently experienced operational disturbances in the tool and die industry in South Africa. The tooling industry in South Africa serves the Packaging, Food, Automotive, Mining and Plastic Forming industries. The Delphi or Expert Opinion methodology was used to select the appropriate respondents who were operations management personnel in the South African tooling sector. The selection was also based on potential users of the system. For the different industrial sectors, a tool room was selected to represent each sector making a selected group of five firms. Similar close-ended questions were used so as to compare the responses. To encourage participation of respondents, the purpose of the study was explained while confidentiality of findings was assured.

The findings from the interview would help in the systems analysis and design phase where a blue print of the system functionality would be presented in the form of a use case model. The analysis phase results in identification of the Holarchies, the Holons in the system and eventually the Holonic Control System architecture.

4 ANALYSIS AND DESIGN OF HOLONIC CONTROL SYSTEM

According to findings of the interviews, the most significant operational disturbances experienced by firms in the TDM sector were:

- Machine breakdown
- Raw materials and spare part stock outs
- Work build-up
- Equipment damage

The use of inappropriate maintenance procedures, late delivery by suppliers, supplier transportation problems, rush orders and supplier production problems were attributed to be the main root causes for the experienced operational disturbances. These findings were used to map the holonic control system requirements.

4.1 Holonic Control System requirements

Figure 4 summarizes the relationship existing between the dynamic events and operational disturbances experienced in the South African tooling industry. This helped establish the corresponding engineering functional requirements the holonic control system should address. To address the identified operational disturbances and their root causes, the Holonic Control System should facilitate Capacity Management of resources, Inventory Management of raw materials and spare parts and Maintenance Management of system resources.

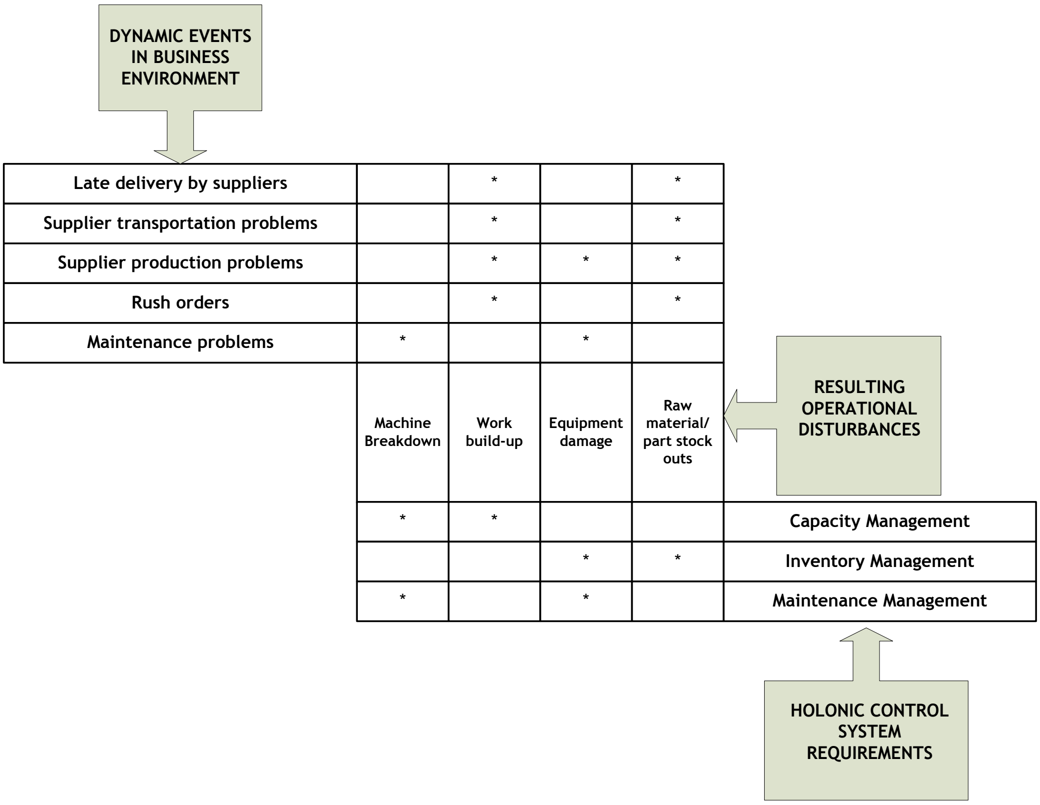


Figure 4: Holonic Control System Requirements

4.2 Use Case Model

Based on the derived Holonic Control System requirements, a use case model was developed to outline the different functions of the system. According to Fletcher et al. [18], use case models help in defining the system goals and domain of operation. A final use case model was developed as illustrated in Figure 5.

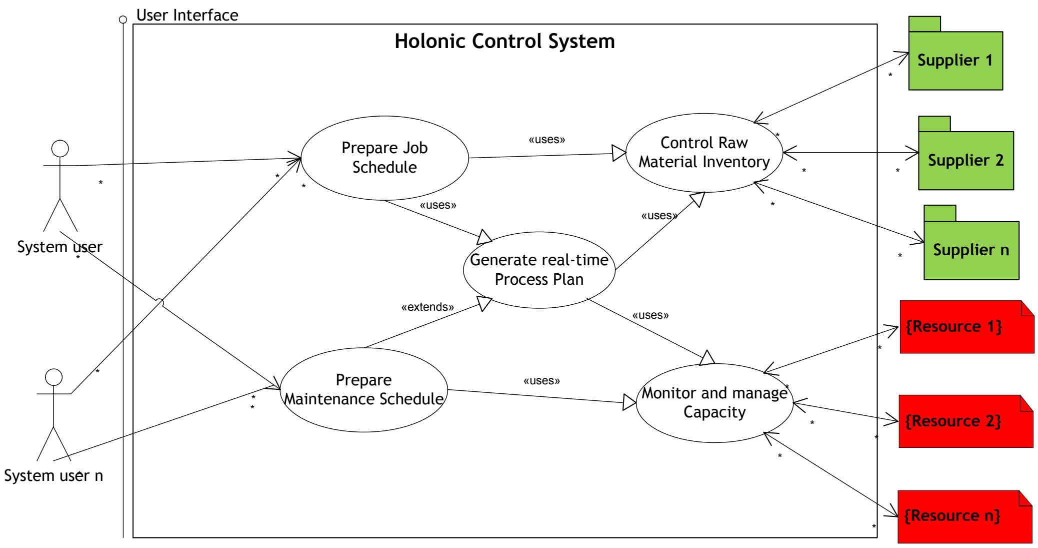


Figure 5: Holonic Control System Use Case Model

The main goals of the system as shown in the use case model are to prepare a schedule for orders and maintenance of machinery in the distributed manufacturing environment. The job scheduling function depends on real-time process planning which uses the raw material inventory control and capacity control functions. System users, who can be operations management personnel, interact with the system by obtaining a feasible job schedule and maintenance plan. The inventory control function is linked to the different suppliers while the capacity monitoring and management function is linked to all the resources (machinery) used in the entire distributed manufacturing system.

4.3 System Holarchies and Holons

The system functions derived from the use case model were used to define the system Holarchies. Each Holarchy contains a set of Holons responsible for accomplishing specific tasks which ultimately solve the sub-problem addressed by the Holarchy. The main Holarchies identified for the proposed Holonic Control System were:

- Inventory Control Holarchy
- Resource Planning Holarchy
- Process Planning Holarchy
- Job Scheduling Holarchy
- Maintenance Management Holarchy

Table 2 summarizes the Holons identified in each Holarchy.

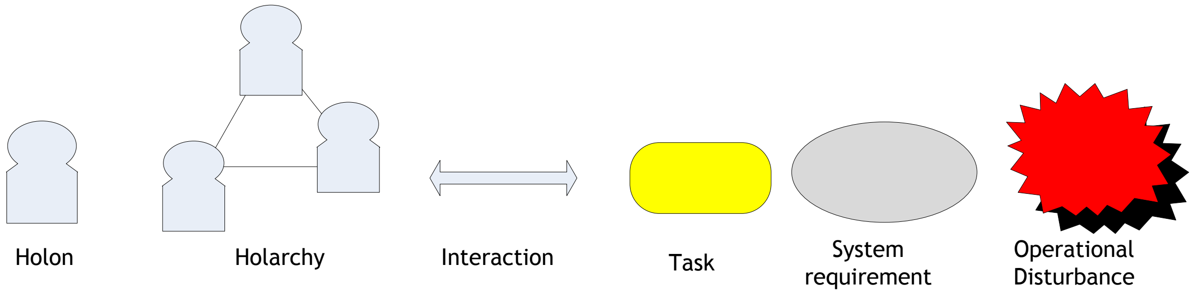
Table 2: Identified Holarchies and Holons

System requirement	Identified Holarchies	Identified Holons
Inventory Management	Inventory Control	• Supplier Holon • Purchasing Holon • Inventory Level Holon • Buffer Holon
Capacity Management	Resource Planning	• Resource Holon • Supervisor Holon • Availability Holon
	Process Planning	• Bill Of Materials Holon • Resource Holon • Routing Holon • Availability Holon
	Job Scheduling	• Order Holon • Routing Holon • Scheduling Holon
Maintenance Management	Maintenance Management	• Resource Holon • Availability Holon • Maintenance Planner Holon • Inventory Level Holon

A Holon can belong to more than one Holarchies. The Inventory Level Holon, Availability Holon and Resource Holon each belong to two or more Holarchies.

4.4 Holonic Control System Architecture

An interaction model was utilized to present the system architecture for the proposed Holonic Control System. The notation for the symbols used in the system architecture is shown in Figure 6.The architecture is illustrated in Figure 7 below showing how the different Holarchies communicate and coordinate their functions in response to different operational disturbances occurring in the business environment.



Key

Figure 6: Notation

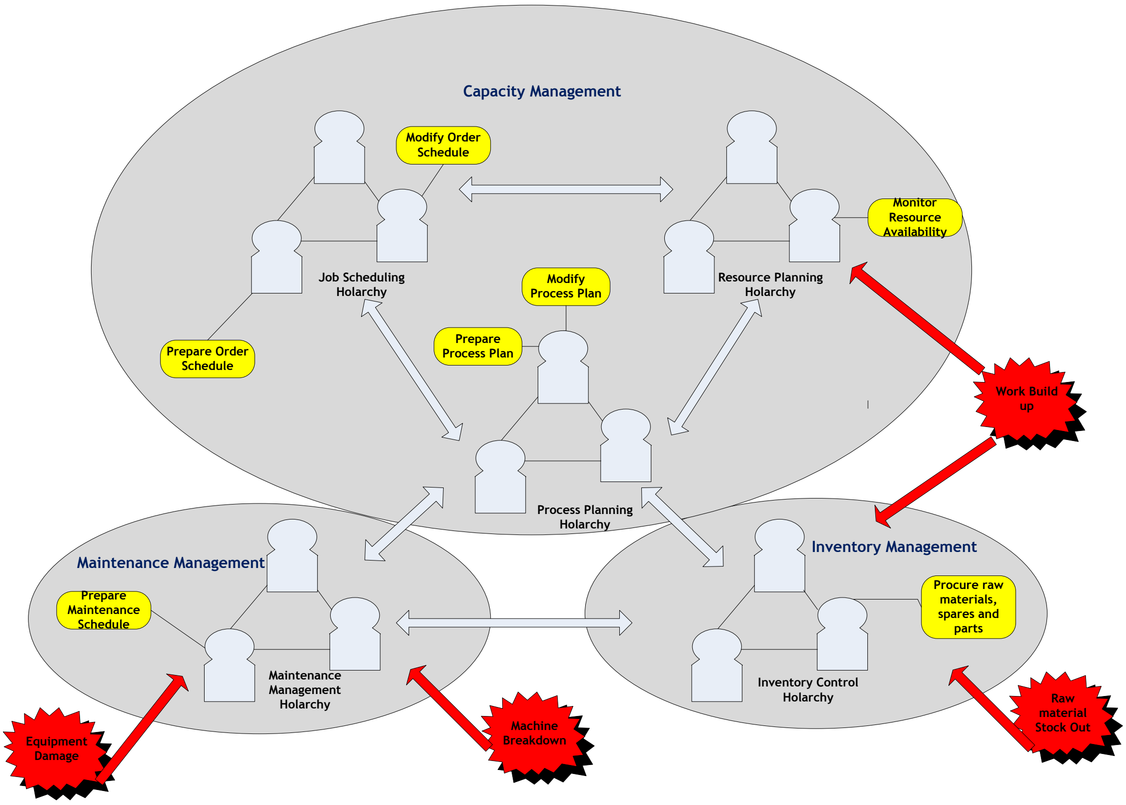


Figure 7: Holonic Control System Architecture

4.4.1 Inventory Control Holarchy

The purpose of this Holarchy is to manage and control raw material inventory so as to avoid the occurrence of stock outs during production. Four staff Holons which cooperate in this Holarchy are:

- **Supplier Holon (SH)**: the Holon represents the different possible suppliers for raw materials in the production chain. They supply information of the catalogue of products and their prices.
- **Purchasing Holon (PH)**: the Holon is responsible for procuring raw materials for an organization before stock outs occur. This is done by bidding different suppliers for the provision and selection of the best supplier option based on set criteria.
- **Inventory Level Holon (ILH)**: the Holon is responsible for monitoring the stock levels of each raw material. Once the reorder level of a raw materials and supplies is reached, the Inventory Level Holon communicates with Purchasing Holon to place an order from a supplier for replenishment.
- **Buffer Holon (BH)**: the Holon is responsible of checking an unanticipated sudden shortage of raw materials due to defective or contaminated raw materials resulting from poor operational procedures, poor storage or material handling techniques. When this occurs the Holon immediately updates the Inventory Level Holon on the sudden decrease in stocks.

4.4.2 Capacity Management Holarchies

The Capacity Management Function consists of three Holarchies which are the Resource Planning Holarchy, Process Planning Holarchy and the Job Scheduling Holarchy.

1. Resource Planning Holarchy

The purpose of this Holarchy is to monitor and manage the production resources which include machinery, equipment and transporters so as to maintain high levels of system availability. The Holarchy comprises of one basic Holon and two staff Holons which are:

- **Resource Holon (RH)**: this basic Holon represents the different machinery and equipment which are being utilized in the production process. This Holon will be directly connected to the set of physical equipment available on the shop floor in the different tool rooms using the system. In the case of a machine breakdown or maintenance procedure, the Holon renders itself unavailable.
- **Supervisor Holon (SH)**: this Staff Holon represents the operations manager's role in a workshop. It has a bird's eye view of the entire set of resources and processes.
- **Availability Holon (AH)**: this Staff Holon is responsible for constantly monitoring the availability of all the Resource Holons in the system so as to update the Supervisor Holon on the system status.

2. Process Planning Holarchy

The purpose of this Holarchy is to generate a real-time, optimal process plan for existing and new work orders. The Holarchy comprises of one basic Holon and two staff Holons which are:

- **Routing Holon (RH):** this Staff Holon is responsible for selecting the best sequence of operations for doing a job based on the current available resources. In the case of a sudden unavailability of a specific resource, the Holon receives communication from the Availability Holon and generates a new sequence. The same process occurs when more capacity is added (new Resource Holons are introduced).
- **Resource Holon (RH)**: this basic Holon represents the different machinery and equipment which are being utilized in the production process. It is the same Holon which is being utilised in the Capacity and Maintenance Management Holarchies. In

this Holarchy, the Resource Holon provides the Routing Holon with information on set of tasks and operations it can perform.

- **Availability Holon (FH)**: This Staff Holon also belongs to the Capacity and Maintenance Management Holarchies. In this Holarchy, the Availability Holon supplies the Routing Holon with information on the availability of system resources.
- **Bill of Materials Holon (BOMH)**: This Staff Holon computes the required raw materials to fulfil an order.

3. **Job scheduling Holarchy**

The purpose of this Holarchy is to generate a real-time, optimal job schedule for all existing and new work orders. The Holarchy comprises of two staff Holons and one basic Holon which are:

- **Scheduling Holon (SH):** This Staff Holon is responsible for generating the optimal job schedule based on the process plan supplied by the Routing Holon and information from the Bill of Material Holon. The Holon uses different set criteria to generate this schedule and updates the schedule in the case of any dynamic changes caused by rush orders or machine breakdowns.
- **Routing Holon (RH)**: this Staff Holon also belongs to the Process Planning Holarchy. It constantly updates the Scheduling Holon with information on the feasible process plans which can be implemented based on current system status. A change in the process plan results in an update of the job schedule.
- **Order Holon (OH)**: this basic Holon represents the work orders currently received from clients. This information is received from the system users and triggers the manufacturing process.

4.4.3 Maintenance Management Holarchy

The purpose of this Holarchy is to manage the consistent maintenance of system resources which include machinery, equipment and transporters so as to reduce the risk caused by wear and tear. The Holarchy comprises of one basic Holon and two staff Holons which are:

- **Maintenance Planner Holon (MPH):** this Staff Holon is responsible for conducting planning of scheduled maintenance procedures for the different existing system resources based on tool life and Mean-Time to failure data.
- **Resource Holon (RH)**: this basic Holon represents the different machinery and equipment which are being utilized in the production process. It is the same Holon which is being utilised in the Capacity Management Holarchy. In this Holarchy, the Resource Holon provides the Maintenance Planner Holon with information on Mean-Time-To-Failure and shelf life.
- **Availability Holon (FH)**: the Staff Holon also belongs to the Capacity Management Holarchy. In this Holarchy, the Availability Holon supplies the Maintenance Planner Holon with information on reasons why a resource is unavailable i.e. whether a machine breakdown has occurred or a machine is due for service.
- **Inventory Level Holon (ILH)**: the Holon is responsible for monitoring the stock levels of supplies (MROs- Maintenance Repair and Operating). Once the reorder level of a raw materials and supplies is reached, the Inventory Level Holon communicates with Purchasing Holon to place an order from a supplier for replenishment.

4.5 Implementation success factors

The design and installation of a Holonic Control System requires the existence of key enabling factors which support sustainability of the system. According to Christensen [19] some of the main success factors of implementing holonic systems and these are:

- Willingness for firms to decentralize operations: McFarlane and Bussmann [20] stated that a Holonic Manufacturing System supports the distributed manufacturing paradigm which depends on a decentralized architecture. Hence, firms which require Holonic Control Systems must be willing to decentralize their operations.
- Networking of production units through enterprise integration.
- Human integration through the adoption of computerized information systems: Most manufacturing systems are still adopting manual methods for their production planning and scheduling functions. Holons can only be utilized in computerized systems.
- Training and motivation to facilitate understanding on how to utilize the technology.
- System security to ensure protection of critical production information: Holonic Systems make use of the internet for transfer of information. Although the internet has immensely improved networking of business functions, a challenge still remains on how to adequately protect the information it carries and stores.
- Sustainability through the maintenance of a consistent power supply.

4.6 Implementation Barriers

Some South African Manufacturing firms still have operational obstacles they need to overcome to successfully implement Holonic Control Systems. These include:

- Adoption of new organizational structures: most firms in South Africa adopt a hierarchical structure with bureaucratic set of procedures. Such centralized structures do not support the holonic endeavour hence firms should aim to flatten their structures.
- Flexibility through adoption of new manufacturing technologies.
- The use of the internet for distributed manufacturing
- Automation of manufacturing functions
- Evolution from manual operational procedures to computerized systems

5 SIMULATION STUDY

It is critical to measure whether the proposed system improves the operational performance of Tool, Die and Mould-making firms. However the analysis of a distributed manufacturing system is not easily achievable with the range of activities involved in the different production units. Firms involved in distributed manufacturing are usually located in different geographical settings. To overcome this challenge, a simulation model which mimics the real system can be used as a tool to conduct numerical experiments.

A simulation-based test-bed for the firms in the tooling industry was developed so as to investigate the improvements the presented Holonic Control System architecture can cause. The test-bed consisted of two modules which are:

- Simulation Module: this module represents the operations taking place in different TDM firms.
- Holonic Control Module: this module implements the defined Holarchies.

The simulation model was created using the Rockwell ARENA Research version. The package was chosen because events like machine breakdowns, rush orders or failures can be modelled easily in ARENA. The holonic control module was developed in Java using the Java Agent Development framework (JADE). The holonic control module receives signals from the simulation model regarding order arrivals, machine failures and other events. Control signals are then transferred to the simulation model from the holonic module on how best to handle events occurring in the simulation model. The model logic together with its relationship to the holonic control module is illustrated in Figure 8.

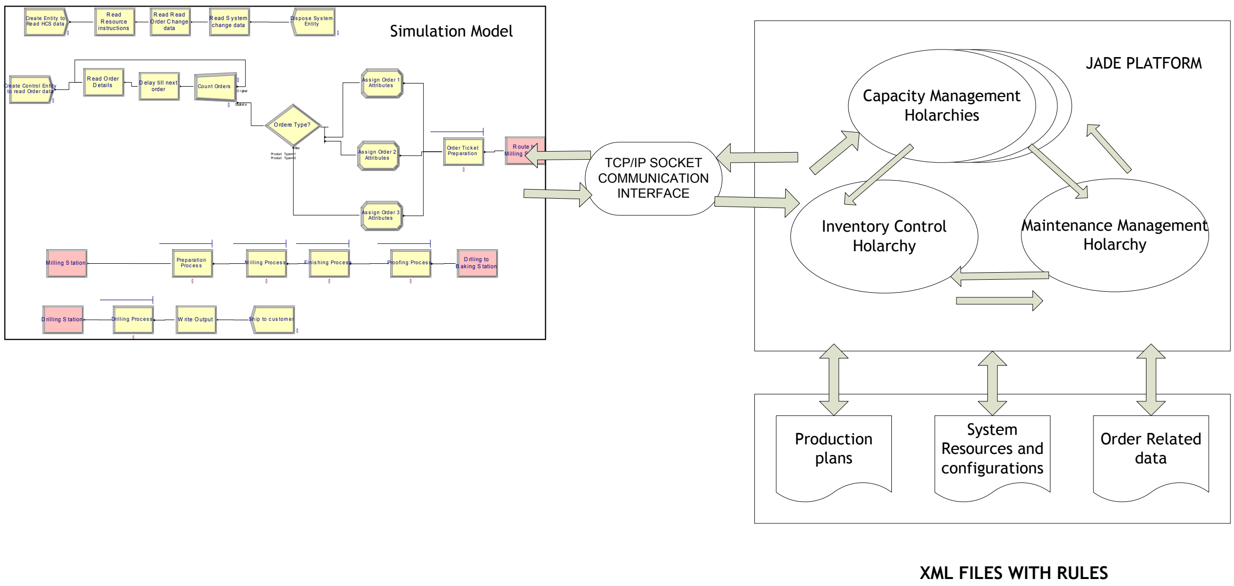


Figure 8: Simulation Model and HCS module

A comparison of results between the model without the holonic module (Model 1) and the simulation model connected to the holonic control module (Model 2) was done. The results are shown in Table 3. The throughput rates, system availability and uptime efficiency were significantly improved by using holons to manage operations.

Table 3: Summary of Results

Performance Measure	Model 1	Model 2
Throughput in 5 days	756 units	833 units
Uptime Efficiency	56%	78%
System Availability	45%	66%

The decision making algorithms for the holonic control system module is shown in Figure 9.

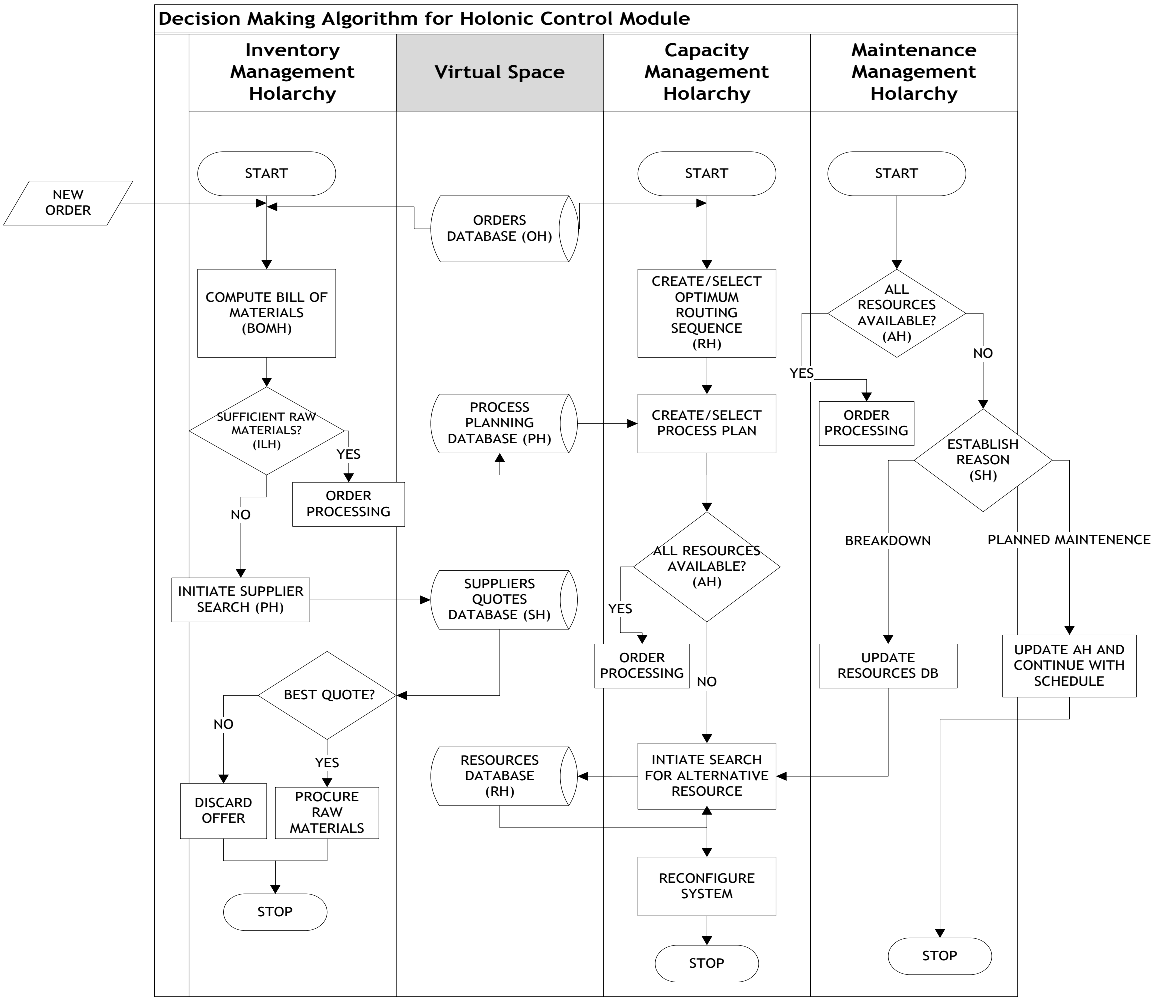


Figure 9: Decision making logic for HCS

6 CONCLUSION

Companies in the Tool, Die and Mould-making sector in South Africa can benefit from implementing Holonic Control Systems. This will enable them to withstand internal and external operational disturbances which occur during daily production and maintain high levels of system availability. The paper presented a proposed HCS architecture for the tooling industry in South Africa. Selected companies in the tooling industry belonging to the Western Cape Province of South Africa will be used for implementation and validation of the proposed system.

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EMPLOYEES VERSUS INDEPENDENT CONTRACTORS: THE APPLICATION OF PRE-EMPTIVE LINEAR GOAL PROGRAMMING TO FIND A SUITABLE STAFFING MODEL

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ABSTRACT

The skills held by the workforce of Technical Engineering Design (TED) companies are the value proposition that TED firms sell to their clients. TED firms typically use a mixed workforce of employees and independent contractors to provide flexibility in resizing their workforce, as customer demand for their services fluctuates. The workforce configuration used affects the daily, strategic and financial sustainability of TED firms, while influencing their competitiveness in winning tenders for new projects. This study developed a pre-emptive linear goal programming model to determine how employment positions should be staffed using employees and/or independent contractors for a local South African division of a global TED firm. A total of 9 dimensions were identified to evaluate the current workforce. The primary dimensions of significance were the corruption risk associated with a skilled position, strategic importance of a skill to the firm, the perceived value of intellectual property held by an employee, and skill retention costs. This study was able to determine a good workforce model of employees and independent contractors, aligned with the specific constraints and strategic workforce objectives that management of the TED firm wished to achieve.

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1 INTRODUCTION

The South African labour market is undergoing dramatic changes, seen from the introduction of the youth wage subsidy and labour unions wanting to scrap the use of labour brokers. South African business is polarised with divisions between protected and excluded workers, with businesses having to contend with on-going unrest in the labour sector and increasing labour costs [1]. Further challenges that managers need to contend with include cultural differences of a diverse South African workforce and the implementation of affirmative action that has created uncomfortable labour relations [2].

In response to these challenges, businesses have turned towards outsourcing activities that were previously performed in-house. Outsourced firms acquire skills directly themselves or further sub-contract to a third party. Outsourcing provides a risk management mechanism for business to increase its labour flexibility. It enables the use of specialised skills as and when required, which would otherwise be costly to maintain in-house. Importantly, using independent contractors frees employers of South Africa's onerous labour legislation [3].

Determining whether to classify a person as an employee or contractor is a difficult decision for a firm to make, which can impact on both the individual and the employer. Table 1 provides a comparison between common differences of employment terms.

Table 1: Common difference between employees and contractors terms of employment [4]

Policy	Employees	Independent Contractors
Layoffs	• Entitled to severance benefits. • Risk of going to the CCMA. • Strongly discouraged by unions.	• No severance compensation. • Relationship allows termination/no renewal of contract.
Firing for Cause	• Require extensive documentation and consultation before firing.	• No restrictions on manager's ability to terminate contract.
Career Development	• Training commonly provided • Promotion opportunities and pay increases	• No additional training provided. • No career ladder access in firm.
Performance Management	• Annual performance review, with clear targets and bonus	• No performance review or pay incentive.
Benefits	• Pension fund, medical aid, access to share options.	• Labour broker may provide limited benefits.
Costs	• Generally lower cost, limited overtime pay.	• Higher per unit cost, can charge for overtime.

However, using a mixed workforce of employees and contractors creates its own set of challenges for businesses. Questions relating to changes in organisational culture, increased risk of intellectual property loss, goal alignment and the impact on business economics all arise. All these factors influence the best mix of employees versus contractors. This paper presents a model for determining this mix using the aforementioned factors. The model is developed using a mixed workforce of employees and independent contractors for highly skilled workers in a South African division of a global Technical Engineering Design (TED) Company. The TED division provides highly specialised engineering design services and technology, in a project orientated environment.

2 CONTEXT

In 2012 the TED Company had sales to customers in South Africa in excess of EUR 400 million and new orders in excess of EUR 500 million. The TED division typically handles numerous projects concurrently that can take anywhere from 1 to 6 years to complete. This division currently consists of a total of 61 people of which 73% are independent contractors and 27% are permanent employees. The South African norm of independent contractors to employees is 13.9% to 63.5% respectively, with 22.5% being unspecified [5]. The typical skills used within the TED division are shown in Figure 1, with the number of employees and contractors in each role indicated.

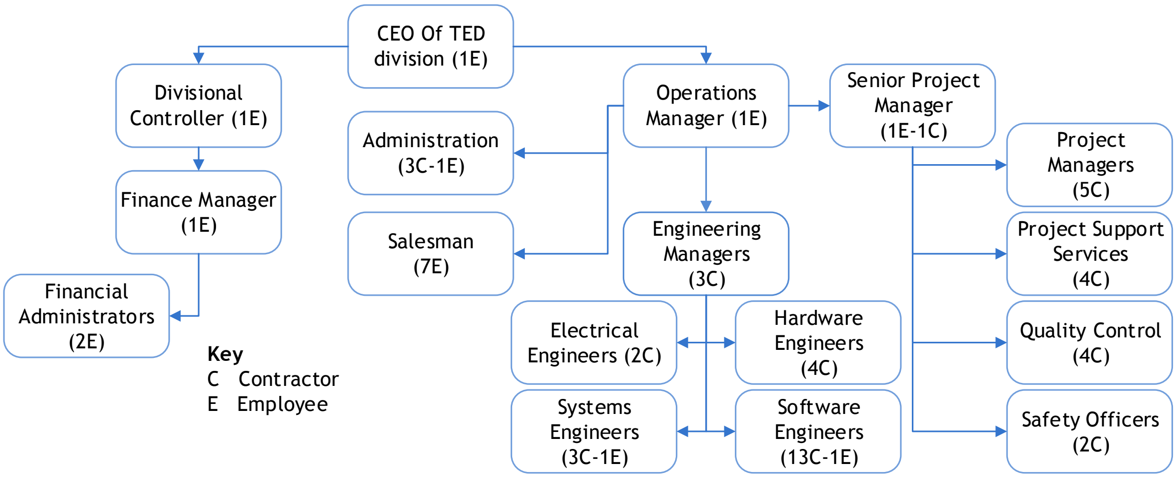

Figure 1: Organogram of TED division

According to the TED Company's internal policies, the division is restricted by the official headcount it can have. Officially the division has a total headcount of 23 staff, consisting of 17 people classified as permanent employees and 6 people classified as contractors. The additional 38 independent contractors are acquired via procurement services through labour brokers and do not reflect in the official head count of the division.

2.1 Purpose of the study

The TED division wanted to ensure that its workforce configuration maximised their competitive advantage within the industry. It is strategically important for the division to win project tenders, which can be worth R10 to R100's of millions and can involve the exclusive use of the TED Company's services for the operational life of a production facility. However, there are the major constraints of irregular customer demand of the division's services and limited availability of specialised skills in the labour market. While the TED division may require certain skills during the design and commissioning of a plant, it does not want to carry the cost of the specialised skills during periods when not required. Conversely, if the TED division does not retain the specialised skills, the skills can be lost to a competitor, making it more difficult to offer a competitive tender when bidding for future projects.

The current high contractor workforce configuration has created further challenges in the division. Management have major concerns over intellectual property risks associated with its reliance on contractors in key positions. Internal policy restricts the ability to train contractors, which is viewed negatively by contractors as limiting their skills development opportunities. The high proportion of contractors has resulted in contractors managing contractors. This has created a distinct lack of organisational goal alignment and uniform company culture. Contractors are not incentivised to meet the TED division's project targets, given the temporary nature of their employment. Contractors also attempt to extend their work allocations for as long as possible, to increase their number of billed hours, by performing re-works with higher job specifications than that which is required. While there is job security offered to employees, some contractors are reluctant to become employees due to lower salaries that will be earned. Cultural differences also exist within the division. The implementation of affirmative action is playing a role in job security, access to job opportunities and changes in employment practices.

Additional concerns of the TED division include:

- Project incentives cannot be provided for contractors to help incentivise good performance.
- The current workforce configuration has created a high cost structure due to the impact of contractors' fees.
- South Africans labour legislation is unclear around laws regarding contractors, with extensions of the law indicating that long-term contractor contracts' can indicate permanent employment.

Given these challenges, the division understands that its current workforce configuration is not the best model to use, given its dependency on contractors for most tasks performed in the division. The TED division wants a workforce configuration that is agile to respond to market demands while considering the impact of softer organisational aspects, and financial implications of such a workforce.

2.2 Objectives of the study

From this study three main issues arise, which require answering:

1. What is the best overall ratio of employees to independent contractors that should be used by the division, given its specific needs?
2. What is the best employment classification for each skill category used within the division?
3. In the event that the division needs to adjust its workforce size, how should this be done for each skill category?

2.3 Research Methodology

To conduct a structured workforce planning exercise, a pre-investigation was conducted by:

- Reviewing the TED division's current human resource policy,
- Understanding what are the prioritised skills required by the division, and
- Understanding the main concerns around using employees or contractors.

With a background understanding of the needs for this study, a comprehensive literature review was conducted to investigate:

- Factors involved in deciding whether to classify a person as a contractor or an employee,
- Quantitative measures required in evaluating the suitability of using employees and contractors, and
- Techniques and principles involved in workforce planning.

From the findings of the literature review, a customised framework and model were developed to answer the specific objectives of the TED division. Data was then collected for the model, followed by an analysis of the model's results and a feasible workforce configuration determined.

3 LITERATURE REVIEW

3.1 Employees versus Independent Contractors

The allocation of an employment classification for an employee or contractor is a problematic decision for a firm to make. Each classification can provide mixed benefits to a firm but creates its own set of challenges in managing the workforce.

Using employees ensures that they are aligned in achieving firm specific goals, due to their socialisation with other employees, organisational culture and pressure from superiors to perform. Increased employee commitment to the firm can be attributed to the job security employees enjoy that enables long term goal alignment. Firms are at less risk of expropriation by employees as they have a stronger allegiance with the firm and internal bureaucratic processes that can, to some extent, control employees. In the case of a high wage environment, the Efficiency Wage Model suggests that employees are incentivised to work harder, and a firm can reduce its turnover while attracting higher quality candidates [6].

It has been found that contractors have better technical knowledge in comparison to employees. However, contractors lack the understanding of firm specific processes which hindered their work. This leads to contractors being used mainly for technical roles, at a premium cost, within the firm rather than user interaction roles [7]. Contracting out allows for smoothing of the workload of the regular workforce. This is despite contractors having a higher per unit cost during peak periods of work. Nevertheless, firms should rather employ highly specialised skills like engineering and draftsman roles, to prevent difficulties in work continuity and expropriation concerns of intellectual property [6].

3.2 Why Contractors Contract?

In a South African context becoming a contractor, through a labour broker, provides access to jobs that would otherwise not be available to the applicant. This is due to a firm's preference to remain flexible and avoid cumbersome labour legislation. Furthermore, labour hired through business procurement services does not reflect in a firm's Black Economic Empowerment rating. Contractors employed through labour brokers have increased chances of obtaining work, following completion of their current contracts [8].

However, the realities of working as a contractor in South Africa does have disadvantages, with labour brokers charging a monthly fee of 8-15% of the contractor's salary. Working as a contractor involves making compromises between:

- Independence from the organisation versus being given the status of an outsider;
- Increased financial security during contracting work versus uncertainty of the next contract;
- Enhanced income versus hidden costs to remain up-to-date in the field, and
- Having one's skills traded as a commodity within the market does not always provide interesting work [9].

It is clear that the role of contractors is varied, with clear benefits for both the firm and an individual to be used as a contractor. While firms face associated management dilemmas, contractors' primary concerns are over job uncertainty.

3.3 Human Resource Models, Management & Architecture

In human resource management (HRM) the most common models applied are the soft and hard versions, which have opposing views of the nature and managerial practises that should be applied. Truss *et al.* [10] found that no organisation implements either approach in the application of HRM. In reality, every workforce is faced with strict organisational goals, coupled with the challenge in managing people. Thus any future HR management model should account for both the soft and hard aspects in configuring a workforce, to leverage the benefits offered by both management approaches.

The principal factor to consider from a HRM perspective is that of employee motivation. Motivation can encourage a particular behaviour that impacts directly on a firm's success or failure of a given strategic objective. The measurement of organisational commitment can provide an indication of an employee's congruency between his beliefs, and acceptance of organisational goals. This can provide insight into an employee's intent to search for a new job and gain an understanding of job turnover rates [11]. The Job Diagnostic Index is one of the most widely used tools in this area. The index measures five dimensions of job satisfaction, by looking at pay, supervision, co-workers, promotion opportunities and work tasks. The tool can enable management to use non-financial facets in order to retain and manage human assets.

HR architecture aims to align employee positions and relationships, to gain a competitive advantage. An HR architecture draws on numerous theories related to economics, organisational theory and strategic management. Each theory offers a different view on how management should configure its workforce, yet all are similar in the two dimensions of the value and uniqueness of a skill. These dimensions should always be present in deciding when to acquire human capital. Skill value is defined as a skills ability to lower a firm costs and increase customer benefits to influence the firm's performance [12].

3.4 Employee Evaluation Methods

The main aim of an employee evaluation and selection systems is to improve a firm's competitiveness and performance, in conjunction with its competitive goals. Given that a firm's success relies on having the right people in the right jobs at the right time, selection of candidates should be based on an organisation's strategic goals and cultural objectives.

Golec and Kahya's [13] proposed the identification of enabling factors that allow for goal achievement. Enabling factors can refer to employee competency based factors and are identified through stakeholder engagement. Identified organisational goals should be ranked by importance, so that candidates can be evaluated against prioritised goals. Heuristic algorithms can be used to evaluate candidates that include a set of constraints to guide the selection process. This typically leads to the creation of a mathematical function, which is able to determine a numerical score for each candidate, enabling relative candidate evaluation through score comparisons.

3.4.1 The Job Diagnostic Survey

The Job Diagnostic Survey (JDS) developed by Hackman & Oldman [14], is a comprehensive tool that can be used to measure three particular variable classes of a specific job of interest. The JDS can measure how a particular job is currently designed to enhance internal motivation and job satisfaction of the people who perform them. The JDS is also able to measure the personal affective reactions people have towards their jobs, and the broader organisational setting in which they work.

3.5 Workforce Planning Techniques

Typically operations research (OR) methods are applied in solving workforce planning problems, with common approaches involving optimisation, simulation or decision analysis. In the context of OR, workforce planning falls under various classifications of problem types, and can be referred to as manpower planning, personal scheduling or team formulation. Each type of problem address a different aspect of workforce planning, and all attempt to determine a good workforce configuration, given a set of constraints and similar objectives. Manpower planning, the focus of this study, emphasises high level workforce planning of a workforce's size and type of employment allocations. Contrariwise the team formulation problem, a variation of the assignment problem, considers a large group of candidates of varying skill types and their personal and social attributes.

Price *et al*. (1980) [15] suggested a two staged approach when attempting to determine a workforce plan. Firstly, to use descriptive techniques like Monte Carlo Simulation to imitate the actual behaviour of organisational polices to determine forecasts for future manpower requirements. Secondly, normative techniques like linear programming and its extensions, can be applied starting from the forecasted requirements to determine a solution according to the stated objective and constraints.

Conversely, Song and Huang (2008) [16] applied dynamic programming to determine a workforce capacity plan based on employee turnover rates, inter-departmental transfers and operational cost limitations due to changes in supply and demand.

Whisman et al. (1988) [17] used goal programming to create a workforce plan that incorporated both quantitative and qualitative objectives. Qualitative objectives involved acquiring staff for specific training grades, smoothing recruitment fluctuations from period to period and maintaining a reasonable level of experience within the workforce. The quantitative objective related to minimising personal costs.

4 MODEL DEVELOPMENT

For this study, a model was developed to provide a focused approach on the critical factors required to determine a workforce configuration. From careful analysis of literature and through stakeholder engagement, two major themes emerged, namely the risks and the financial feasibility of using a mixed workforce configuration. These themes consist of various sub-themes, shown in Figure 2, which were identified as the prioritised factors to evaluate the TED division's workforce.

All workforce evaluation factors shown in Figure2 had been identified in various literature sources to evaluate an employment position, with the exception of the corruption risk. The TED division's stakeholders, consisting of 3 employees and 1 contractor, considered the corruption risk factor to have the highest prioritisation in determining whether a skill position should be internalised or externalised. In the TED Company, corruption was seen as inherent to specific skill types, with contractors having a higher perceived risk than that of an equivalent employee in the same role.

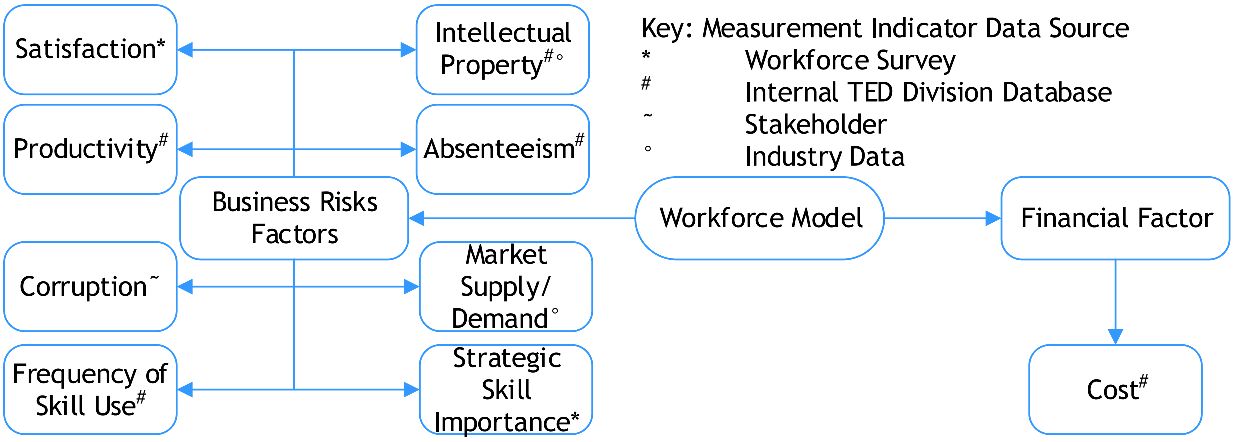

Figure 2: Workforce planning model indicating workforce evaluation factors

Given that the TED division wanted to evaluate their workforce against the objectives of minimising its business risk factors and the financial impact of its workforce, pre-emptive linear goal programming (GP) was seen as the best technique to use. GP would enable each employment position to be to be designated based on a prioritised order of both the soft risk and hard financial evaluation factors that were identified.

4.1 Goal Programming

Goal programming (GP) is applied when multiple decisions are required. Each objective (goal) can be expressed as a function of a target cost, hiring or employment quota (etc.). Each objective is included as a constraint which should be satisfied within a specified range by the decision-maker. Empirically, GP is considered to provide good results and provides an indication of the degree to which certain goals can be attained [15].

In goal programming there are three types of goal classifications:

1. A lower one-sided goal (≥), which sets a lower limit that does not want to be exceeded, but falling above the limit is acceptable.
2. An upper one-sided goal (≤), which sets an upper limit that does not want to be exceeded but falling below the limit is acceptable.
3. A two-sided goal (=), sets specific targets that should not be missed on either below or over the specified amount.

GP can be further classified as:

a. Non-pre-emptive goal programming, where all goals are considered to be equally important.

b. Pre-emptive goal programming, where goals are rated on a hierarchy of priority levels. When this GP is solved mathematically, the most important goal (highest assigned penalty level) receives priority, followed by the second most important goal and so forth [18].

Given that a GP is a special form of a linear programme, it can be solved using the simplex method algorithm. Mathematically, GP's are always expressed as minimisation problems whereby the GP finds the positive deviation, of deviation variables $\boldsymbol{d} = [d_1^{+/-},\ldots, d_m^{+/-}]$, about decision variables $\boldsymbol{x} = [x_1,\ldots,x_n]$. For deviation variables $\boldsymbol{d}$, the +/- refers to the over or under achievement of a stated goal.

The objective function of a GP is expressed as $Z = \boldsymbol{p}^+\boldsymbol{d}^+ + \boldsymbol{p}^-\boldsymbol{d}^-$, where $\boldsymbol{p}^{+/-} = [p_1^{+/-},\ldots, p_m^{+/-}]$ represents the assigned priorities in a pre-emptive goal programming. Z is subject to the goal constraints $\mathbf{Ax} - \mathbf{d}^+ + \mathbf{d}^- = \mathbf{b}$, where $\boldsymbol{b}$ is the requirements vector expressed as $\boldsymbol{b} = [b_1,\ldots,b_m]$. **A** is referred to as the technological coefficients which consists of a $m \times n$ matrix of elements a_{ij}, where $i = 1,\ldots,m$ and $j=1,\ldots,n$. By converting a GP into a linear programme, goals are stated as constraints with non-zero solutions of $\boldsymbol{d}$ indicating goals are achieved with a deviation [16].

In the case of a pre-emptive GP the assigned penalty weightings must be scaled by a factor $M_1, M_2,\ldots,M_{p-1}$. M_1 represents a vastly larger number than M_2, M_2 vastly larger than $M_3\ldots M_{p-1}$, where p is the number of ordered priority levels considered for the model [18].

4.2 Workforce Planning Model Formulation

Each of the risk and financial sub-factors, in Figure 2, were measured on various dimensions, described in equations (1) to (9). The evaluation dimensions for each sub-factor were determined from literature and through stakeholder engagement.

$$Satisfaction = f\{supervision,\ growth,\ motivation,\ security,\ pay,\ fringe\ benefits,\ social\ orientation\} \quad (1)$$

$$Productivity = f\{performance\ measurement\} \quad (2)$$

$$Absenteeism = f\{annual\ leave,\ unpaid\ leave,\ sick\ leave\} \quad (3)$$

$$Intellectual\ property = f\ \{current\ pay,\ market\ pay,\ duration\ spent\ at\ TED,\ strategic\ importance\ of\ skill\} \quad (4)$$

$$Strategic\ Skill\ Importance = f\ \{management\ rating,\ non\text{-}management\ rating\} \quad (5)$$

$$Frequency\ of\ skill\ use = f\ \{skill\ demand,\ utilisation\} \quad (6)$$

$$Market\ Supply/Demand = f\ \{market\ salary,\ perceived\ availability\} \quad (7)$$

$$Corruption = f\ \{internal\ rating\} \quad (8)$$

$$Cost = f\ \{cost\ to\ company,\ overtime\ cost\} \quad (9)$$

4.2.1 Data Collection

Data for each of the sub-factors described in equations (1) to (9) was collected through one of the four sources shown in Figure 2.

The workforce survey used, was largely based on the Job Diagnostic Survey developed by Hackman and Oldman [14]. The survey used a Likert scale system for respondents to answer questions. In the application of Likert scales, there is the common assumption that regular intervals of equal magnitude can be applied across the point scales. A major flaw in this method is the assumption of independence and lack of correlation amongst factors. An alternative approach to avoid the shortfalls of Likert scales is to normalise the values using the formula:

$$z = \frac{(x-\mu)}{\sigma} \quad (10)$$

Where z is the z-score value of an x value belonging to a distribution with mean μ and standard deviation σ.

The method of normalising a score is based on view that people are good at identifying whether something is good or bad/positive or negative but have difficulty considering multiple inputs. Normalised survey scores help interpret the results in terms of their relative ranking to one another, and to the mean and standard deviation of the score's population [18].

Calculated scores from the workforce survey were group by skilled type. The mean normalised scores were determined for both employees and contractors in the same skill type, for use in the GP model.

For data collected from the TED division's internal database, the mean values of employee and contractor data was used for the various skill types.

4.3 Pre-emptive Goal Programming Workforce Model

A linear pre-emptive goal programme was used to describe equations 1 to 9 mathematical. The decision set used in the model was for all the skill types shown in Figure 1. An additional skill type of 'All' was included in the decision set to determine the best overall ratio of employees to contractors, without considering each specific skill type individually.

The objective function for the GP gave priority, in descending order, to the corruption risk, intellectual risk, strategic importance of skills to the TED division and cost factor when evaluating an employment position. The remaining factors in Figure 2 were un-weighted in the objective function.

The GP was subject to constraints derived from equations 1 to 9. Each constraint had an employee and contractor variable multiplied by a numerical constant used to describe the specific constraint score for the employee or contractor variable.

The GP was converted into a linear programming (LP) problem through the introduction of deviation variables prior to the problem being solved. A LP was run for each skill type in the decision set.

For the 'All' skills type, an additional constraint was added to the model to determine the effect of different ratios of employees to independent contacts used within the workforce.

The final workforce configuration that the TED division should use, was determined by analysing the results gathered from sensitivity reports generated by the LP. Mathematically the GP converted to a LP can be expressed by:

Decision Set:

S Set of all skill groups considered in the model.

Variables:

i Corresponding to the function describes in equations (1) to (9), where *i* = 1 to 9

j Skill type, where *j* = 1 to 13, for each skill represented in *S*.

u Number of employees in *j*.

v Number of contractors in *j*.

z Number of candidates considered for the workforce plan for *j*.

w_j Proportion of employees in *j*.

x_j Proportion of contractors in *j*.

$y^{+/-}_i$ Deviation variable for *i*.

Constants:

Calculated score, for factor *i* for employees *j*.

Calculated score for factor *i* for contractors *j*.

$$= \qquad (11)$$

St.

$$\sum \qquad = \sum \qquad (12)$$

$$= \qquad (13)$$

$$= \qquad (14)$$

$$= \qquad (15)$$

$$, v \qquad (16)$$

$$= \qquad 0, \qquad = \qquad (17)$$

5 DISCUSSION AND RESULTS

From the workforce survey, it was possible to identify the strategically important skills of the TED division. Normalising the survey scores, helped to identify which skill groups should be internalised and those staffed by contractors. Thus, all the skills that have a positive score in Figure 3 are considered essential to the division and should preferably be staffed by employees. Currently only sales and finance is completely staffed by employees, with 1 software engineer (out of a total of 14) and 1 senior project manager classified as an employee.

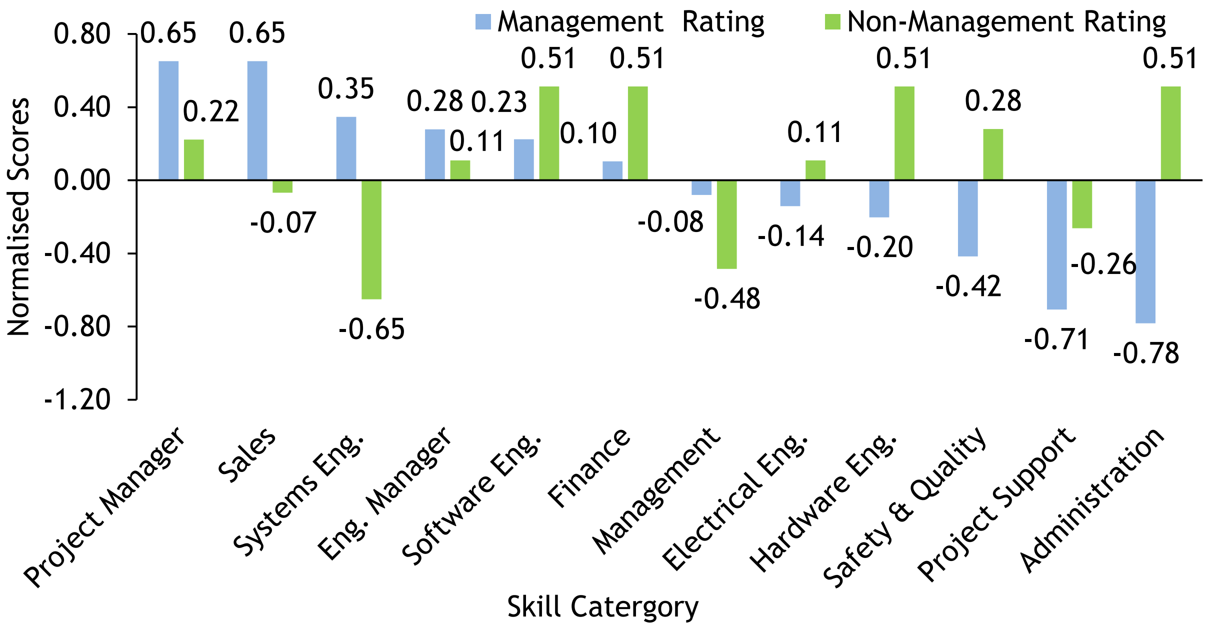

Figure 3: Normalised mean strategic skill importance scores

Surprisingly, management rated the strategic importance of itself lower than that of other skill positions, as seen in Figure 3. Management's mean strategic importance score also reflected a negative standard deviation score to that of the overall mean strategic importance of their skills. This negative score implies that management's position can be staffed by contractors given a lower importance relative to other skill groups. However in reality, having contractors in management positions is known to create problems related to goal alignment and highlights the allocation of staff depends on the model's input data.

From the optimal solutions generated by the linear programmes of each skill category, shown in Figure 4, a workforce configuration of 63% employees to 37% contractors is produced. This classification of the workforce was largely determined by the assigned priority levels of the risk and financial factors identified in Figure 4, which have all be incorporated into the LP. Skill categories with high corruption ratings, intellectual property ratings, skill importance ratings and high contractor costs are favoured completely for employees.

The proposed workforce configuration shown in Figure 4 would only be viable if the demand for the TED divisions services were continuous and provided sufficient amounts of work for all staff. The workforce classification in Figure 4 can still be used to determine which skill types should remain completely staffed with contractors, with greater flexibility still required in the skill categories with employees only.

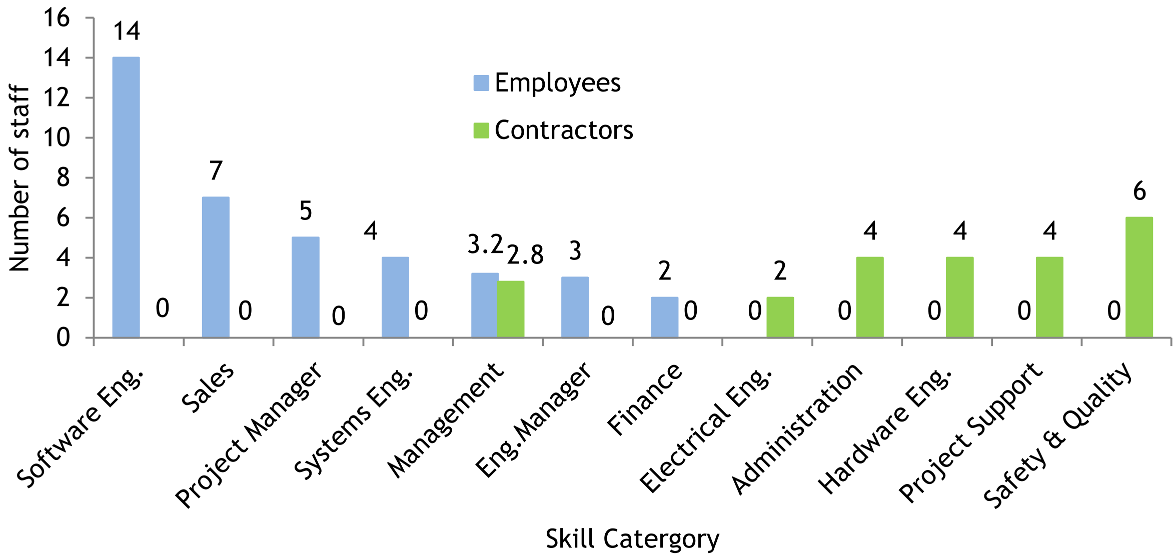

Figure 4: Optimal workforce configuration for all skills

The 'All' skills category results, shown in Figure 5, indicate that the lowest objective function value was obtained for a workforce configuration of 80% employees and 20% contractors. From evaluating the sensitivity reports generated for each ratio considered, it was found that as the number employees increased and number of contractors decreased,

- There was an increase in:
    - Staff motivation and job satisfaction levels;
    - The number of tasks completed by an employee than a contractor in the same position.
- There was a decrease in:
    - Staff absenteeism levels;
    - The amount of time spent on project tasks;
    - In the perceived corruption risk to the TED division,
    - Costs.

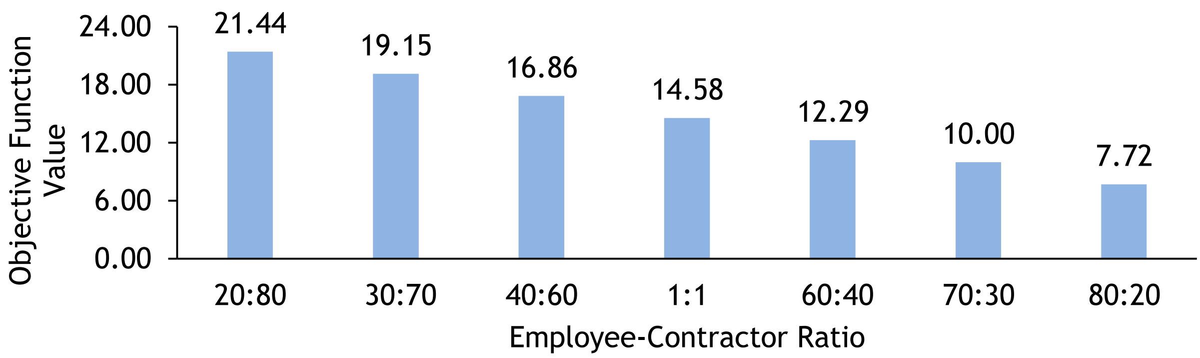

Figure 5: Objective function magnitudes for workforce ratio combinations of employees to contractors

Based on the ratio findings an overall workforce configuration of approximately 40% employee to 60% contractors was recommend for use. This ratio provides a compromise between the risks the division faces, and helps maintain workforce flexibility, while considering the practical implications of changing from the TED division's current workforce configuration. Furthermore from the sensitivity reports generated, it was found that there was only a marginal improvement in goal achievements for employee ratios above 40%.This is also evident by the objective function values shown in Figure 5, which improve marginally less as the proportion of employees increases.

Having determined an overall workforce ratio, each skill category was evaluated on the dimensions of the value and uniqueness that a specific skill offers. This resulted in the workforce configuration shown in Figure 6, consisting of 43% employees to 57% contractors. This proposed workforce configuration enables easy resizing in most skill positions by having a mixture of employees and contractors. Importantly, at least one employee has been allocated to each of the engineering skills to enable work continuity and manage work specific risks.

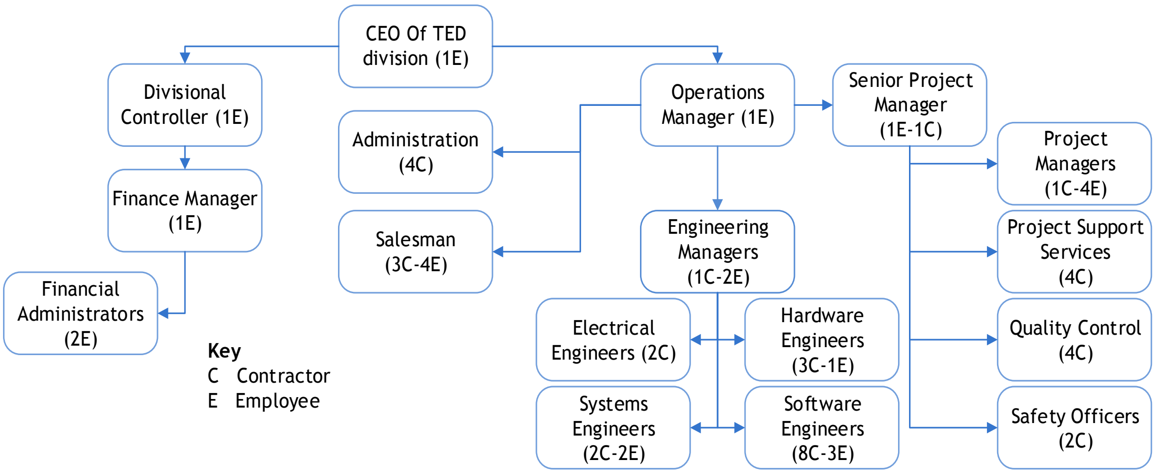

Figure 6: Proposed workforce configuration

6 CONCLUSIONS

Theories of workforce planning and the application of pre-emptive linear goal programming have been applied in finding a suitable workforce configuration for a division of a technical engineering design company. The model constructed enabled each skill type used within the division to be evaluated against a prioritised list of 9 dimensions. The use of a pre-emptive linear goal programme provides a customised approach to finding a workforce configuration specific to the needs of the division. The approach used can be easily adapted to similar workforce planning exercises with specific scenario requirements. It is recommended that further work be done on including customer demand for skills into the goal programming model.

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INVESTIGATION INTO THE APPLICATION OF THE SYSTEMS-ORIENTATED SUPPLY CHAIN RISK MANAGEMENT MODEL IN MANUFACTURING SMALL AND MEDIUM ENTERPRISES

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ABSTRACT

In 2012 South African Small to Medium Manufacturing Enterprises (SMME's) contributed between 52% and 57% to the Gross Domestic Product (GDP). Ensuring that these businesses remain in operation is crucial to driving economic growth and stability in the country. SMME's, however, lack the resources to apply risk management, hence leaving their supply chains vulnerable and their businesses susceptible to failure.

This research paper verifies the applicability of the System-Orientated Supply Chain Risk Management (S-O SCRM) model created by Oehmen *et al* (2010) as a tool to monitor and mitigate risks for SMME's. The model was adapted and tested in 3 SMME's in SA using semi structured interviews and visual sensemaking techniques to collect all relevant data.

Through implementation of the S-O SCRM model several potential risks were identified and suitable mitigation strategies were developed to treat the root cause of these threats. The technique developed can be implemented by the business owner hence proving that this method of analysis is an applicable means to monitor an SMME's supply chain while not requiring additional resources from the business.

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1 INTRODUCTION

Disruptions in a supply chain can impact a business greatly from direct cost such as labour to indirect costs such as loss in reputation. Many new tools and techniques are being introduced into the market, including: TQM, lean manufacturing and strategic sourcing. As businesses are faced with increasing risks to their supply chain, the understanding of these risks are an integral part of managing them successfully [1].

Although supply chain risk management is a relatively new field most of the research conducted is currently aimed towards supply chains of larger manufacturing companies. This paper focuses on the smaller firms that are equally exposed to supply chain risks such as their larger counterparts. SMME's not only contribute towards the GDP but also created 61% of the employment opportunities found in the country [2] and therefore SCRM in SMME'S is an integral part to ensuring the long term growth.

The System-Orientated Supply Chain Risk Management(S-O SCRM) model established by Oehmen *et al* [1] was developed and tested on large enterprises and therefore had to be adapted to make it applicable to SMME's in SA. All modelling requirements stated by Oehmen *et al* [1] were addressed to ensure the technique implemented was valid after all changes were implemented.

The following research questions were posed for this research paper:

1. Is the System-Oriented Supply Chain Risk Management model an applicable tool for an SME's in South Africa to utilise?
2. Will the Systems-Orientated Supply Chain Risk Management model provide a comprehensive assessment of a SMME's risks?

The paper is structured as follows: a literature review, the research methodology implemented, observations and results established, discussion and a conclusion to complete the paper with recommendations for future work.

2 LITERATURE

Research conducted focussed primarily on the definition of supply chain risk management, SMME's and the S-O SCRM model used in the study. The information studied is summarised to ensure a greater understanding of topics being analysed.

2.1 Supply Chain Risk Management (SCRM)

A supply chain is the flow between; new product development, marketing, operations, distribution, finance and customer service [3]. The controlling of a supply chain involves managing product, information and financial flows to ultimately increase profits of the business. Supply chain risks can be described as any problem that occurs and causes negative effects in the supply chain and for the company [4]. Although there are several methods available on identifying risks, many do not provide the means in which to develop mitigation strategies - the primary reason for this being that businesses are so diverse that no one business solution will be suitable in another business [5].

Due to globalisation there are now both local drivers that originate at a supply-chain entity or particular market and global drivers that originate supply-chain-wide or globally. This leads to both local and global consequences that would impact either particular or multiple markets. Risks can be categorised in areas as shown in figure 1 which also provides example of where the specified risks are likely to be found. Categorising risks aids in identifying the area under threat and developing a targeted approach to prevent or reduce the risk occurrence by the relevant departments [5].

Supply risks	Process risks	Demand risks	Corporate-level risks
• Supplier failure • Supply commitment • Supply cost	• Design • Yield • Inventory • Capacity	• Forecasting • Change in technology or in consumer preference • Receivable	• Financial • Supply chain visibility • Political/Social • IT systems • Intellectual property

Figure 1: Supply Chain Risk Categorization Areas [5]

2.2 SMME's in South Africa

The South African National Small Business Amendment Act of 2003 and 2004 has classified 5 types of SMME's that include: survivalist enterprise, micro enterprise, very small enterprise, small enterprise and medium enterprise [6].

The definition of SMME's as stated in the National Small Business can be seen in table 1.

Table 1: Classification of Manufacturing SMEs in South Africa [6]

Sector/ Subsector	**Size or class**	**Total full-time employees** *Less than:*	**Total annual turnover (R million)** *Less than:*	**Total gross asset value (R million)** *Less than:*
Manufacturing	Micro	5	0.2	0.1
	Very Small	20	5	2
	Small	50	13	5
	Medium	200	51	19

2.3 The System-Oriented Supply Chain Risk Management Model

The model developed by Oehmen *et al* (2010) is comprised of two components: the risk structure model and the risk dynamic model. These models are then combined to follow a three phase SCRM integration approach - all of which are described below:

2.3.1 Risk Structure Model

The risk structure is composed of 2 elements: the risk cause system and the risk effect system. In figure 2, detailed headings for each element can be seen as well as the integration between the two systems. The casual system aims to find all potential risks within the company based on the focus company, the supply chain and the environmental factors related to the business. An effect system is then utilised to determine what the impact of the risk will be and which specific company targets will be affected. Not meeting business targets can result in either a loss in potential sales or an increase in the total cost of the business. This ultimately leads to a negative impact on the company's economic value added (EVA).

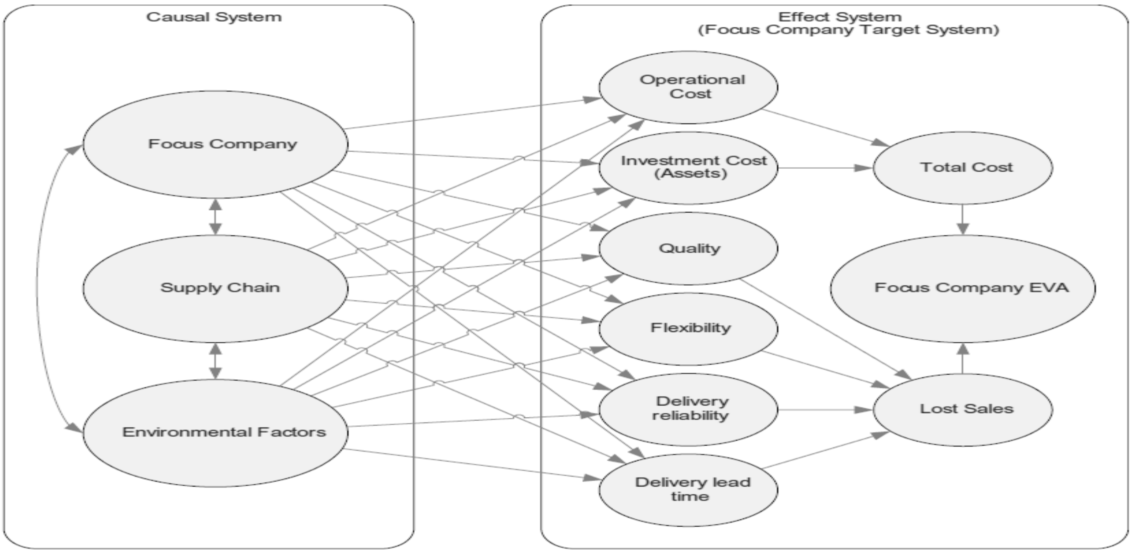

Figure 2: Oehmen et al.'s Generic Risk Structure Model [1]

2.3.2 Risk Dynamic Model

To complete the risk dynamic model successfully a comprehensive risk structure model must be developed. Final risk states are identified which then undergo a root cause analysis to determine the stages that will lead to the actual risk transpiring. The root cause is performed through a 5 why's analysis that aims to discover all possible initial causes that will result in the risk occurring. Once all the causes are identified, the risk dynamic model is completed by linking all the spaces between the cause and effect using the risks identified in the risk structure model. By performing this process a deeper understanding of the actual reason behind the risk manifesting is developed and hence a more practical solution can be created.

2.3.3 Supply Chain Risk Management Integration

Similar to the general approach taken in risk management [7] there are 3 phases that are associated with the integration of the model. This 3 phase approach can be seen in figure 5 which outlines the steps and order in which each phase must be executed. This approach is used to complete the SCRM procedure and create mitigation strategies based phase 1 and phase 2.

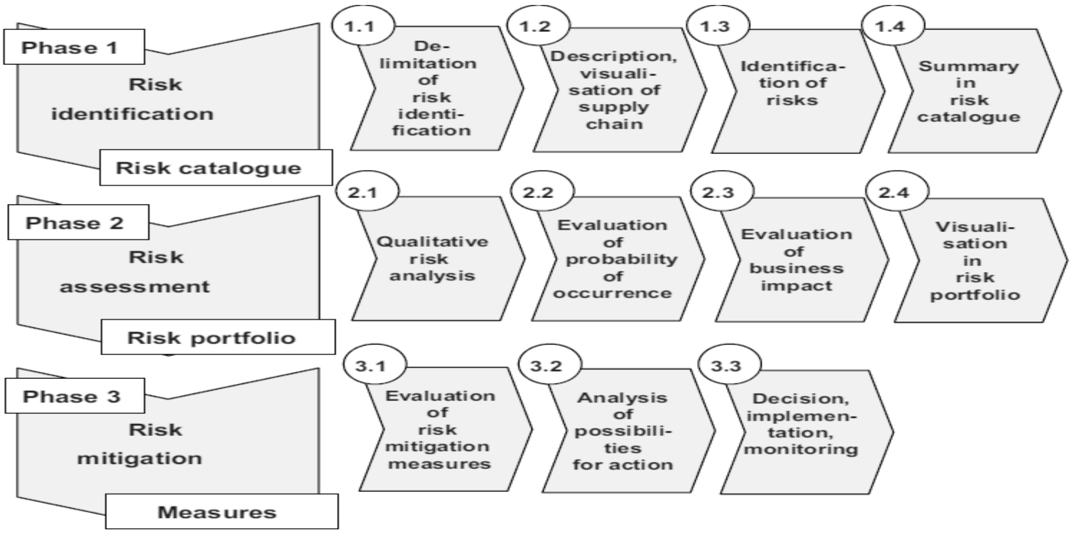

Figure 3: Supply Chain Risk Management Integration Model (Phases & Steps)[1]

3 RESEARCH METHODOLOGY

The method utilised to collect data along with the models used to capture all the relevant information will be outlined and validated in this section.

3.1 Research Instruments

These are the tools and techniques that were implemented in research project:

3.1.1 Phase 1: Supply Chain Risk Identification

Risk identification must occur at 3 levels: supply chain risk, focus company risks and environmental factor risks which all form part of the causal system shown in figure 2. Each of these sections utilised a different tool to determine potential risks:

- *Supply Chain Risk – Supply Chain development*:
    - This indicates the visibility that the company has throughout their supply chain.
- *Focus Company Risks - Ishikawa diagram and Porters Five Forces:*
    - The Ishikawa diagram will focus on the internal structure of the company while Porters Five Forces analyses the competition faced by the business.
- *Environmental Factor Risks - P.E.S.T. analysis:*
    - As we are researching SMME's the PEST analysis provided a comprehensive analysis of all potential environmental risks for these size businesses

All the above mentioned models are completed during the first meeting and aim to create the risk structure model for the company.

3.1.2 Phase 2: Supply Chain Risk Assessment

In this phase risks need to be ranked, the root cause analysis must be conducted and the risk dynamic model must be completed.

Reputation has been added as a target objective in the risk effect system (figure 2). According to Slack and Lewis, [8] reputation forms part of the operations strategy matrix that is utilised to evaluate the business performance objectives. The addition of reputation as a target increases the applicability of the model to businesses as reputation is viewed as a critical factor to number of sales.

As the model is implemented at SMME's in SA, to simplify the risk effect system and make it accessible to the business owners, all target objectives of the business will directly affect the profit of the business. This eliminates the lost sales, total costs and focus company EVA by replacing it with a simpler profit objective.

When ranking the risks, formula 1 utilised:

$$Final\ Risk\ Value = \sum_{i=1}^{j}(effect_i \times impact_i) \qquad \textbf{(1)}$$

Where: j = number of nodes entering the risk

Each target objective is assigned a value that relates to the *impact* that this objective will have on the profit of the business. The sum of all the impact values must be equivalent to 1. Each risk is awarded a probability based on the *effect* it has on the target objective it is linked to. All values leaving the target objective nodes must also have a sum value equal to 1. All risks that are awarded a *final risk value* greater than or equal to 0.1 will undergo the root-cause analysis. Any value below 0.1 is not viewed as a threat to the business and therefore does not require further analysis.

The risk dynamic model outlined in section 2.3.2 must then be conducted for the company as it forms part of the risk assessment phase. This consists mainly of a 5 why's analysis.

A second meeting will be required to complete this phase. All final state risks need to be identified and linked to the relevant target objectives as well as potential root causes must be brainstormed before the meeting takes place to ensure that the dynamic model can be completed efficiently.

3.1.3 Phase 3: Supply Chain Risk Mitigation

Through the root cause analysis an understanding for the risks and how they can occur is developed. This will now allow the business to establish mitigation strategies that will target the core problem and not provide a short term "quick fix" that targets one of the risks rather than all the risks that resulted in the problem.

This phase occurs during the second meeting and all potential solutions are discussed in terms of the dynamic model to ensure that all risks along the risk path established are tackled by the solution. Possible mitigation concepts should be identified before the interview to assist in stimulating the procedure and ensure that there are no road blocks or dead ends during the process.

3.2 Data Collection Procedure

As SMME's are constrained by limited staff resources, a workshop would not be feasible and hence a semi-structured interview procedure is utilised to collect the data required. The research tools mentioned in section 3.1 provided the structure and controlled the flow of the interview, however, it is not limited by these models and the interviewee is given the freedom to share any relevant information.

To help increase the interviewee's understanding of the research being done, a visual sensemaking approach will be applied during the interview. To achieve this technique the cycle in figure 6 will need to be replicated.

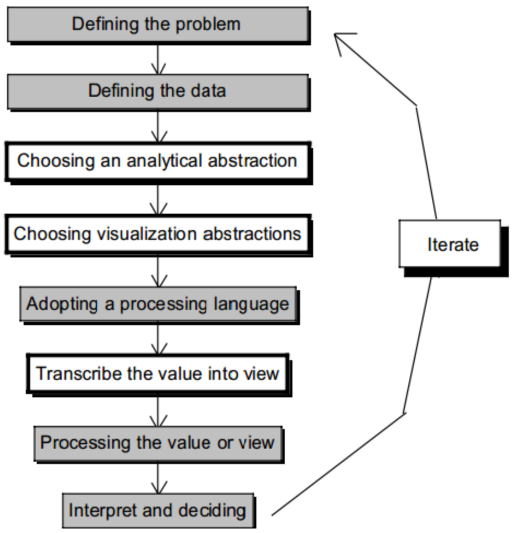

Figure 4: Visual Sensemaking Cycle [9]

The above cycle was replicated by:

- Having a completed model for each of the research tools (heading, sub headings and examples) - this gives the interviewee an idea of what is required in each field in terms of their own businesses
- A sheet consisting of blank models is completed while the interview is conducted, as information is received it is placed under the relevant headings - this reduces

repetition and allows the owner to understand how the information given is being translated.

4 OBSERVATIONS AND RESULTS

This section will provide company details along with the risk dynamic models created and some of the mitigation strategies developed through the process.

4.1 Company Profiles

A summary of all the companies used for this research study is given in table 2.

Table 2: Company Summary

	Business Outputs	**Interviewee**	**SMME Classification**
Company A	Bolts, screws, rivets and washers	Co-Owner	Small
Company B	Precision metal pressed parts, tool making, bending, welding fabrication and general manufacturing (all industries)	Operations Manager	Medium
Company C	Designs, manufactures (fabricates) and distributes wrought iron garden furniture	Owner	Small

4.2 Final Models Developed

Through the 2 meetings conducted at the business the completed models found in figures 5 to 7 were developed.

All the risks established for each company are displayed in the figure accompanied by the values awarded for the impacts, effects and the final risk value calculated. From the figure it can be seen that only risks that had final risk values greater than or equal to 0.1 were subject to the risk dynamic process.

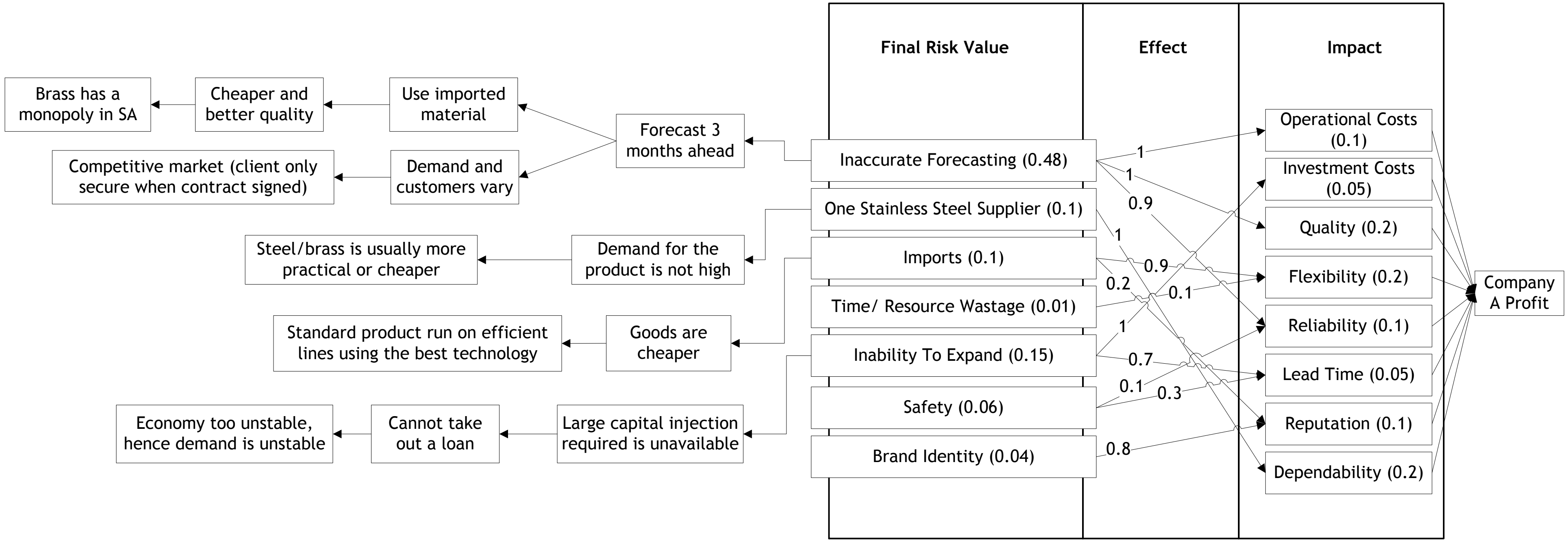

Figure 5: Final Risk Dynamic Models – Company A

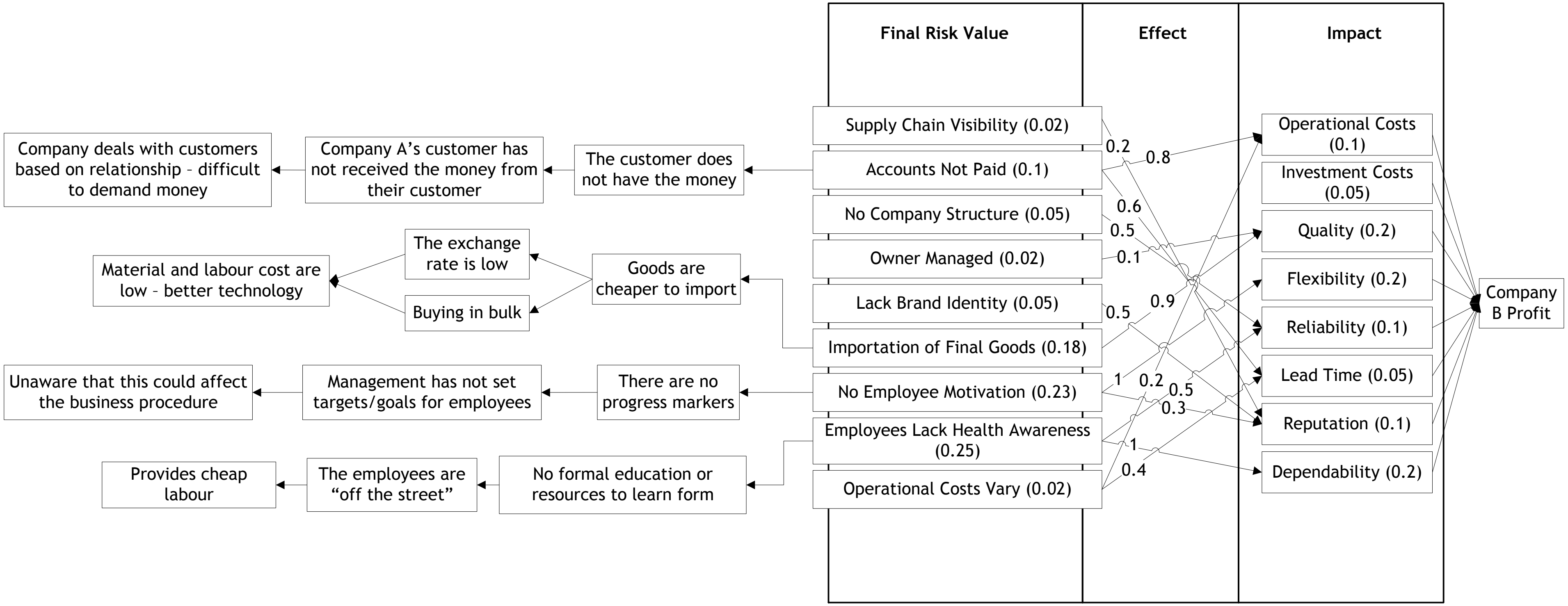

Figure 6: Final Risk Dynamic Models – Company B

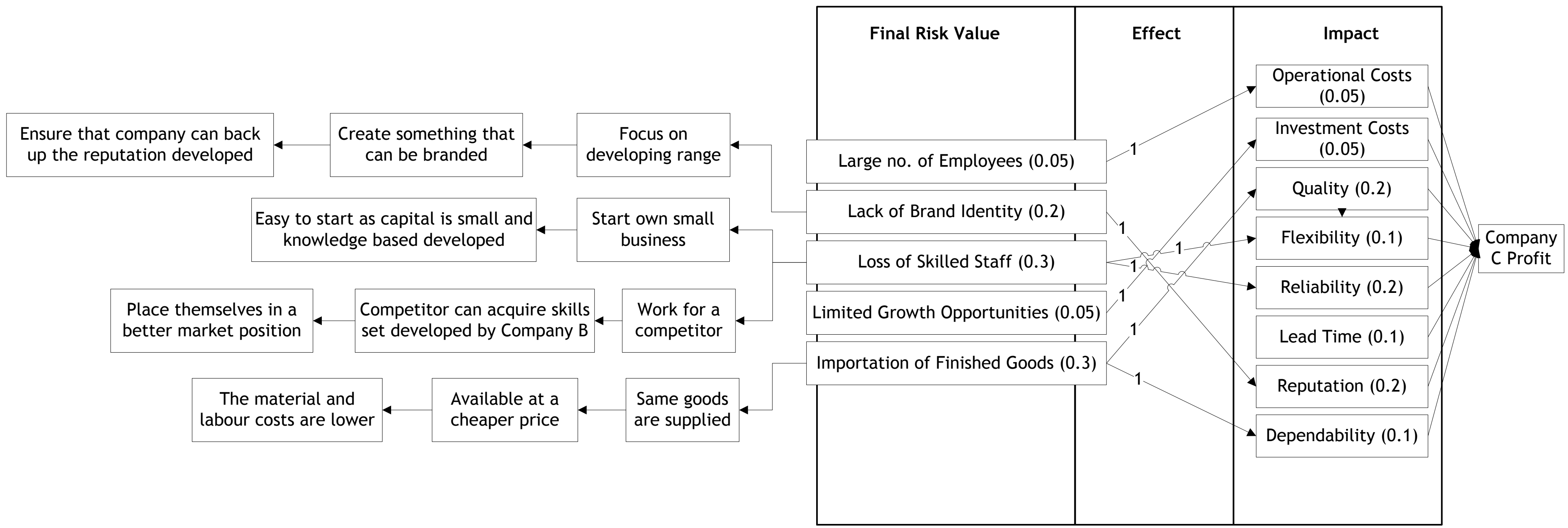

Figure 7: Final Risk Dynamic Models – Company C

4.3 Mitigation Strategies

Once the dynamic models were developed, mitigation strategies could be developed. One mitigation strategy for each company will be outlined in this section to provide an example of how the dynamic analysis contributed to creating a strategy that would target the root cause.

4.3.1 Company A

Risk: Inaccurate Forecasting

Due to the instability in the market, demand for goods fluctuates regularly, making forecasting challenging. The lead time for receiving the raw materials is much longer for imported goods, making forecasting important as shortages will result in profit losses. Raw materials for production need to be constantly available to ensure that the business is able to satisfy their customer's needs consistently.

To ensure that forecasting is done correctly there needs to be proper inventory monitoring and management. Calculations can also be done to calculate the point of reorder to ensure that material is purchased in time to maintain the correct buffer levels of stock. If the company has the finances there are software packages that can be purchased to perform all the calculations, however as it is an SMME capital expenditure, it is not viable. A more realistic approach will be to monitor their purchasing history and do the calculations manually first to test if placing more emphasis on good inventory control will ensure better forecasting and therefore less sales losses.

4.3.2 Company B

Risk: Employees Lack Health Awareness

In order to keep production costs low, the business hires workers that do not have any formal education and then train them to perform the work required. This training however does not extend to teaching them basic health and hygiene that they have not received through the schooling system. As the business operates in such a confined area there is a large risk that all employees can be affected by a disease at the same time, hence crippling production.

The business needs to ensure that all employees are aware of health and hygiene so that contagious diseases do not spread. This will also aid in increasing the life expectancy of the staff ensuring that the staff lead better lifestyles and are able to work more effectively.

To do this the company should arrange a day in which the workers receive a lecture/talk on health and hygiene. If the business is more focused on health they can arrange health days in which the staff undergo tests and check-ups as well as receive all the required medications and instructions on how to combat the disease. For this business the first option lies within budget, however, if the staff respond positively to the talk, health days will be arranged in the future.

4.3.3 Company C

Risk: Importation of Finish Goods

Countries like China and India have the ability to manufacture goods much cheaper than local manufactures and hence businesses are opting to import goods instead of utilising the local manufacturers. The only area where a local manufacturer can compete is on quality in this industry. Therefore all products need to be of superior quality to persuade customers to purchase local goods over the cheaper imports.

The root cause identified that importers are able to provide cheaper goods due to their use of modern technology making their manufacturing process more efficient. In terms of technology small businesses cannot compete and therefore suggesting that machinery be purchased is not a viable solution.

A more practical approach would also be to take advantage of the cheaper material available by importing. As the material is standard and many companies require the same goods they can import together in bulk. This will mean less capital expenditure required by each business and the amount ordered by the individual businesses will be a reasonable quantity. One obstacle that could prevent this solution from being successful is that greater storage space will be required to accommodate the imported stock. There will also be a need for larger buffer stock levels to account for the longer lead times associated with importation.

4.4 Summary of Observations

Some of the observations made during the interview and interesting results obtained will be discussed in the section.

When conducting the interviews it was noted that no formal evaluation of the supply chain risk management had been conducted by the businesses in the past.

Currently risks were managed on a trial and error basis where only once a problem was created would a solution be generated to overcome the obstacle faced. This shows the lack of knowledge in the field of supply chain risk management. The only reason this method is employed is based on the fact that the companies are unaware that tools are available to analyse potential risks and that this can be done by the company itself.

The visual sensemaking process proved to be a valuable interview technique as it aided in stimulating the generation of possible risks in the business.

This model has been simplified to a point where the interviewee is able to generate their own risks, with the interviewer only required to steer the conversation and extract the required information. Many of the risk conclusions were drawn by the owner through the process. This is only possible due to the example models displayed during the interview that help the owner to understand what is required (visual sensemaking process).

Due to the industries all forming part of the metal fabrication sector many of the risks established were similar.

The main threat to all SMME's in this sector will be loss of sales to imported goods. The businesses are finding it difficult to compete with Chinese and Indian industries that can produce goods at a cheaper rate.

Forming mitigation strategies to tackle this is challenging as the South African economy cannot compete. SA government should apply stricter importation regulations to encourage businesses to opt for locally manufactured goods over the imported counterparts.

Another similar threat is the lack of brand identity, where a niche market is found branding is important to ensure maximum gain from the market. Both Company A and C have found niche markets, however they have yet to establish a brand identity. One of the limiting factors causing this to occur is that the company is unaware of the benefit that a brand can bring.

All the SMME's analysed have room for growth but this growth requires capital and businesses will not take the risk of investing due to the instability of the economy. This could mean limiting growth for the entire country as development of SMME's will result in job creation and hence government should aid and incentivise SMME growth.

5 DISCUSSION

All relevant findings noted will be shared in the discussion.

The changes made to the System-Orientated Supply Chain Risk Management model were done to simplify the model and make it more applicable to small to medium manufacturing enterprises in South Africa. These changes included using both an Ishikawa diagram and Porters Five forces when analysing the focus company, introducing reputation as a business objective in the effect system, simplifying the dynamic model so that all objectives affect only the profit and creating a decision tree rating approach to rank the risks established.

The data collection method utilised visual sensemaking and semi structured interviews. This method was successful as it allowed the interviewee to share all relevant information and not be confined to the questions stated. Completing the diagrams with the interviewee also aided in the flow of the meetings as they were constantly aware of what has been said, thus reducing repetition and utilising the time more effectively.

From the results drawn the modelling method supported all requirements, addressed the network character of supply chain relationship and risks, included risk causes and risk effects, illustrated the dynamic behaviour of the system- i.e. showing possible development paths of risks, supported hierarchical structuring, showed the interrelation of different supply chain risks, supported qualitative data and can consider future quantitative modelling approaches - stated by Oehmen, Ziegenbein, Alard, & Schönsleben (2010) [1].

By implementing the model at the 3 businesses and discovering all potential risks it can be stated that the System-Oriented Supply Chain Risk Management model is applicable for analysis of an SMME's potential risks. The root cause analysis that was conducted is only feasible if performed with the business- this ensures that the results from the study are a true reflection of what the business experiences. This applies to the mitigation strategies as well. Many theories may sound feasible, however only with the deeper understanding of exactly how the business operates, can we judge whether the solution will work when implemented.

The applicability of the model is limited to the metal fabrication industry as these were the only types of businesses utilised in the study. Due to the homogenous nature of SMME's it can be extrapolated however, that the model is applicable in all SMME's. As there is limited information available on SMME's and their characteristics are similar to the above mentioned statement, it cannot be taken at face value and more research would need to be conducted to fully substantiate this conclusion.

To address the research questions stated in the introduction:

Is the System-Oriented Supply Chain Risk Management model an applicable tool for an SME's in South Africa to utilise?

By implanting the model in small to medium manufacturing enterprises within SA we were able to determine that the System-Oriented Supply Chain Risk Management model is an applicable tool to implement.

Will the Systems-Orientated Supply Chain Risk Management model provide a comprehensive assessment of a SMME's risks?

The results generated through the study prove that this technique can effectively discover potential risks facing the business and through the assessment create mitigation strategies to combat these risks effectively.

The research conducted was successful in tackling the questions asked and comprehensive conclusions were drawn regarding the use of the System-Oriented Supply Chain Risk Management model in South Africa.

6 CONCLUSION

- The instruments used to collect data included plotting the supply chain, Porters Five Forces, Ishikawa diagram and a P.E.S.T. analysis
- The interview technique included semi structured interview and utilised visual sensemaking tools
- Research was done to make the models more applicable to SMME's in SA and completed diagrams were established to support the visual sensemaking technique
- The SO-SCRM model provided accurate results in terms of identifying all major and minor risks in the business
- The model worked for all businesses that were tested - showing applicability within SMME's ,however due to the limited sample size the validity of this result is compromised

7 RECOMMENDATIONS FOR FUTURE WORK

- To increase the visual sensemaking aspect for the risk structure model a value stream map of the operation could be plotted and this could be analysed for potential risks in the focus business
- The model can be tested on businesses that would like to start up as a tool to determine potential risks for the business
- Determine if the current model and method developed can be implemented by a business owner alone to successfully implement supply chain risk management

8 ACKNOWLEDGEMENTS

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AN AHP-BASED EVALUATION OF MAINTENANCE EXCELLENCE CIRTERIA

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ABSTRACT

A state of Maintenance Excellence is when an organisation has achieved best maintenance practice standards and has reached the benchmark for the performance of maintenance operations. Various models exist in literature that highlight what elements need to be present in an organization in order to achieve maintenance excellence standards. However, these standards have to be prioritised according to the current state of the organisation's operations. The Analytic Hierarchy Process (AHP) is a technique that is useful in establishing the priority and importance of individual decision-making alternatives through pairwise comparisons. In this study, the AHP process is used to evaluate a set of organisation-specific maintenance excellence criteria. A railway rolling stock maintenance organisation in the Western Cape region of South Africa is used as a case study for this exercise. By applying AHP to the results obtained from a survey conducted at the case study, some inconsistencies were found in the judgments made by the respondents. AHP was then used again to revise these judgments to make them more consistent. The end result of the study was a set of weighted and prioritized maintenance excellence criteria which will be useful in the organization's endeavors to attain maintenance excellence.

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1 INTRODUCTION

The concept of Maintenance Excellence is gaining wide acceptance as maintenance organisations look for ways to set objectives that will help them to meet their goals. However, identifying which goals are important is one thing, but prioritising them according the needs of the organisation is another. A technique is then required which can give the decision-maker an opportunity to make an informed choice on which objectives to prioritize. The Analytic Hierarchy Process (AHP) is one such technique which is designed to help the decision-maker perform this function, given a set of decision variables. AHP is a tried and tested decision-making tool that has been used to enhance the effectiveness of decision-making processes and to deal with the sometimes subjective linguistic judgments that arise when expressing relationships and correlations. The objective of the work presented here is to broaden the use of this approach by applying it in evaluating the importance of a set of Maintenance Excellence criteria. A survey, carried out at a maintenance organisation in the railway industry, acts as the foundation of this study. The structure of the paper is as follows; there is a brief discussion on the body of knowledge regarding maintenance excellence and the maintenance excellence criteria. A literature review of the AHP method is also done including the steps taken in order to execute it. A brief overview of the case study used in this research is then given. The section following that focuses on the steps taken to execute the AHP-based maintenance excellence criteria evaluation. Concluding remarks on the work carried out in the paper will then be done in the last section.

2 LITERATURE REVIEW

2.1 The Maintenance Excellence Criteria

According to Smith & Hawkins [1], Maintenance Excellence is when an organization has achieved best maintenance practice standards, which are essentially a benchmark for the performance of industrial maintenance. According to them, an organization that has adopted the principles of maintenance excellence will most likely achieve 30-50% reduction in maintenance spending within 3-5 years and also realize production volume increases. It can also be referred to as asset management excellence which is when a plant performs up to its design standards and equipment operates smoothly when needed [2]. Given in Figure 1 are some factors to consider for achieving a state of maintenance excellence.

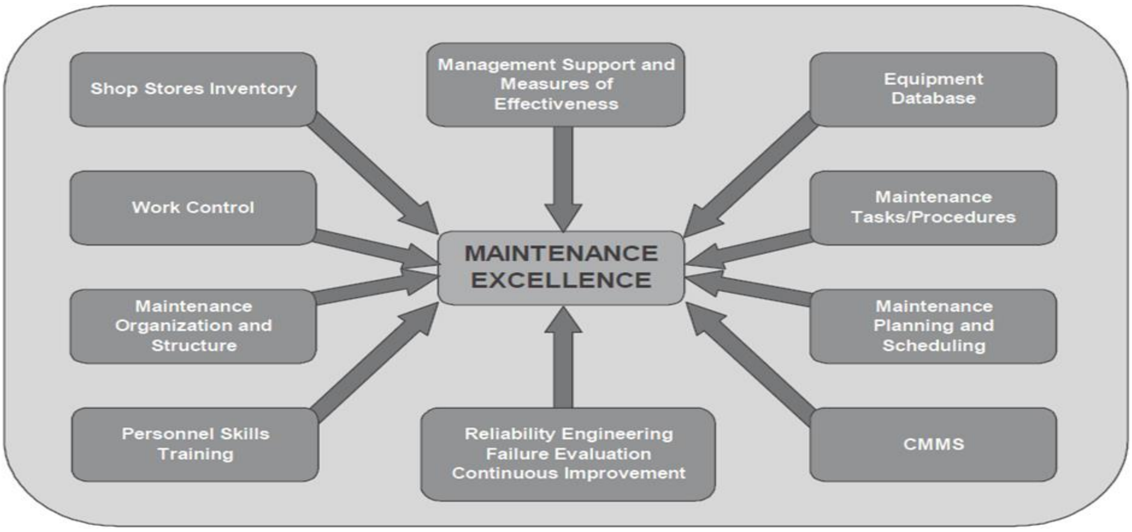

Figure 1: Factors to consider for Maintenance Excellence [1]

Lazreg & Gien [3] give an alternative maintenance excellence model with ten distinct areas, each representing a different aspect of the organization as shown in Figure 2. The purpose of the model is to determine where the maintenance organization's strengths are so as to make improvements and identify areas of opportunity. The ten areas are subdivided into those concerned with *what* results need to be achieved (Results) and areas concerned with *how to achieve* these results (Enablers).

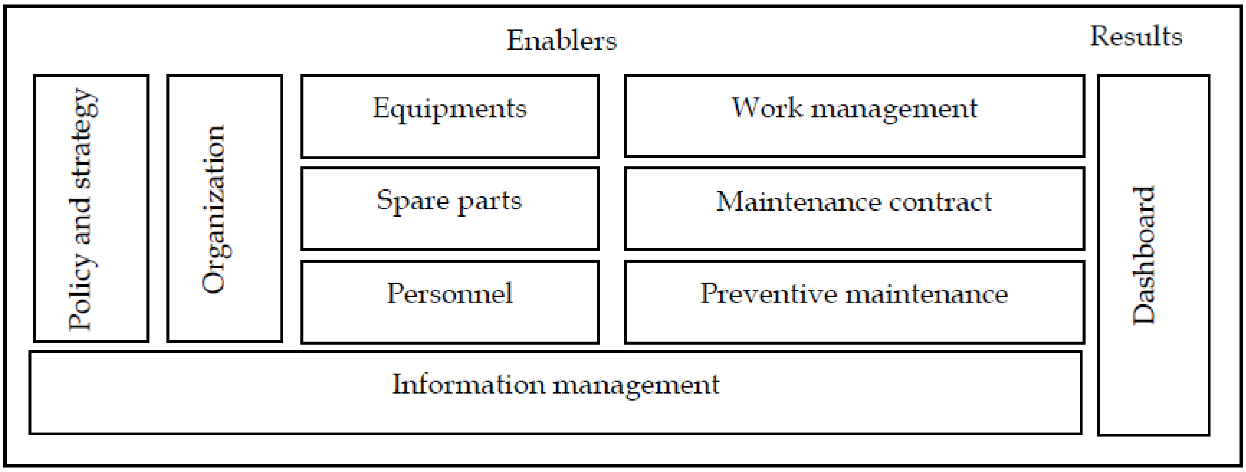

Figure 2: The Maintenance Excellence Model [3]

A maintenance excellence pyramid discussed by Campbell [4] is illustrated in Figure 3. The pyramid acts as an overall strategy or roadmap that can be used to guide choices on how maintenance is managed and what level the organization is. This pyramid stresses the need of having the right solid foundation, starting with the right management and strategy, before any other steps can be taken on the road to achieving maintenance excellence.

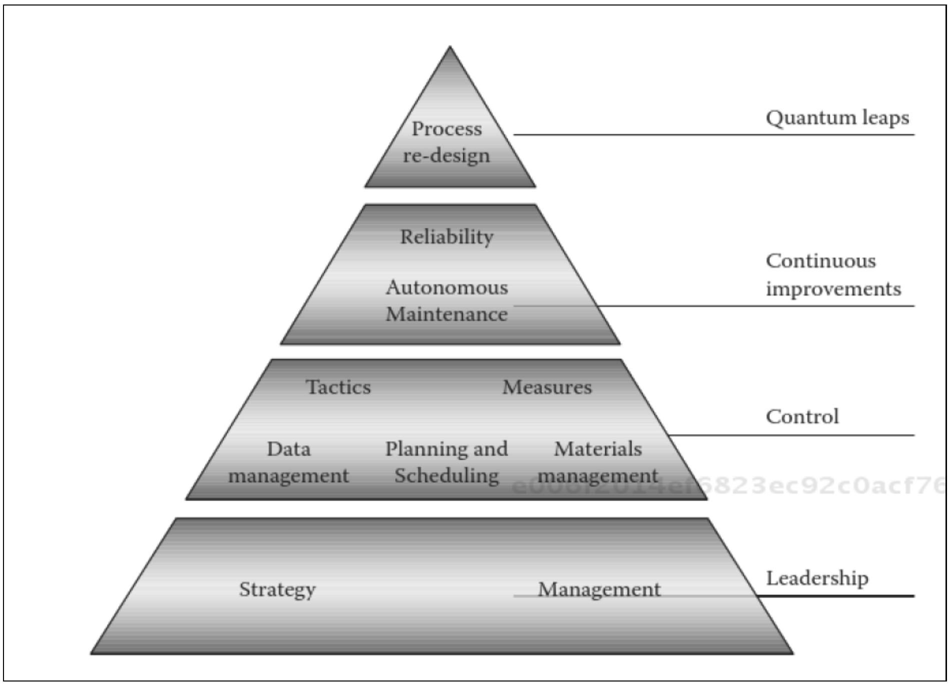

Figure 3: A maintenance excellence pyramid [4]

2.2 The Analytic Hierarchy Process Method

The Analytic Hierarchy Process (AHP) is a systematic decision-making approach that was developed in 1971 by Thomas L Saaty. A very detailed literature review of the many applications of AHP is given by Vaida & Kumar [6] who highlight just how broadly the process has been used. According to the study, AHP has been used in education, engineering, government, industry, management, manufacturing, finance sector and so forth. The reason why it has been so widely used is because of its simplicity, ease of use and flexibility [7].

The process does however have its critics with the earliest being Belton and Gear [8], who state that they discovered many instances where the addition of an alternative causes a change in the relative importance of criteria and thus overall preferences order. They recommend that the pairwise comparison questions be more specific than those advocated in the original method. This view is supported by other studies such as one carried out by Aiqin [9] who propose a new method of rank preservation based on what they call the judgement matrix consistency.

The technique can be summarised in the following steps [5]:

1. Break down the decision-making problem into a hierarchy which is a particular type of system based on the assumption that the entities which are identified, can be grouped into disjoint sets with the entities of one group influencing the entities of only one other group. Figure 4 shows a breakdown into three levels with the potential to have many more levels.

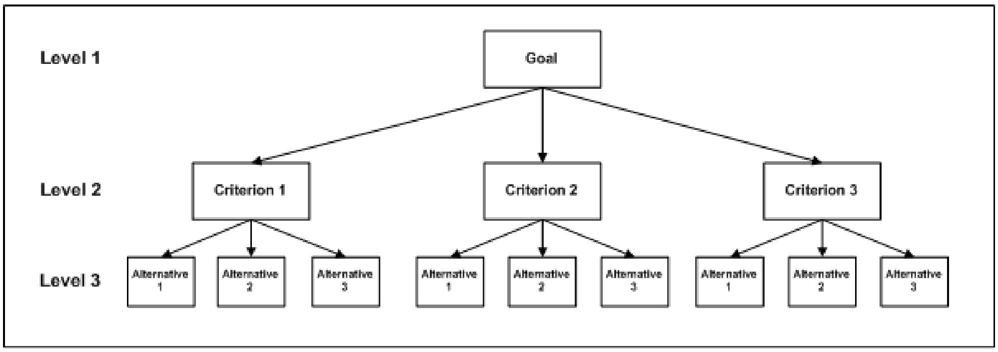

Figure 4: Analytic Hierarchy Process Levels

2. Make pairwise comparisons and establish priorities among the elements in the hierarchy. This helps to determine the strengths or priorities of the elements in one level relative to their importance for an element in the next level. The procedure for doing this is as follows :

Complete a pairwise comparison matrix A for objectives,

$$\begin{bmatrix} \end{bmatrix} \tag{1}$$

Where, indicates how much more important the ith element is than the jth element for constructing the column vector of importance weightings. For all i it is necessary that =1 and $a_{ij} = 1/a_{ji}$. The possible assessment value of with the corresponding interpretation is shown in Table 1.

Table 1: Assessment of

	Interpretation
1	Objective i and j are of equal importance.
3	Objective i is weakly more important than objective j.
5	Objective i is strongly more important than objective j.
7	Objective i is very strongly more important than objective
9	Objective i is absolutely more important than objective
2,4,6,8	Intermediate values

3. Normalise the resulting matrix. This is done by dividing each entry in column i of A by the sum of the entries in column I. This yields a new matrix $\mathrm{A_w}$, in which the sum of the entries in each column is 1, as shown below.

$$A_w = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{11}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \cdots & \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & \ddots & & \\ \vdots & \vdots & & \ddots & \vdots \\ \frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \cdots & \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix} \quad (2)$$

4. Compute c_i as the average of the entries in row i of A_w to yield column vector C

$$C = \begin{bmatrix} c_1 \\ \vdots \\ \vdots \\ c_m \end{bmatrix} = \begin{bmatrix} \frac{\frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{m} \\ \vdots \\ \frac{\frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{m} \end{bmatrix} \quad (3)$$

Where c_i represents the relative degree of importance for the ith criteria in the column vector of importance weightings.

5. Calculate and check the consistency of the pairwise comparison in the following manner:
   i. Compute $A \cdot C$:
   ii. Compute δ which is called the maximum or principal eigenvalue:

$$A \cdot C = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_m \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{bmatrix} \quad (4)$$

The closer δ is to m, the more consistent is the result.

   iii. Compute the consistency index (CI) as follows:

$$CI = \frac{\delta - m}{m-1} \quad (5)$$

   iv. Compare CI to the random index (RI) for the appropriate value of m to determine if the degree of consistency is satisfactory. After conducting some experiments at Oak Ridge National Laboratory [5], an average RI for matrices of the order 1-15 using a sample size of 100 was generated and is shown below.

m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If CI is sufficiently small, the decision-maker's comparisons are probably consistent enough to give useful estimates of the weights for the objective function. If the consistency ratio, given by CI/RI is less than 0.10, the degree of consistency is satisfactory, but if it is greater than 0.10, serious inconsistences may exist, and the AHP may not yield meaningful results. In situations where that happens, it is necessary to revise judgements and in order to help that revision there are three methods that have been shown to work [5].

Method 1: Form a matrix of priority ratios w_i/w_j and consider the matrix of absolute differences $[|a_{ij} - (w_i/w_j)|]$ and attempt to revise the judgement on the element(s) or row sums with the largest such difference.

Method 2: Form the root mean square deviation using the rows of (a_{ij}) and (w_i/w_j) and revise the judgements for the row with the largest value. The procedure can then be repeated to note improvement.

Method 3: The procedure consists of replacing all a_{ij} in the row in question by the corresponding w_i/w_j and recalculating the priority vector. Repetition of this process has been noted to produce convergence to the consistent case.

3 CASE STUDY

The case study chosen for this research is a railway rolling stock maintenance organisation based in the Western Cape region of South Africa. The main activity that takes place there is the maintenance, repair and overhaul of train sets and their various subcomponents. Figure 5 shows the current management structure at the case study in question. It should be mentioned that this structure is still going through changes as the organisation restructures its operations. According to a recent study carried out by Rommelspacher [11] at the case study, the current overall maintenance policy is shared between time directed maintenance (TDM) and run to failure (RTF). According to Wessels [12], TDM is a maintenance policy that uses the hazard function of part failure to determine when a part is replaced based on the organisation's definition of allowable risk. RTF is generally known as a maintenance policy that allows a machine to run until it breaks down before repairing it. There is currently a shift within the organisation to move from TDM and RTF to Condition Directed maintenance/Predictive maintenance which is a more tactical maintenance policy. Such tactical maintenance policies are good enablers for Maintenance Excellence as demonstrated in the models discussed earlier in section 2.1.

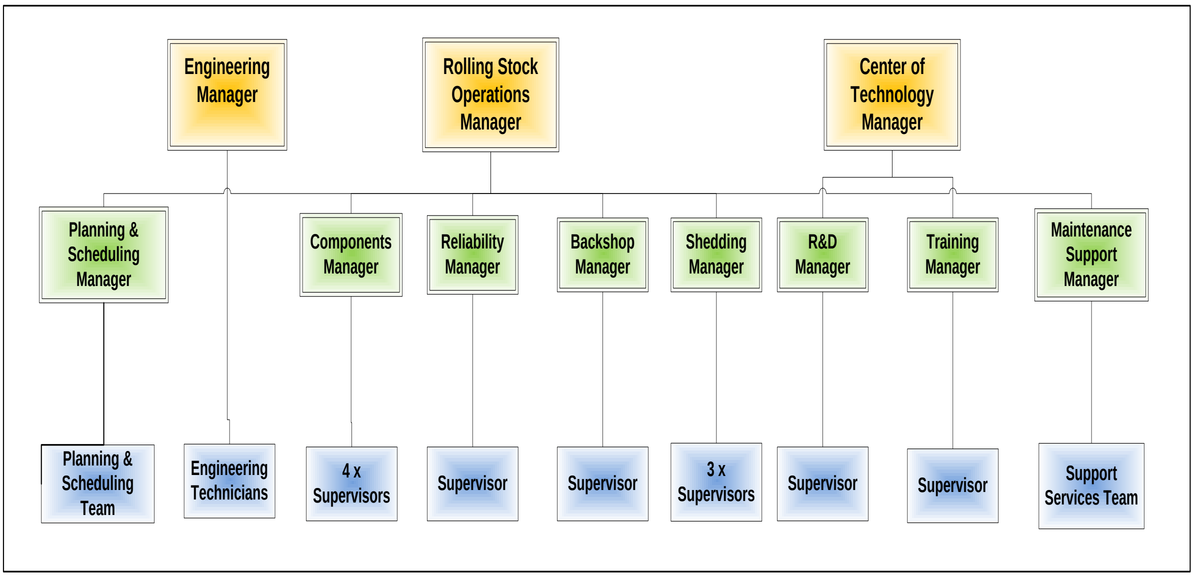

Figure 5: Rolling Stock Organogram of Case Study

4 AHP EVALUATION

A Maintenance Excellence survey was carried out in order to obtain the data necessary for the study. The survey constituted of a set of questions derived from maintenance excellence criteria in literature, as discussed in section 2.1, which are relevant to rolling stock maintenance.. Ad-hoc interviews with key personnel were also carried out and from them, the author gained an understanding of the critical areas that affect the performance of the maintenance function of the organisation (e.g. use of FMMS/SAP). These critical areas were included in the maintenance excellence survey. Management and supervisors of the relevant sections, as shown in the organogram in Figure 5, were asked to fill out the questionnaires giving an indication of where they perceived the organisation to be; in as far as each maintenance excellence criteria is concerned. Table 2 shows the results of the survey conducted at the case study with Table 3 showing the sample of respondents together with their respective sections. The Priority Scores were obtained by first assigning weights of 1, 2, 3, 4, and 5 for the reactions “Excellent”, “Good”, “Average”, “Poor” and “Bad” respectively. The rationale of this weighting is that the more a particular ME practice is viewed as lacking in the organisation, the higher the weight and subsequently the higher the priority it will receive. These weightings were then multiplied by the number of responses and then added together to give the final score. An example of such a calculation is given below for the weighting of “Spare Parts and Material Availability” (SP):

$$\text{"Excellent"} \times 1 + \text{"Good"} \times 2 + \text{"Average"} \times 3 + \text{"Poor"} \times 4 + \text{"Bad"} \times 5$$

$$= 0 \times 1 + 1 \times 2 + 2 \times 3 + 10 \times 4 + 4 \times 5$$

$$\underline{\mathbf{= 68}}$$

Table 2: Respondents' Results and Weighting

Number of Responses								
Serial Number	ME Practice	Excellent	Good	Average	Poor	Bad	Priority Scores	Rank
1	**CI**		6	8	3		48	**11**
2	**FMMS**	1	1	5	8	2	60	**2**
3	**SC**	3	9	4	1		37	**15**
4	**DOP**	3	6	7	1		40	**14**
5	**MGT**		5	8	4		50	**9**
6	**SP**		1	2	10	4	68	**1**
7	**WO**		2	10	4		50	**9**
8	**MAINT**		5	8	5		54	**6**
9	**SKILLS**		4	10	1	1	47	**13**
10	**POL**		2	10	5		54	**6**
11	**CONTR 1**		3	13	3		57	**4**
12	**CONTR 2**	1	6	7	5		54	**6**
13	**KPI**		3	4	9	1	59	**3**
14	**WI**		2	8	5		48	**11**
15	**QUAL**		6	8	3		48	**11**

Table 3: Survey Sample Profile

Section	Respondents
Components Shop	1 Manager & 2 Supervisors
Reliability Shop	1 Manager & 2 Supervisors
Engineering	1 Manager
Support Services	1 Manager & 2 Supervisors
Research & Development	1 Manager & 2 Supervisors
Lifting Shop	1 Manager & 2 Supervisors
Training	1 Manager

In order to determine the consistency of the results of the survey, a Pairwise comparison based on the Priority Scores was made using the Analytic Hierarchy Process (AHP). Figure 6 shows a pairwise comparison matrix constructed according to Eqn. (1) for these scores.

	CI	FMMS	SC	DOP	MGT	SP	WO	MAINT	SKILLS	POL	CONTR 1	CONTR 2	KPI	WI	QUAL
CI	1	1/7	7	5	1/3	1/7	1/3	1/5	3	1/5	1/5	1/5	1/7	1	1
FMMS	7	1	9	7	5	1/5	5	5	7	5	3	5	3	7	7
SC	1/7	1/9	1	1/3	1/7	1/9	1/7	1/7	1/5	1/7	1/7	1/7	1/9	1/7	1/7
DOP	1/5	1/7	3	1	1/5	1/9	1/5	1/7	1/5	1/7	1/7	1/7	1/7	1/5	1/5
MGT	3	1/5	7	5	1	1/7	1	1/3	3	1/3	1/5	1/3	1/5	3	3
SP	7	5	9	9	7	1	7	7	9	7	7	7	5	7	7
WO	3	1/5	7	5	1	1/7	1	1/3	3	1/3	1/5	1/3	1/5	3	3
MAINT	5	1/5	7	7	3	1/7	3	1	5	1	1/3	1	1/3	5	5
SKILLS	1/3	1/7	5	5	1/3	1/9	1/3	1/5	1	1/5	1/5	1/5	1/7	1/3	1/3
POL	5	1/5	7	7	3	1/7	3	1	5	1	1/3	1	1/3	5	5
CONTR 1	5	1/3	7	7	5	1/7	5	3	5	3	1	3	1/3	5	5
CONTR 2	5	1/5	7	7	3	1/7	3	1	5	1	1/3	1	1/3	5	5
KPI	7	1/3	9	7	5	1/5	5	3	7	3	3	3	1	7	7
WI	1	1/7	7	5	1/3	1/7	1/3	1/5	3	1/5	1/5	1/5	1/7	1	1
QUAL	1	1/7	7	5	1/3	1/7	1/3	1/5	3	1/5	1/5	1/5	1/7	1	1

KEY:

CI	Continuous Improvement Efforts
FMMS	Use of FMMS/SAP
SC	Schedule compliance
DOP	Detailed Operating Procedures
MGT	Management support
SP	Spare parts and material availability
WO	Work orders/Job cards
MAINT	Maintenance Organisation and structure
SKILLS	Personnel Skills training
POL	Maintenance Policy & Strategy
CONTR 1	Maintenance Contracting 1
CONTR 2	Maintenance Contracting 2
KPI	Key Performance Indicators
WI	Workforce Involvement
QUAL	Conformance Quality

Figure 6: ME Pairwise Comparison Matrix

This matrix is then normalised and gives the new Matrix according to Eqn. (2) as shown in Figure 7.

	CI	FMMS	SC	DOP	MGT	SP	WO	MAINT	SKILLS	POL	CONTR 1	CONTR 2	KPI	WI	QUAL
CI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FMMS	1/7	1/8	0	0	1/7	0	1/7	2/9	1/8	2/9	1/5	2/9	1/4	1/7	1/7
SC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DOP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SP	1/7	3/5	0	1/9	1/5	1/3	1/5	1/3	1/7	1/3	3/7	1/3	3/7	1/7	1/7
WO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAINT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONTR 1	0	0	0	0	1/7	0	1/7	1/8	0	1/8	0	1/8	0	0	0
CONTR 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPI	1/7	0	0	0	1/7	0	1/7	1/8	1/8	1/8	1/5	1/8	0	1/7	1/7
WI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QUAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 7: Normalised ME Comparison Matrix

The importance weighting of each ME criterion is then derived from this matrix according to Eqn. (3) and the consistency measures according to Eqn. (4). These are displayed in Table 5 where they are ranked from the one with the highest ranking to the one with the lowest.

The Consistency Index is calculated from Eqn. (5) where δ is given by Eqn. (4) and is equal to 17.45 and $m = 15$, thus giving:

Table 5: Importance Weighting of ME Criterion

ME Criterion	Importance Weighting	Consistency Measure	Rank
Spare Parts and Material Availability	0.26	19.33	**1**
Use of FMMS/SAP	0.15	19.54	**2**
Key Performance Indicators	0.12	19.12	**3**
Maintenance Contracting 1	0.09	19.01	**4**
Maintenance Organisation & Structure	0.06	18.00	**6**
Policy and Strategy	0.06	18.00	**6**
Maintenance Contracting 2	0.06	18.00	**6**
Management Support	0.04	17.06	**9**
Comprehensive Work Orders	0.04	17.06	**9**
Continuous Improvement Efforts	0.03	15.89	**11**
Workforce Involvement	0.03	15.89	**11**
Conformance Quality	0.03	15.89	**11**
Personnel Skills Training	0.02	15.85	**13**
Detailed Operating Procedures	0.01	16.29	**14**
Schedule Compliance	0.01	16.85	**15**

For m = 15, we have $\boldsymbol{RI}$ given by 1.59. This gives a Consistency Ratio of:

$$\frac{0.18}{1.59}$$

$$= \mathbf{0.11}$$

The value of 0.11 is just outside the scope of the acceptable threshold value of 0.10. There is therefore a need to revise the judgements made so that they fall within the acceptable limits and to do that, Method 3 from is used. This yields the results shown in Table 6.

Table 6: Revised ME Importance Weightings

ME Criterion	Importance Weighting	Consistency Measure	Rank
Spare Parts and Material Availability	0.17	16.96	**1**
Key Performance Indicators	0.15	18.05	**2**
Maintenance Contracting 1	0.12	18.06	**3**
Use of FMMS/SAP	0.11	17.30	**4**
Maintenance Organisation & Structure	0.08	17.33	**5**
Policy and Strategy	0.08	17.33	**6**
Maintenance Contracting 2	0.08	17.33	**7**
Comprehensive Work Orders	0.06	15.19	**8**
Management Support	0.04	16.47	**9**
Continuous Improvement Efforts	0.03	15.77	**10**
Workforce Involvement	0.03	15.77	**11**
Conformance Quality	0.03	15.77	**12**
Personnel Skills Training	0.02	15.88	**13**
Detailed Operating Procedures	0.01	15.09	**14**
Schedule Compliance	0.01	14.73	**15**

Figure 8 shows the difference between the values of the original importance weightings and the revised ones.

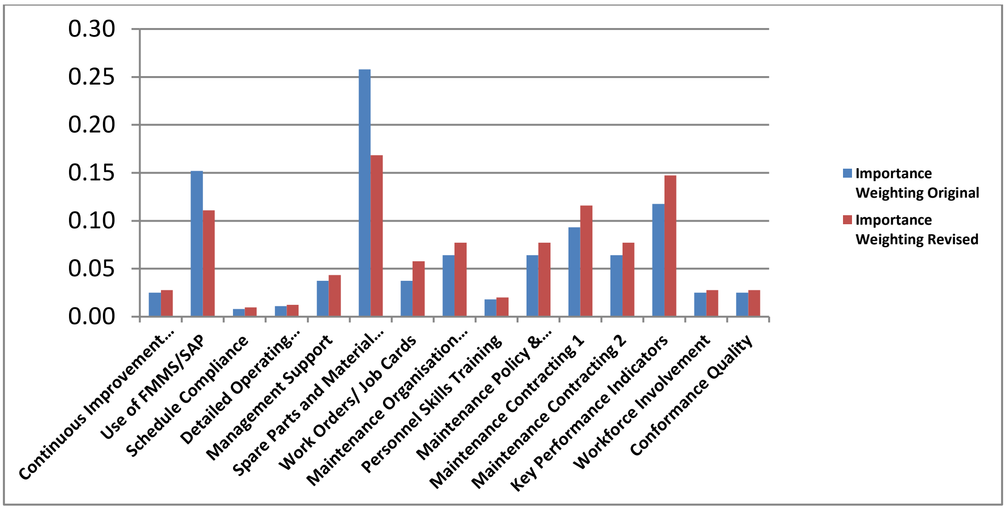

Figure 8: Revised vs. Original Importance Weightings

The Consistency Index is calculated from Eqn. (5) where δ is given by Eqn. (4) and is equal to 16.47 and $m = 15$, thus giving:

For = 15, we have given by 1.59. This gives a Consistency Ratio of:

The new value for the consistency ratio is below the threshold of 0.10 hence giving acceptability to our pairwise comparison.

5 CONCLUDING REMARKS

In this study, the evaluation of a set of maintenance excellence criteria using the Analytic Hierarchy Process has been highlighted. The set of criteria was obtained from a maintenance excellence survey conducted at a rail maintenance organisation aiming to achieve maintenance excellence but facing the problem of how to prioritise the different set of goals. The AHP approach was then used to evaluate the judgements from the survey in order to first determine their consistency and then secondly to give each of the criteria an importance weighting. Inconsistences in the results of the survey were found, showing a consistency ratio out of the acceptable threshold of 0.10. This anomaly was rectified using prescribed AHP methods in order to give more consistent judgements and hence producing what should be more accurate importance weightings of the various maintenance excellence criteria. Future work might involve going back to the case study to find out what initially caused the inconsistencies picked up by the AHP method. This will help give an even more accurate picture of the rankings and importance of each of the maintenance excellence criteria. The main contribution of this paper has been in using the AHP method in a unique setting in the rolling stock maintenance environment in order to find the best way of achieving maintenance excellence.

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ANALYSIS OF PERFORMANCE MANAGEMENT SYSTEM AT A LOCAL MANUFACTURING COMPANY

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ABSTRACT

Effective use of performance management (measurement) system enables companies to improve on their competitiveness in the marketplace. Through a case study research, the paper reviews the performance management system of a local manufacturing company. Most researchers have focussed on wide range of performance management surveys and few paid attention to individual companies, which is the focus of this paper. The balanced score card framework was used to evaluate both internal business processes and external outcomes. Four perspectives of the scorecard; financial, customer, process and learning were looked into. The paper established that top management is clear and committed to the company's strategy and goals. The company is struggling to increase its market share due to lower levels of productivity. High levels of rework were noticed on the shop-floor and are impacting negatively on their cash-flow. These problems have led to poor customer retention due to unmet delivery dates. The paper proposes that the company must initiate staff development programmes to enable a culture of continuous improvement.

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1 INTRODUCTION

It is important for companies to, "align their performance management systems with their strategic goals", [1], in-order to achieve competitiveness, growth and sustainability [2]. At strategic level, performance measurement systems (PMS) are used to formulate and direct organisational strategic objectives and activities, [2], to establish the strengths and weaknesses of the organisation [3]. At operational level, PMS are used to ensure that customer requirements are met,[2], provide standards for establishing comparisons, provide visibility and a "scoreboard" for people to monitor their own performance level,[2, 3], to highlight quality problems and determine areas for priority attention, [1,4] and to provide feedback for driving the improvement effort, [2, 4].

In this respect, performance measurement and appraisal systems have come to play indispensable roles in helping organisations to reach their goals of productivity, profitability and competiveness, [2], and making sure that their systems operates effectively and efficiently, [5]. Most companies have some kind of measurement system that keeps track of various financial and operational performance measures (often referred to as metrics) [6]. Company A, which is the unit of analysis in this paper, introduced the Balanced Scorecard in 2009. While the company carries out its own evaluations periodically, none of them have been done by an outside body, hence the motivation of this study.

Various performance measurement frameworks have been developed [7, 8] as shown in Table 1. However the most popular of these is the balanced score card (BSC) developed by Kaplan and Norton, [8]. The BSC emphasises on the balance between the use of financial and non-financial measures to achieve strategic alignment, [1,2] and is the focus of this study.

Table 1: Various Performance Measurement Frameworks [7, 8]

Selected frameworks	Performance measurement attributes
Belschel and Smith (1991)	Measures linking CSFs (quality, flexibility, customer service, resource management, cost, flexibility) to process drivers
Fitzgerald et al (1991)	Results, determinants,
Kaplan and Norton (1992)	Scorecard of financial, customer, internal, learning and growth
Smith (1997)	Value and non-value adding, drivers
Otley (1999)	Objectives, strategies, performance targets, incentives, information flows
Kennerley and Neely (2000)	Performance prism, stakeholder satisfaction, strategies, processes, capabilities, stakeholder contributions
Neely and Jarrar (2004)	The Performance Planning Value Chain (PPVC)
St-Pierre and Delisle (2006)	The Performance, Development, Growth Benchmarking System (PDGBS)
Balachandran et al (2007)	The Unused Capacity Decomposition Framework (UCDF)
EFQM 2010	The EFQM Excellence Model

This study focusses on the BSC because that is the framework the company has implemented since 2009.

1.1 Research Objective

To analyse the use of Balanced Score Card as a performance measurement system used in Company A.

1.2 Research Questions

To achieve the above-mentioned research objective, the author created the following research questions related to the study of performance management systems:

- To what extent do the employees understand the use of BSC as a performance management system?
- To what extent does the management evaluate and communicate results of the implemented BSC?
- What are the performance improvement strategies being implemented?

2 LITERATURE REVIEW

2.1 Performance Management and Performance Measurement

In literature the terms “performance management” and “performance measurement” are used interchangeably [10]. Armstrong and Baron[11], defines *performance management* as a strategic and integrated approach aimed at delivering sustained successes to the company by improving individual and group performances and also developing the capabilities of teams and individuals. Performance management also involves training, team work, dialogue, management style, attitudes, shared vision, employee involvement, multi-competence, incentives and rewards, [6, 7, 10]. Lebas, [12] defined performance measurement as measures based on key success factors, measures for detection of deviations, measures to track past achievements, measures to describe the status potential, measures of output, measures of input, and these are the measures that will be analysed in this paper through the BSC. However this paper uses both terms, (performance management and performance measurement) interchangeably.

2.2 Performance Appraisal

Performance appraisal is “…an organisational system comprising deliberate processes for determining staff accomplishments to improve staff effectiveness,” [13]. It is a *discreet* event that most organisations perform periodically [14] to evaluate employees´ performance [15]. Performance appraisal is used to facilitate effective communication between managers and employees, [as well as providing feedback that can immediately be applied by employees to improve their performance, [14]. Managers show employees how improving their overall performance and developing new skills will lead to additional responsibilities, [12]promotions and increased monetary benefits, [15]

2.3 Balanced Scorecard

The Balanced Scorecard (BSC) is a performance measurement framework that was developed by Kaplan and Norton [8], that enables organisations to clarify their vision and strategy, and translate them into action, [2,3]. The scorecard is designed to link strategy to operations, [1,8], by establishing operating objectives and quantifiable performance measures based on strategic direction, (mission and vision statements), [1,3], and measures actual performance against these,[8]. It provides feedback around both the internal business processes and external outcomes, [16] in order to continuously improve strategic performance and results,

[9]. When fully deployed, the BSC transforms strategic planning from an academic exercise into a powerful and pragmatic approach to improve performance [17]. The BSC, normally a key output from strategy formulation, focusses on four perspectives that are aimed at satisfying stakeholders, namely financial performance, customer value performance, internal business process performance and innovation performance and lastly learning and growth, [8, 15]. Both financial and customer perspectives are intended to reflect the needs of stakeholders and target groups, [1, 3, 8,16]. The internal business perspective focusses on internal operations that are important for customer satisfaction and efficiency, [1, 8, 10,16].

Figure 1: Balanced Scorecard Management System, Adapted from [8]

2.3.1 Balanced Scorecard categories of performance:

2.3.1.1 Financial perspective

Financial performance is a key measure of a successful business, as it reflects its ability to continue to secure new business, to increase its market share, [8,16], and to achieve high levels of productivity, which continue to improve year-on-year, [10]. The financial performance measures focuses on revenues, sales, profitability, earnings, return on capital, and cash flow, [16,18].

2.3.1.2 Customer perspective

Under customer value performance the BSC focusses on market share, customer satisfaction measures and customer loyalty, [1, 3, 8, 16]. Quality and reliability deliver benefits for customers which ensure that they rarely move on to an alternative supplier, [18]. Leading businesses deliver what they promise to deliver, reliably and on-time. Delivering products on time will in turn lead to perceived value and quality, and growth in customer satisfaction, [2, 4]. High levels of customer retention can, over time, result in more profitable customers, [10], and ensure that new business results in growth, [17]

2.3.1.3 Internal process perspective

Internal business process performance focusses on "...internal operations important for customer satisfaction and efficiency...", [7]. The measures typically include productivity rates often called yield rates, quality measures, timelines-cycle time and unit cost data, [16]. A well designed and delivered service will meet customer needs, providing a clarity of product/service concept and distinctive service, [16, 18]. The flow of work will be controlled and generally smooth, with speed and timeliness giving the business an additional edge in the marketplace, and suppliers playing their part through their own reliability and responsiveness, [7, 8].

Innovation performance focusses on new ideas for services and products, [2,8], that will give customers additional reasons to be loyal and to increase their commitment to the business, [11,12]. Typical measures for innovation include rate of improvement in reducing defect rates, the percentage of revenue from new products, employee suggestions and time it takes to market new products from inception of a new product to its introduction to the market, [8,16].

2.3.1.4 Learning and growth perspective

Employee performance measures are level of staff morale, knowledge, turnover and use of best demonstrated practices, [8, 13,]. Leading businesses understand that their success is heavily dependent on the health, safety and welfare of their employees, [3,10]. They understand the proven link between satisfied employees, satisfied customers and business success, and act accordingly, [18]

2.3.1.5 What Balanced Score Card Do

Bain and Company, [16], summarised what BSC do:

- Articulate the business's vision and strategy
- Identify the performance categories that best link the business's vision and strategy to its results (e.g. financial performance, operations, innovation, employee performance)
- Establish objectives that support the business's vision and strategy
- Develop effective measures and meaningful standards, establishing both short –term milestones and long term goals
- Ensure company-wide acceptance of the measures
- Create appropriate budgeting, tracking, communication and reward systems
- Collect and analyse performance data and compare actual results with desired performance
- Take action to close unfavourable gaps

The above BSC attributes will be used to create a set of questions that will be used to survey Company A's performance measurement system. However some authors such as Kennerley and Neely, [18] have highlighted a number of the balanced scorecard shortcomings, as shown below, and these are out of the scope of this study.

- Absence of a competitiveness dimension
- Failure to recognise the importance of aspects such as human resources, supplier performance and
- No specification of the dimensions of performance

2.3.1.6 Implementation of BSC in SMEs

The motivation for SMEs in implementing BSC is primarily to reduce number of failures by paying attention to leading indicators such as customer satisfaction and quality. SMEs want to stay in business by developing growth potential. Gumbus [19], stated that, "SMEs use BSC for continuous improvement which is important for growth". Anderson [20], argued that, "BSC can be used as a tool by SMEs to meet the challenges of introducing a more efficient strategic planning process while retaining the competitive advantage of having relatively simple structures". These less complex organisational structures and fewer employees found in SMEs enables them to develop and implement BSC in a shorter period of time than large corporations, [20]. Employees can then easily understand the company's strategic plans and objectives. Through BSC implantation SMEs can develop longer term plans, [21], which they can use to create future value [22]. Henschel, [21], further argued that,"SMEs can connect BSC and business planning in creating an instrument for risk identification and risk evaluation".

However BSC implementation barriers that SMEs have to deal with include lack of human and financial resources [23], lack of skills, tacit knowledge, unfamiliarity with strategic management techniques and processes [24]. SMEs owner managers are sensitive to share business information and strategic planning with their employees [25]. SMEs concentrate on short term objectives and financial gains. Garengo (2005), [26], stated that SMEs focus on less BSC measures than large firms, this phenomenon brings in mis-alignment between strategy and performance measures.

3 RESEARCH METHODOLOGY

The research methodology of this study included relevant literature review, and detailed case study on one medium sized manufacturing company. Case studies, [28] can be used to explore, describe, explain and compare while Denscombe, [29], stated that case studies focus on one instance's relationships and processes in a natural setting with the possibility of using multiple sources and methods for both data gathering and analysis. The triangulation method was used for data gathering as suggested by Williams and Scandura, [30]. Triangulation offers more complex, overlapping descriptions of the case and makes the report more trustworthy [31]. From literature a questionnaire was developed. The questionnaire focussed on six perspectives and measurements as shown in Table 2, and sought to establish if employees in Company A understood the Balanced Scorecard Framework used in their company.

Table 2: BSC perspectives and measurements used in the questionnaire

Perspective	Measurements
Strategy	Definite strategy, Strategy focussed on customers, updating of strategy, strategy translated into company, department, unit and individual goals and objectives, managing of key financial and non-financial information
Financial performance	Growth in profit, sales, market share, total asset turnover, net cash flow and cash flow to sales
Customer value performance	Customer satisfaction measures, customer satisfaction relative to competitors, customer loyalty, customer complaints
Internal business process performance	Productivity rates, quality measures, unit cost data, cycle times, yield rates, use of performance measurement tools
Innovation and learning performance	Revenue from new products, employee suggestions, rate of improvement index, investment in new product development
Employee performance	Employee satisfaction, employee turnover/loyalty, remuneration and benefits benchmark, employee training, employees' knowledge in measuring their performance

4 FINDINGS

50 questionnaires were circulated and a total of 18 was received giving a response rate of 32 %. The responses received were from Managers, Engineers, Technicians, Production and Marketing personnel. The summary of the company's Balanced Score Card is as shown in Table 3.

Table 3: Summary of the Company's Balanced Score Card

Perspective and question	**Goals**	**Objectives**	**Measurements**
Customer- *How do customers see us?*	Continuously improve customer satisfaction	Decrease lead time, Increase on time delivery, Reduce customer complaints	Average lead time, Percentage of delivery on time, Number of customer complaints
Internal business- *What must we excel at?*	Continuously improve manufacturing excellence	Decrease cycle time, increase quality, improve yield	Productivity rates, quality measures, unit cost data, cycle times, use of performance measurement tools
Innovation and Learning-*Can we continue to improve and create value?*	To continue to develop and deliver new innovative products	Increase sales of new products, Reduce development time	Percentage of sales obtained from new products
Financial- *How do we look to shareholders?*	Continuously improve on financial performance	Decrease costs, Increase sales growth, market share, return on investment	Quarterly sales growth and operating income by division, increased market share

4.1 Employees' Understanding of the Balanced Scorecard's Perspectives

Figure 2 shows that almost 50 % of the respondents indicated that strategy was considered as a high priority in the company, with 20 % of the respondents, mainly from management, indicating that strategy was considered an essential component at senior levels. 30 % indicated that strategy was considered a medium priority. Generally it was observed that personnel in Company A, understand their company's strategy, [8,16]. However various departments did not have a detailed strategy map, thus impacting negatively on the non-financial performance measurements as suggested by Ittner et al, [32].

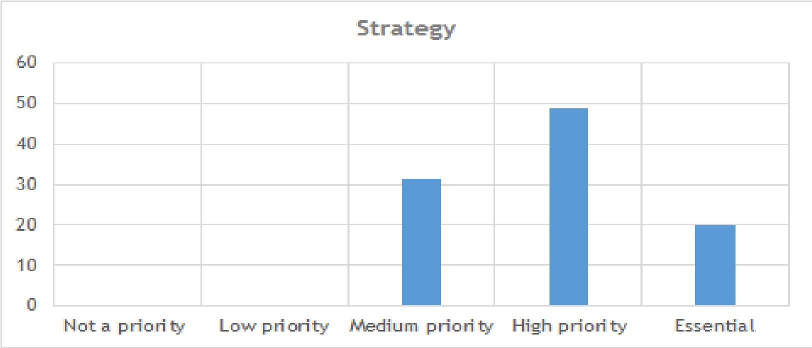

Figure 2: Employees' understanding of strategy according to the BSC metrics

Figure 3 shows that almost 90 % of the respondents understood the financial performance metrics which are the need for growth in profit, increase in sales, market share and total asset turnover, [8, 16, 18]

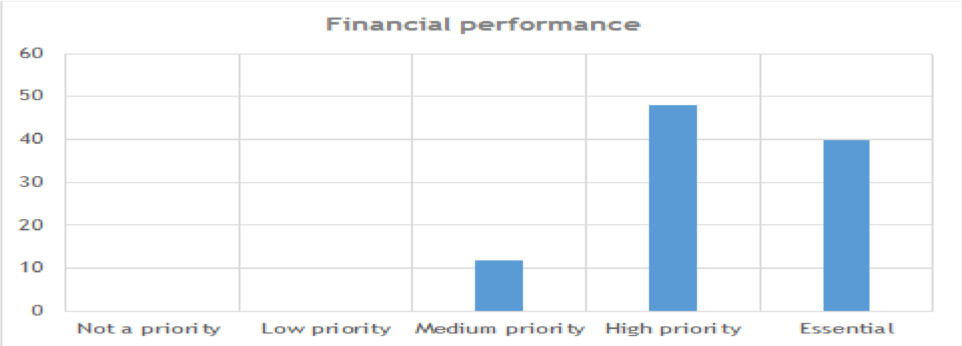

Figure 3: Employees' understanding of financial performance according to the BSC metrics

Figure 4 shows that 75 % of the respondents consider customer satisfaction as an important part in the implementation of the BSC. Issues such as customer loyalty and complaints are taken into consideration in their daily business, this supports the suggestions put forward by reference [10] that customer satisfaction somehow guarantees customer retention, which will promote profitability and market share, [8, 10]

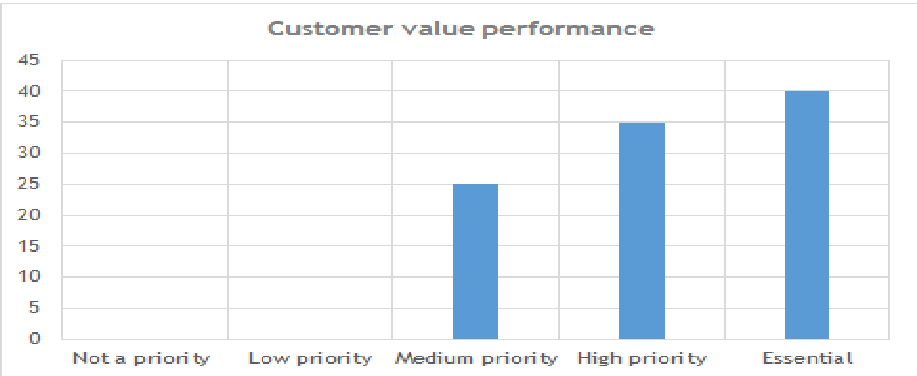

Figure 4: Employees' understanding of customer value performance according to the BSC metrics.

Figure 5 suggests that critical internal operations that enables the company to satisfy the customer needs, [3, 8, 10, 17] are not well understood by majority of the employees. The consequences are that productivity and quality issues will be compromised, [17]. Measures of warranty, repair and treatment of defects and returns is also affected because of non-uniform understanding of the internal business process performance, [10].

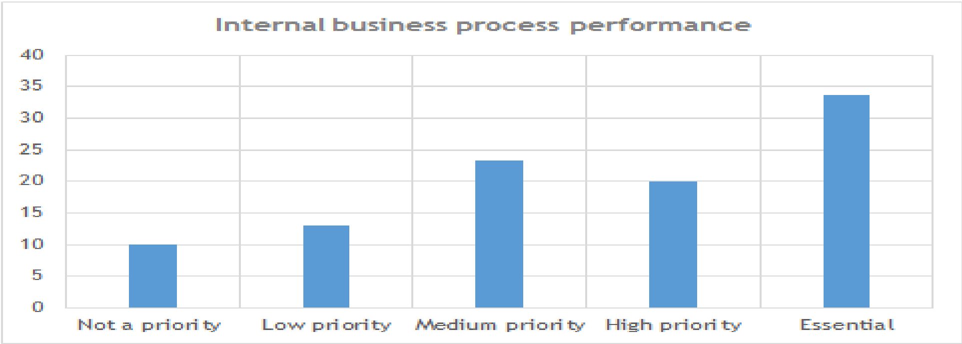

Figure 5: Employees' understanding of internal business process performance according to the BSC metrics.

Figure 6 shows that about 65 % of the respondents indicated that the company emphasises the need to generate revenue from new products that can be sustained from a high investment in new product development, [10]. However during the interviews most employees indicated that their suggestions were not taken into consideration by management. This contradicts BSC's objectives on employee morale, [13].

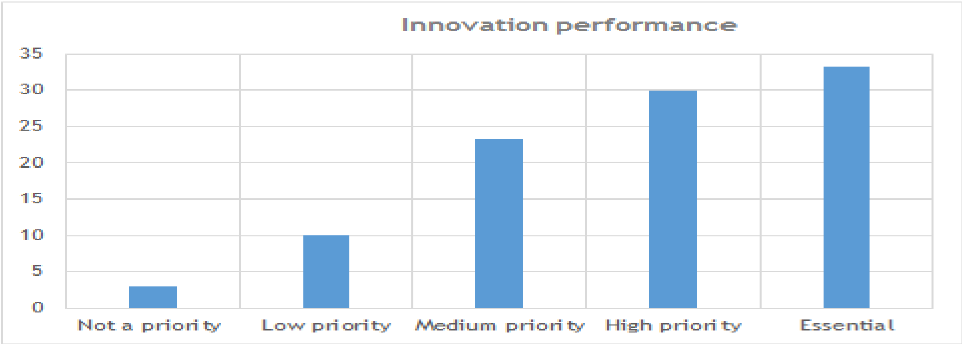

Figure 6: Employees' understanding of innovation and learning performance according to the BSC metrics.

Figure 7 shows that about 60% of the respondents indicated that employees were dis-satisfied, due to remuneration and benchmark benefits that were not well understood, [14,15], and that the company was not training its employees on how to measure their performance,[15]. This was found to be affecting the smooth implementation of the BSC, [4, 10, 18]

In summary figures 1 to 7 shows that employees have a mixed understanding of the BSC perspectives. Employees demonstrated a strong and passionate understanding of strategy, financial, customer value and innovation and learning performances. Employees' understanding of the internal business process and the employee performance was found to be weak. This was found to compromise the effective and efficient implementation of the BSC, [4, 10, 18].

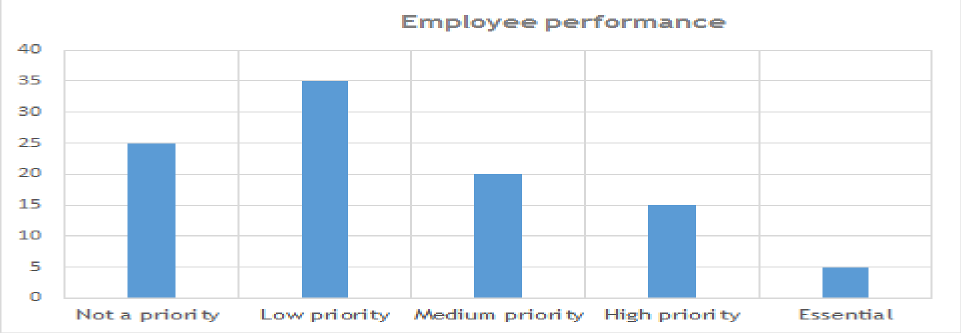

Figure 7: Employees' understanding of employee performance according to the BSC metrics.

4.2 Use of Graphical and Statistical Methods, Re-works and Un-met Deliveries

Table 4 shows use of graphical and statistical methods used in the company. Statistical analysis and Taguchi loss functions including the design of experiments are not used at all. Use of Pareto charts was expected to give the workshop personnel a clue on how to improve the quality standards, [33] which in-turn would have reduced the amount of rework done.

Table 4: Frequency of use of graphical and statistical methods

Graphical and Statistical method	Frequency of use
Pareto	10
Histogram	16
Scatter diagrams	4
Run charts	3
Control charts	15
Regression analysis	0
Taguchi methods	0

Figure 8 shows the 2013 percentage of re-work levels that were done in the workshop. These levels of re-work does not support the outcomes expected from a company that has implemented a BSC, [10].

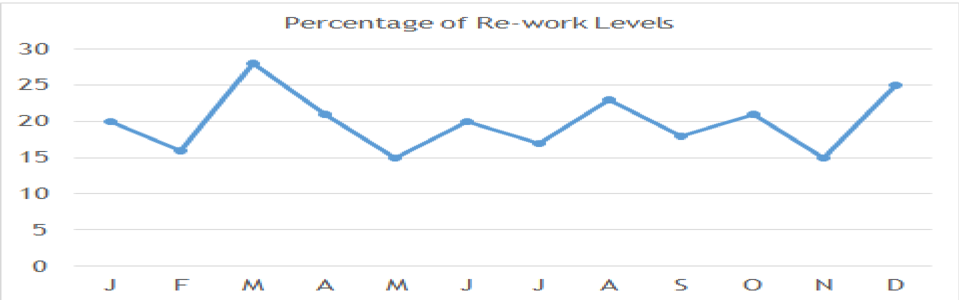

Figure 8: Percentage of Re-work levels

Re-works affects internal processes such as work scheduling, [33], and workflow processes that will cause production delays that knocks on throughput, [4] eventually affecting delivery capability and customer satisfaction levels, [8, 10, 16].

Figure 9 shows the percentages of un-met delivery targets in the four quarters of 2013. The company is failing to satisfy its customers and this is impacting negatively on customer value performance perspective, [16]. The unmet delivery targets also confirms the poor state of internal processes, [18], found in Company A.

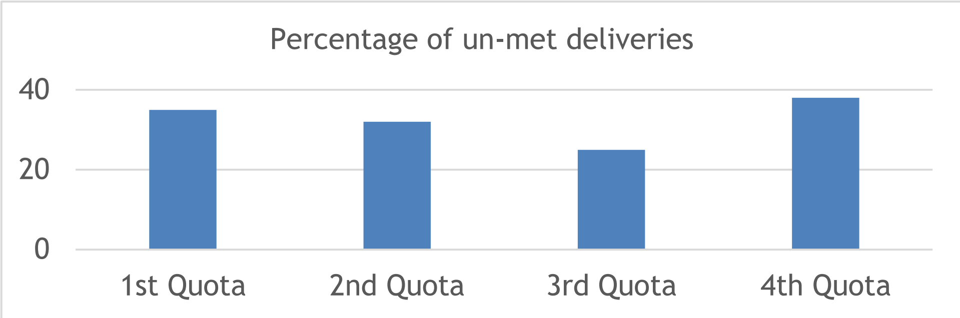

Figure 9: Percentage of un-met deliveries

The study established that management does communicate the results of the implemented BSC as exhibited by the use of graphical methods such as Pareto, Histograms and control charts. These graphical methods were used as shown in figures 8 and 9 above.

4.3 Discussion on Findings

The paper established that top management is clear and committed to the company's strategy and goals. Most employees are aware of the Balanced Score Card perspectives. The company is struggling to increase its market share due to lower levels of productivity, as evidenced by high levels of re-works. High levels of rework were noticed on the shop-floor and are impacting negatively on their cash-flow. This was supported by figure 5, which showed that employees had varied understanding of the internal business process performance. Employees do not understand internal business metrics such as productivity rates, quality measures, cycle times and the use of appropriate performance measurement tools. These problems have led to poor customer retention due to unmet delivery dates as shown in figure 9.Staff must be trained on BSC measurements.

Employee performance appraisal-was found missing. Managers were seen to have been focussing more on employee performance plans with their elements and standards measuring behaviour, actions and processes without also measuring the results of employee's work. This has resulted in low worker morale. Workers' motivation was found to have been dampened by non-employee performance appraisal system. The working environment was found to be meeting industry standards on issues like ventilation, temperature and lighting. However workers generally felt in-secure and their inter-relationships were found to be weak. The author suggested to management that they must set up rewards systems that acknowledges groups instead of individuals. This will in turn improve group empowerment that can then suggest their own solutions to their problems. Data on financial and innovation performance was found to be scanty and no meaningful conclusions could be made. Barriers found in the implementation of BSC as performance management system were that; employees had no enough performance measurement system knowledge, and the existed the performance measurement tools or model are complex, employees do not know how to tailor them to suit their own activities.

Figures 8 and 9 show levels of reworks and unmet deliveries that were experienced by Company A in 2013. It is important for Company A to initiate staff development programs in-order to reduce the negative impacts of these two problems. Workers must also be developed to understand their internal processes.

5 CONCLUSIONS

The paper proposes that the company must initiate staff development programmes that will enable a culture of continuous improvement, [4, 10, 33]. Staff must be taught how to measure their own performance. The company must focus on reduction of the 7 wastes namely; defects, over-production, waiting, non-utilised talent, transportation, inventory, unnecessary motion, and excessive processing, [33]. The company must improve on its work instructions, [34], and must set up inspection points along their production line, [4]. The author also recommended that the company must make use of automated jigs. These jigs might be expensive to set up but will reduce the amount of reworks which will then give the company an opportunity of a higher throughput and lowering of production costs.

6 LIMITATIONS

The study focussed on one medium manufacturing company. The response rate was so low making the results ungeneralisable. The study focussed on whether employees understood the implementation of the BSC. Future studies can focus on statistical analysis on the company's business performance. Future research can also focus on how industrial psychology issues have impacted on the smooth implementation of the BSC in Company A. Industrial psychology issues that can be looked at include behaviour of workers, communication, social interaction, and leadership. It is also important to note that leadership influences the organisational setting- context strategy, values and can direct change.

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INVESTIGATION OF CHALLENGES FACED BY SMALL AND MEDIUM ENTERPRISES IN NEW PRODUCT DEVELOPMENT

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ABSTRACT

A case study research was carried out on four manufacturing small and medium enterprises that are involved with new product development. Literature suggests that survival, growth and competitiveness of small and medium manufacturing enterprises are based on their ability to develop and introduce new products into the market. New product development has become a central mechanism through which a company's strategy can be put into practice. Literature suggests that few articles have been written on new product development problems faced by small and medium manufacturing companies. The paper confirmed constraints faced by small and medium enterprises in developing new products such as lack of resources, poor coordination among various departments, lack of project management structures, weak strategic thinking, poor absorptive capacity and non-use of new product development frameworks. Small and medium companies must enable flexibility of staff movement among various departments to enable concurrent development of new products. Problems associated with lack of resources can be averted through formation of industry portals that can aggregate flexibility and agility. The time taken to develop new products can be reduced through sharing of information with their alliances and external networks including universities.

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1 INTRODUCTION

In the present day of globalized markets, rapid technology changes and sophisticated customer preferences, new products and their development are, an important source of competitive advantage [1, 2].This was supported by Soumala and Jokionen, [3] who reported that the "capability to develop new products is a critical determinant of a firm's competitiveness". Human and manufacturing resources available within an organization must be utilized in an integrated fashion in order to create competitive products in short product development cycles [4]. Badiru and Theodoracators,[5] also agreed that timeless of new product development requires communication, co-operation and co-ordination of design and manufacturing functions. The process of New Product Development, (NPD), is regarded as a complex system since it connects many employees working in different departments and organisational units [6]. NPD is associated with high risks and uncertainty, [1, 2], which at times leads to high failure rate [7, 8]. Successful coordination and management of new product development processes continue to be a challenge in many organisations [9, 10], more-so in small and medium enterprises (SMEs) who are into NPD and manufacturing, hence the motivation for this study. A company's long-term success is critically influenced by its ability to respond quickly to, "dynamic customer needs, increased complexity of product design and rapidly changing technologies [11].

The demands on product development performance in terms of speed, accuracy and cost have become higher, [2], and can only be achieved if a company meets the industry specific knowledge [12]. However NPD performance in SMEs is affected by various challenges as suggested by De Toni et al, [13], namely; the excessive cost of product development projects, the uncertainty of market acceptance, limited base of managerial competencies, lower availability of financial resources and weaker attraction of skilled manpower. These SMEs also face problems such as poor coordination among various departments, lack of project management structures, poor absorptive capacity and non-use of product development frameworks, [3, 4, 7].

The focus of this study will be on the competency levels of senior personnel who are directly involved in day-to-day activities of managing NPD activities such as, managing trade-offs, dynamics of technology, customer preferences, time pressure, group dynamics and large economic investments, [3, 14]. Cooper and Kleinschmidt, [15], established that, "many managers profess to have a systematic process plan in place for product development; an audit of what actually happens on the shop floor reveals many gaps and deficiencies". Through the use of Theory of Expert Competence, this paper will investigate competency levels of senior personnel involved with NPD in four SMEs that are into NPD and manufacturing. This work complements the study of De Toni, [13], who identified that there is limited base of managerial competencies in SMEs, and that NPD processes and planning processes are not well researched in SMEs. The words competency and expertise will be used inter-changeably.

The motivation of the study is that senior personnel involved in NPD are involved in reflexive relationships, built on trust and mutual accommodation with other employees [16], which allows effective utilisation of resources in coming up with new products. It is also important to note that this paper focusses on NPD senior personnel competences, since they form core competences of an organisation, which are unique [17], cannot be duplicated by competitors and gives an organisation its characteristic.

2 SUMMARY OF CASE STUDIED COMPANIES

All four companies are SMEs in the manufacturing sector and have exhibited a capacity to design, develop and manufacture new products, through their Research and Development (R & D) departments. Company A is into design and manufacture of products such as agricultural components like pumps and valve bodies, sewer and water reticulation pipes and sprinklers through casting processes. Company B is into manufacturing of farming components such as ploughs, plough dishes, harrow discs, hoes, picks and shovels including assembly and servicing of tractors. Company C is into manufacturing through casting and extrusion processes. Their products are agricultural plastic parts for drip irrigation and sprinklers. Companies A, B and C supply both domestic and export markets. Company D is into manufacturing of hydraulic equipment used both in the agricultural and mining industries. Their market is mainly domestic.

Table 1 shows a summary of number of employees, number of years in business, yearly turnover and percentage of turnover that is re-invested into new product development activities.

Table 1: Financing of NPD activities in studied companies

Companies

Aspect	A	B	C	D
Number of employees	105	80	65	75
Years in business	20	15	17	18
Turnover (R-Million)	200	170	150	180
Re-investment for NPD (% of turnover)	10%	15%	12%	16%

2.1 RESEARCH OBJECTIVES

a) The major aim of this research is to investigate competency levels of senior personnel involved with NPD in SMEs.

b) To investigate training strategies required to improve competency levels of senior personnel managing new product development.

2.1.1 Research Questions

(i) To what extent do competency levels of senior personnel affect NPD in SMEs?
(ii) What type of training is required to improve competency levels of senior personnel managing new product development processes?

3 LITERATURE REVIEW

3.1 New Product Development

Products have a life cycle, as reported by [7], which passes through a series of stages which include development, growth, maturity/saturation and decline. The decline stage of mature products is caused by changes in customer preferences, product technology, competitive activities and other environmental factors. In this phase sales decline, profit margins dwindle and at times this leads to product withdrawal from the market. It is this realization as established by [2, 4] that compels organizations to continuously develop new products to remain competitive.

In business and engineering, new product development (NPD) is the term used to describe the complete process of bringing a new product or service to market [8]. There are two parallel paths involved in NPD, one involves the idea generation, product design and detail engineering; the other involves market research and market analysis, [9]. Owens, noted that, companies see new product development as the first stage in generating and commercializing new products within the overall strategic process of product life cycle management and is used to maintain or grow their market share. Successful new product development depends on good organization and effective management as reported by Clark and Wheelwright, [18]. The traditional design environment involved segregated cubicles of designers, who were confined to their own worlds of design ideas. This approach worked in the past, as established by [8, 18], because consumers were less sophisticated, and the market was defined more by whatever product was available to the consumers. Current global trend promotes team approach, (cross functional approach) in new product design, [4], which allows people with different perspectives to exchange ideas in order to create a better product than would have resulted from their individual efforts.

New product design starts by defining markets for new or of existing products. Recognition of customers' needs leads is an initial assessment which includes market assessment, appraisal of the competition and preliminary market forecast, as reported by [14]. Engineering and economic analysis then follows which includes preliminary product design, preliminary process design, cost estimation and preliminary financial analysis as reported by [5,8]. Development and testing of the new product then takes place through use of prototypes. Final planning, which includes a marketing plan, a proposal for full-scale production and full analysis of profit potential, is then done. The last phase is the launch phase, which includes management approval, production of the product and an initiation of full-scale operations [19], developed what have become a common NPD process which has eight stages namely; idea generation, idea screening, concept development and testing, business analysis, beta testing and market testing, technical implementation, commercialisation and new product pricing. Figure 1 and 2 shows some of the NPD models/ frameworks that are commonly used.

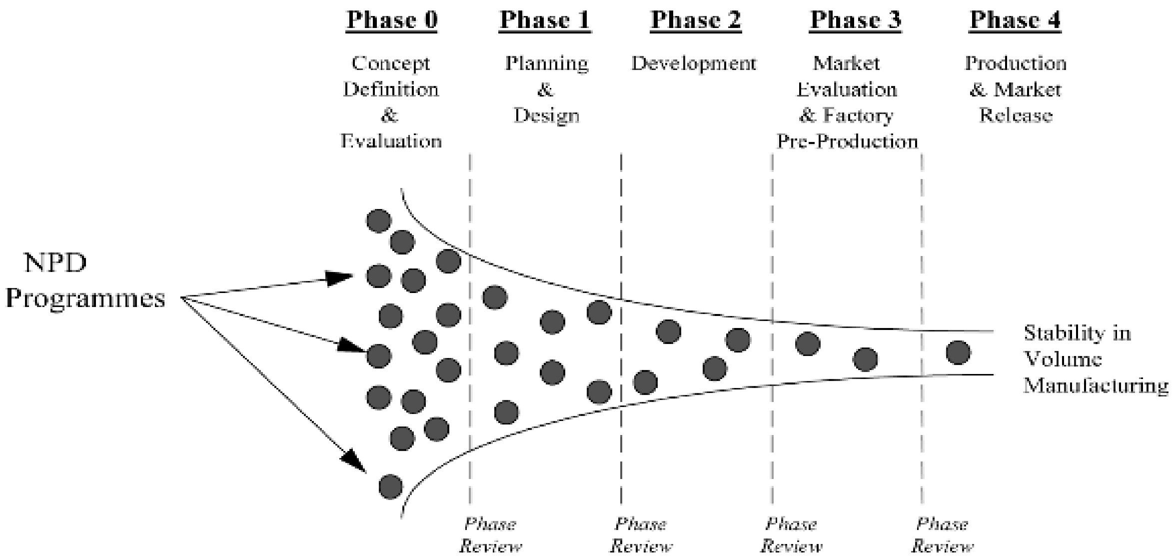

Figure 1: NPD process (after Shepherd [20])

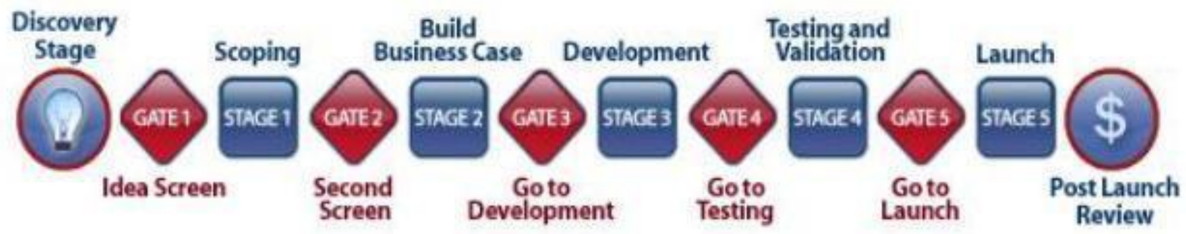

Figure 2: The stage-gate Process, by Cooper and Edgett [21]

Many NPD problems identified in literature appear to be caused by implementation related issues, [8], rather than any fundamental failing of any NPD framework. Implementation involves major management components such as planning, leading, and controlling and these are usually a factor of the competency levels of senior personnel leading NPD activities. Almeida and Miguel, [22], developed from literature dimensions of new product development process, as shown in figure 3. The proposed dimensions are strategic, organizational, technical, planning, control and operational. Their model has two levels structural and operational. These levels indicate two levels of integration in the product development process. The structural level refers to how the product is developed while the operational level refers to the application of the organizational standards in a specific project such as planning and execution of the development project. From strategic, organizational, and management theory, [22], it can be shown that the product development processes are led and executed by senior personnel involved with NPD activities.

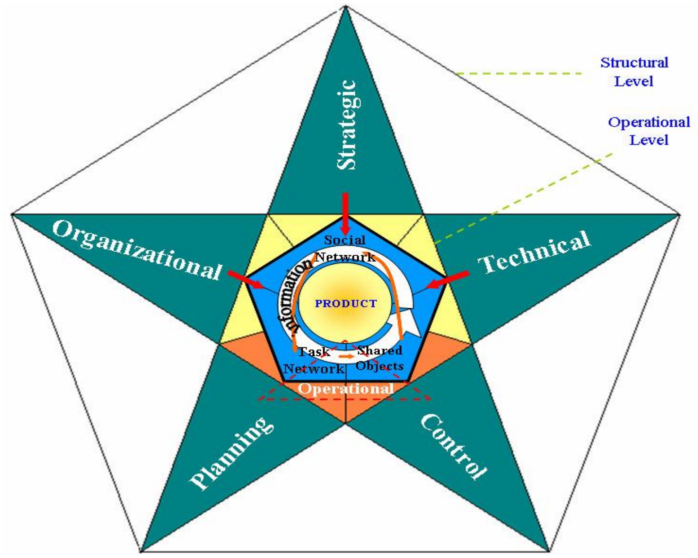

Figure 3: Representation of the conceptual model of the product development process (Adapted from Almeida and Miguel [22])

Research and Development strategy entails that an organisation continues to create value in terms of developing new products that are unique and can-not be imitated by competitors, [18]. The strategy to develop unique products requires organisations to develop unique capabilities. These capabilities are realised through the competencies of senior personnel involved in new product development. An organisation with unique excellent competencies has an ability to develop an adequate return on capital invested in their development, [16, 18].

3.2 Theory of Expert Competence

Smith and Mireless, [23], reported that experts command competence motivation, which is the drive to demonstrate self-imposed levels of achievement in attaining personal, professional and job related standards of excellence. In this paper senior personnel involved in NPD are treated as experts. These individuals are defined as having the necessary skills and abilities to undertake NPD projects with success. These NPD experts are expected to have the two types of knowledge; “explicit, “know what” and tacit, “know how”, [23]. They are recognised within the NPD profession and are regarded to perform at highest levels. According to the Theory of Expert Competence; the skills and abilities that emerge or do not emerge in these experts depend on five factors: domain knowledge, psychological traits, cognitive skills, decision strategies and task characteristics [24].

Adequate domain knowledge is obtained not only from textbook knowledge but from experience working on real problems such as NPD projects. [24]. This type of knowledge is a prerequisite for being an expert. “Shanteau [24] further argues that experts display a common set of psychological traits, which were described by [23], “as self-presentation… the creation of and maintenance of a public image. These traits contribute to the decision style found in many experts; they include strong self-confidence, excellent communication skills, ability to adapt to new situations and a clear sense of responsibility”. Experts use both formal and informal decision strategies, [24]. In engineering management these traits fall under leadership and communication abilities of senior personnel in NPD and these abilities will be investigated in this study.

Cognitive skills possessed by experts include, “highly developed attention abilities, a sense of what is relevant, the ability to identify exceptions to rules and the capability to work effectively under stress. They include making use of dynamic feedback, relying on decision aids, decomposing complex decision problems and pre-thinking solutions to tough situations, [24]. Task characteristics determine whether experts behave competently or not. Regardless of knowledge obtained by an expert, traits, skills and strategies, competence observed in an expert depends on the task, such as NPD. This paper will make use of the Theory of Competence to investigate factors that affect competency levels of senior personnel involved with NPD.

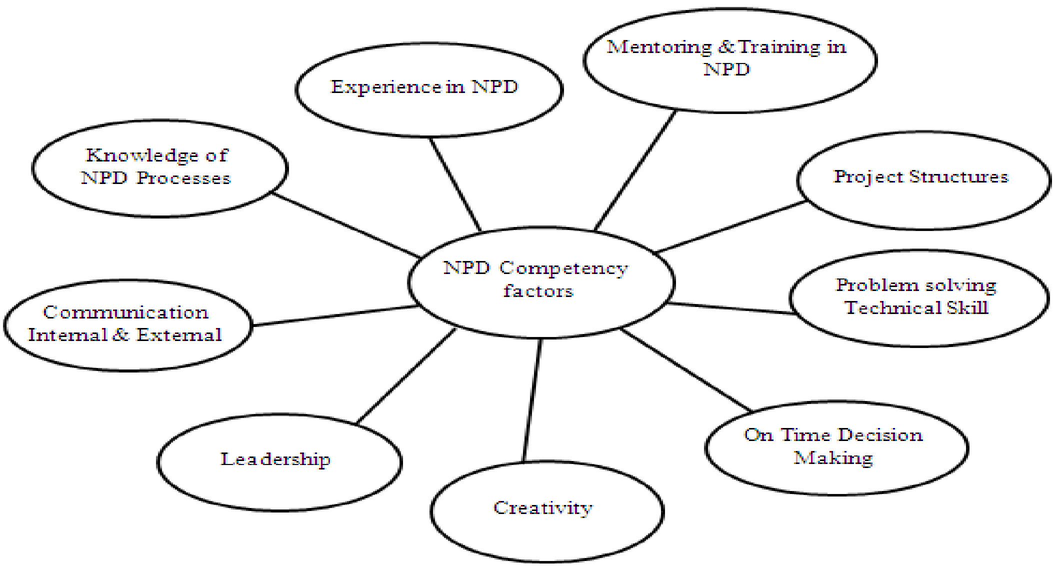

Figure 4: New Product Development Competency Factors.

4 RESEARCH METHODOLOGY

The research methodology of this study included relevant literature review, and detailed case studies. These case studies were used to explore, describe, explain and compare NPD activities done in the four companies [25]. Descombe [26], stated that, "case studies focuses on one instance's relationships and processes in a natural setting with the possibility of using multiple sources and methods for both data gathering and analysis". The triangulation method was used for data gathering as suggested by Scandura [27]. The method included extensive literature review, a cross functional mail survey (with well-prepared questionnaires) and in depth case studies including interviews. Triangulation offers more complex, overlapping descriptions of the case and makes the report more trustworthy, [28]. The questionnaire focused on new product development competence factors shown in figure 4 the questionnaire was distributed to senior personnel involved with new product development. Targeted departments were Research and Development, design office, manufacturing, marketing and finance

5 RESEARCH FINDINGS

The responses received were 9, 12, 13 and 11 for companies A, B, C and D respectively.

5.1 Sources of Knowledge and Skills

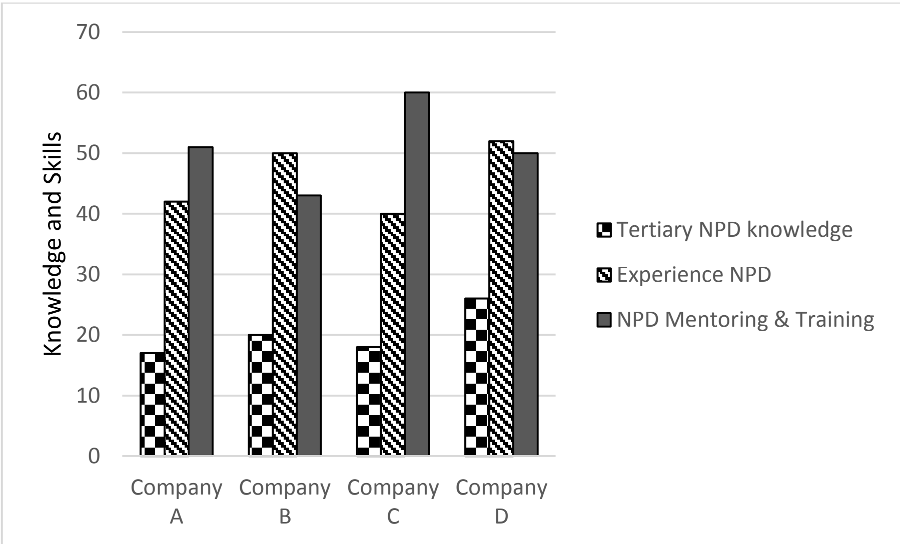

Figure 5: Senior Personnel's NPD Sources of Knowledge and Skills

All respondents indicated that most employees had no formal training or knowledge to discharge duties involving new product development diligently. Lack of knowledge and training hampers the development of new products. Most of the respondents indicated that they acquired their NPD experience from networking and sharing information in conversations with other colleagues at work and in their social networks.

The results show that all companies rely on mentoring and in-house training for employees to get knowledge and skills in NPD activities. Respondents showed that they now have some experience in NPD that ranged from 3 to 15 years. NPD competence can be improved if NPD is taught at tertiary level. Issues such as market intelligence and patent searching was found missing amongst most of the respondents. The issue of involving customers in formulating product parameters was also not given due attention. Most companies do not carry out patent searching. This is a shortcoming in that resources might be wasted in trying to develop already existing products.

Most respondents indicated that there is no new product development framework followed at their companies. New products are developed in a haphazard manner due to either lack of resources or lack of manpower. The link between these companies' business strategies and NPD was found to be weak. During interviews senior personnel failed to explain how much the business strategy influenced NPD.

5.2 Cognitive Skills

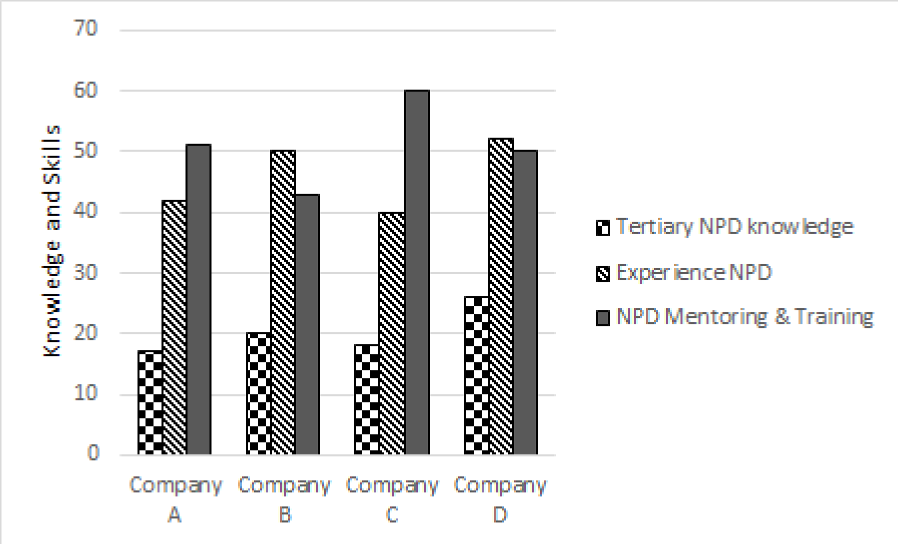

Figure 6: Senior Personnel's' Levels of Cognitive skills

Creativity was found to be high in almost all companies. However competences of problem solving and multi-tasking were noticed to be very low. These low competences affect senior personnel in their day to day NPD activities. Multi-tasking was found to have been affected by lack of training in NPD activities. Most senior personnel had difficulties in paying attention to their daily duties and meeting the demands of cross functional meetings.

Competence of creativity was found to be high in companies C and D, in A and B it was well below 50 %.

5.3 Psychological traits

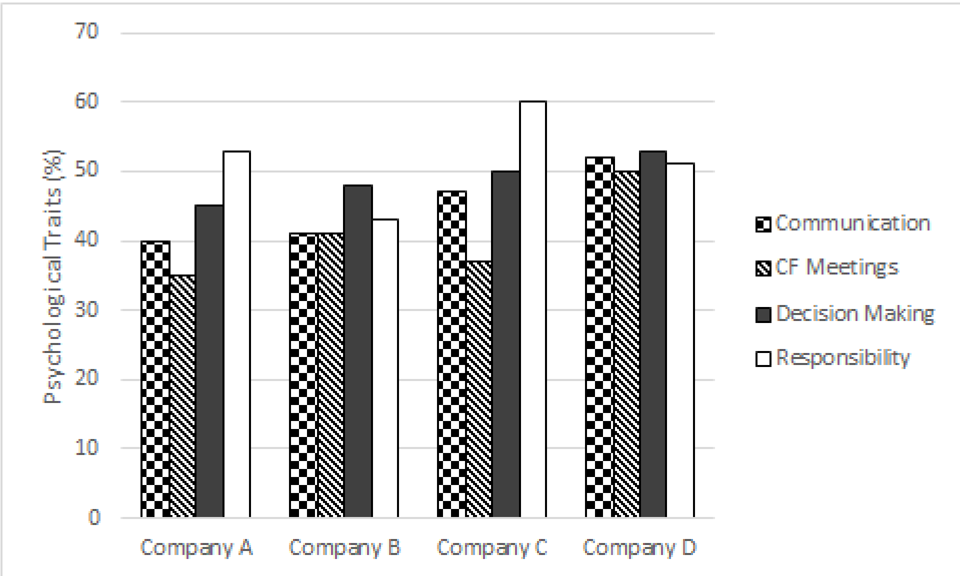

Figure 7: Senior Personnel's Psychological traits

Psychological traits are one of the most important competence factors that help NPD processes. Communication reduces product development time as it keeps the development team focused. Communication plays an important role in charting the direction and objectives of the company. However the research established that there is poor coordination among various departments. Formal and informal meetings are lacking as indicated by low responses on cross functional meetings. This is in disagreement with [40] who indicated that formal team briefings are essential for the dissemination of information and discussion of current status.

5.4 Discussion

Lack of NPD knowledge and training that was established in Figure 5 agrees with the US National Research Council, [30] which established that, "most engineering curricula do not focus on the entire product realization process",, in its finding on why American firms were lagging behind their competitors like Japan and the U.K. Lack of formal training robs senior personnel of tacit knowledge, [23]. NPD knowledge can also be improved through patent searching. Patent searching was found missing in all companies and this contradicted the findings done by Ulrich 14], who reported that, "Patent searching is an important link in information gathering and it makes available technical information and concepts that are protected",

There is need for these SMEs to focus on their strategies. Current global trends dictates that successful product development requires a strategy as well as a process (model) as indicated by [14] A design model speeds up designing, thereby reducing development time and costs. "Cravens and Piercy [36] established that NPD process continues to evolve and become more sophisticated, hence the need to have an established NPD process that can be updated regularly".

Figure 6 indicated that creativity as quite high in all companies. Scandura and Williams, [27] reported that creativity is the mental process that leads to conceptualisations, artistic forms, solutions, ideas, theories or products that are unique and novel". NPD demands that employees work in a supportive environment that will enable their creativity to flourish, [28], since creativity is the most valuable resource needed in new product development. "Yin [25] established in their research that high levels of worker motivation results in high levels of creativity, which results in better new product development practices".

Coordination among various departments was found to be weak. This has a negative effect on the timelines for NPD as well as teambuilding. It is the responsibility for management to nurture a corporate culture that influences team building for the benefit of NPD activities. Smith and Mireless, [23] suggested that teams are built and defined by shared values, strong organizational culture and socialization". It is the work and duty of NPD senior personnel to see that their organizations', policies, procedures and values are enablers of team building, since this has the effect of breaking down barriers among various departments. Results of shared thinking are faster and stronger due to synergies of cohesive problem-solving groups, [17].

NPD senior personnel must create boundary-less organizations, which are flexible, responsive to change and facilitate the free exchange of ideas and information, [14]. During interviews, most workers alluded to the fact that most senior personnel do not make decisions in time, they consult with top management first. This affects product development timelines with some negative effects of delays and demotivating staff as well. However most experts are willing and take responsibility for the jobs they do. Accepting responsibility is an important competence factor as it puts senior personnel in charge and it somehow motivates them to achieve more.

According to work performed by Cooper et al [15], potential problems in NPD may arise with the implementation of a new product development process. More bureaucracy, tighter controls that might thwart creativity and slower decision making are all potential problems that might plague the introduction of any formal process. Indeed, many of the problems identified appear to be caused by implementation related issues rather than any fundamental failing of the NPD framework.

6 RECOMMENDATIONS

The research confirmed general problems associated with new product development found in innovation management literature. Factors that were found to affect senior personnel in making competent decisions on new product development include weak business strategy, limited support for innovation and weak management practices.

The research established that competences are an individual's traits or personality aspects that are important for professionally discharging duties at hand. Individual competences are concerned with the fundamental characteristics that are inherent in a person's actions in relation to all kinds of tasks and situations. It is the duty of management to recognize skill and expertise of employees and to nurture and motivate employees. It is recommended that core competencies be created through interactions of staff and connections between the organisation's objectives, strategy, structure and culture Most employees in similar jobs hold similar qualifications and experience, but they are differentiated by, "their individual's effort, enthusiasm, motivation and underlying self-image that distinguish the successful employee from the unsuccessful one [31].

The traditional over the wall approach, were product development activities are uncoordinated amongst various departments involved in new product development, is still prevalent in most companies. This reflects a deficiency in formal training and strategy with regards to new product development methodologies. Undergraduate and Postgraduate courses in institutions of higher learning must have curricula that address new product development aspects.

Non-use of NPD framework has compromised the involvement of customers. Successful new product development requires that customers and suppliers should be involved in the development process at the earliest moment as indicated by [32]. New product development models such as Quality Function Deployment QFD, Evolutionary process, Stage Gate process emphasizes the involvement of the customer at the design stage. This reduces both development costs and time and ensures that the designed new product has a market. Customer satisfaction as established by [14, 32] is one of the facet that can be used by a company to assess the success or failure of new product development, involving the customer in the early stages of product development is therefore a very important aspect.

The research proposes that companies use four perspectives on organisational learning that were developed by [31], in improving the competence of senior personnel leading NPD activities.

The first perspective is the individual behaviour perspective focusses on the informal, unconscious behaviour of a single organisational member and the interpersonal interactions among a number of members of an organisation [33]. Improving the behaviour of senior personnel enhances their team participation, a requirement for NPD [5].

The second perspective is the decision support perspective which focusses on individual learning process in an organisation. The learning process includes use of information technology and decision models that support decision making [30, 32]. Decision making is a very important competence in NPD.

The third perspective is the management and organisational structure perspective which concentrates on collective learning process guided by formal organisational structure and management systems through formal planning, control processes, operating procedures and reward systems [14, 30]. Senior personnel will understand their responsibility and authority as well as how to coordinate staff from different departments. This in turn will improve NPD timelines.

The fourth perspective is the corporate culture perspective that focusses on social, informal relations, collective habits, behavioural patterns and attitudes existing in an organisation. Corporate culture emerges from collective learning processes and it guides and shapes collective and individual behaviour [33]. The corporate culture will improve senior personnel's competence in values and norms.

NPD companies must improve their monitoring of innovation and management of technology. Product technology is a critical factor in product design as it can dramatically change the competitiveness of products Companies are encouraged to monitor publications done by university research arms, the armed forces, private foundations and the government. It is also important for these companies to make use of NPD metrics such as customer feedback and new ideas that have a potential for breakthroughs and adoption. Employees must be taught how to work with marketing, research and engineering groups in organising and classifying new ideas.

6.1 LIMITATIONS

Few SMEs were studied making the results ungeneralisable. Costs associated with new product development as reported by Jensen et al [34] such as, "poor designs, product malfunctioning, product liability claims, expensive product recalls and potential higher production costs," were not looked into. The dynamics of core competencies due to product-market strategy of the firm changing was not part of the research. The commercial performance of new products [35], that can be studied through business analysis stages that include sales forecasts, cost estimation, profit projections, risk assessments and cannibalization of sales were not looked into, and can form basis of future research. The research did not reach out to these companies' customers. Absorptive capacity influenced by Research and Development was also not covered.

6.2 FUTURE WORK

Future research may look at internal and external efficiency with regards to a company's potential in new product development. The efficiencies can be measured against new product development metrics such as development time, acceptance by customers, reworks, and development costs. There are various subsets of product development strategy, and these include product development diversification strategy, product modification strategy and revolutionary product development. However this paper did not cover any of the subsets of product development strategy, and this can be considered as part of future work.

7 CONCLUSION

The paper presents an investigation of the competence levels of senior personnel involved with new product development. The competency factors looked into were sources of NPD knowledge, cognitive skills and psychological traits. The study established that formal training in new product development is lacking, and this was found to impact negatively on NPD timelines. On cognitive skills creativity was found to be high but problem solving and multitasking skills were found to be weak. Psychological traits competence was found to be affected by poor communication standards that led to poor coordination among various departments. The paper proposed that senior personnel's competency levels can be improved through organisational learning.

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EVALUATION AND REDESIGN OF A PARTICULAR SELECTED ENVIRONMENT OR SET OF EQUIPMENT FROM AN ERGONOMIC POINT OF VIEW

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ABSTRACT

This research evaluated and proposed a redesign a pallet refurbishment company from an ergonomic point of view. Ergonomics is: “the science of fitting jobs to the people who work in them.” The aim of the project was to incorporate ergonomics into the system design and as a result, optimise the human well-being as well as the overall system performance. Various ergonomic assessments were performed. Passive and active surveillance was undertaken as well as obtaining information from group discussions and evaluating the training and awareness of the workers. The full system was evaluated, identifying ergonomic hazards, for example: lack of workstations, which formed the basis for the ergonomic re-designs. A final concept was chosen using a weighted evaluation methodology. The final design was fully specified and costed. The expected benefits were quantified and conservatively calculated to be: ±30 extra pallets could be refurbished in a day, leading to an increased profit of R10 362.60 a month. The return on investment was calculated to be 1604.8%, with a payback period of 2 months. The net present value was calculated to be R240 726.48 over a 3 year investment period. The utilisation of the entire plant could potentially increase from 66.25% to 91.25%.

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1 INTRODUCTION

Ergonomics is 'the science of fitting jobs to the people who work in them' [1]. Ergonomics traditionally focuses on creating and ensuring a safe work environment with easy to use equipment, and thus improving the efficiency of employees. The field focuses on items such as; design of workstations, controls, displays, tools etc. to meet the physical requirements, capabilities and limitations of employees [1]. It is a science that relies on continuous improvement of the work system and interaction between humans and their environment.

Company X is a family owned, pallet refurbishment company situated in Alberton, Gauteng. There were 8 employees working for the company at the time of the project. Company X operate on tight margins, in a competitive market with low barriers to entry. Company X experience both operating and capital constraints.

The objective was to create a work environment that catered for the employees' safety and well-being as well as to improve the efficiency and performance of the organisation. The anticipated benefits driving the business case included:

- Lesson chance of injuries,
- Increase productivity through higher throughput,
- Decrease non-value adding activities such as: handling, searching for components, walking to material supply locations etc.
- Decrease lead times by evaluating the design of work organisation and shop floor layout,
- Lower cost,
- Increase accuracy,
- Increase employee morale,
- Improve employee engagement.

Therefore, the purpose of the project was to test whether ergonomics, a field of science traditionally used in high technology, capital intensive environments, could be meaningfully applied to a labour intensive, low technology and capital sensitive environment and be commercially viable.

2 LITERATURE REVIEW

Ergonomics focuses on three key areas, namely: person/ people, job/ task, environment. [2]
The first focus area is the person/ people performing the task(s). This area is divided into the physical and mental components of the employees, as well as evaluating factors such as the anatomical, biomechanical, psychological and physiological properties of the employees.
The next focus area is the job/ task. In this area, ergonomics assesses what the worker is doing, how frequently the worker is performing a task, the duration and intensity of the task, the objects involved as well as the required movements performed on the object. For example: is the object pushed, pulled, lifted? Physical attributes of the object, such as the shape, size and couplings are also evaluated. [2]
The last focus area is the environment which is divided into two parts, namely the external and internal environment. The external environment looks at where the employee is working. For example, is the worker exposed to cold, direct sunlight, vibrations etc.? The internal environment is comprised of the work organisation, team work, safety culture etc.

Ergonomics is a unique discipline as it combines three fundamental characteristics [3]:

1. It has a systems approach,

2. It is design driven,
3. It focuses on two closely related outcomes; performance and well-being.

Ergonomics takes a systems approach - Ergonomics considers different aspects of the person and environment (as mentioned above), as a result of this, issues on multiple levels within the system can be identified and addressed [3].

Ergonomics is design driven – Ergonomics can be used in stages such as: planning, implementation, evaluation, maintenance, continuous improvement of systems, redesign and design etc [3]. Ergonomics is differentiated from other disciplines such as sociology and anthropology because of the design aspect [3].

Ergonomics focuses on two closely related outcomes: performance and well-being – The two mentioned outcomes influence each other. In order to ensure the success of both, they should be understood to be strongly connected and dependant on each other [3].

3 METHODOLOGY

The methodology used in this paper focused on the integration of ergonomics with lean principles. The focus was on incorporating ergonomic risk assessments with prioritization methods such as process mapping in order to select areas or processes for analyses. The ergonomic assessments were used to identify potential ergonomic and productivity problems and areas for improvement. By applying ergonomic design concepts to workstations and understanding how workers interact with their environment, tools, material etc. productivity can be improved and costs due to error, sick leave will be reduced.

“Every system is perfectly designed to get the results it gets.” [4] (1994) explains that the system design is often the aspect that needs changing; therefore a holistic view was taken when performing the analysis.
Initially, a set of criteria were established for the investigation and redesign and were as follows:

- Safety of the workers needs to be improved. The new designs should consider safety in more depth than the current state.
- Cost of the new design should be minimised as much as possible.
- The new design should improve aspects such as employee morale, employee engagement etc.
- Time spent by workers looking for raw material should be decreased.
- Reduce chances or likelihood of injuries.
- Design of workstations should minimise the time spent lifting, rotating or turning pallets (manual material handling).
- Design of workstations should minimise the likelihood of back, shoulder or ankle injuries or pain.
- Design of work organisation should allow for the ease of pallet transportation within the factory.
- Design of work organisation and work stations should minimise the time spent workers lift their hands above their crown (head) or shoulders while lifting pallets.
- The new design should facilitate an improvement in productivity by increasing the efficiency.

There were also some key constraints to the possible redesign:

- Company X operates under financial constraints.
- Capital constraints are present in the form of equipment and machinery.
- Labour intensive operations are required in the pallet industry.
- Lack of technology available to solve the problem of handling pallets by hand.

The investigation and evaluation of the company environment was done using the following techniques:

- **Passive surveillance** in the form of injury records, such as first aid reports, accident reports, workers' compensation etc.[5] The goal was to assess whether such records existed, whether an awareness regarding a safe and healthy work environment existed, as well as to identify where the highest incidences of injuries were occurring, as well as the types of injuries.
- **Consultation** with employees and management staff, for example, informal discussions, group discussions etc.
- **Active surveillance:** Area inspections, walk through surveys, direct observations of workers.
  Techniques and tools such as: Body Part Discomfort Survey (BPDS) [5], Ergonomic Risk Awareness Assessment [5], Musculoskeletal Disorder (MSD) Hazard Identification Tool [6], Rapid Entire Body Assessment (REBA) [7], Hazard [8] and Caution [9] Zone Checklists and an Ergonomics suggestion box to involve all employees in the process and improve employee engagement.

4 EVALUATION OF ENVIRONMENT

4.1 Caution Zone Checklist

The first tool used was the WISHA Caution Zone Checklist [9]. This is used as a screening tool to determine if an activity has ergonomic stressors present for a sufficient duration of time to become a problem. The tool focuses on specific ergonomic stressors which included the following: awkward posture, high hand force, highly repetitive motion and repeated impacts. Workers were observed on various days, at different times while performing their tasks. (Please note: all assessments were done with the help of an ergonomist and an occupational therapist who specialised in ergonomics.) In this project, the caution zone checklist assessed the movements or posture required to perform tasks in the different work stations of the company.
The caution zone checklist identified that five out of six areas evaluated can be classified as "caution zones".

4.2 Hazard Zone Checklist

After analysing the above mentioned checklist results, particular problem areas were identified. These were identified by using the Hazard Zone Checklist. This tool focuses on the detailed aspects of the actual tasks being performed, which included: gripping (pinch and power), force (lifting, lowering, pushing, and pulling), awkward/ fixed postures, repetition, as well as other hazards for e.g.: repeated impacts, contact stress, hand-arm vibration, whole body vibration, cold/ hot temperatures. The duration of the ergonomic stressors were taken into account. The problematic areas included:

- The current workstations. Workers have to put themselves in awkward postures in order to perform the tasks of the job. For example, workers have to work with their backs bent forward more than 45 degrees without any support or ability to vary posture.

- It was identified that fine motor skills of the hands are not required for the job; however, high hand force in the form of gripping an unsupported object weighing more than 4.5kg occurs. The duration is more than 3 hours a day.

4.3 Musculoskeletal Disorder (MSD) Hazard Identification Tool

In order to validate the results from the Caution and Hazard Zone Checklists, a MSD Hazard Identification Tool [6] was used.

A simple equation can be used to explain what causes MSDs [6]:

Force + Awkward Position + Repetition + Long Duration = Increased MSD Risk

Similar results were seen from this investigation. The results showed that workers are required to lift and lower loads in such a manner that have a high possibility of causing work related MSDs.

4.4 Rapid Entire Body Assessment (REBA)

REBA focused on the postural analyses of the workers, both static and dynamic. REBA allowed for the objective measure of the MSD risk caused by tasks. Tasks that involved the whole body could be assessed, therefore making it applicable to the pallet industry. The MSD hazards considered included: force, posture, repetition and duration.

Different ergonomic stressors are given different scores, for each part of the body. While observing the workers, the scores are allocated according to a predetermined table and set of rules, giving an outcome of a "REBA score". The REBA score gives an indication of the severity of the current state/work environment. The REBA score was 15, thus placing it in the category of "11 and above", making it a very high risk environment - where change needs to be implemented.

4.5 Body Part Discomfort Survey (BPDS)

Different workers from the three different workstations completed the survey. The workstations were: pallet stripping, pallet repairs and pallet spraying. Workers were asked to give each body part a discomfort score as well a score indicating how often the discomfort was experienced. This was done at the end of the work day. The survey focused on fine detail, including scoring the left and right hand side of the body separately for each body part where applicable.

This tool involved the workers in the process, therefore aimed at improving worker engagement. All surveys reflected similar results, showing workers experienced discomfort at the end of the work day in three major muscle groups, namely: back (lower and upper), shoulders and neck.

Discomfort can be a precursor to injuries, therefore the BPDS allowed for the ergonomic hazards to be addressed before injuries occurred. The advantage of the BPDS was that it revealed discomfort that may not lead to specific injuries or cause workers to take sick leave. For example; standing for prolonged periods of time causes discomfort to the knees and legs but may not appear in injury statistics. Although they do not appear in injury statistics, they need to be addressed as they could potentially affect work performance.

Other assessments were conducted which included: group discussions, assessing the workers' ergonomic risk awareness knowledge as well as direct observations in the different work stations. The observations identified factors such as: no work rotation, lack of workstations, debris filled walkways, constant bending, twisting and working off ground level, poor ventilation and insulation, noise pollution, poor lighting, close proximity of workstations, slip, trip and fall dangers, ineffective use of personal protective equipment (PPE) etc. These assessments indicated similar results and thus a trend of ergonomic hazards and work-related MSDS were identified, leading to a further investigation incorporating different tools. These tools included (please note these are select examples of tools used):

4.6 Value Added and Non Value Added Activities

The avoidable non- value adding activities included:

- Workers walking from one workstation to the next (±12m), located on opposite sides of the factory, to fetch raw materials.
- Transporting the pallets from the back of the factory to the truck parked 10 -15m outside the factory, and ±37m from spraying department.
- Unnecessary manual material handling at repair and stripping work stations. This leads to fatigue, increased risk of developing work related MSDs and time wasting due to inefficiencies.

Figure 1 shows a spaghetti diagram of the flow of products in the factory. Please note the diagram is not to scale.

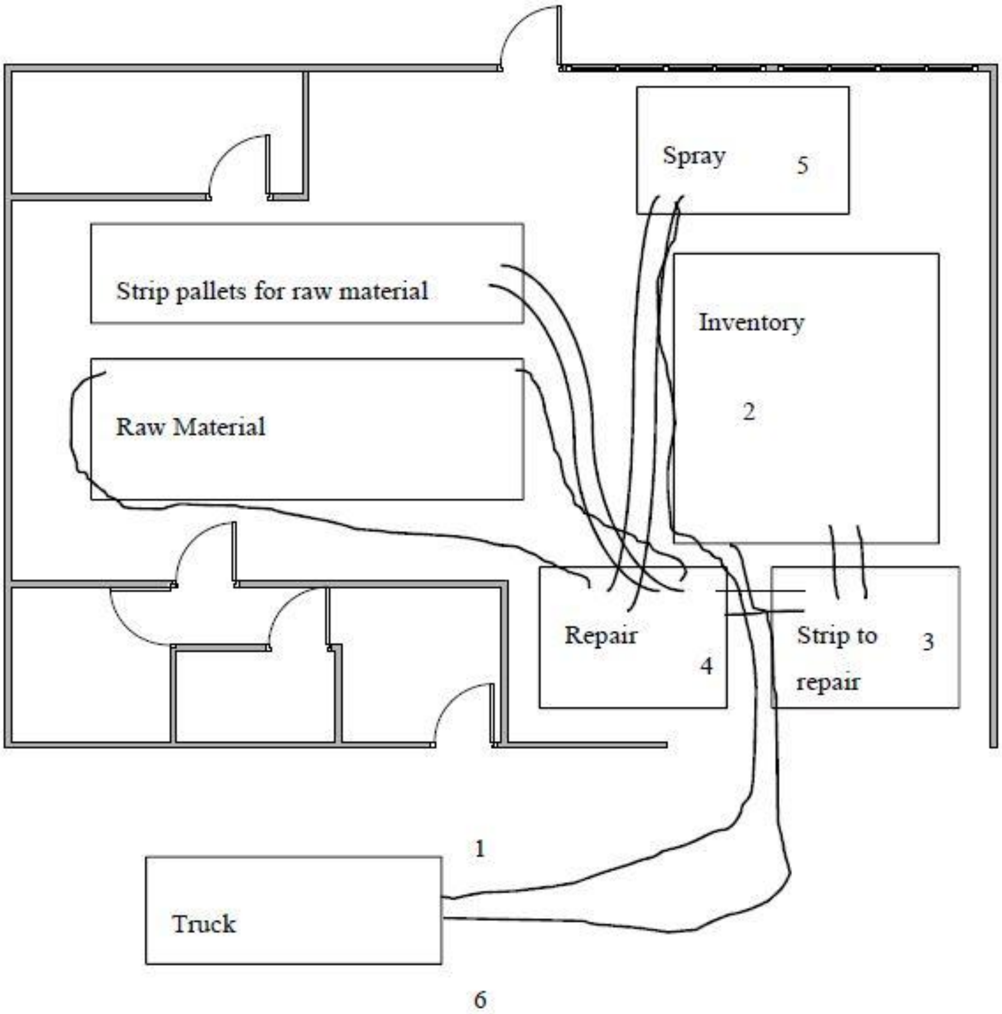

Figure 1: Spaghetti diagram showing current state

4.7 Process Mapping

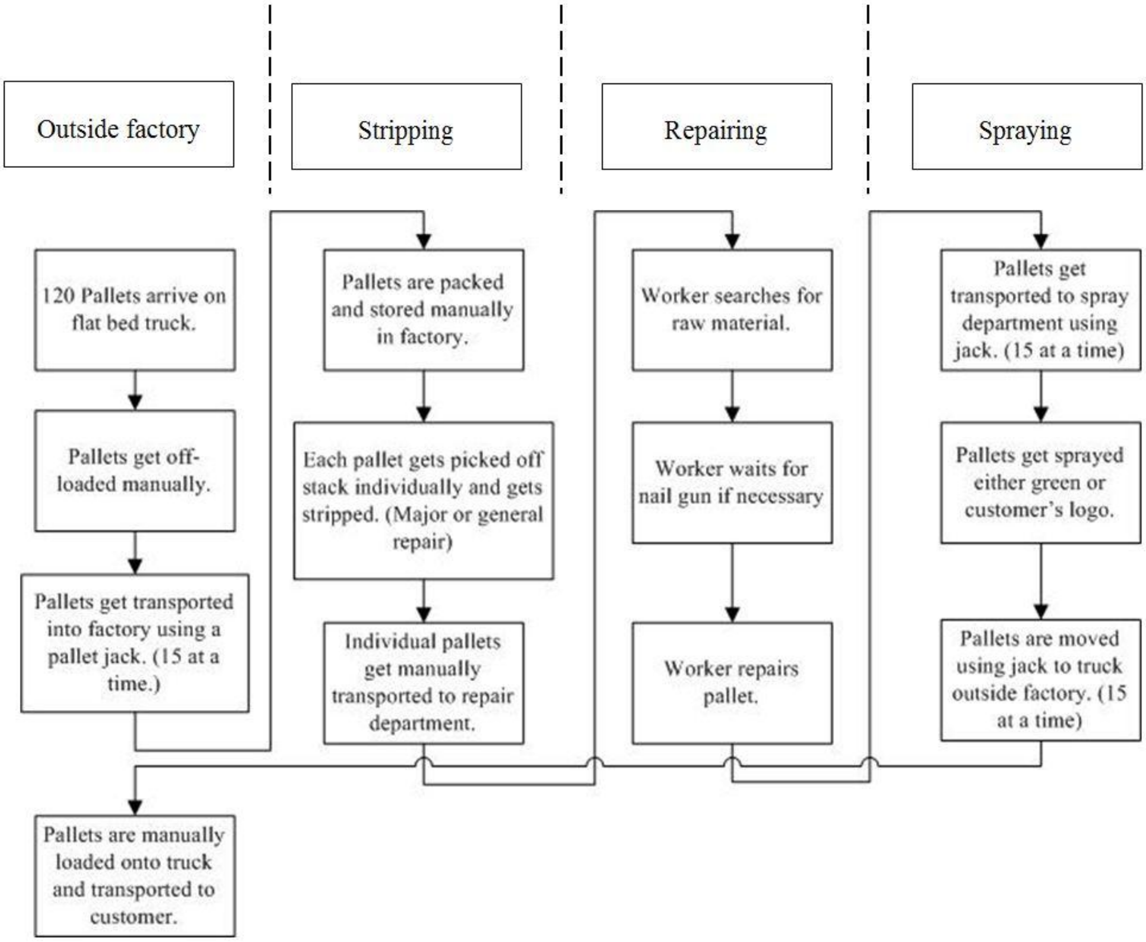

Figure 2: Process Mapping

Figure 1 shows the movement of the pallets within the factory. One can see there was not a systematic flow as pallets moved from one side of the factory to the other, on various occasions (positions: 1-2; 4-5 and 5-6 as seen in Figure 1) leading to the waste of unnecessary movement. Figure 2 shows the processes that each pallet went through. As seen in Figure 1 and Figure 2, activities leading to inefficiencies and time wasting included:

- Finished goods travelling from the back of the factory from the spraying department to the truck parked outside ±37m away,
- Excessive Manual Material Handling,
- Repairers looking for and walking to the raw material location,
- Nail gun constantly jamming due to insufficient training,

4.7 Cause and Effect Diagram

The cause and effect diagram in Figure 3 shows the likely causes of MSD hazards present identified using the MSD Hazard Identification Tool, consultation with workers and management staff as well as direct observations of the shop floor.

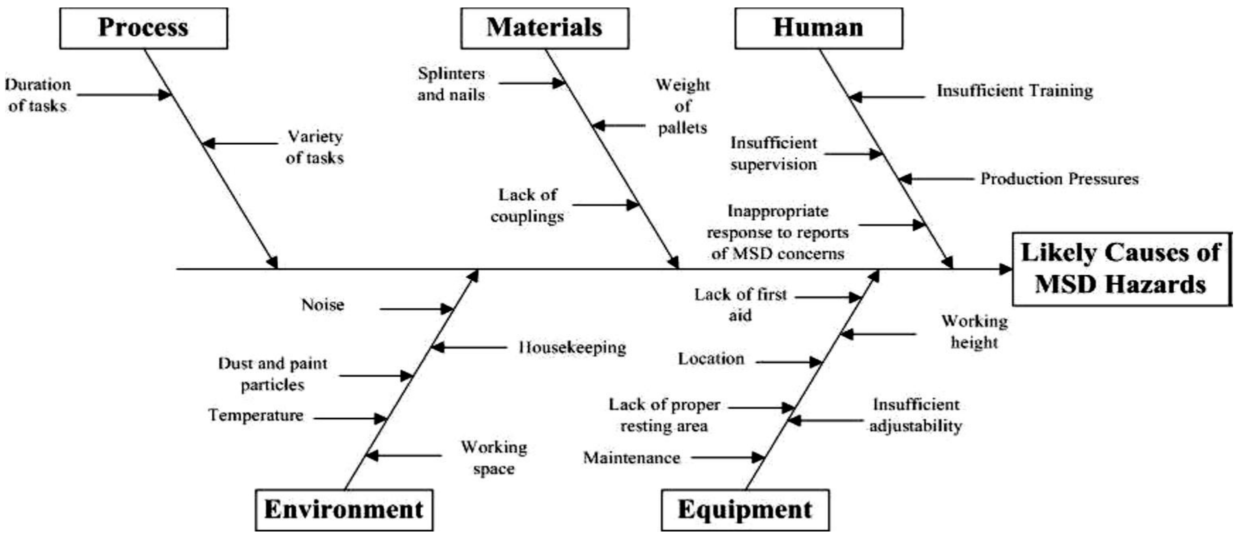

Figure 3: Cause and effect diagram of possible MSD hazards.

The 'Human' elements were aspects such as insufficient training. Insufficient supervision allowed the workers to not always wear their PPE, and thus sustaining injuries as a result. Production pressures placed upon the company by their customers, made the workers work longer days and take fewer breaks. The lack of action once a worker reports a work related MSD decreases employee morale and engagement as well as demotivates the workers from reporting in the future.

Under 'Equipment': it was seen that there was no set area for the workers to rest while on their tea or lunch breaks. Workers either sat on the floor or on the finished goods waiting to be delivered. The maintenance of the hammers and PPE needs to be improved with the hammer having lost the entire rubber lining on the handle.

As stated above these are select examples, other tools used to complete the investigation included:

- 5S – the tool was used to achieve the goals of:
  - Reduction in waste and variation,
  - Improved productivity.
- Ohno's 7 wastes – the following wastes were identified:
  - Waste of Waiting,
  - Waste of Unnecessary Motions,
  - Waste of Unnecessary Inventory.
- Matheson Scale of Physical Demand and Work Classification – this provided a guide as to how much the workers should be lifting, according to the characteristics and classification of the work. It was seen that workers should not lift loads of ±9.1 – 22.73kg, 34 – 66% of the day. Observations indicated that this does occur. (Pallets weigh roughly 20 – 22kg)

- Time and Motion Study – factors such as the following were identified as contributors to time wasting:
    - Moving stack of broken pallets,
    - Clearing walkways,
    - No supervision,
    - No seating,
    - Twisting, lifting and turning of pallets etc.

5 FINAL DESIGN

Three possible solutions were developed to address the problems identified. When developing the design concepts, the DuPont model was referred to. The DuPont model states that any business can do three things in order to make more money, namely: (1) increase the revenue, (2) decrease the costs, (3) improve the asset optimisation. For this project, the third case will most likely be the most applicable. All concepts were fully specified and costed. Each made use of different strategies to determine the best design for the company. The concepts were compared with the requirements and constraints initially formulated. Once the concepts conformed to these, they were compared using the criteria gathered from the initial investigation. A weighted evaluation system was then used to determine the most appropriate design that catered for the majority of the company's constraints and requirements. This ensured the final design was aligned with the customer's needs.
The final design aimed at combining ergonomic principles as well as industrial engineering tools and techniques.

Examples of general recommendations included:

- Replace all worn out **personal protective equipment** (PPE) and supply earplugs, goggles etc.
- **General resting area**. Comfortable chairs and tables should be available when workers are on their break. Workers sat on the floor or broken pallets which added to the discomfort identified through the assessments.
- Replace burnt out **lights**. (Two lights were currently working in the factory at the time of the project.)

Further softer side of the analyses recognised the need for:

- **Job rotation**. This would increase the stimulation of workers as well as distribute the physical labour in a more fair way. By rotating the jobs, the possibility of developing work related MSDs decreases as workers are exposed to different tasks, and thus the frequency of the potential hazards decrease per person.
- Developing a **safety culture**. Includes the increase in supervision as well as PPE usage.
- **Training** of the workers in the correct method of lifting heavy weights without the aid of couplings as well as the correct stretches in order to warm the muscles up, especially in winter. The work requires a jerky motion, stretching would alleviate muscle pain as well as the possibility of pulling a muscle. The training would be conducted by an occupational therapist specialising in ergonomics.
- **Incentives and appraisals**. In order to motivate the workers, incentives and appraisals are suggested. On average, the workers earn between R96 to R100 a day. Therefore, if they achieve their target set by quantifying the benefits of the final concept, they will get 15% of their daily rate (±R15) as bonus. If they achieve more than this target, each worker will earn R1.50 a pallet.

- **Leadership rotational program**. This aims to improve employee engagement and promote self-directed workstations as well as increase the accountability of the workers.

Examples of suggestions regarding the workstations included:

- A **rack step** for the sprayer in order to reach the top pallets. Currently the worker would stand on old paint cans which were dangerous and unstable.
- **Rotation tables**. A variety of MSDs would be addressed and reduced by introducing a rotating table. Strain placed on workers' backs, necks and shoulders would be alleviated. Research shows that forward functional reaching should be kept to within roughly 43cm from the front of the body [10]. As soon as the reach exceeds this amount, the shoulder and back muscles are stressed. The use of a rotating table allows the workers to rotate the pallet to the area that needs repair, reducing the reach distance. [10]
- **Standing workstations** were recommended in the stripping department. **Sitting workplace** is suggested for the stripping department and **sit/ stand workstations** and rotation tables for the repair department. Please see Figure 4 for an example. The respective heights relating to Figure 4 (as seen in the figure marked A – H), are further detailed in table 1.

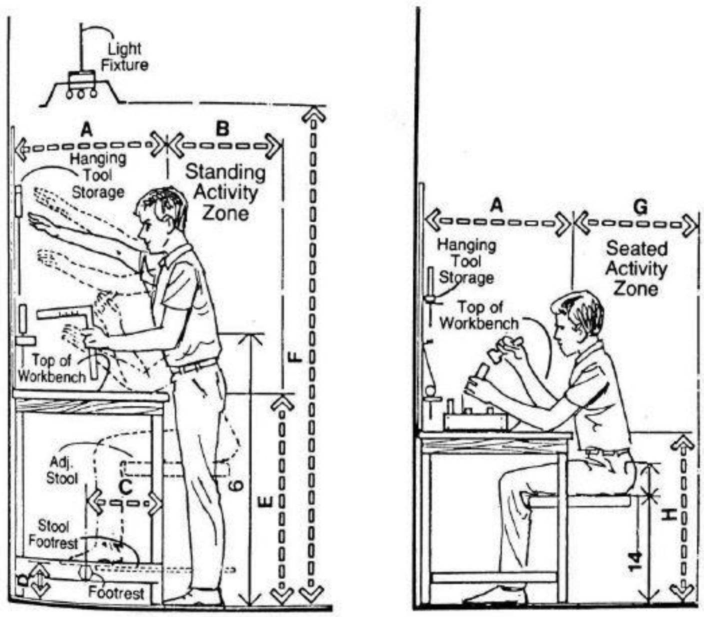

Figure 4: Sit/ stand workstations (left) and sit workstations (right). [11]

Table 1: Height ranges relating to workstations. [11]

A	45 - 91cm	E	86 - 91cm
B	45cm	F	213cm
C	15 - 23cm	G	45 - 60cm
D	17 - 23cm	H	74 - 76cm

To improve the flow of products in the factory, some of the following suggestions were made:

- **Demarcate walkways and aisles** according to the NIOSH standards. The minimum clearance for aisles and corridors for two persons passing should be: 137cm and for a two-wheeled hand truck such as the pallet jack: 76cm. [12]
- **Process layout** of workstations. The principle of process layout is to minimise the distance between the departments, avoiding long distance movement of materials, as well as arranging the departments in sequence of operations. [13]

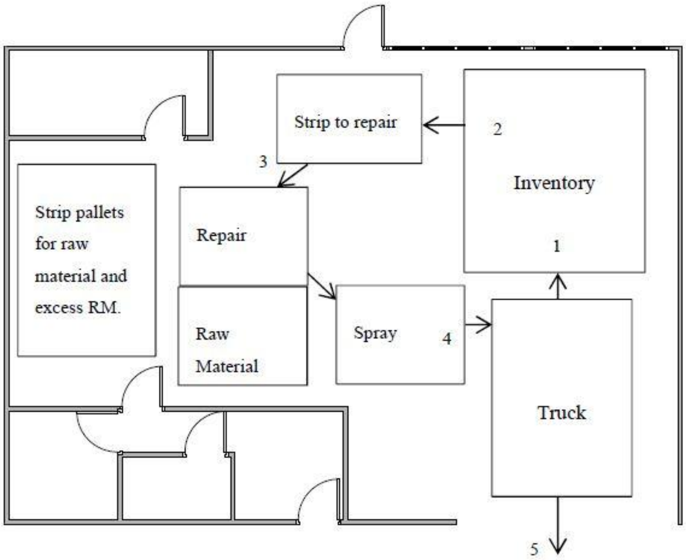

Figure 5: Process layout for final concept.

As seen in Figure 5, the new proposed process layout includes the truck coming into the factory, using the available ramp. The pallets will then be offloaded; one by one they will be stripped, then moved to the repair department, and finished in the spraying department, where they could either be loaded immediately, or wait in the area to the left of the truck.

The advantage of the new layout is: the spraying department is close to the entrance, therefore increasing the ventilation of the factory. The stripping department, where the most dust occurs, is situated near the other entrance of the factory (at the back), thus adding to the ventilation. The proximity of workstations is also addressed, as the spraying department is removed from the other departments. The compressor cord will not need to span the entire factory floor thus reducing slip, trip and fall dangers. The repairers will be given a box, so they can fill it up with slats of wood, bearers etc. that they will keep close to their workbench. This will eliminate the majority of movement occurring in and around this work area. Currently, they have no means to carry more wood or bearers than what they can physically carry.

6 BENEFITS CASE - QUANTIFYING THE BENEFITS

In order to build the benefits case, the expected benefits should be quantified. A conservative factor of 25% was applied in order to increase the validity of the results and ensure that the cost benefits case will materialise.

From the expected time savings due to the increased efficiencies of the final concept, it was seen that 1296 minutes will be saved in a day. This value is the sum of all the time savings for all 8 workers. No double benefits were added to this figure. Therefore, in order to express it in terms of plant capacity: this translated to roughly 30 extra pallets to be refurbished in a day.

6.1 Utilisation

Referring to the utilisation of the total plant, one will look at both the availability and the utilisation thereof.

The utilisation of the plant was negatively impacted by a number of inefficiencies ranging from: insufficient training, undue fatigue, lack of flow of products, wasteful micro-movements, excess manual material handling etc. and on average reduced available plant capacity by 2 hours per day. The current utilisation of the plant was ± 66.25%.

The chosen design would potentially increase the utilisation to ±91.25%

6.2 Feasibility Study

In order to ensure the financial validity of the design, the net present value, return on investment (ROI) as well as payback period were calculated and are seen in Table 2:

Table 2: Feasibility Study.

Net Present Value	R 240 726.48
Return on Investment	1604.80%
Payback Period	2 months

7 PROJECT SCHEDULE

Change management is important when many different aspects of the business are changed or modified. Effectively, all three aspects of the company, namely: people, process and technology were adapted or changed to a certain degree. People don't always accept change, which is why all attempts were made to include the workers in the process. For this reason, the changes will be implemented on a staggered basis using the concept of change management.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusion

- The chosen environment was the pallet refurbishment company-Company X. Before the investigation, it was understood that small companies operating on tight margins struggle to identify ergonomic hazards and maintain safe work environments. Currently, there is a lack of available technology to make the pallet refurbishment sector a safer sector of industry.
- Various ergonomic assessments were performed.
- From the assessments, ergonomic hazards were identified, therefore warranting the need for ergonomic designs as well as a further investigation into the environment, using industrial engineering techniques and tools.
- The expected benefits of the final concept were quantified and found to be: ±30 extra pallets would be refurbished in a day, leading to an increased profit of R10 362.60 a month. The ROI was calculated to be 1604.8%, with a payback period of 2 months. The NPV was calculated to be R240 726.48 over the 3 year investment period.
- The utilisation of the entire plant could potentially increase from 66.25% to 91.25%.
- A Pareto analyses was undertaken when dealing with the two products – major and general repairs. It was identified that the general repairs are the more profitable product, where the major repairs are currently running at a loss. More money can be made with the general repairs, therefore the focus should be on this product.

- The chosen concept shall be introduced on a staggered basis, using the concept of Change Management.

In conclusion, *"A clean and safe environment is a productive environment."* (Anonymous)

8.2 Recommendations for Future Work

- The last S in the 5S is for Sustain. It is crucial to sustain the principle of 5S on an on-going basis. This also follows the principle of continuous improvement by Dr. E. Deming. Therefore, planned maintenance every Friday afternoon is suggested. The workers finish at 2pm on Fridays, therefore, if 15 minutes to half an hour is spent tidying up, making sure slats of wood are in the correct bins or positions, nails have been picked up etc. the new week can begin with a tidy workplace.
- To evaluate the success of the leadership program. If the workers respond well to the program, it should continue. However, if the workers do not respond well and the aim of increasing employee morale and engagement fails, the second option is to get the workers to appoint a leader who will act as the foreman. The communication channel will work through the foreman as a result.
- The competitive analyses showed that companies that refurbish pallets are able to do it at a cheaper rate than Company X. The reason being: they repair on the client's premises. This idea should perhaps be further investigated by Company X. It is a viable option as Company X only serves a single customer. This would eliminate overhead costs such as rent as less space would be needed. Transportation costs to and from the factory would also be reduced. The alternative of this option is also worth investigating. Company X can look to acquire customers who have space constraints, and don't have premises available for companies to use to repair their pallets.
- Exploring the option of working two Saturdays a month. It was discussed with the owner, that if more pallets can be repaired in a day, the client is able to send more pallets. (The client's reserves of broken pallets is vast) Therefore, if the workers come in for two Saturdays a month, working 4 hours, a profit of R2 866.60 can be made.

9 Acknowledgments

The author would like to acknowledge the help and contribution of the Ergonomist, Occupational Therapist and Human Factors Specialist who were consulted during the project. In addition, a big thanks to the University of the Witwatersrand for the technical support as well as to the staff at Company X for allowing the company to be the subject of the project.

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A DECISION SUPPORT SYSTEM FRAMEWORK FOR MACHINE SELECTION

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ABSTRACT

Selecting the right machinery to machine a part is a multi criteria decision making problem which is crucial in production planning. The process becomes more complex and tedious when one has to choose from a variety of machines available in an online registry. This paper investigates this decision making process with the objective to increase machine utilisation for small, medium and micro enterprises. A real time information based decision support system is necessary to assist the decision maker. A decision support system framework for machine selection for a manufacturing agent is proposed based on the Analytical Hierarchy Process (AHP). A human expect uploads parameters for a part that has to be machines. Based on these parameters, suitable machines are sought for from an online machine registry and ranked according to their capability to produce the desired part.

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1 INTRODUCTION

Globalisation has opened up competition for manufacturing companies from competitors both locally and abroad. This has necessitated a change in the manufacturing strategies the companies are using in order to remain competitive. Most of the manufacturing companies are moving towards being more agile and lean hence they are implementing distributed manufacturing systems. This creates an opportunity for Small to Medium Enterprises (SMEs) as they most of the time they specialise on certain manufacturing operations which other companies can subcontract them to do. The biggest problem the SMEs face is limited financial resources which results in them failing to own high value machinery they would want to use. An e-manufacturing framework has been developed to enable the SMEs to increase machine utilization and manufacturing capabilities by sharing manufacturing resources. Selection of machinery to machine a part is a Multi Criteria Decision Making problem. The complexity of the problem is increased when the choices of machinery become dynamic as is the case in the proposed framework. In this paper we present a methodology for machine selection to be used by a manufacturability agent which is part of an e-manufacturing system [1]. The rest of the paper is structured as follows. Section 2 contains related literature, section 3 discusses the proposed framework and section 4 discusses the decision making methodology. The paper finally ends with a conclusion.

2 RELATED LITERATURE

2.1 Multi-Criteria Decision-Making

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) [2]. 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.[3]. To solve a MCDM problem a decision tree is constructed using the criteria relevant to a particular decision and the weighting/scoring of the criteria and the alternatives for each different criterion. Several MCDM methods have been developed in literature with Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) being the mostly widely used methods [2, 4, 5, 6, 7, 8, 9, 10].

2.2 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach which was introduced by Saaty [11, 12]. It uses well-defined mathematical structure of consistent matrices and their Eigen vector to generate weights on the selection criteria [13, 14, 15]. To make decisions with AHP the following steps should be followed [16]:

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.

2.2.1 *Problem definition*

The facilitator sits with 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 [17], Saaty and Forman [18] have developed 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 [19], [20], [21]. According to Lin and Yang [22] it is best that each hierarchy does not contain more than seven elements otherwise the elements should be clustered, then divided into an additional hierarchy.

2.2.2 *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 4.1.1.

Table 1: Fundamental scale of absolute numbers [14]

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 j has the reciprocal value when compared with i	A reasonable assumption
1.1–1.9	If the 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.

2.2.3 *Determination of priorities*

The priorities of each element can be determined by finding the Eigen vector of the pairwise comparison matrix. This can be achieved by raising the matrix to large powers and summing each row and dividing each by the total sum of all the rows [16]. In our approach we use the approximation of the priorities by adding each row of the matrix and dividing by their total. Once the priorities have been found the Principal Eigen value can be obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix.

2.2.4 *Consistency checks*

The degree of consistency in the judgement of the priorities is measured by Consistency Ratio (CR). To calculate CR the Consistency Index (CI) should be derived using the following formula [11]:

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

Where λ_{max} is the Principal Eigen value of the pair wise comparison matrix and n is the dimension of the matrix.

Consistency Ratio is then given by

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

Where CI is the Consistancy Index and RI is the Random Consistency Index given in Table 2. If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

Table 2: Random indices [11]

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

According to Ishizaka and Labib [23] several other consistency measures close to Saaty's have been developed [24, 25, 26, 27]. Saaty's consistency measure has also been criticised for allowing contradictory judgements [28, 29] and also rejecting reasonable judgements [30] but it is still the most used measure.

2.2.5 *Application of AHP in machine selection*

From the literature several methods of applying AHP in machine selection have been proposed. Arslan et al [6], Yurdakul and Ic [31], Ic and Yudakul [32], Wang and Chin [1] and Ayag, Z. and O¨zdemir [33] have developed models that use the technical data of machines obtained from catalogues to select machinery. Yusuf et al [5] uses components of a machine. Lin and Yang [22] developed a model for machine selection in a Flexible Manufacturing System (FMS). Oeltjenbruns et al [34] developed a model that explores different planning alternatives ranging from extending the life of existing machinery to total system and to evaluate these alternatives through economical and technological criteria replacement with a new manufacturing. Most of the models proposed in literature are used for the selection of machinery when purchasing machinery. To the authors' best knowledge, a study that links machine selection to the part to be machined is not available in the literature. In our proposed framework the parameters of the part to be machined are linked to the parameters of the machines available.

3 MACHINE SELECTION FRAMEWORK

In the selection of machinery three factors are considered to ensure that a manufacturer remains competitive. These are the quality of products, cost of production and delivery time as shown in Figure 4. With machines being able to do a variety of operations, the selection of machinery which can be used to machine a part becomes a multi criteria decision making problem, hence AHP methodology has been adopted. The objective of the application of AHP is to select the suitable machine for machining a part from an online registry. In this paper we regard capability as the quality factor since the objective is to select a machine capable to manufacture a part. Cost and time factors will be discussed in subsequent papers.

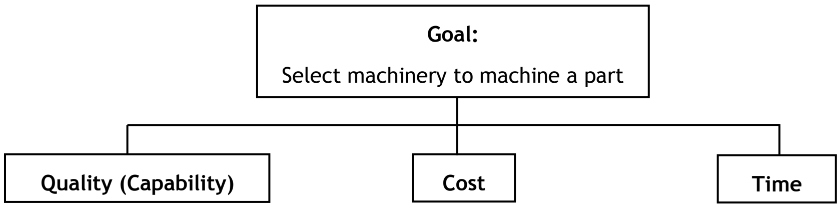

Figure 1: Machine selection top hierarchy

3.1 Decision Criteria

The objective is decomposed into a 4 level hierarchy of decision making criteria. The top level of the hierarchy is shown in Figure 4 and the second level is shown in Figure 5. The second level of the hierachy consists of productivity, flexibility and conformance to specification given for a product. Productivity sub criterion has to do with the rate at which the machine produces products. It contains the following machine attributes maximum spindle speed (MS), maximum power (MP), number of spindles (NS) and rapid traverse (RT). Flexibility sub criteria have to do with minimizing the number of set ups on the machine. It contains the number of axis on a machine (NA), swivelling range of the rotary table (RA), number of tools in the tool magazine (NT) and the control mechanism (CM) on the machine (i.e. CNC, NC or manual). The specifications sub criteria contains tolerances the machine can achieve (T), work envelope for the largest part that can be machined on the machine (WE), quality certification and references the company has (QC). The quality certificates a company has and references can also be used as an indication of whether the company will be able to produce a part with the desired quality. From a survey conducted most of the manufacturers indicated that they prefer working with companies they have previously done business with and those refereed to them by friends and other customers.

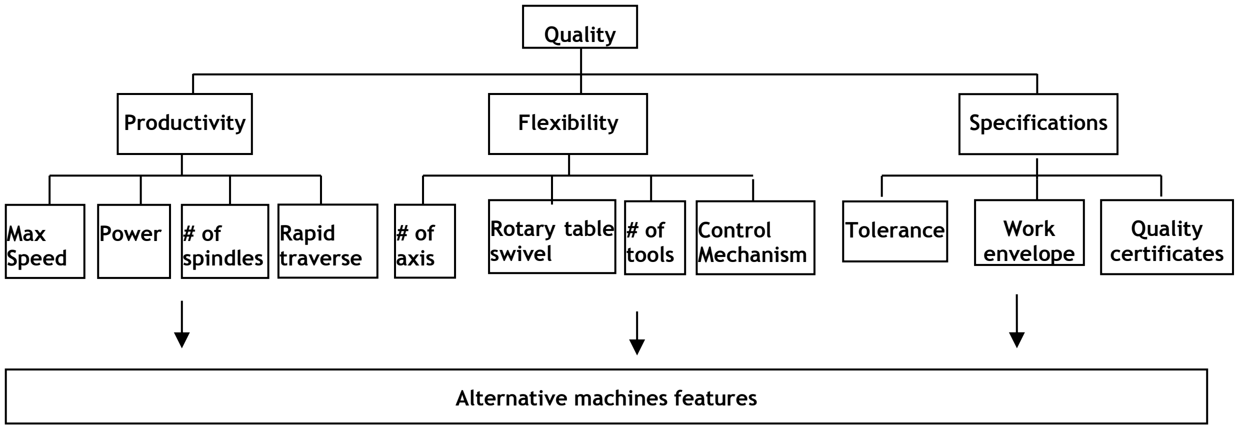

Figure 2: Quality priority

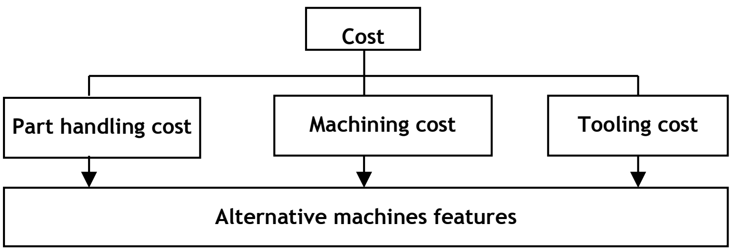

Figure 3: Cost factors

Production costs in Figure 6 are considered before the overall costs of subcontracting a machine. This enables that the benefits gained from using the machinery which might be rejected from the first glance if subcontracting costs are considered at an early stage of decision making. The objective is to select a machine with the minimum cost but maximum benefits. The time priority in Figure 7 ensures that parts are machined within the required time.

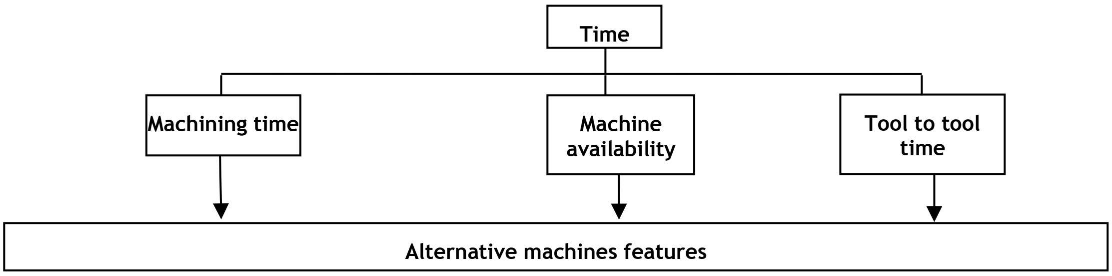

Figure 4: Time factors

4 METHODOLOGY FOR DECISION MAKING

The methodology proposes to rank the machinery from the best suitable machine at the top to the worst suitable machine at the bottom. A human expect inputs the required specifications for the part they want to machine. In the first stage of decision making the machines which do not meet the required specifications are filtered out. For those machines that are left the next step is to perform a pair wise comparison of the criteria and sub criteria to determine their ranking. Due to the large number of machines that one may have to choose from and the different number of alternatives when each search is done, it may be difficult to compare the alternative rankings. Instead of comparing the weights on the alternatives we adopt the approach by Çimren et al [35] where the weights of the decision criteria are used in ranking the machinery.

4.1 Machine ranking

In order to rank the machine each criteria ranking is determined by the following steps.

4.1.1 *Pair wise comparisons*

The decision maker enters relationships between the general criteria i.e. quality, cost and time. A half matrix where the relationships of the criteria on the rows are compared to the criteria on the columns is developed. Questions asked are in the following format:

If quality is on the row and flexibility on the column the question is asked as "*How important is the quality of the product to the production time?*" The answers to the question are given in the scale 1-9 (refer Table 1). If the criterion on the row is less important to the one on the column the inverse of the scale in table is given.

For a scenario where quality (Q) has extreme importance compared to cost (C), quality has strong importance to time (T) and the cost has very strong importance to time the pair wise comparisons are shown in Table 3.

Table 3: Pairwise comparisons

	Q	C	T
Q	1	9	7
C		1	1/7
T			1

4.1.2 *Pair-wise comparison matrix*

The pair wise comparison matrix is completed by the putting the inverse of the scales for the inverse relationships as shown in Table 4.

Table 4: Pairwise comparison matrix

	P	F	S
P	1	9	7
F	1/9	1	1/7
S	1/7	7	1

4.1.3 *Priority determination*

The pair-wise comparison matrix is normalised by dividing the values in each column by the column sum as shown in Table 5. To determine the priorities of each criterion, the normalised principal Eigen vector is obtained by averaging across the rows.

Table 5: Normalised pairwise comparison matrix

	Q	C	T	Priority
Q	0.80	0.60	0.69	0.70
C	0.09	0.07	0.01	0.06
T	0.11	0.47	0.10	0.23
Sum	1.25	15.00	10.14	

From Table 5, quality is considered as most important, followed by time and then lastly the cost. The priority ranking for quality ($Q_{p)}$, cost (C_p) and Time (T_p) are 0.70, 0.06 and 0.23 respectively. Ideally the sum of the priorities (Q_P+C_P+T_P) = 1.

$$\lambda_{max} = 1.25 * 0.72 + 15 * 0.063 + 10.14 * 0.22 = 4.016$$

$$CI = \frac{4.016 - 3}{2} = 0.51$$

$$CR = \frac{0.51}{0.58} = 0.88 = 0.9\% < 10\%$$

Since $CR < 10$ the judgement can be accepted hence we move on to the sub criteria priority ranking.

4.1.4 *Sub criteria priority ranking*

Calculate the priority ranking for the sub criteria using the steps 1 to 5. For example for productivity the pair wise matrix can be developed as shown in Table 6:

Table 6: Productivity sub criteria priority ranking

	MS	MP	NS	RT
MS	1	9	7	5
MP	1/9	1	7	7
NS	1/7	2	1	1/5
RT	1/5	1/7	5	1

The priority ranking for maximum spindle speed (MS), maximum power (MP), number of spindles (NS) and rapid traverse (RT) will be 0.57, 0.26, 0.04 and 0.12 respectively and CR is 7.4%.

Using the same method shown section 4.1.1 to 4.1.3 the priority ranking for the flexibility and specifications sub criteria is calculated. The priority ranking for number of axis, swivelling range of the rotary table, number of tools and control mechanism in the flexibility sub criteria are found to be 0.59, 0.18, 0.17 and 0.06 respectively with CR = 7.7%. The priority ranking for tolerance, work envelope and quality certificates in the specifications sub criteria are found to be 0.68, 0.09 and 0.23 respectively with CR = 6.5%.

4.1.5 *Calculate machine attribute contribution*

A part with specifications shown in Table 7 is used to illustrate how machine attribute contributions for machines with specifications given in Table 8. The specifications given in Table 8 contribute to the quality criteria. The attribute ranking for each machine attribute in sub criteria is calculated using the method illustrated in sections 4.1.1 to 4.1.4.

Table 7: Part specifications

MS	P	NS	Rapid Traverse			NA	RA	NT	CM	T	Work Envelope			QC
			X	Y	Z						X	Y	Z	
5000	10	1	45	45	40	3	90	10	CNC	0.01	50	30	20	ISO 9000, SABS

Table 8: Available Machines

Co	Mac ID	Type	MS	P	NS	R Traverse			NA	RA	NT	CM	T	Traverse			QC
						X	Y	Z						X	Y	Z	
A	M01	HMC	10000	29	1	45	45	40	5	130	42	CNC	0.008	800	800	550	2
A	M05	HMC	5000	15	1	23	23	7	3	45	20	CNC	0.05	780	780	400	2
B	CM2	VMC	1500	11	1	2.7	2.3	1.3	3	0	1	M	0.1	880	360	300	1
B	CM6	UMC	15000	20	1	45	45	40	5	130	42	CNC	0.008	800	800	550	1
C	DA4	VMC	1500	7.5	1	2.7	1.8	1	3	0	1	M	0.1	780	280	400	2
C	SA2	HMC	18000	20	1	45	45	40	5	130	42	CNC	0.008	800	800	550	2

The contribution of each attribute on the machine is calculated using Equations 3 and 4. For attributes with a single value the attribute contribution is given by

$$f(x) \qquad \overline{\qquad\qquad\qquad} \qquad \textbf{(3)}$$

For attributes with a range of values the attribute contribution is given by the triangular distribution

$$f(x) \qquad \begin{cases} \dfrac{2(x \quad a)}{(b \quad a)(c \quad a)} \\ \dfrac{2(b \quad a)}{(b \quad a)(c \quad a)} \end{cases} \qquad \textbf{(4)}$$

Where x is the part attribute, a minimum value of the attribute on the machine, b is the maximum value of the machine attribute and c is the median between the maximum and minimum machine attributes.

The machine attribute for the quality criteria are shown in Table 9. The overall contribution for each machine attribute is calculated by multiplying the machine attribute ranking by the machine attribute contribution and is shown in Table 10. The machine contributions for cost and time criteria are summarised in Table 11.

Table 9: Machine attribute contribution

Co	Type	MS	P	NS	RT			NA	RA	NT	CM	T	Traverse			QC
					X	Y	Z						X	Y	Z	
A	HMC	2	2.9	1	1	1	1	1.67	1.44	4.2	1	1.25	16	26.67	27.5	1
A	HMC	1	1.5	1	0.51	0.51	0.18	1	0.5	2	1	0.2	15.6	26	20	1
B	VMC	0.3	1.1	1	0.06	0.051	0.033	1	0	0.1	0	0.1	17.6	12	15	0.5
B	UMC	3	2	1	1	1	1	1.67	1.44	4.2	1	1.25	16	26.67	27.5	0.5
C	VMC	0.3	0.75	1	0.06	0.04	0.025	1	0	0.1	0	0.1	15.6	9.333	20	1
C	HMC	3.6	2	1	1	1	1	1.67	1.44	4.2	1	1.25	16	26.67	27.5	1

Table 10: Overall quality machine attributes contribution

Co	Type	MS	P	NS	RT	NA	RA	NT	CM	T	Traverse	QC
A	HMC	1.15	0.76	0.04	0.12	0.98	0.26	0.73	0.06	0.86	1.41	0.23
A	HMC	0.57	0.40	0.04	0.02	0.59	0.09	0.35	0.06	0.14	1.37	0.23
B	VMC	0.17	0.29	0.04	0.00	0.59	0.00	0.02	0.00	0.07	1.06	0.11
B	UMC	1.72	0.53	0.04	0.12	0.98	0.26	0.73	0.06	0.86	1.41	0.11
C	VMC	0.17	0.20	0.04	0.00	0.59	0.00	0.02	0.00	0.07	0.82	0.23
C	HMC	2.06	0.53	0.04	0.12	0.98	0.26	0.73	0.06	0.86	1.41	0.23

Table 11: Overall cost and time machine attribute contribution

Co	Mach ID	Type	Cost			Time		
			Part handling cost	Machining cost	Tooling cost	Machining time	Machine availability	Tool to Tool time
A	M01	HMC	0.1243	0.0020	0.0043	0.2556	0.1969	0.0387
A	M05	HMC	0.1243	0.0030	0.0086	0.1534	0.1181	0.0249
B	CM2	VMC	0.2072	0.0075	0.0103	0.0767	0.0656	0.0058
B	CM6	UMC	0.2072	0.0040	0.0065	0.1917	0.1181	0.0387
C	DA4	VMC	0.2072	0.0067	0.0129	0.0639	0.0622	0.0058
C	SA2	HMC	0.2072	0.0020	0.0052	0.2556	0.1477	0.0387

4.1.6 *Calculate the overall machine attribute score*.

The overall attribute score is given by multiplying the priority scores of the general criteria, sub-criteria and the attribute contribution.

$$Overall\ score = General\ criteria\ priority * Subcriteria\ priority * attribute\ contribution \quad (5)$$

The overall machine attribute scores for quality, cost and time are shown in Table 12 and Table 13 respectively.

Table 12: Overall quality machine attribute score

Co	Type	MS	P	NS	RT	NA	RA	NT	CM	T	Traverse	QC
A	HMC	0.5718	0.3813	0.0221	0.0595	0.0443	0.0117	0.0329	0.0026	0.1297	0.2137	0.0345
A	HMC	0.2859	0.1972	0.0221	0.0104	0.0266	0.0041	0.0157	0.0026	0.0208	0.2084	0.0345
B	VMC	0.0858	0.1446	0.0221	0.0019	0.0266	0.0000	0.0008	0.0000	0.0104	0.1603	0.0173
B	UMC	0.8577	0.2630	0.0221	0.0595	0.0443	0.0117	0.0329	0.0026	0.1297	0.2137	0.0173
C	VMC	0.0858	0.0986	0.0221	0.0015	0.0266	0.0000	0.0008	0.0000	0.0104	0.1247	0.0345
C	HMC	1.0292	0.2630	0.0221	0.0595	0.0443	0.0117	0.0329	0.0026	0.1297	0.2137	0.0345

Table 13: Overall cost and time machine attribute score

Company	Machine ID	Type	Cost			Time		
			Part handling cost	Machining cost	Tooling cost	Machining time	Machine availability	Tool to Tool time
A	**M01**	HMC	0.01	0.0001133	0.00024	0.05787	0.0445704	0.0088
A	**M05**	HMC	0.01	0.00017	0.00049	0.03472	0.0267422	0.0056
B	**CM2**	VMC	0.01	0.0004249	0.00058	0.01736	0.0148568	0.0013
B	**CM6**	UMC	0.01	0.0002266	0.00036	0.0434	0.0267422	0.0088
C	**DA4**	VMC	0.01	0.0003777	0.00073	0.01447	0.0140748	0.0013
C	**SA2**	HMC	0.01	0.0001133	0.00029	0.05787	0.0334278	0.0088

4.1.7 *Determine Machine ranking*

The overall machine rank is calculated by summing up all the overall attribute scores. The machines are ranked in ascending order of the machine ranks. The machine with the highest machine rank is more suitable to machine the part hence it appears first. From the example given the most suitable machine to machine the part is SA2 from company C.

Table 14: Machine total score

Company	Machine ID	Type	Total Score
C	SA2	HMC	1.95555679
B	CM6	UMC	1.74578927
A	M01	HMC	1.62287843
A	M05	HMC	0.90304234
B	CM2	VMC	0.51599939
C	DA4	VMC	0.44759253

5 CONCLUSION

Machine selection is defined as a Multi Criteria Decision Making problem with the objective of selecting the best suitable machine for machining a part. The paper presents a decision support system framework for the machine selection for a manufacturing agent. When a part is uploaded on an online registry the part features are compared with the machines that have been uploaded to filter out the machines that do not have the required specifications. The AHP methodology is then implemented to determine the machine ranking and its suitability to machine a given part. The proposed methodology enables the application of

AHP methodology in an environment with a large or dynamic number of alternatives. The framework will be implemented inform of a manufacturability agent.

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A CENSUS OF SOUTH AFRICAN INDUSTRIAL ENGINEERS, BASED ON DATA EXTRACTED FROM LINKEDIN

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ABSTRACT

The first South African Industrial Engineers graduated in 1963. Since then, the number of graduates per annum has grown to more than 200 per annum. Many of these Industrial Engineers use the social network, LinkedIn, to publish their professional profile and to build professional networks. The purpose of this paper is to make use of the information published on LinkedIn to determine who employs South African Industrial Engineers and which skills are attributed to them. LinkedIn-data were harvested, warehoused and analyzed of 362 persons who hold a Bachelor degree in Industrial Engineering from a South African university. In conclusion, the feasibility of this methodology is contemplated and the results of this investigation are discussed.

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1 INTRODUCTION

It is now about a century since Industrial Engineering is recognised as an academic discipline. The first academic department in Industrial and Manufacturing Engineering was established at the Pennsylvania state university in 1909 [1]. In 1963, the University of Pretoria was the first South African university to award degrees in Industrial Engineering [2]. Stellenbosch University [3] and the University of the Witwatersrand followed a few years later. To date these three universities are the only South African universities that provide qualifications that are meeting Engineering Council of South Africa's (ECSA) educational requirement for registration as a professional Industrial Engineering [4]. In 2015 the North-West University will become the fourth South African university that provide this qualification.

Traditionally, arising from the industrial revolution, Industrial Engineering is concerned with the design, management and improvement of manufacturing processes. These days, the Industrial Engineering skill- and mindset that is used to optimize processes and systems in a manufacturing setting are also be used in other product and service contexts to optimize processes and systems.

The problem that is addressed by this paper is that, although there is an awareness of who employs South African Industrial Engineers and for which skills, an census of South African graduates in Industrial Engineering has not recently been conducted.

Social networks brought forward a new way of social and professional interaction. Ellison and Boyd [5] defines a social network site as a "web-based service that allow individuals to (1) construct a public or semi-public profile within a bounded system, (2) articulate a list of other users with whom they share a connection, and (3) view and traverse their list of connections and those made by others within the system." LinkedIn is an example of social network which is predominantly used for professional networking and interaction.

The purpose of this paper is to make use of the information published on LinkedIn by Industrial Engineers themselves to determine who employs Industrial Engineers and for which skills. In pursuit of this purpose, three research questions are asked:

RQ 1: How can data contained by LinkedIn data be used to gain information about as Industrial Engineers in South Africa?

RQ 2: Who employs Industrial Engineers?

RQ 3: For which skills are these Industrial Engineers employed?

2 METHODOLOGY

During September and October 2013 data were harvested from the LinkedIn profiles of 362 professionals who obtained a Bachelors in Engineering degree from the either the University of Pretoria, Stellenbosch University of the University of Witwatersrand. The harvested data was then stored in three separate Excel-based data-marts which allowed data aggregation and analysis. The fact tables of these three data marts are indicated in Figure 1.

Employment datamart	Education datamart	Skills datamart
- LinkedIn ID - Employer / - Job description - Date started - Date ended - Number of months (date ended-date started) - Industry	- LinkedIn ID - University which awarded Bachelors degree - Date started - Date ended	- LinkedIn ID - Skills description - Number of endorsements

Figure 1: Datamarts

This harvesting process was done “manually” with copy and paste actions. According to Wu *et al*. [6] Avatara is and in-house online analytical processing (OLAP) system at LinkedIn that provides a generic batch processing platform, allowing any developers to build OLAP cubes with a single configuration file [6]. Unfortunately, Avatara did not provide the analytics operations required for this study. For this reason, the data were extracted from LinkedIn and then, cleaned, stored and analysed offline.

A limitation of this study is that the complementary (“Free”) LinkedIn option (refer to first column of Figure 2 only provide limited profile and search access. The sample size is furthermore limited by the fact that profile-data were only harvested if the profile owner indicated specifically that he/she obtain a Bachelors degree in Industrial Engineering from either the University of Pretoria or Stellenbosch University or the University of the Witwatersrand.

	Free	Business	Business Plus	Executive
View full profiles	Up to 2nd degree	See full profiles of everyone in your network - 1st, 2nd and 3rd degree.		
Profiles per search	100	300	500	700
Search Filters	None	None	Seniority, Company Size, Interests, Fortune 1000	Seniority, Company Size, Interests, Fortune 1000, Functions, Years of experience, Your groups, New to LinkedIn

Figure 2: Information access and search option, per LinkedIn option

For the past 10 years a total of approximately 200 Industrial Engineers graduated in South Africa. Before that the average annual graduation rate was even less. Hence, this sample of 362 profiles represents about 10% of the total population. If this study is scoped to include only Industrial Engineers that graduated the past 10 years (2003 – 2012) the sample size will be even more than 10%. From Figure 2 is can be seen that the number of profiles of recent graduates included in the sample significantly exceed the number of earlier graduates. Strategies to increase this sample size and representativeness are discussed in the concluding section of this paper.

After the data were stored in an MS-Excel data warehouse, data-filters, pivot tables and manual manipulation was used to clean, aggregate and visualize the data.

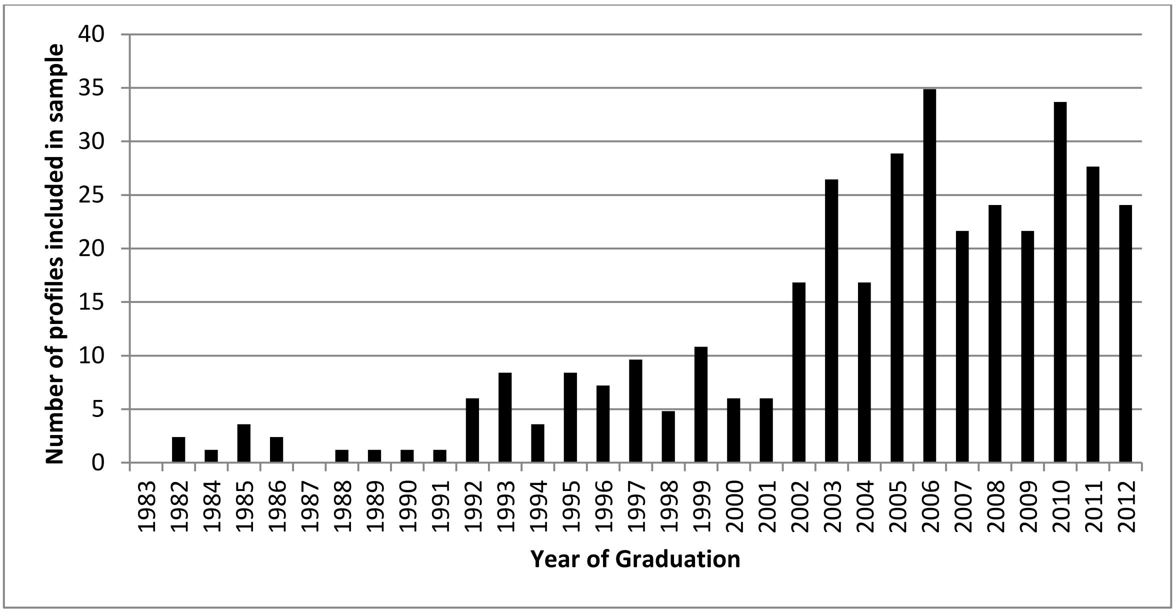

Figure 3: LinkedIn profiles included in sample

3 RESULTS AND DISCUSSION

In the previous section it was explained how data were harvested from LinkedIn profiles, warehoused and aggregated to get a picture of what South African Industrial Engineers are doing. In doing so, the first research question is addressed. The second and third research questions are considered in this section:

3.1 Who employs South African Industrial Engineers?

Some of the companies that employ Industrial Engineers are indicated on the x-axis of Figure 4, Figure 5 and Figure 6. The total experience (expressed in terms of man-years) of Industrial Engineers included in this study are indicated on the y-axis of these figures. Companies that employ the sampled Industrial Engineers for less than 8 man years, are not indicated in these figures, but they are listed in Exhibit 1.

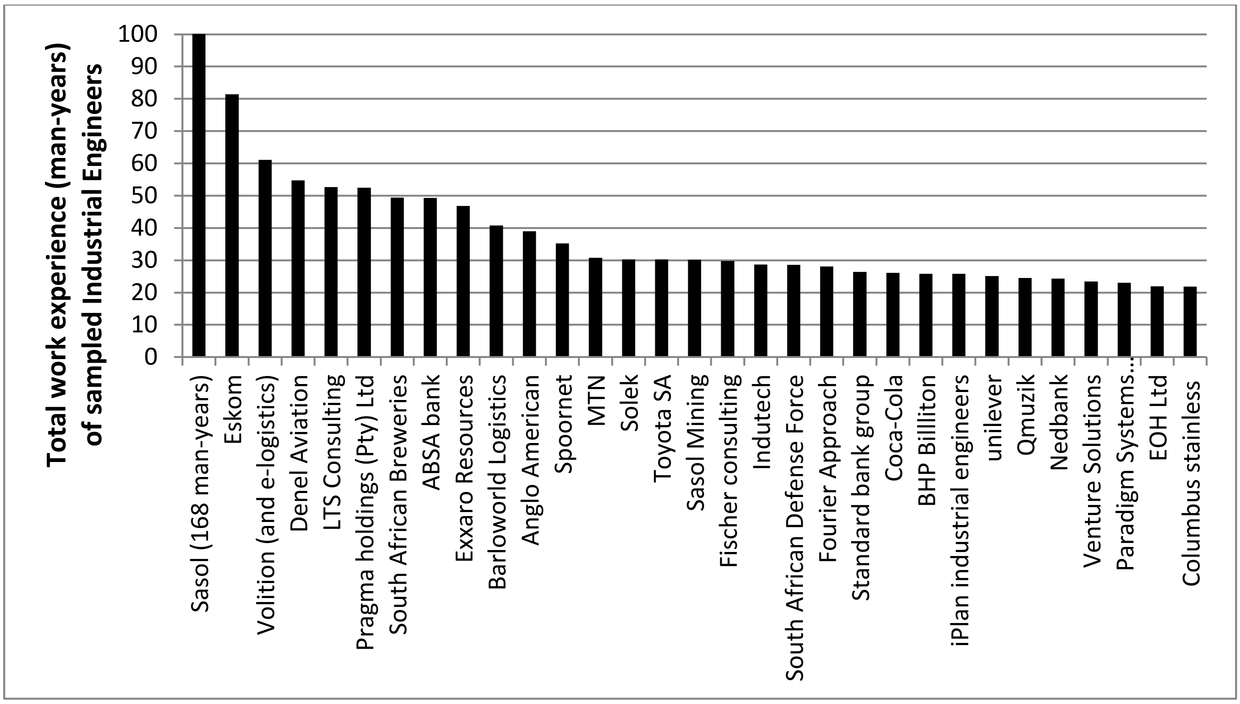

Figure 5: Total work experience (man-years) of sampled Industrial Engineers (1)

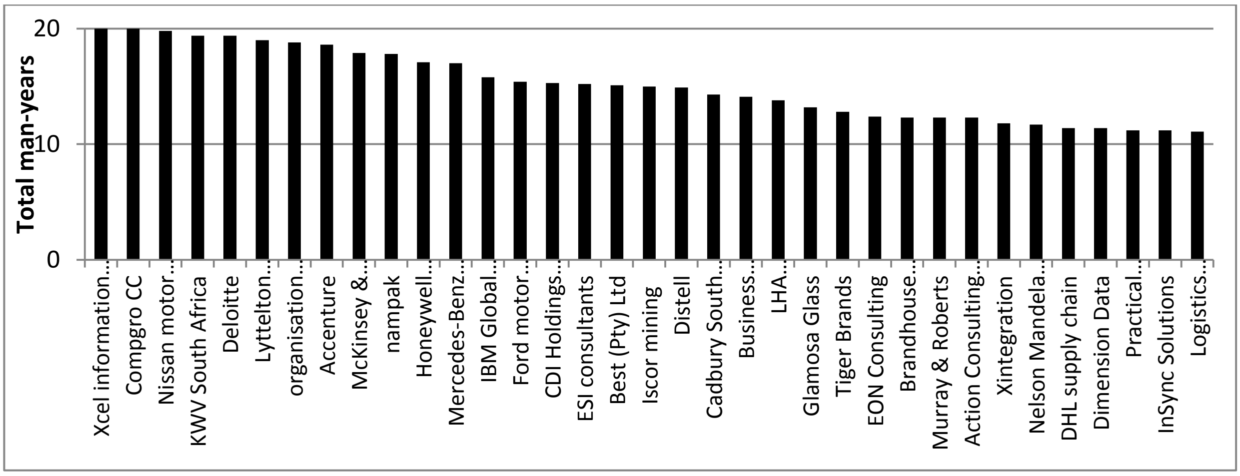

Figure 6: Total work experience (man-years) of sampled Industrial Engineers (2)

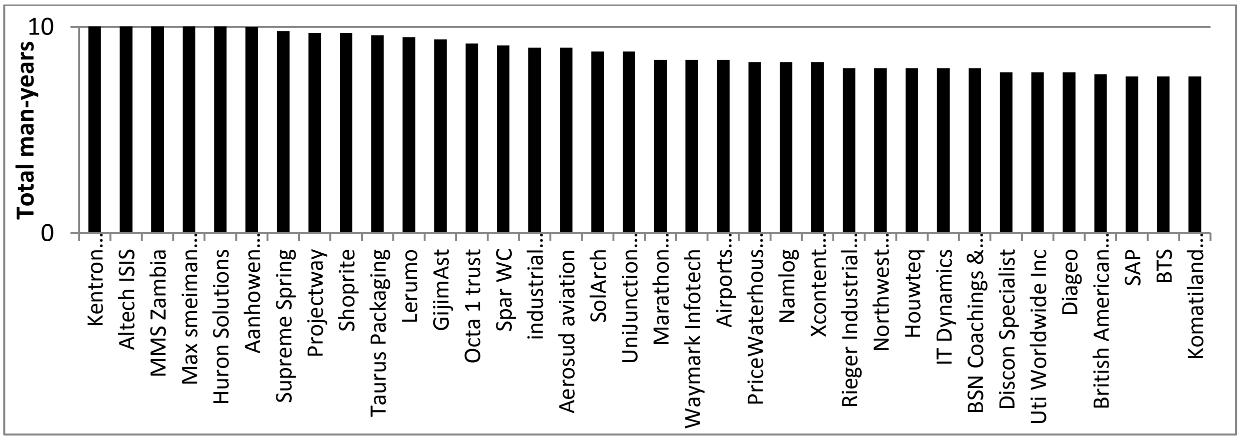

Figure 7: Total work experience (man-years) of sampled Industrial Engineers (3)

Exhibit 1: Other Employers of Industrial Engineers

BevServ; BG Group; Bigen Africa; BKS (Pty) Ltd; Blankbook Website & Online marketing; BMGi; BMW South Africa; BNS; Board Longyear; Bombardier Transport; Bombela concession company; Booyens Beleggings; Bosal; Boxmore; BPLC Manager Consultants; Bragan Chemicals; British International Engineers South Africa; BroadReach Healthcare; Broco logistics management solutions; Bubal; Business improvement facilitation; Business Modelling Associates; Business planning; Business School NMMU; Butyl Seal (Pty) Ltd; Calmasil (PBD Boeredienste); Cape Tech plastics; Cape town container terminal; CBI Electric Solutions; CCI Growthcon (Pty) Ltd; CCSIR Meraka Institute; CDI consulting; Ceenex; Charlotte Maxeke Johannesburg Academic Hospital; CHEP; Chevron; Chillisoft; Chris van Schoor Manufacturing and Logistics Consulting; City of cape town; Clyde Bergemann Africa; Coleus Packaging (Pty) Ltd; Colliers International; Comat International contracted to South African Airways; Commuter Transport Engineering; Consiliarii; Conways aluminium; Corpative; Corvus future design; Council for Scientific and industrial research; Courier and freight group; CPC Project services LLP; Cquential solutions; Crickmay and Associates; Crux Technology; CShell Building and construction; Cside Excellence; CSIR; Cyest corporation; DaimlerChrysler; Dataflow; Dawn wing global express; DCM consulting; De Beers; Degussa; Discovery Health; DNA Jumpoint; DNA supply chains; Donaldson Filtration systems; Dovetail; Dresser-Rand; Duo d'Musique; Duro Pressings Pty (Ltd); DVT; Dynamic Strategies; EC Harris; EcoBoards; Edge Growth; EDS Group; EDS Technologies; EGO; ELPROM; Enerweb; EnhanceEPM; ePostal / Postbank; Ernst & Young; ESS Asset Care specialts; ESTEQ; ETP; Euphoria Golf Estate & Hydro; Exactitude Consulting; Expertool; Fair Cape Dairies; Fairprice; Faritec Holdings; FedGroup; FIHRST Management services; Filehound CC; First national bank; FlowCentric Technologies Pty (Ltd); Fortna; Frost & Sullivan; Gain; Gant AB; Gaussian ; Gener-8-Power Solution centurion; General Motors south Africa; GIBB engineering & Science; Glaxo SmithKline; Global Business Excellence; Global challenge; Going North; Golden Frys; Golf Estate Management services; Goodyear SA; Gordon Institute of business Science; Graduate school of Technology Management; Grinaker LTA; Grundfos Management A/S; Guala Closure South Africa; Hall Longmore; Hatch0; House4Hack; HPE (Pty) Ltd; Hugotronics; Huhtamaki Felxible Packaging; Hulamin; Huntleigh Africa; HVAC international; Icon Consulting; IDS Scheer; IEsolutions SA; Iluka Resources; Imana Foods; impak; Imperial Distribution; Imperial Group; imperial logistics; Improvement Projects Manager; Imre Consulting; Incito (AST Group); Incose SA Chapter; independent consultant; Independent researcher and industrial engineering consultant; Industrial Development Corporation of SA Ltd. (IDC); InnovationManager.se; Inpak; Integrear Indicium; Intellegent Africa; IOR Global (EMEA) GmbH; IQ Business; Irvin & Johnson; IS Partners; ISEMsa; IT4Africa; ITE Consulting; Johannes F. Pienaar Consulting; JP Consulting; jumpoint (Pty) Ltd; Just Property Group; Kalahari Plant; Karlson & Higgins; KESSA Engineering Solutions South Africa; Keto Pumps; KFC - Yum! Brands; KHS; Kimberly-Clark; knowledge based engineering; KnowledgeXtend; KPMG Advisory; Learning Strategies; leruma Holdings; Letter27; LEW; LGA Logistics; Licensing Executives Society International; Light project management cc; LO Consulting; Loadtech (Pty) Ltd; LogSystems development; London Underground; L'Oréal; LoveShots Photography; Lugory Consulting; MAC consulting; Macsteel Service Centres S.A.; Magna BC; Magna FS; Main street holdings; Maintenance Consulting africa; Major Telecommunications company; MAN Diesel & Turbo; MAN truck & Bus; Marstec; Martin-Bouwer; MAXAM; MBB Consulting Services; McCain Foods; MCG Industries; media film service; Media24-Spree; Medical services organisation; mediclinic; Medipark; Megkon; melbro; Melrose Atteridge; Meritec; Merrill Lynch; MG & Associates; Midas Group; MIH; Mineral sands; Minova SA; MiX Telematics; Modular Mining Systems; ModusBPS (Pty) Ltd; ModusPBS (Pty) Ltd; Mondi Packaging; moneypenny film accounting services; MorkelErasmus Photography; MOTE Travel; MSO; Murendi Concrete; Namakwa Sands; Nashua mobile; National aerospace centre of Excellence; Navita; NEC Africa; NECSA; Nedq; nestle; Niehaus Ungerer Laboratories; Nigel Metal Industries; Noise Clipper; Nolwana; Nuclear Energy corporation of SA; Nutricor; OIM; Old mutal; On the Dot Distribution; OPSI Systems; Optimum Coal; Optipro Solutions; Oracle corporation; OrderCloud; OTR; Ovations; P3 Group; Panskus Gmbh; Paras Africa; parcel express; Partners in Performance; PBMR; PEC metering (Pty) Ltd; PEPKOR logistics; ; PESCO; PFG Building Glass; Pfisterer (PTY) LTD; PG Group; PGAluminium JHB North; Pick 'n Pay; Pieter Pretorius Consulting and training; Pitching-in Foundation; Planet fitness; plessey; PLM Applications Engineer; PPG industries; PQ Africa; Precision Press; Private - house plans; Private Company; ProActive Integrators; Pumptron (Pty) Ltd; Pumptron-Mihandzu (Pty) Ltd; Purdue University; PWC; Q-Core consulting; Qdata business consulting; QGC - A BG Group business; QlikView South africa; Quality engineering development; QuinXi; Engineering & Management consulting; Rainbow Chickens limited; Rand Merchant Bank; Realnet Commercial ; Resolve solutions partners; Resonance Music; Restwise; Rethink management consulting; Rhenish Girls' High School; RIC Consulting; Rieter Feltex; Robertson & Caine International Yachts; Robertsons factory; Romatex (Pty) Ltd; Rotek; S360 Business Business Systems; SAAB; Safair (Pty) Ltd; Safcor Panalpina; Sandvik; Sappi; SARS; Schlumberger; Schnellecke; Sci-Bono Discovery Centre; SCNext - The Youth of Supply Chain; Sea harvest; Sealy; Self-employed; Shikongonyi Transport and Projects; Shivango Technologies; ShopWare; Siemens; Sign & Seal Construction; Silica; SilverBridge; Simulation engineering technologies; Sirius Engineer (Pty) Ltd; SIS Global; Sizwe Africa; Smith International; Softworx; Sole proprietor; Solutions Architecture; South African Venture Capital Association; Southpaw Solutions; SpaceBric; Spearhead Rugby Academy; Spencer Consulting; SPX Corporation; Standard Corporate and invest Bank; Stealth startup; Step advisory; stone Three Venture; Storage management system; Super Group; supply chain services; SWO Consultants Inc.; Synchrony; Syncreon, Netherlands; Synntech; Takata; Techworld Consulting Engineer; Telkom; Tellumat; Tempus publishing; Tenaris; TFM; TFMC; The Centre for Mechanised Mining systes; The Creative Counsel; The Cyest Corporation; The intellectual property show on Summit TV; The IQ Business Group; The nature conservancy; The Rare group; The Sweat Shop; The unlimited world; Thermal Test laboratory; Thinc Business Solutions; Thinking People; Thinkshoppe Web solutions; Tilos; Timken South Africa; TLB; Toll infrastructure Services; Touchstone Renard Ltd; TradeMark Southern Africa; training leadership consulting; Trans50; ; Transnet; transport for London; Tranter Rock Drills; TrenStar (Pty) LTD; Trium Investments Pty Ltd; Tronox; Trupact Consulting; Technology;TurgisConsulting; Turner and Townsend; Tweni Upholstery and interiors; TWP Projects; TYME; Ultramain systems; Umthombo Technologies; union Carriage & wagon; UNISA; Unitrans; UP solutions; UPS SCS; USB-ED & African eDevelopment; Uti Freight forwarding; Uti Integrated Logistics; Uti south Africa; UTI Sun Couriers; Valstand Learning; Value and supply chain consulting; VBKom projects; Vector Logistics; Vega Capital; venture Rosslyn plant; Ventyx; VIEWcc; Vimbli - strategic onboarding Solutions; Virgin; Virtual consulting engineers; VIZIYA Corp; VWSA; Weatherford; Websoft Maven; Weir Minerals; Wellco Health Limited; WesBank; wiGroup; Wild Eye Destinations & Photography; Wishlist corporation; Xstrata Coal; York Timbers; Zobber

The fact-table of the *Employment datamart* (refer to Figure1) includes a field, named *Industry*. Most of the companies included in Figure 4, Figure 5 and Figure 6 have a company

LinkedIn-profile on which their primary industry is indicated. This information was used to compile Figure 7.

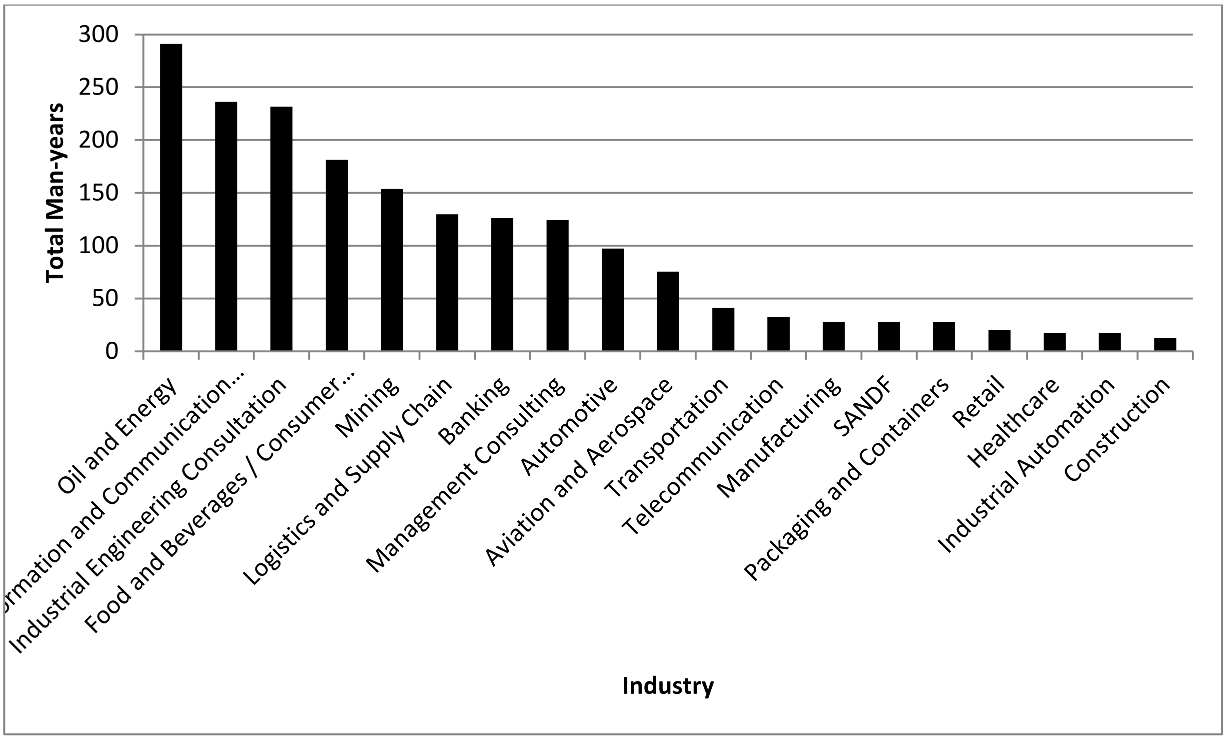

Figure 8: Industries in which most of the 362 sampled Industrial Engineers are employed

3.2 For which skills are Industrial Engineers employed?

LinkedIn provide the option for professionals to indicate on their profiles which skills they attribute to themselves. Their peers can then confirm these skills by endorsing the profile owner. This data were captured in the *Skills Datamart* (refer to Figure 1). The endorsements index is calculated as follows:

x_{ij} = number of endorsements per profile *i* per skill *j*

n_i = total number of endorsements per profile

endorsement index for skill *i* for profile *j* = $y_{ij} = x_{ij}/n_i$

endorsement index for skill *i* = $\overline{y_{ij}}$

Figure 8 indicates the skills that are mostly attributed by Industrial Engineers to themselves and endorsed by their peers. *Industrial Engineering*, *Supply Chain Management* and *Business process analysis/ design / engineering* have the largest endorsement index.

Skills	Endorsements Index
Industrial Engineering	28.6
Supply Chain Management	28.3
Business Process Analysis / Design / Mapping	28.2
Process improvement/ optimization	19.0
Project Engineering / Planning / Management	18.1
Business Analysis/ Development / Engineer / Architecture	14.8
Continuous Improvement / Kaizan / Six Sigma	13.0
Data analysis / data modeling / analytics / operations res	9.1
Strategy Management / Planning	8.7
Management	8.5
Process and system simulation	7.7
Engineering	7.6
Logistics	6.7
Lean Manufacturing	5.8
Operations Management	5.3
Mining	4.2
Manufacturing	3.2
Microsoft Office	2.7
ERP	2.6
Business Intelligence	2.5
Change Management	2.5
Microsoft Excel	2.4
Systems analysis/engineering / optimisation / modeling	2.4
Procurement	2.2
Requirements analysis	2.0
Microsoft project	1.8
Change Management	1.7
Program Management	1.7
Maintenance management / strategy	1.6
Matlab	1.5
Integration	1.5
Operations Research	1.5
Entrepreneurship	1.4
Production Planning / management	1.3
Financial Modeling / Risk / Analysis / structuring	1.2
Root Cause Analysis	1.2
Demand planning / forecasting / management	1.1
Warehouse management	1.1
Research	1.0
SAP	1.0
FMCG	1.0

Figure 9: Skills that Industrial Engineers attribute to themselves

4 CONCLUSION AND FUTURE WORK

The purpose of this paper was to make use of the information published on LinkedIn by Industrial Engineers themselves to determine who employs Industrial Engineers and for which skills. In pursuit of this purpose, three research questions were asked

RQ 1: How can data contained by LinkedIn data be used to gain information about as Industrial Engineers in South Africa?

Despite the limitations of the complementary (*free*) LinkedIn-option, it was possible to harvest employment and skills data of 362 persons who graduated as Industrial Engineers in South Africa. This represents about 10% of all persons that graduated the past 20 years. If only the past decade is considered, 20% of these persons are represented. For future work, this sample can be increased if the LinkedIn *Business* or *Business Plus* option is purchased.

For this study, only LinkedIn-data were used. Many BEng(Industrial)-graduates indicated no or only higher qualifications on their profiles. The quantity of integrity of profiles can be increased if the qualifications are validated with actual graduation lists.

Attempts were made to harvest data from the LinkedIn-data directly via LinkedIn-APIs. These attempts were not successful. If successful, this process could enhance the efficiency and effectiveness of the data warehouse process significantly.

The analyses presented in this paper involved simple online analytical processing (OLAP) in terms of the aggregation and visualization of data. Further analytics procedures can produce even more information such as career path and industry-skill correlations. **RQ 2:** Who employs Industrial Engineers?

Although the Industrial Engineering discipline originated from the industrial revolution and mass production age, Industrial Engineers are now designing and improving tangible and intangible processes and systems in all sorts of industries. For future work it may be interesting to determine if there is a correlation between the graduates' universities and their career path or skill set. Furthermore, results from quantitative analyses could be followed up by qualitative studies.

RQ 3: For which skills are these Industrial Engineers employed?

It may not be surprising that *Industrial Engineering* is the most endorsed skill attributed to Industrial Engineers. A follow-up study can be executed to determine the link between what the skills attributed to Industrial Engineers and the content of the undergraduate curriculum.

The purpose of this paper was to make use of the information published on LinkedIn by Industrial Engineers themselves to determine who employs Industrial Engineers and for which skills. Enough answers were generated to conclude that this purpose was achieved. However, this study provided even more avenues for further investigation than answers. Modern technology and techniques of social interaction

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SYSTEMS ENGINEERING IN THE RESEARH AND DEVELOPMENT ENVIRONMENT

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ABSTRACT

Methods employed in research and development (R&D) to develop technology, generally follow a linear model. This is a sequential process whereby fundamental knowledge is developed in research and then used in an applied research domain. The applied research may eventually lead to technology development i.e. the development of new products and services. One of the shortfalls of this model is the lack of consideration given to design engineering and production. This research investigates the processes, methods and tools that are currently used to develop technology as well as the nature of the technology developments to determine if systems engineering methods and tools can be applied in an R&D environment. A case study is presented based on the Square Kilometre Array (SKA) Project. This is a project in the R&D environment and is the unit of analysis in this research.

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1 INTRODUCTION

The current system of research and development is characterized by Mahdjoubi [1] as a linear model of innovation. This is because a sequential process is followed whereby fundamental knowledge is developed in research and then used in an applied research domain. The applied research may eventually lead to the development of new products and services.

Projects that are undertaken in the current system of research and development generally focus on creative discovery and innovation, which generally utilizes multiple trial and error cycles in a fuzzy process [2]. Projects on the research end of the research and development spectrum focus on development of knowledge. Projects on the technology development end of the spectrum focus on technology demonstrators and are generally characterized by technical uncertainty [2] as technologies are not yet at a mature state. Technologies developed in a research and development environment are inserted into products in the product development environment [2].

A shortfall highlighted in the linear model by Mahdjoubi [1] is the lack of attention to design and engineering. Another shortfall identified by Shultz et al [2] in this paradigm is a lack of a creative concept generation process [1].

Hitchins [3] states that creativity alone is of little use and any idea or concept generated must make a positive contribution in the real world. The concept must be producible and affordable which may require tradeoffs in order to achieve. Systems engineering has provided a process that allows development of solutions, in environments of change and uncertainty that balance cost, schedule, performance and risk in order to realize a system that is economical to produce and can be supported throughout its life cycle [4]. This leads to the research question:

How can systems engineering enable improvements in specific areas in technology development projects in order to improve technology outputs into product development?

The objective of this research is to investigate how technology development is executed in the research and development environment and what processes and tools are currently employed in this regard. Case studies and semi-structured interviews were used in the research as the investigation is qualitative in nature.

The following sections of this paper present a literature review introducing the research and development environment as well as systems engineering concepts. The Square Kilometer Array (SKA) project is presented as a case study and preliminary results are discussed.

2 LITERATURE REVIEW

The literature review provides a general overview of the Research and Development Environment and the systems engineering process. There are, however, some specific systems engineering concepts that relate to the research and development environment and these will be then be introduced.

2.1 The Research and Development Environment

Basic research, applied research and development are each areas which form part of research and development and what Mahdjoubi [1] defines as the Linear Model of innovation.

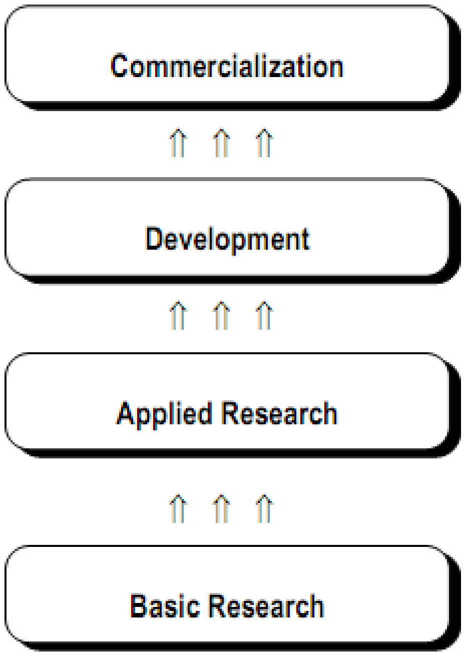

Figure 1: The Linear Model of Innovation [1]

Basic research is focused on developing knowledge and has no link to a particular application. In applied research the aim is to build knowledge but the focus narrows toward a more specific aim or application [1]. Experimental development uses the knowledge that has been gained in research with the focus on producing new products, processes or services. Each successive area in research and development is dependent on the knowledge gained from the previous area. This is the reason that Mahdjoubi [1] refers to this as the linear model as the knowledge generated is passed on sequentially in time and the outputs from one area sequentially forms the input into the next area of research and development as illustrated in figure 1.

It is a practice by leading companies to separate research and development, also called technology development, and product development [5]. The definition of technology in this paper is adopted from Schulz et al [2], which defines two different types of technology, primary and secondary technology. Primary technologies are components or sub-systems that are used to improve the functionality of products. Secondary technologies are those technologies that enable the realization of the primary technology, such as processes, methods and tools, management and organizational technologies as illustrated in Figure 2.

Figure 2: Relationship between Enabling Secondary Technologies and Primary Product Technologies [2]

The objective of the product development environment is to deliver the required product to customers. The interface between the two environments occurs when technologies from technology development are inserted into products in the product development environment [2]. Separating the two environments ideally allows technologies to mature prior to being moved into a product development for further development [5].

This approach has been found to reduce technical risks in product development which in turn improve cost and reduce development cycle times [5]. Correcting problems prior to product development has been estimated to save 10 times as much in costs when compared to correcting problems during product development [5]. This is also in agreement with a study into leading technology companies by Booz & Company [6] where a technology manager from Lockheed Martin Corporation states that the product development and commercialization stages are the most risky and that during the investigation stages the value of a project can go up by a factor of 10. Having mature technology prior to the start of a product development has been found to be a major contributor to the time to market and overall success of the product [5].

2.2 Systems Engineering Concepts

The International Counsel on Systems Engineering (INCOSE) defines systems engineering as follows,

> *"Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. 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." [7]*

Furthermore a system is defined as,

> *"A combination of interacting elements organized to achieve one or more stated purposes."[7]*

It is evident from the definition that systems engineering considers the problem from a holistic perspective. The basis of this is systems thinking. The characteristics of systems thinking is that the system of interest is considered in the context of the system within which it is contained as well as the interactions with other systems that it interfaces with [8]. The concept of hierarchy in a system considers that a system has many levels and may be constructed of elements which in turn may be systems themselves.

This holistic perspective promotes the understanding that the properties or behaviour that results from a system with many elements is due to the interaction of the various elements and is not attributable to a single element of the system. This is known as the principle of emergence and is a fundamental concept in systems thinking and in the analysis and development of systems [3]. A holistic perspective of a system also considers the entire life cycle of the system, which is also evident in the definition of systems engineering. Generic life-cycle stages for a development project as defined in the INCOSE Handbook [7] are shown in figure 3. Between each stage there is a decision point, known as a review, which has defined criteria in order to decide on whether to proceed to the next stage. These decision points allow risks to be assessed and allow formal approval to proceed to the next stage of development.

Figure 3: Generic Life Cycle Stages of a System [7]

As a system becomes more complex, that is the more elements and interactions are present, the higher the possibility that unwanted and unpredictable behaviour can emerge. One of the objectives of the systems engineering process is to minimize the unwanted emergent properties of the system and develop the required emergent properties. The approach used in systems engineering is to use the hierarchy principle to decompose a system into more manageable pieces for development [9].

The required emergent properties of the system are generally defined by the stakeholders needs (also known as requirements) which form part of the inputs to the systems engineering process. Figure 4 is an overview of the systems engineering process that is used by the United States Department of Defence.

In Figure 4 the first step in the process is requirements analysis. This step adds value to the stakeholders by ensuring the requirements are of a certain quality and are complete by analysing the problem. The requirements analysis results in the definition of the systems requirements. In order for the system to meet the requirements the required behaviour of the system must be defined. This is done in the functional analysis (also called functional decomposition) step of the process.

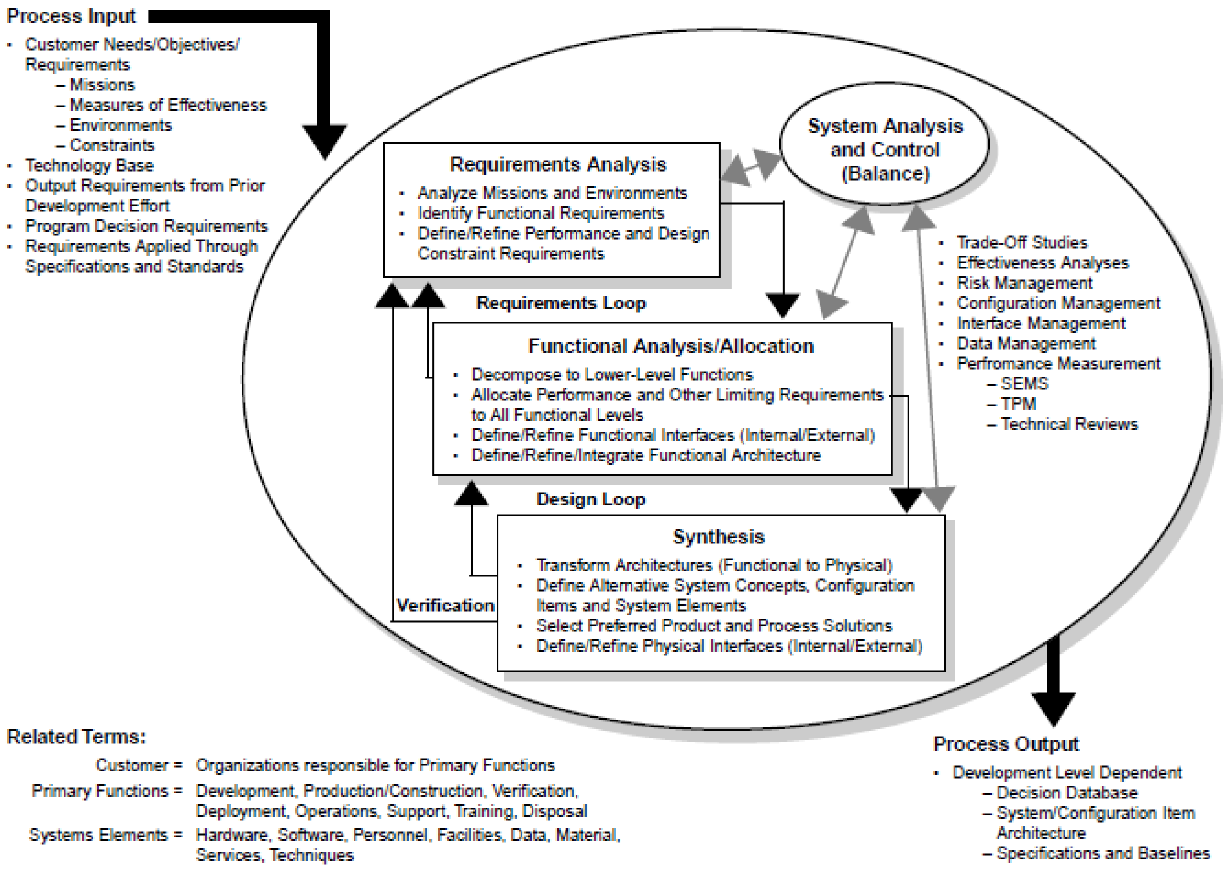

Figure 4: Overview of the Systems Engineering Process [4]

From the functional definition of the system, the structure or physical solution is then developed by allocating functions to sub-systems (hardware, software). The functional and physical development of the system culminates in the architecture of the system which is one of the key outputs of the process. The architecture of the system is the arrangement of components (or sub-systems) and the relationships between them [9]. A modular architecture consists of elements that each function independently and interface, with well-known interfaces, to other elements [9]. When a system cannot be decomposed easily and there are many interactions it is said to have an integral architecture [9].

In Figure 4 there can be iterations, indicated by the requirements and design loops, which allow for continuous refinement of the system solution. The system solution is verified to ensure that the system is built correctly and validation is used to ensure that it meets the stakeholders defined needs. The whole process is managed using systems engineering management which on a higher level manages risk elements, the overall technical development strategy and configuration management.

2.3 Systems Engineering in the R&D environment

Figure 5 links key systems engineering concepts to the R&D environment:

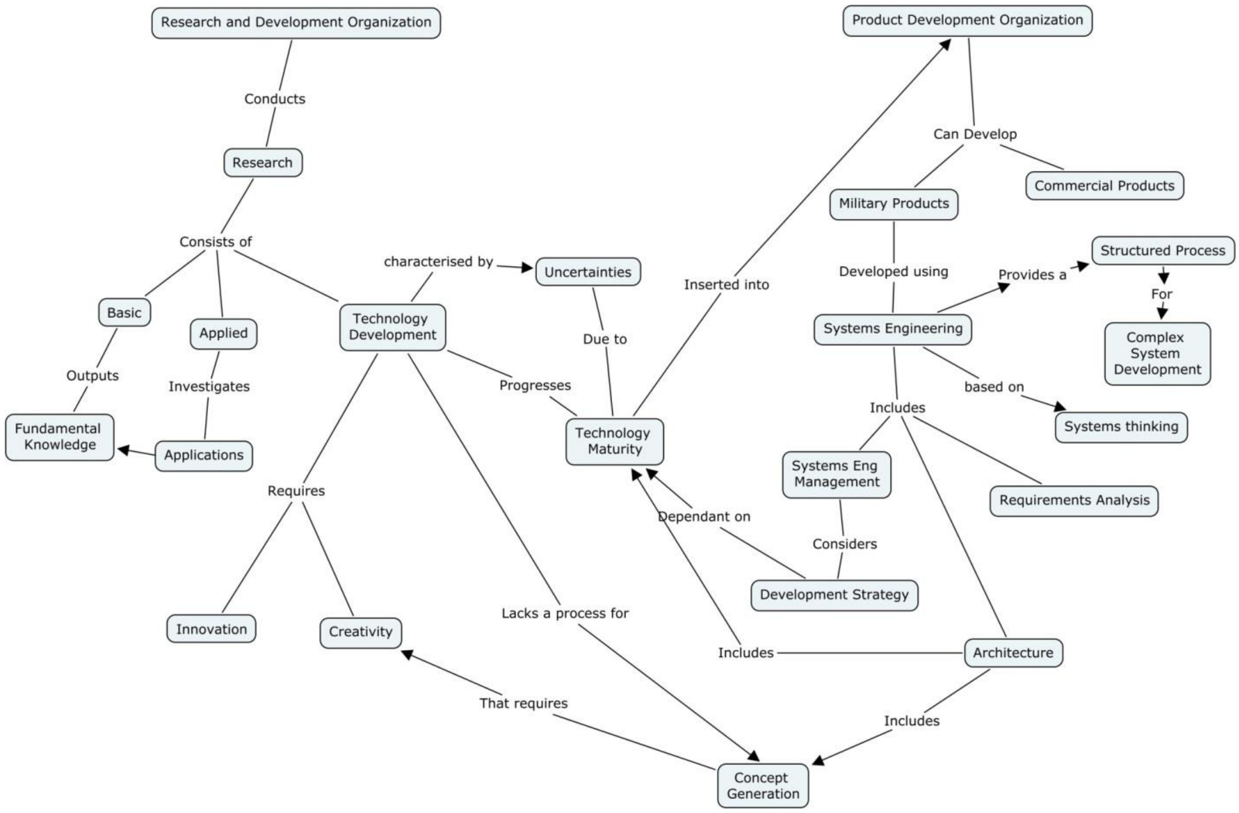

Figure 5: Concept Map linking Systems Engineering Concepts to R&D Concepts

The concept map is a schematic representation of the key concepts from the literature. It was constructed in order to show the relationships between systems engineering concepts and the characteristics of the research and development environment. The concept map reveals that there are specific concepts from systems engineering that are related to the research and development environment such as considerations of technology maturity and technical uncertainties.

The concept of technology maturity is elaborated further to explain why it is an important life-cycle consideration in the design and development of a system. The concept of a development strategy is also introduced as this defines a path to be followed during the development in order to deal with uncertainties. Uncertainties that have been identified in the literature include operational requirements, technology obsolescence, budget and the operational environment [10].

Technology maturity is an important factor in reducing development cycle times and in reducing technical risk [5]. As a technology matures the less susceptible it is to changes allowing for easier incorporation into the development process [10]. In the concept map it is shown that technology maturity is also considered as part of the systems engineering process in architecting.

Technology Readiness Levels (TRLs) is a scale developed by the United States Department of Defence to measure technology maturity [4]. TRL 1 is the lowest maturity level and represents basic technology research with basic principles observed. TRL 9 is the highest maturity level and represents a proven technology that has been successfully developed in mission operations [4]. Using a defined measure of maturity allows for decision making during technology development which can influence the technical development strategy. Mooz and Forsberg [11] define the technical development strategy as consisting of the following 3 parts:

- Development method/model

- Development strategy
- Delivery strategy

The development method or model is the way the systems engineering process is organized [12]. The Vee model, shown in Figure 6, is an example of a development model. The left side of the Vee model is a decomposition and definition process and results in the high level user requirements being decomposed to system level and then further until component level so that definition of system level and component level specifications can be achieved [12]. The right side of the Vee model focuses on fabrication and assembly of specified components into sub-systems and integration of these sub-systems which results in the final system. At each level verification is performed to ensure conformance to specifications. At the end of the process the system is validated against the user requirement to ensure acceptability to the user.

Other examples of development models are Waterfall or Spiral models [11]. The selection of the development model must take into account various development uncertainties such as technical, requirement and budgetary uncertainties. Each model has unique characteristics that can be advantageous or disadvantageous to the system development and has to be considered in the context of the problem to be solved.

The development strategy can be either evolutionary or incremental. Evolutionary processes focus on delivering prototypes to the user where there is initial requirements uncertainty [10].

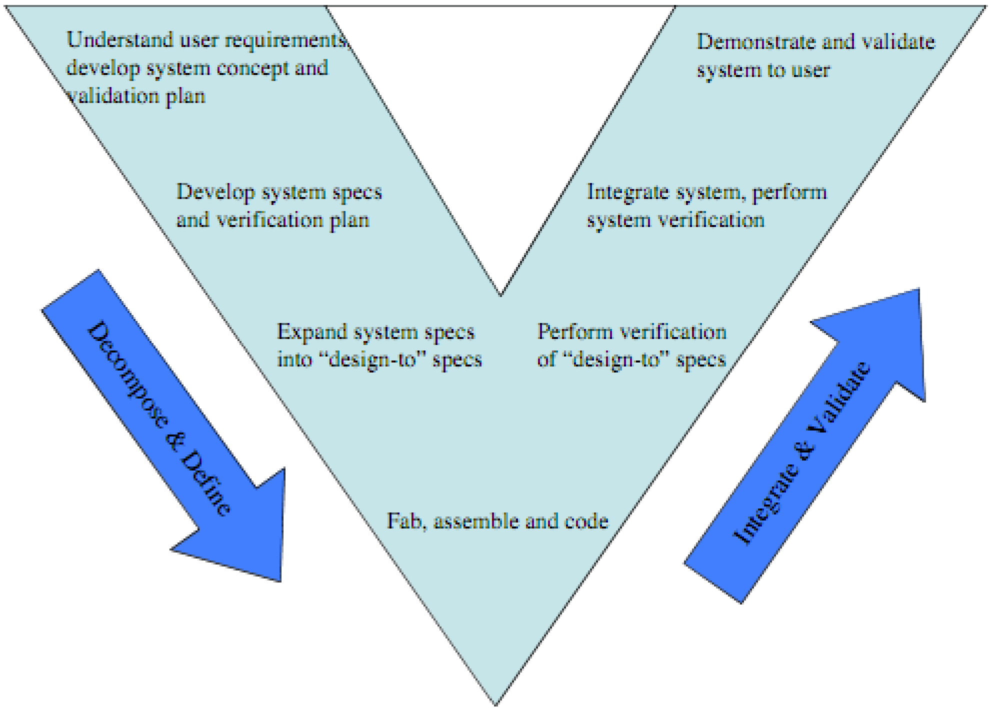

Figure 6: Vee development model [10]

An incremental development is advantageous when there are technical uncertainties as it delivers an initial capability and allows for additional capability to be added as more advanced technology matures [10]. Any of the development models may be applied to support a given development strategy [11], which is selected based on the problem to be solved.

In the technology development environment where there is inherent technical uncertainty an evolutionary development strategy, together with an appropriate development model that considers the level of technology maturity, can potentially provide a structured approach to mature technologies.

Another important consideration is the rate of change of technology. The life cycle of a technology is far shorter than that of a product [10]. In considering the impact of a new technology holistically, the changes in the product into which it is being inserted must also be considered. As a technology matures improvements in technology generally take place at lower levels because at higher levels initial architectural decisions have already been made and can be difficult to change [9]. A radical change in technology may influence the interface of a technology to the product it is being inserted into and may require changes in the product itself. Architectural considerations of the technology must be made and this is an inherent part of the systems engineering process as shown above.

A system should be developed to be flexible to incorporate evolving technology. One approach that is used to allow a system to be flexible and adaptable to technology changes is an open system approach [4]. An open system approach promotes the use of future technology advancements by emphasizing flexible interfaces and maximum interoperability [4].

The detailed development processes used by companies to mature and develop technologies are not available in the literature. The literature that has been reviewed also reveals that no structured process for concept generation for technology exists [2]. Although there are structured plan driven processes for the product development environment the literature does not detail a structured plan driven development process for technology development.

The current research is focused on investigating the processes that are used and what are the technology considerations in a contemporary development project undertaken in a research and development environment.

3 RESEARCH METHOD

Yin [13] describes the following characteristics that make a case study approach applicable:

- A contemporary phenomenon is being investigated in its context
- The boundaries of the phenomenon and context are not clearly evident

The case study approach was found to be applicable in the current investigation since the study of the processes, methods and tools that are applied in a development project cannot be investigated independently and is dependent on the context of the development itself. The complexity of the development influences the development process. The boundaries of the problem are also not clear since there are many variables (complex problem environment) that influence the development.

In this investigation an organization that undertakes a complex development project is used as the case. In order to build a complete description multiple sources of evidence were used. Project documentation was used as the main source of evidence and interviews were used to supplement the documentation. A process was followed to develop the interview questions from theory questions decomposed from the central research question so that specific interview questions could be asked that would then link back to answer the central research question. Table 1 illustrates the theory questions and some of the interview questions.

Table 1: Examples of Theory Questions and Interview Questions

THEORY QUESTION	INTERVIEW QUESTION
What is the nature of the technology development environment and the context in which development is undertaken?	What is the nature of the system being developed?
	What were the key challenges facing this project?
Is there currently a structured process in use for technology development?	Describe the development process, its high level elements and its sequencing. Was the process iterative? Where these iterations planned?
	Was the total lifecycle of the system considered?
What methods and tools are currently employed in technology development to develop technology?	Were there specific development methods used in the project?
	What computer-based tools where used for development?
	Was modelling and simulation (M&S) used during development and for what purposes?
How is the technical development process managed?	Was a development process used in this project? Describe the planning and the process tailoring?
	Was the technological maturity of the components of the system assessed as part of the architecture development?

In order to answer the research question, a structured plan and development process was part of the evidence that was found in the documentation. The methods and tools employed in the development process form part of the evidence to determine what is currently being used. Data relating to the nature of the risks and development uncertainties, with focus on technology development risks, faced by the project was also investigated.

If a systems engineering process is being followed a Systems Engineering Management Plan (SEMP) will be available. A well written SEMP provides all the guidance as to the structure of the Systems Engineering process and how Systems Engineering will be performed [7]. The SEMP is a document that is expected to contain the majority of the evidence of the development strategy, development process, technical management aspects as well as tools used in the development.

4 SQUARE KILOMETRE ARRAY (SKA) CASE STUDY

4.1 Overview of the SKA Project

The Square Kilometre Array (SKA) is an array of radio telescopes that will have a collecting area of one square kilometre. A radio telescope collects radio waves emitted from objects and uses signal processing to form an image from the radio waves. Before the actual Square Kilometre Array is built there are 2 pre-cursor projects that are being undertaken. KAT-7 is an engineering prototype for the MeerKAT array. The MeerKAT array, which is currently under development, has started being constructed in the Karoo. MeerKAT will consist of approximately 64 dishes. A rendition of the type of dish that will be used is shown in Figure 7.

Figure 7: Rendition of a MeerKAT Dish (Image Credit: SKA South Africa)

4.2 Selection of SKA South Africa Telescope Development as a Case Study

The SKA project is an unprecedented project in South Africa. The system to be developed is not available commercially off-the-shelf and has to be designed and developed from scratch which makes it an ideal context to investigate the development process. The detailed considerations for selecting this as a case study are as follows:

- The Development Environment – The SKA and MeerKAT are tools that will primarily be developed to be used by the radio astronomy scientific community. This development makes it applicable to an investigation of a development in the research and development environment. The computer technology utilized in the astronomy environment evolves rapidly within the development period of the system [14] which poses additional challenges.
- Technical considerations – The design and construction of the dishes as well as the surrounding infrastructure such as the data processing and data storage technology make this a highly technical undertaking. The fact that some of the technology is still being matured means that there is considerable technical risk. A system breakdown structure for the system is shown in figure 8 to illustrate the system levels and the various sub-systems. Each of the system elements as illustrated in Figure 8 are systems on their own which makes the entire MeerKAT system a complicated system which has many levels.

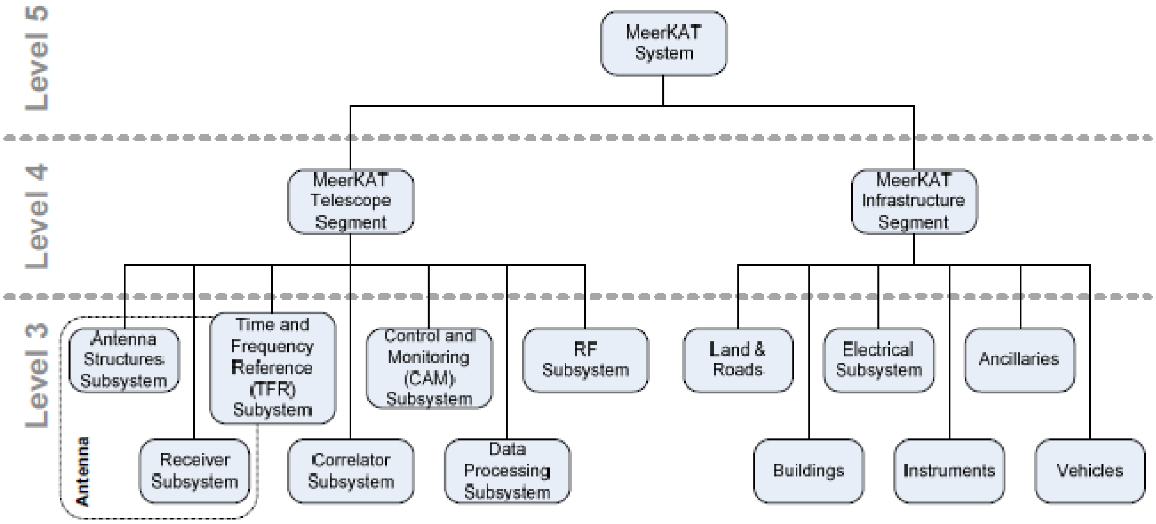

Figure 8: MeerKAT System Breakdown Structure (Credit: SKA South Africa) [15]

- Scale of the development – The MeerKAT array will consist of approximately 64 dishes spread over a large area in the Karoo and the SKA approximately 3000 dishes spread over a large geographical area in Southern Africa and Indian Ocean Islands.

4.3 Preliminary Results and Discussion

In this section some preliminary findings are presented that were collected from project documentation such as the Systems Engineering Management Plan (SEMP) and Concept Trade-off Report. This discussion will be limited to mainly the development stages (concept exploration and product engineering). Table 2 below lists the areas that were looked at as part of the build-up of the case study as well the detailed elements considered under each area.

Table 2: Elements Investigated in Case Study

AREA	DETAILED ELEMENTS
Development Processes, Methods and Tools	• Process Structure • Process Activities (Requirements analysis, Architecting, Implementation, Integration) • Process Outputs • Requirements Analysis and Management Tools • Modelling and Simulation • Testing
Technical Management Aspects	• Technical Management Plans • Development Planning and Phasing • Baselines and Reviews • Technology maturity considerations

The development approach followed by SKA SA is a systems engineering approach in order to reduce risk as a result of the technological complexity and unprecedented nature of the development. Development models and a precursor development (KAT-7) allowed a gradual risk reduction in terms of technical development. The approach also facilitated the maturing of the organizational development processes as the system complexity gradually increased.

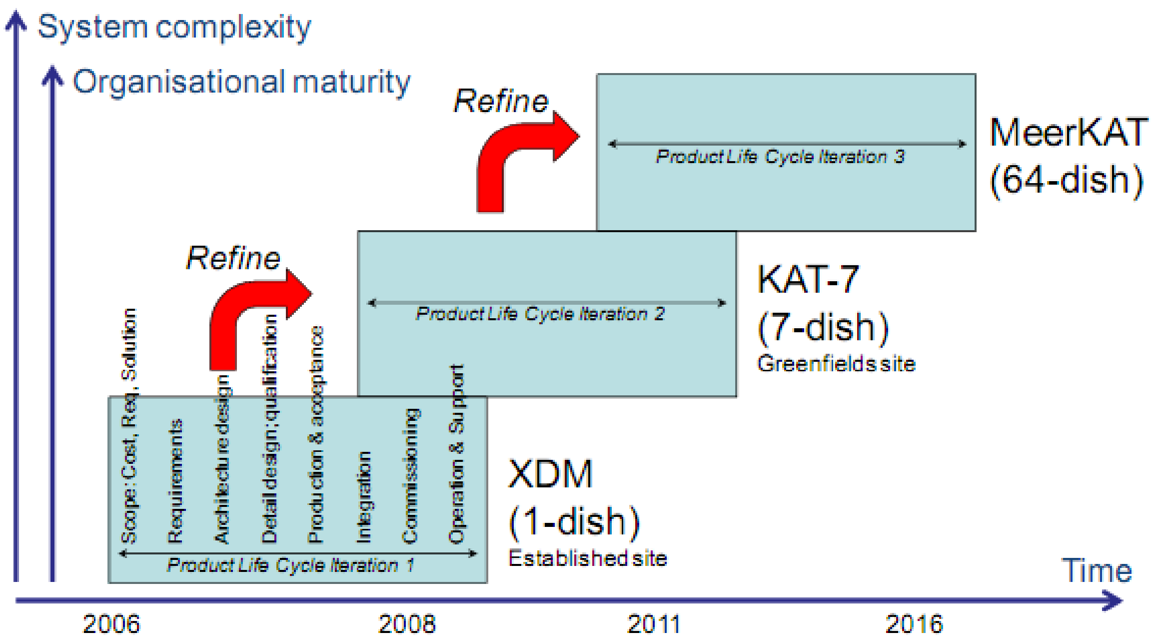

Figure 9: Risk Reduction Approach in System Development Process (Credit: SKA South Africa) [16]

The development model (XDM) and the KAT-7 array were taken through a complete life-cycle development, from requirements definition to operations and support, as shown in Figure 9. The acquisition of the KAT-7 array began in 2008 and the commissioning stage was started at the end of 2009 [17]. Although difficult to measure this directly, evidence shows that a structured systems engineering process can deliver a system in a very short space of time.

The processes are refined with each system development and lessons learned are carried to the next development which is a very effective approach. A more detailed view of the stages of the development process followed by SKA South Africa is shown in Figure 10 and Figure 11. A Systems Engineering Management Plan (SEMP) document outlines the entire systems engineering approach and defines all technical management tasks of the project. The following important sections were defined in the SEMP:

- Systems Hierarchy
- Systems Engineering Stages
- Baselines
- Reviews
- Project and Change Control Management

Investigation of the SKA SA SEMP reveals that the process is clearly defined to a level that can guide the development process and provide technical control of the project.

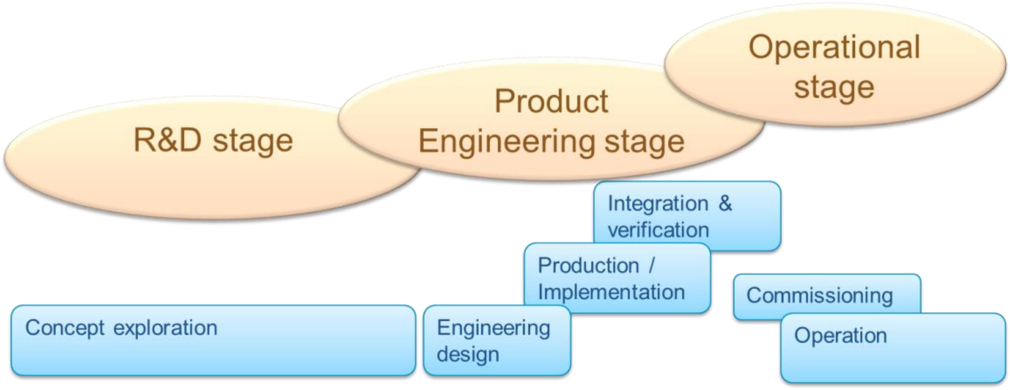

Figure 10: SKA South Africa Development Process [16] (Credit: SKA South Africa)

Requirements are defined in the requirements definition stage and the focus at this stage is requirements analysis in order to define the problem and what is required [15]. At the end of the requirements definition stage there is a requirements review and a requirements baseline is established. However there is some iteration between the requirements definition and concept definition stages and according to the SEMP the concept design review cannot be closed if the requirements baseline is not established.

The emphasis in the SEMP is to capture a complete, unambiguous, traceable and verifiable set of requirements. This is in agreement with what is emphasized in the INCOSE Handbook [7] for what is regarded as characteristics of good requirements. It was also found in the SEMP that a software based tool was used to manage the requirements specifically at the levels 3 and 4 of the systems hierarchy.

During the research and development stage, concept architectures are defined and explored. These concept requirements are driven by the high-level science requirements [15] and these eventually flow down through the defined hierarchy (Figure 6) to the component level through the architecting process (functional analysis and definition of the physical architecture during the concept definition). The system concept is iterated until there is convergence to a system that meets the technical requirements and life-cycle cost requirements. Figure 9 also shows the requirements flow down from the user system level to the lower levels.

The major output of the concept definition stage is a concept trade-off report. This report details the derived requirements, alternative concept architectures and the trade-offs between the options in terms of performance cost and risk. There is evidence of mathematical modelling for certain sub-systems for trade-off analysis of the concepts. The concept trade-off report is used as an input to the Concept Design Review together with the concept design document. The design review is used to review the trade-off report and to establish a concept baseline.

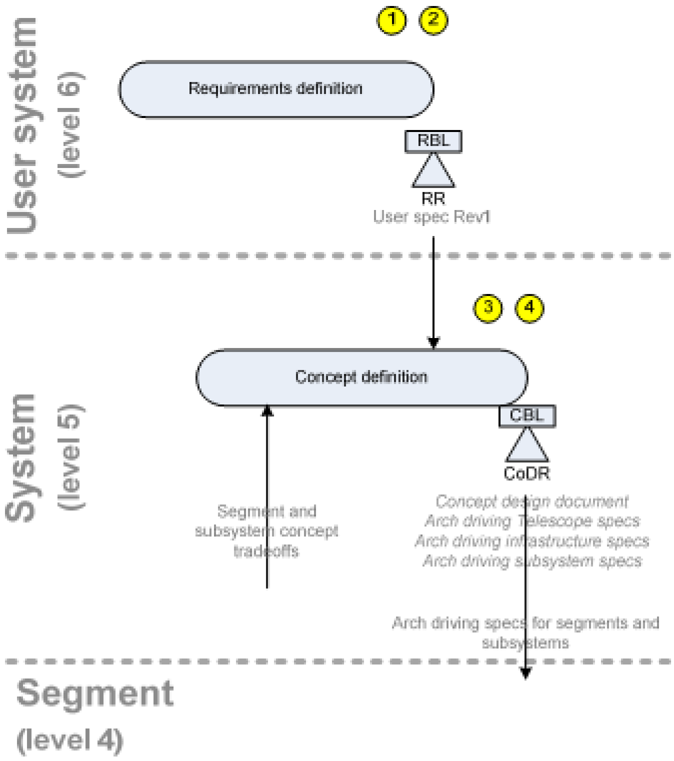

Figure 11: Concept Definition Stage of the Development Process (Credit: SKA South Africa) [15]

The level of technology maturity is a factor that impacts the cost and schedule of the development going forward [5]. In the detailed analysis of the concept trade-off report there was no explicitly defined measure of technology readiness. In taking the concept forward, although risks are highlighted, there is no evidence of considerations on the potential impact of technology maturity on the concepts.

The SEMP however outlines a technology strategy and that technologies should be mature by the time a qualification baseline is reached. There is no definition of technology maturity in terms of a scale or a definition of acceptable readiness of a technology. Further investigation is required here as there may be subsequent versions of the SEMP that defines technology maturity for this project. It is acknowledged in the strategy that technology in this domain evolves rapidly and emphasizes modularity as well as standardized interfaces to ensure future upgradeability of the system. This statement implicitly defines an incremental development strategy that will take advantage of new technology to expand the capability of the system in future.

A lack of a well-defined measure of technology maturity may impact the development process later, however further investigation is required to reveal this. It is unclear from the documentation as to how it is determined whether or not a technology is mature enough to progress to the next stage or if it requires more cycles in the concept definition to mature. This can be a risk to the project as there is no clearly defined criteria and targets to allow decisions to be made on whether a technology should move forward or remain in the R&D stage for further development.

The next stage in the development process is the product engineering stage. The selected concept architecture from the Concept Design Review is used as an input to this stage. Further requirements definition is performed for the lower levels of the system down to component level. The detailed activities performed in the production stage are shown in Figure 12 and Figure 13. There is decomposition on the left hand side of Figure 12 in order to obtain lower level requirements and perform lower level design followed by bottom up building, testing and integration on the right hand side. It can be seen that the development method resembles the Vee development model shown in Figure 6.

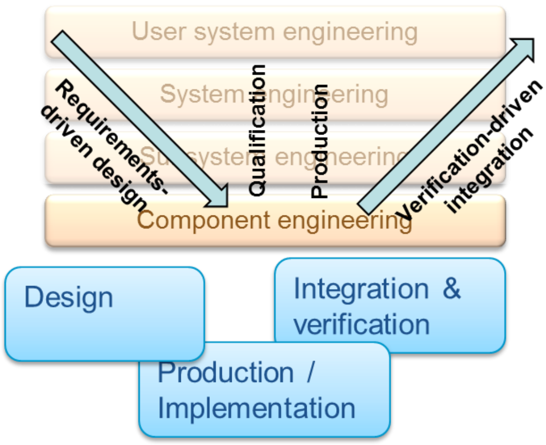

Figure 12: The Product Engineering Stage (Credit: SKA South Africa) [17]

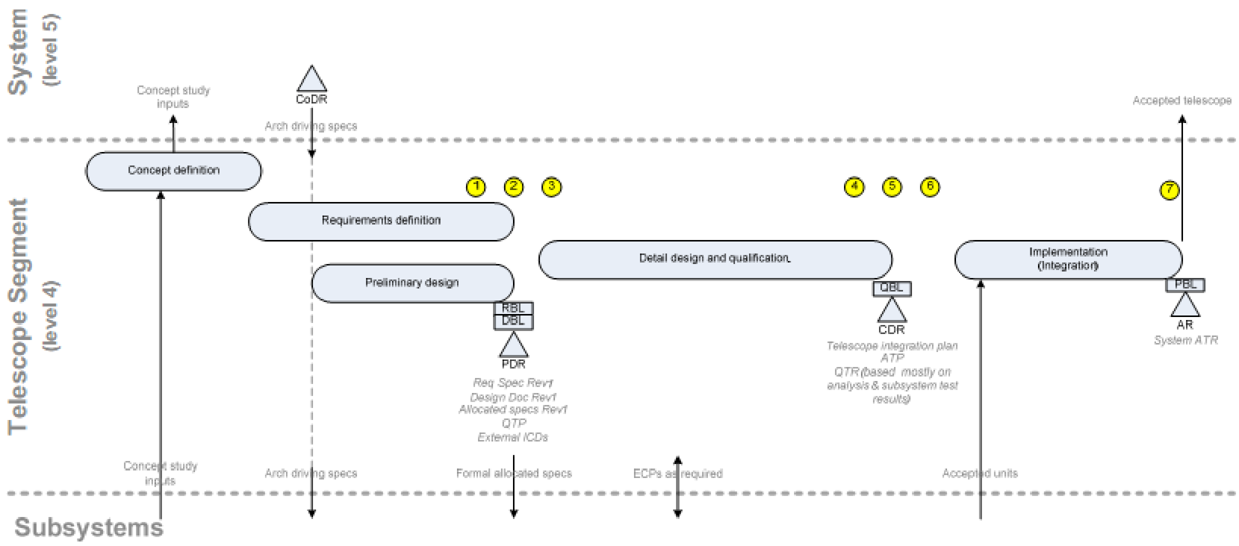

Figure 13: Detailed Sequencing of Activities (Credit: SKA South Africa) [15]

The design stage has two phases, the preliminary design stage and the detail design and qualification. Both phases have a review at the end and baselines that have to be established before proceeding to the next phase. The criteria to establish the baseline is well documented in the SEMP.

This approach is used for all sub-systems and there is minimal evidence of tailoring this method to suit the different sub-systems shown in the system hierarchy. The different sub-systems have their own risks, from evidence in the concept trade-off report, and may be at various levels of technology maturity however there no evidence that the tailoring of the development strategy (incremental vs evolutionary) or the development method itself is considered based on unique risks in these sub-systems. A deeper investigation by looking at each sub-system in more detail and the development effort through the detail design phase may reveal if any advantages can be realized from these considerations by investigating what challenges were experienced during the development.

5 CONCLUSION

To conclude:

- The SKA South Africa MeerKAT case study is presented and the Systems Engineering Management Plan and the Concept Trade-off reports were examined as part of the investigation to determine what processes, methods and tools are used during the development of the MeerKAT array.
- From the case study, applying a systems engineering approach has allowed the development team to progress from an experimental development model to the commissioning of a small array (KAT-7) in a short space of time. Iterations in development allowed the team to continuously refine the systems engineering process as the system complexity increased. This shows systems engineering allows for a structured process to develop technology and enables for continuous improvement of the outputs of a development.
- The preliminary findings of the analysis of the documentation show that systems engineering processes, methods and tools are being applied by SKA South Africa to develop the telescope system and that these are in line with current systems engineering technical management practices.
- No evidence of the explicit definition of a scale to measure technology maturity in the development process has been found. The consideration of technology risks on the tailoring of the development model itself was not evident. Further investigation by looking at a sub-system in more detail is required in order to investigate the effect of technology development on the later stages of the development and the life cycle of system.

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INVESTIGATING THE EFFECT OF TOOL WEAR AND SURFACE INTEGRITY ON ENERGY EFFICIENCY DURING THE MACHINING OF TI-ALLOYS

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ABSTRACT

Manufacturing processes carried out on modern machine tools are still energy and resource intensive. In order to comply with future sustainability legislations and standards these processes should become more energy and resource efficient. The strategic objective of companies still remains to increase the production throughput rate, reduce the inventory and operating costs while keeping the products within the quality constraints of the voice of the customer. Increasing the material removal rates (MRR) will influence the energy efficiency, tool failure rate and the work piece's surface integrity. Thus, a better understanding of the effects cutting mechanisms have on energy efficiency during high speed machining (HSM) are gaining interest. In this research study the effect of various cutting conditions on surface integrity, tool wear and energy efficiency were investigated. Cutting speed and feed rate were varied while the depth of cut was kept constant during the turning of Ti6Al4V under flood lubrication. Tool wear and surface roughness both deteriorated with an increase in the material removal rate. It was also found that worn cutting tools produced a higher work piece surface hardness than a new tool. The energy usage for a specific cutting distance also decreased with an increase in material removal rate. Future work is also outlined.

1 INTRODUCTION

The growing demand for increased production of Titanium (Ti) alloy components imply that machining processes need to be carried out at higher cutting velocities (v_c) and feed rates (f_n) [1]. At the same time, this increase in MRR reduces the work piece's dimensional accuracy and surface integrity and mostly reduces tool life. Managing energy and resource efficiency have also become a key strategy for most production plants. Thus, manufacturers have to balance energy efficiency management programs with the overall cost implications due to quality and downtime issues. Guo et al [2] argue that reducing energy consumption during production is one of the main practices for promoting environmental friendly manufacturing. Research [3] found that most of the energy consumption of machining processes is taken through driving the machine auxiliary functions and that the actual cutting processes take very minimal energy. Up to 35% of the total energy is used by the spindle. It was also found during an environmental examination [4] of machining processes that for the total energy consumed by the machine tool, very little amount of energy is required for cutting. Still, it remains critical to understand the effects of increasing the material removal rate on tool wear and surface integrity at the cutting interface to ensure the balance with energy efficiency. Machining also remains one of the most frequently used manufacturing activities it is estimated that approximately 15% of all manufactured components are produced using machining operations [5].

Titanium alloys have high strength-to-weight ratio, good bio-compatibility characteristics and high temperature toughness. These factors make titanium alloys desirable for industries like the aerospace, chemical processing, biomedical applications, automotive, missile development and nuclear installations [6, 7, 8]. Due to titanium alloys' good corrosion resistance the material is also gaining ground in application in the marine industry [9]. These very same relative superior qualities makes Ti-alloys also difficult to machine. The material has a very low thermal conductivity and Young's modulus (114 GPa) [8]. Most cutting tool materials lose their hardness at elevated temperatures resulting in the weakening of the inter-particle bond strength and consequent acceleration of tool wear, [10]. Possible surface and subsurface alterations may appear as plastic deformation or take the form of micro-cracks, phase transformations and heat-affected zones. It also produces segmented chips during machining operations that causes micro-vibrations [11]. This forced vibration from the cutting action, due to the process of shear localization, can lead to catastrophic tool failure. The temperature generated within the primary, secondary and tertiary shear zones of the cutting process also affect the tool wear rate and high cutting temperatures can result in severe tool wear [12, 13]. There are different types of tool wear mechanisms that can influence the tool wear and subsequently the tool life during machining Ti-alloys [13]. Under normal machining conditions flank wear predominate crater wear and defines the failure criteria for cutting tools [14]. Tool wear types include adhesion, abrasion, delamination, diffusion, micro-chipping and plastic deformation [15, 16]. The flank wear criterion for cutting tools according to the ISO Standard 3685-1977 (E) [17, 18, 17] and industrial practice is where V_B=300 μm.

In this research study the effect of different cutting parameters on tool wear, surface integrity and energy efficiency were studied. The objective is to understand the effect of cutting speed (v_c) and feed rate (f_n) on tool wear, surface integrity and energy efficiency during the machining of Ti-alloys.

2 EXPERIMENTAL SETUP AND DESIGN

Turning experiments were performed on an Efamatic CNC lathe (model: RT-20 S, Maximum spindle speed 6000 RPM). A Kistler, Model 9625B, 3-axis dynamometer along with Type 9441 B Charge Amplifiers and a National Instruments multi-channel data acquisition system were used. This dynamometer was used to measure the three components of the cutting force: F_x (radial force), F_y (tangential and main cutting force) and F_z (axial feed force).

Labview Signal Express software data acquisition system was used to output the data to a windows based personal computer. A solid carbide tipped tool (CNXMX 12 04 A2-SM with coating) mounted on a Sandvik tool holder (DCLNL 2525 M12) was used for turning Ti6Al4V with conventional flood cooling. Ti6Al4V (Grade 5) titanium alloy was supplied in annealed condition at 36 HRC as a solid round bar (Ø=75.4 mm x 250 mm long). The work piece chemical composition and mechanical strength characteristics (as per the material certificate) are presented in Tables 1 and 2 respectively. The experimental set-up is shown in Figure 1.

Table 1 Chemical Composition of the Titanium Alloy Material used

Element	Al	V	C	Fe	N	O	H	Others	Ti
% Content	6.0	4.1	0.02	0.14	0.01	0.16	0.001	0.5	89.069

Table 2: Mechanical Properties of Ti6Al4V

Mechanical Characteristic	Treatment Condition	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Reduction of Area (%)
State/Value	Annealed	969	847	13	28

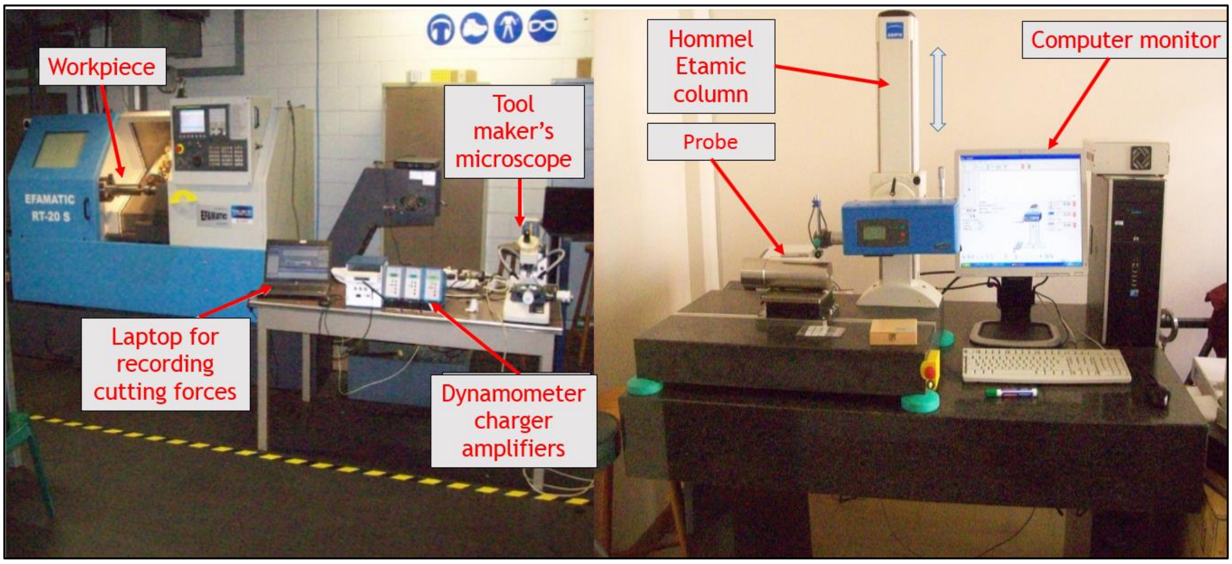

Figure 1: Experimental set-up (a) Cutting forces measurements and (b) Surface roughness measurements

Table 3 below summarises the machining conditions used during the experiments. Tool wear was observed and measured using a Mitutoyo Optical tool maker's microscope model 176-801D. Power measurements were taken using a KYORITSU ELECTRICAL 3 PHASE DIGITAL POWER METER MODEL 6300 with the KEW POWER PLUS2 power signal recordings captured

Table 3: Turning parameters of Ti6Al4V under flood Coolant

Parameter	Unit	Conditions
Cutting Speed, v_c	mm/min	150, 200, 250
Feed Rate, f_n	mm/z	0.1, 0.2, 0.3

and read off an Acer Aspire 5551 Laptop running on Windows 7. The cutting conditions were varied during the experimental process with cutting speed, v_c = 150- 250 m/min and f_n= 0.1-0.3 mm/rev. The depth of cut was kept constant at 0.5 mm. The Hommel-Etamic T8000 RC was used for the measurement of surface roughness. Each measurement of surface roughness was repeated four times and the average values were recorded. The software used to analyse the surface roughness is Turbo Wave V7.53. The work piece effective machining length was kept constant for the cutting experiments at 190 mm.

3 EXPERIMENTAL RESULTS AND DISCUSSION

Optical measurements of the tool wear were taken at different cutting speeds and feed rates conditions. Graphical tool wear images at various spiral cutting distances were also monitored during cutting operations and are as shown on Figure 2. The dominant wear mechanism observed was on the flank, followed by crater wear on the rake. Increasing cutting speed enhanced thermal and chemical activities on the tool chip interface. An increase in mechanical load (f_n) caused an increase in fracture mechanisms.

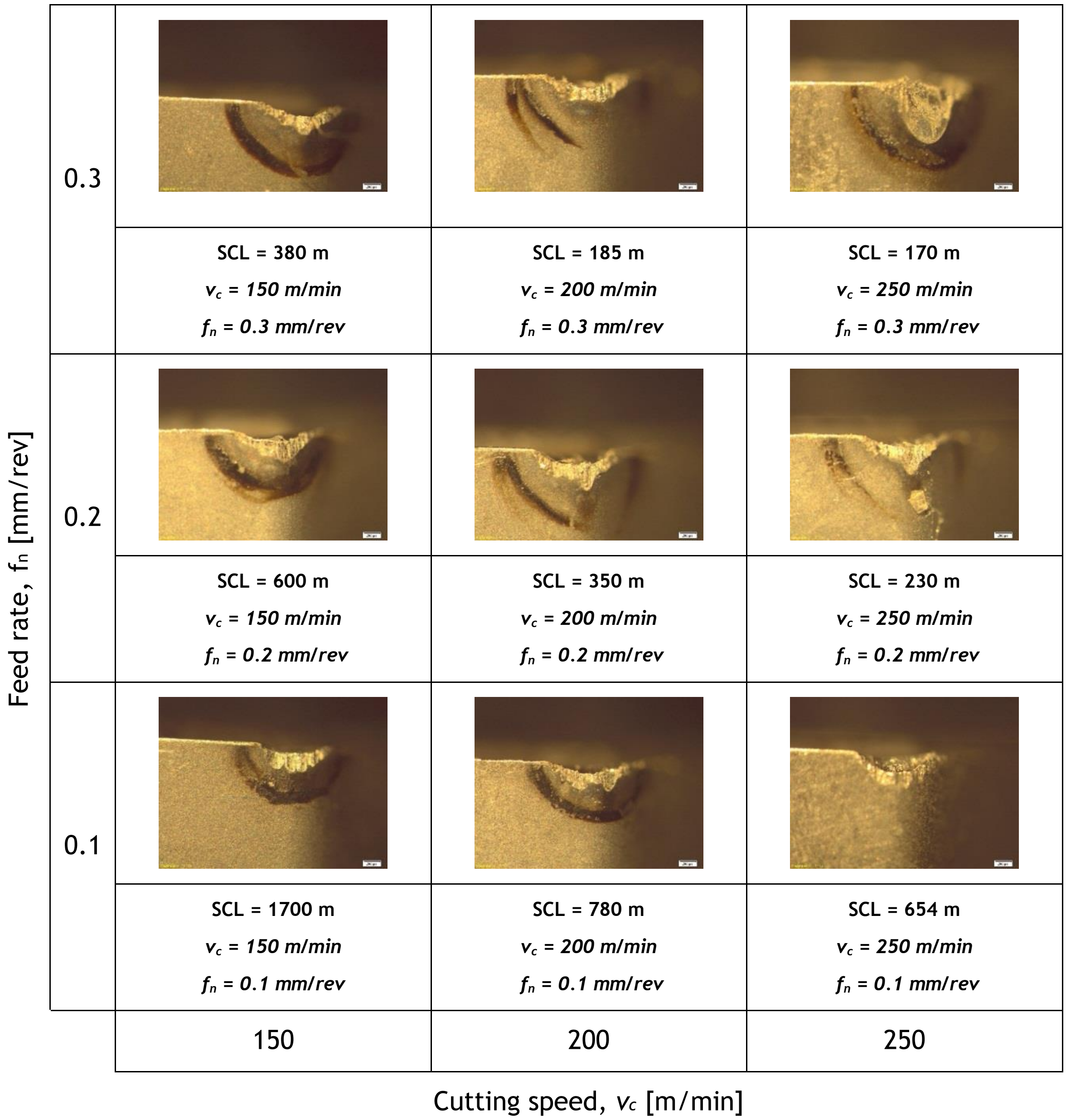

Figure 2: Tool flank wear as a function of cutting speed and feed rate

The spiral cutting length (SCL) was measured at the maximum flank wear of V_B=300 μm. It has been observed that the feed rate and cutting speed have an effect on flank wear. However, feed rate had more detrimental effect on spiral cutting length than cutting speed in these experiments. Figure 3 illustrates the spiral cutting length for different cutting conditions.

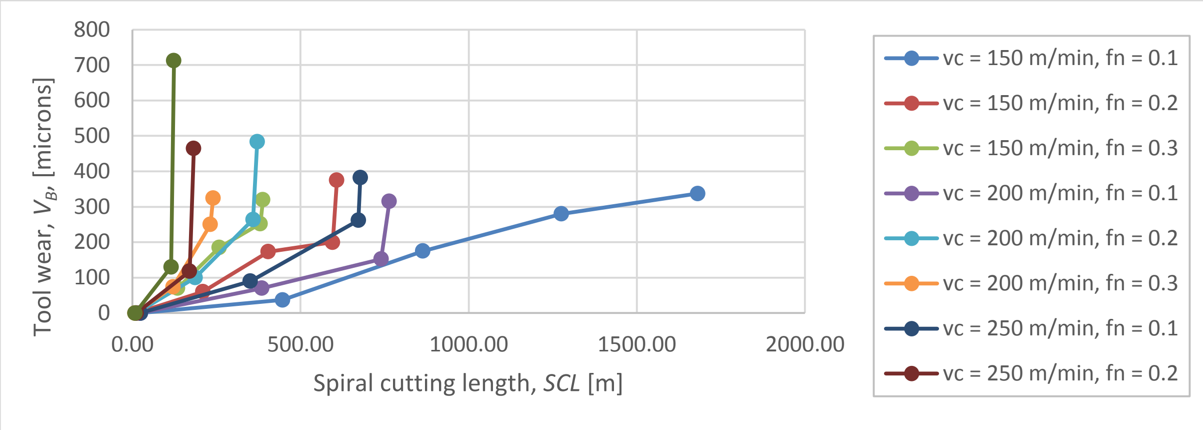

Figure 3: Spiral cutting length vs tool wear

Increasing the cutting speed increased the thermal loading which increased the tool wear rate. Figure 4 shows the effect of feed rate on the work piece surface roughness. Increasing the feed rate produced rougher work piece surfaces.

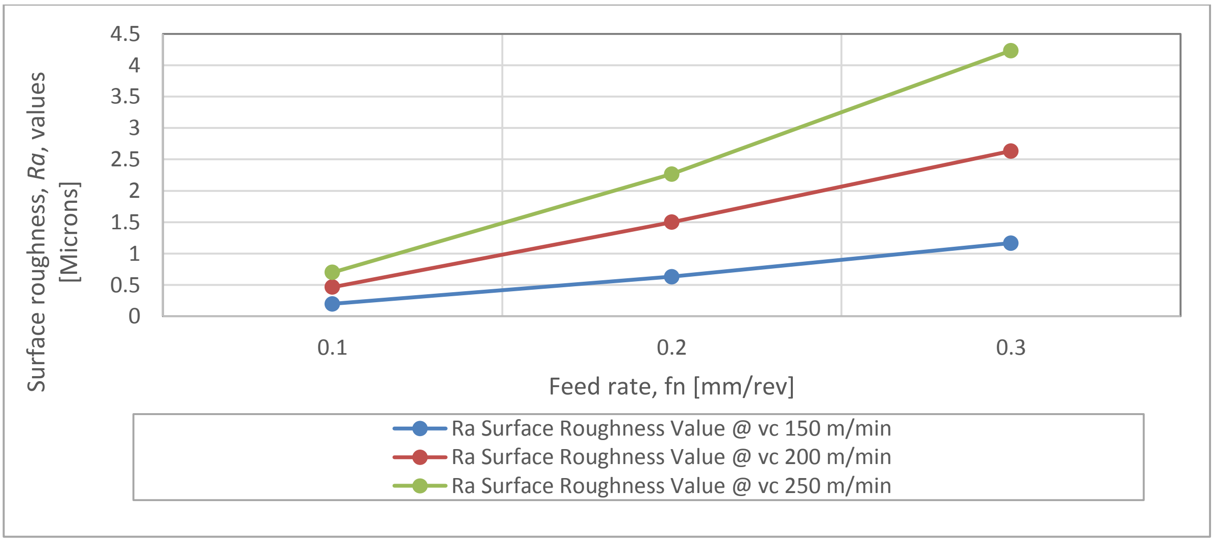

Figure 4: Feed rate vs surface roughness values at varying cutting speeds on first pass

Figures 5 and 6 shows the microstructure of the machined surface with new and worn tool produced during the turning of Ti6Al4V at a high cutting speed ranges (v_c = 150 - 250 m/min and f_n = 0.1 - 0.3 mm/rev). The white arrow indicates the direction of cutting action. The subsurface microstructural deformation caused by machining, consisted of deformed grain boundaries in the direction of cutting and elongation of grains.

Figure 5 seems to have more deformation when compared to Figure 6 and from these results it suffices to conclude that worn tools do not have much effect on the machined surface as much as new tools. A new tool produces a rougher surface than a worn tool. The nature of microstructure distortions findings tend to complement the types of defects which were analysed and reported by Che-Haron [19].

There is plastic deformation of the top layer of the machined surface when machining Ti6Al4V alloy at these cutting conditions. This can be seen for most cutting conditions with both a new or worn tool.

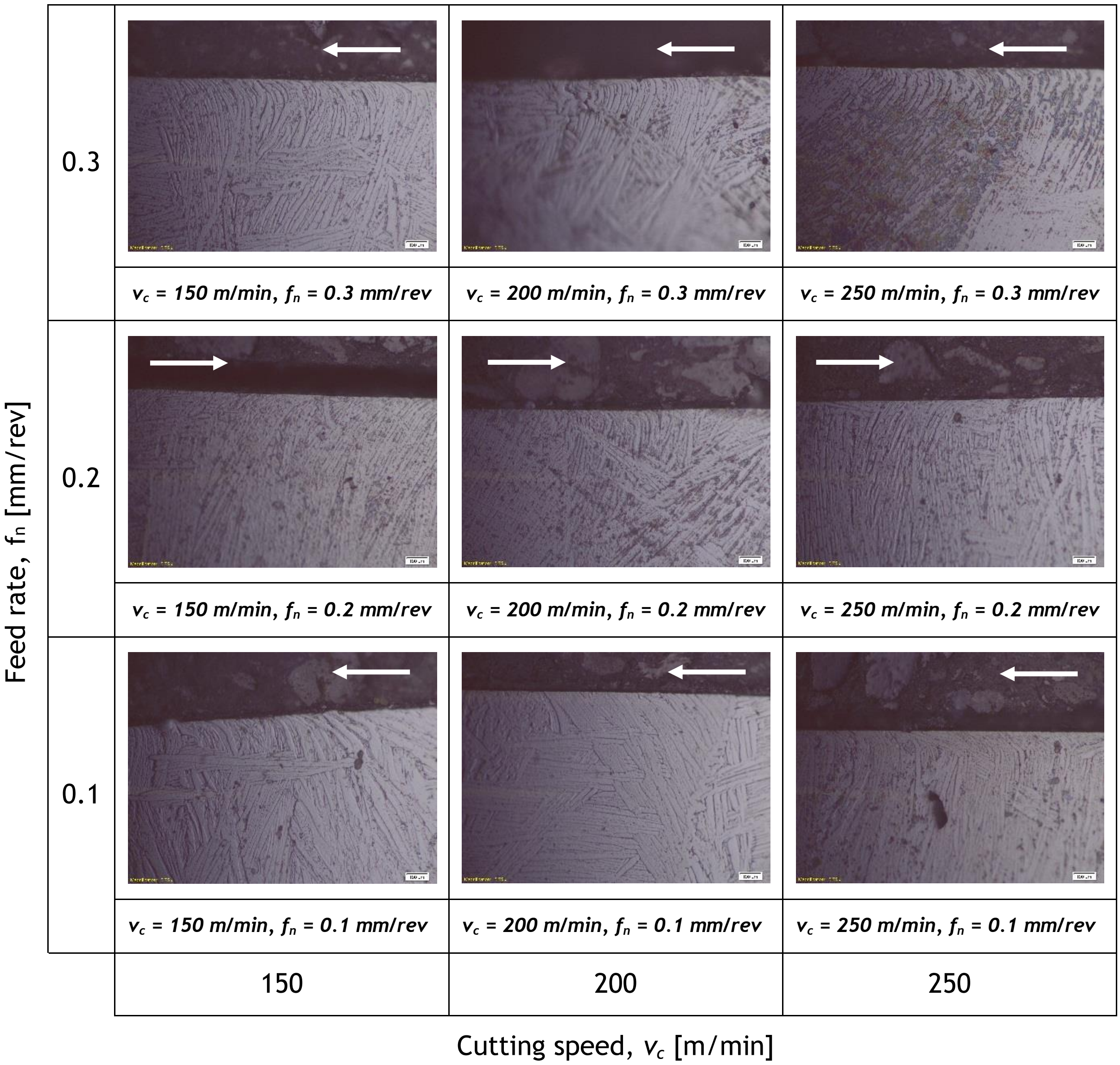

Figure 5: The effect of cutting speed and feed rate on the work piece surface integrity with a new cutting tool edge

The sub-surface deformation process is influenced by the occurrence of severe shear stresses generated under aggressive high speed machining conditions coupled with the observed high tool wear above. There was no noticeable change of the surface due to plastic deformation as the cutting parameters increased from this view.

Furthermore, there was also no evidence of sub-surface defects such as cracks, laps and visible tears after turning Ti6Al4V alloy under the flooded cooling conditions.

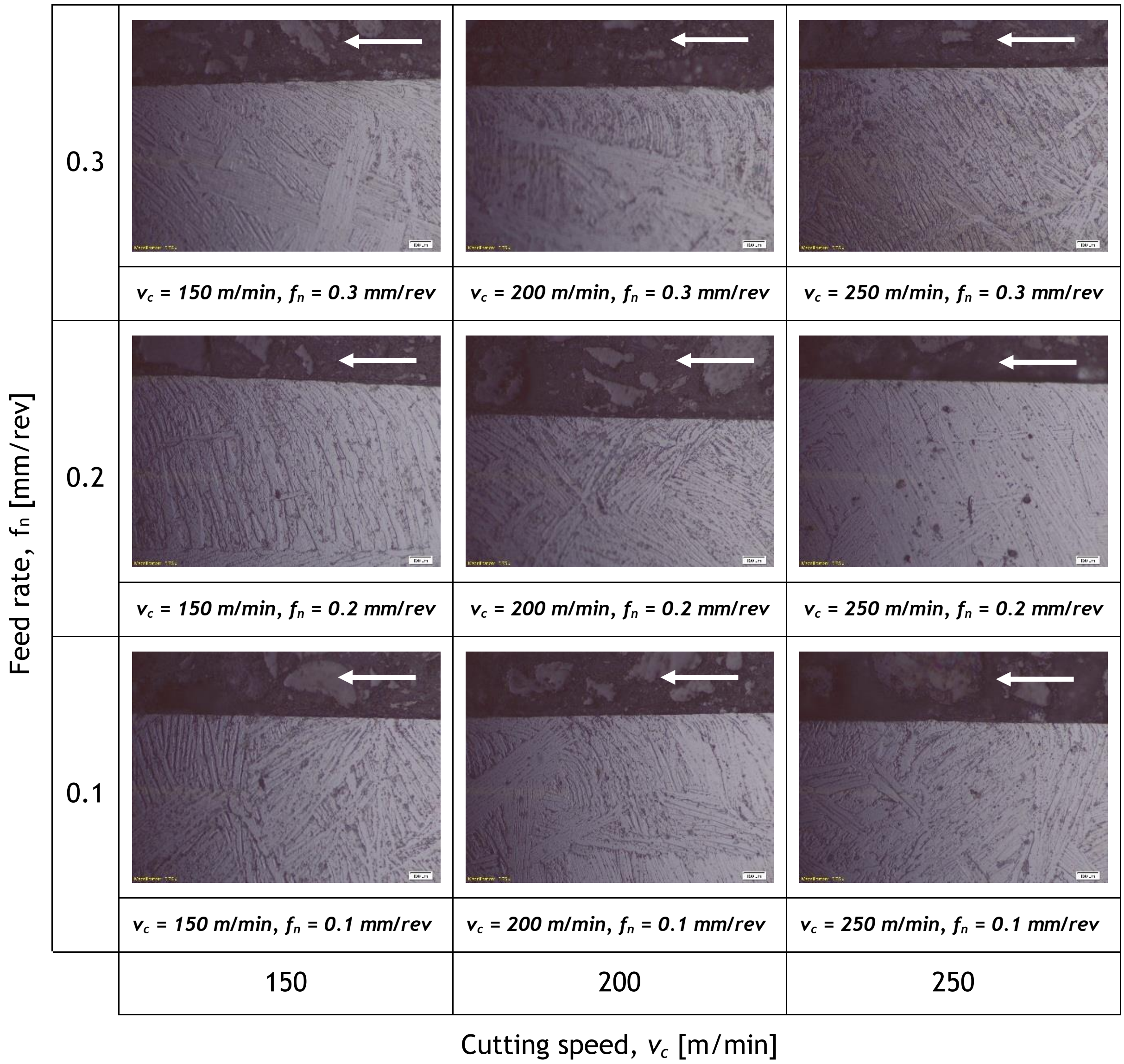

Figure 6: The effect of cutting speed and feed rate on the work piece surface integrity with a worn cutting tool edge

Figures 7 and 8 are the graph plots displaying the micro-hardness depths at cutting speed of 150 m/min and the feed rate ranges 0.1 - 0.3 mm/rev where Figure 7 is a plot for a new tool and Figure 8 being the plot for a worn tool. The graph shows that the increases in feed rate also cause an increase in the surface micro-hardness on the work piece. In all cutting conditions work hardening of the deformed layer beneath the machined surface up to 500 μm caused higher hardness than the average hardness. Worn tools tend to affect the machined surfaces differently and gave higher surface hardness than new tools.

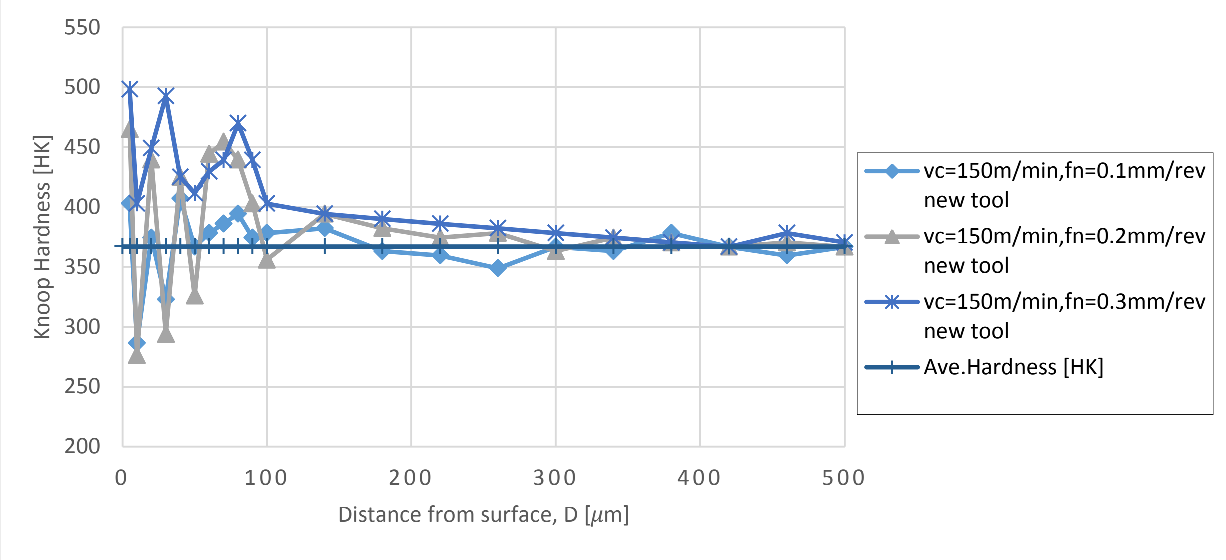

Figure 7: Micro-hardness versus distance from the surface at v_c = 150m/min with new tool

It is observed from comparing the micro-hardness profiles in Figure 7 and 8 that the pattern of micro-hardness variation is below the average hardness for a distance of 40 μm and 140 μm respectively from the surface for the feed rates of 0.1 mm/rev and 0.2 mm/rev (Figure 7). In comparison with Figure 8, the micro-hardness profiles tend to be similar at the three feed rates of 0.1, 0.2 and 0.3 mm/rev. The micro-hardness values fluctuate and pick between the depths, below the surface, of 10 μm and 80 μm before tending to come down to the average hardness value within the depth range of 80 to 500 μm.

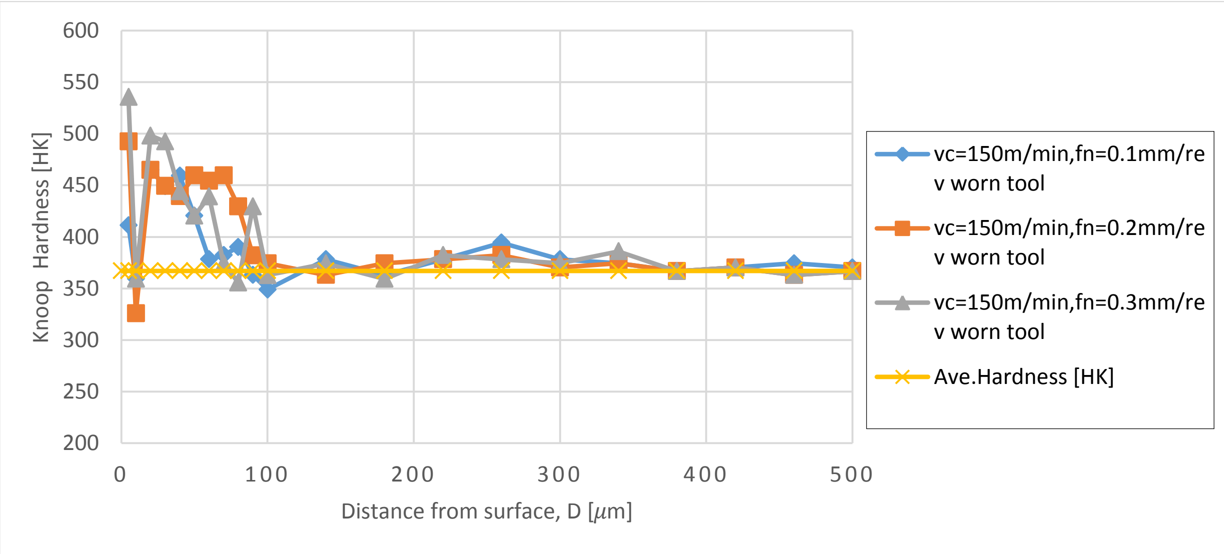

Figure 8: Micro-hardness versus distance from the surface at v_c = 150 m/min with worn tool

Figure 9 and 10 show the effect at a cutting speed 200 m/min at different feed rates of 0.1 - 0.3 mm/rev, while machining with a new and worn tool. Results show that at the cutting speed of 200 m/min, as feed rate increases the hardness decreases at a distance of 5 μm from the machined surface. However, the worn tool increases the hardness even more. The hardness values at 100 μm decrease significantly 5 μm below the machined surface.

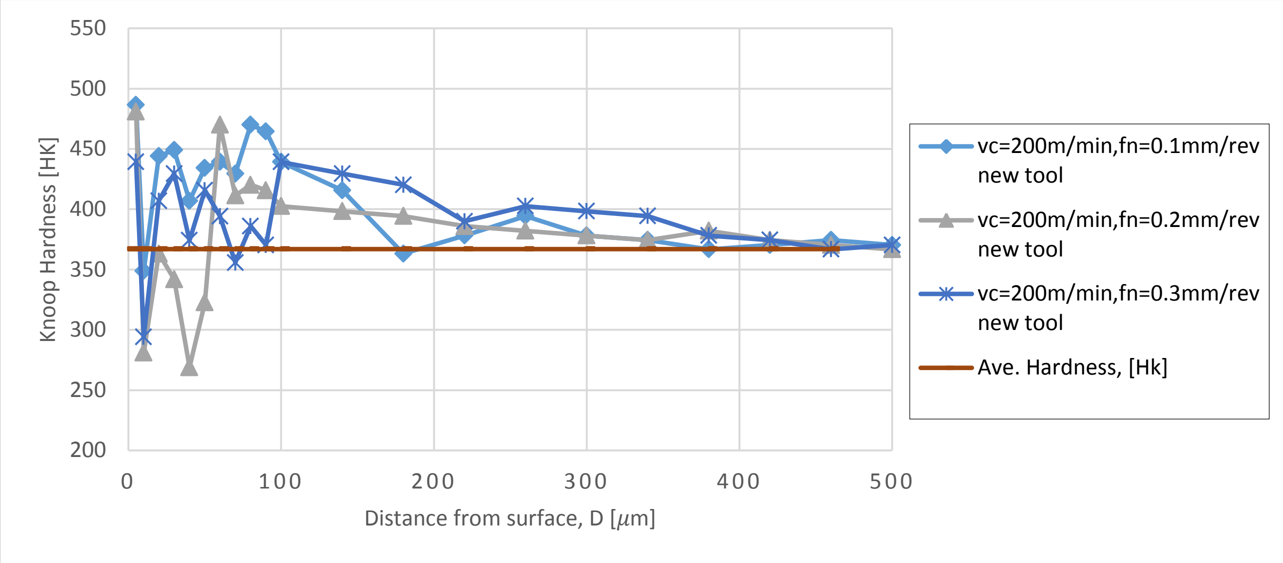

Figure 9: Micro-hardness versus distance from the surface at v_c = 200 m/min with new tool

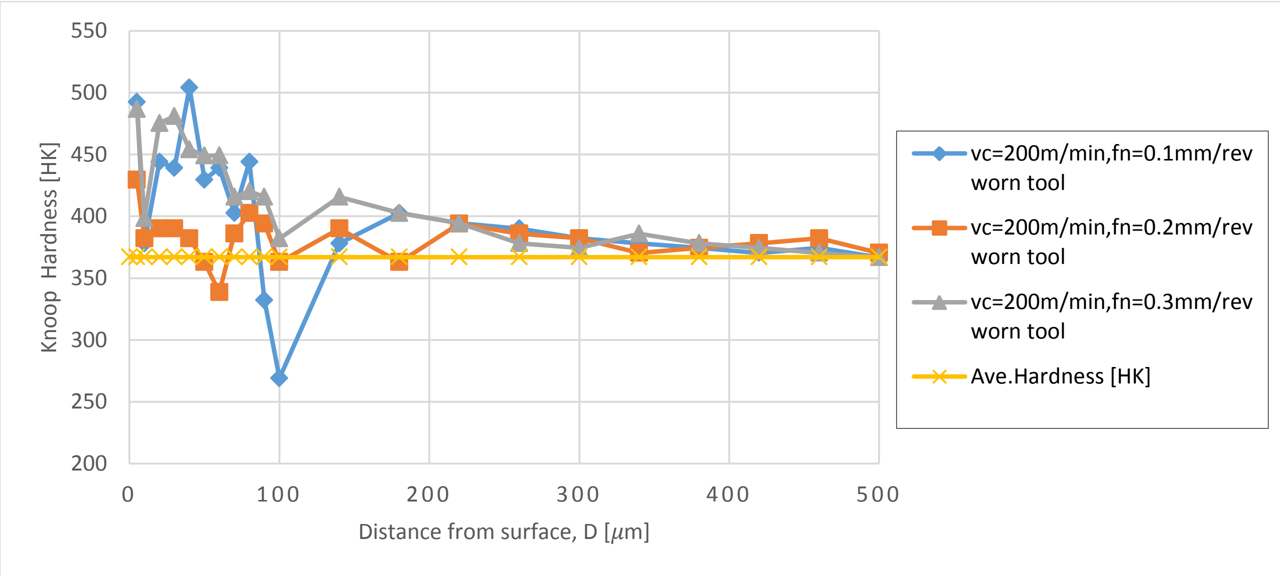

Figure 10: Micro-hardness versus distance from the surface at v_c = 200 m/min with worn tool

Figures 11 and 12 show the plot of micro-hardness at a cutting speed of 250 m/min and feed rate of 0.1 - 0.3 mm/rev at a different tool conditions. The highest hardness was recorded when using a worn tool.

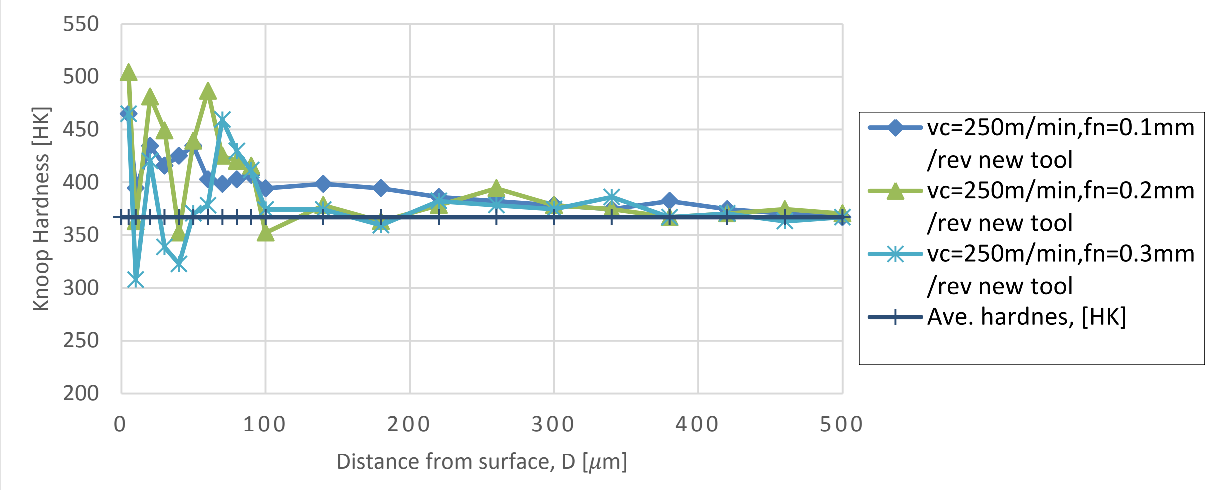

Figure 11: Micro-hardness versus distance from the surface at v_c = 250 m/min with new tool

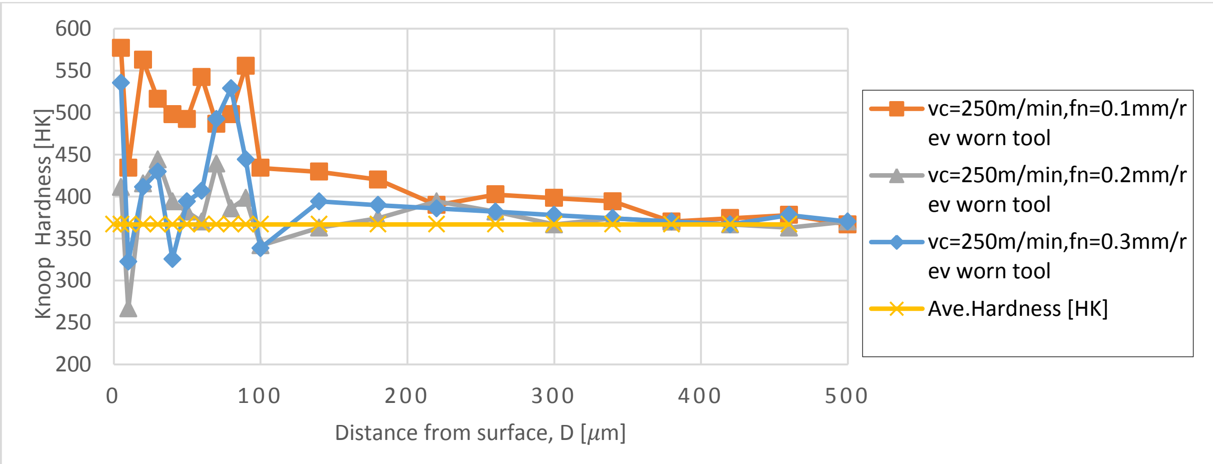

Figure 12: Micro-hardness versus distance from the surface at v_c = 250 m/min with worn tool

The total energy consumed to cut one pass (length of cut, l_m=170mm) as a function of cutting speed and feed was found to decrease dramatically as a function of increased feed rate and cutting speed. In all cases the same amount of material was removed albeit with dramatically different energy consumptions. When cutting at the highest cutting speed (250 mm/min) with the largest feed rate (0.3 mm/rev) and comparing to the lowest cutting speed (150 m/min) and lowest feed rate (0.1 mm/rev) there is a dramatic difference in energy consumption.

This equates largely to the machining time. It is clearly beneficial to operate the machine on an as needed basis only and for the shortest possible time. This once again points towards the energy consumption of the ancillary systems of the machine tool and the mechanical losses during operation.

This is further emphasised in Figure 13 where energy is depicted as a function of material removal rate. It clearly shows that the energy usage is strongly influenced by material removal rate. High material removal rates are generally commensurate with high performance and high speed machining and may have significant benefits as far as total energy use during machining.

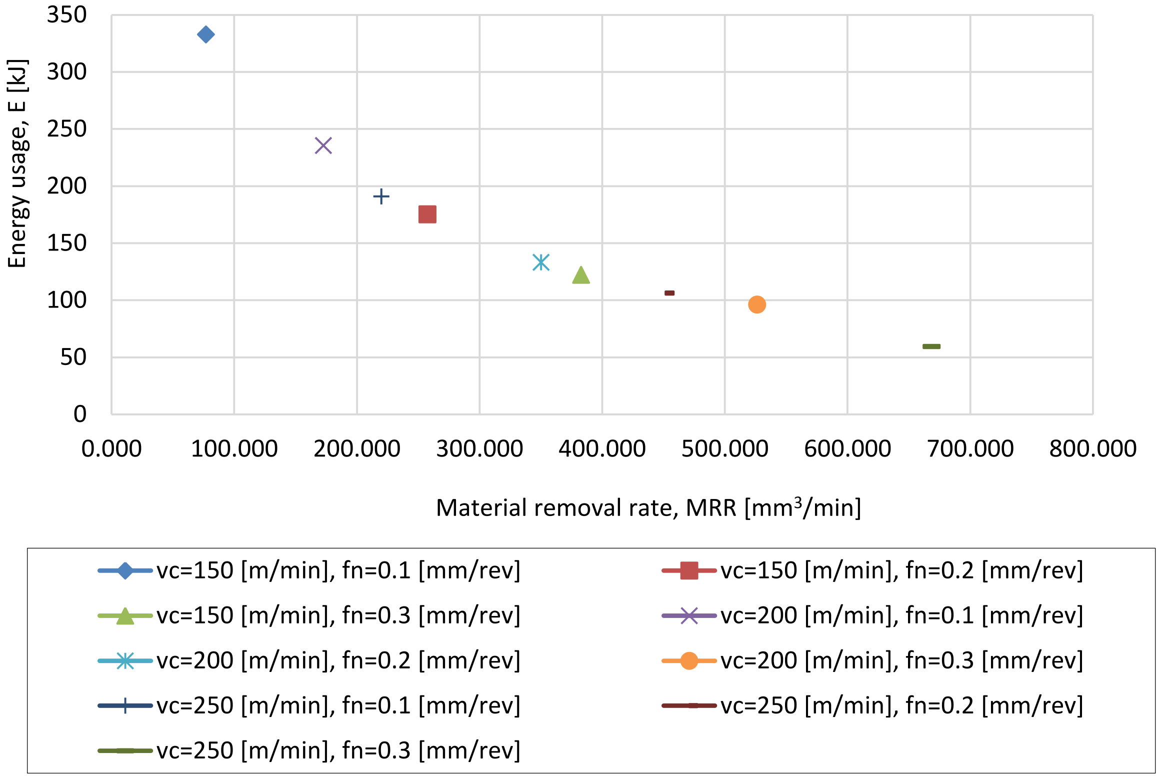

Figure 13: The effect of material removal rate on energy usage for different cutting conditions

4 CONCLUSION

The research experiments focused on the machining of titanium alloys using carbide cutting tools. The tool wear and surface roughness both deteriorated with an increase in material removal rate. It was also found that worn cutting tools produced a higher work piece surface hardness than a new tool. As far as overall energy management is concerned the data clearly demonstrated that higher material removal rates are preferred for significantly lower energy consumption. This is largely the effect of reduced machining time at the higher material removal rates which is essential for the same energy usage rate associated with the machine tool ancillary support systems. The higher material removal rates do however lead to increased tool wear. The experimental results showed that there is significant scope for improved energy management during machining and more specifically during machining of Ti-alloys. This can be achieved through the selection of optimum cutting conditions within high speed machining range such that energy use can be minimised.

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OPEN COMMUNITY MANUFACTURING

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ABSTRACT

In the current competitive economic environment, start-up companies struggle to accomplish production tasks alone. Digitisation helps to solve most product or service customisation challenges with open co-creation platforms and toolkits. The concept of Open Community Manufacturing (OCM) systems is introduced. OCM uses open design platforms to create value at the base of the pyramid, by empowering incubators through distributed manufacturing systems. OCM systems embrace new ways of technology transfer, ideas and risks, so as to create the most collaborative environment possible. This research study evaluated several open design platforms, projects and toolkits that can be used as social innovation support system to develop distributed manufacturing entrepreneurs. It was found that economic value can be created using open design, simply due to mass collaboration where people are living, experiencing and expressing gradually more within digitally enabled social- and peer networks in distributed communities. OCM finds synergy amongst various stakeholders in order to mobilise developing communities. This allows products to be manufactured economically in smaller, more flexible quantities for the customised demand.

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1 BACKGROUND AND MOTIVATION

Poverty remains an issue of the modern world. Despite that South Africa (SA) is the most developed country in Africa, there are still regions suffering from severe poverty. More than half of the working population belongs to the so called base of the pyramid (BoP). In order to comply with tighter legislation, Broad-Based Black Economic Empowerment (B-BBEE) policies and to receive tax benefits, several stakeholders attempt to address this issue with passive social responsibility programs.

Poverty can not only be addressed by programs that adhere to and support sustainable business conduct, growth plans and the Millennium Development Goals. Therefore, it is critical to find a synergy amongst various stakeholders and that actions are orchestrated to support the development goals. The call for systems and strategies to mobilize the target population and to ensure distributed value creation even in isolated regions remains unanswered.

In addition to this, the recent financial crisis that shivered the global economy caused an economic bear run even in developing nations. These conditions make it really hard to foresee that traditional Technology Transfer (TT) actions (e.g. foreign Greenfield investments) will be enough to radically accelerate economic growth.

Since the industrial revolution in the eighteenth century manufacturing has been considered to be the main engine of economic growth and development. It contributes to the quality of life of individuals, to growth of wealth in a nation as well as power and position of a state. Manufacturing is the backbone of modern industrialized society, as it always has been cornerstone of the world's economy. Having a strong manufacturing base is important to any society or community, because it stimulates all the other sectors of the economy. Therefore, manufacturing deserves strong and continuous endeavour of all actors in a modern society to ensure prosperity, better life and sustainable development. Few in SA doubt the essential need to grow the manufacturing sector of the country. Some universities and non-profit organisations even invested in community factories (e.g. FabLabs and BURN design lab) to encourage manufacturing movement. Still, there is a shortage of new concepts which would fast-track the development of this sector.

Small and medium sized enterprises suffer from the shortage in skills (know-how), appropriate technology and the lack of a collective support system. This leads to inefficient value creation, a high degree of energy (resources) wasted in production processes and frightening pollution. The ability to co-create value independently (even in socially- and geographically isolated regions), together with improved teaching capabilities can open numerous possibilities for developing countries. These statements highlighted some of well-known challenges and facts, which affect development in SA.

In order to find innovative systems to alleviate poverty in SA, this contribution proposes the concept of open community manufacturing as a new technology transfer mechanism. It is based on principles of value co-creation, networking, open design, and ubiquitous manufacturing. This approach is defined with a model and demonstrated in two case studies. These case studies illustrate low- and high technology products.

2 SUSTAINABLE DEVELOPMENT AS INNOVATION DRIVER

A balanced sustainable development framework will ensure that a country's geographic area is utilised effectively, the country's people are healthy, skilled and educated; the infrastructure is sufficient and that there are abundant employment opportunities within respected governance systems. Considering that sustainable development entails meeting the needs of the present without compromising the ability of future generations to meet their own needs - this concept has become a real innovation driver to grow the formal economy.

2.1 Base of the pyramid (BoP)

The base of the pyramid represents the largest (4 billion), but poorest (live on less than US$ 2.50 per day) socio-economic group [1]. These are the people that should receive basic needs and basic services to survive. The BoP was first introduced in the work by Prahalad et al. [2] attempting to raise awareness of the world economic pyramid and the vastly untapped market. Since then, there have been considerable attempts toward developing economically viable initiatives to serve the BoP.

In theory, organizations targeting this segment operate under the proposition of mutual value creation, which suggests that creating more value for the BoP creates more value for the venture [1]. In other words, in order to grow the formal economy, stakeholders need to help create value inside the informal economy as shown in figure 1 by investing in education, infrastructure, skill-, supplier- and enterprise development programs.

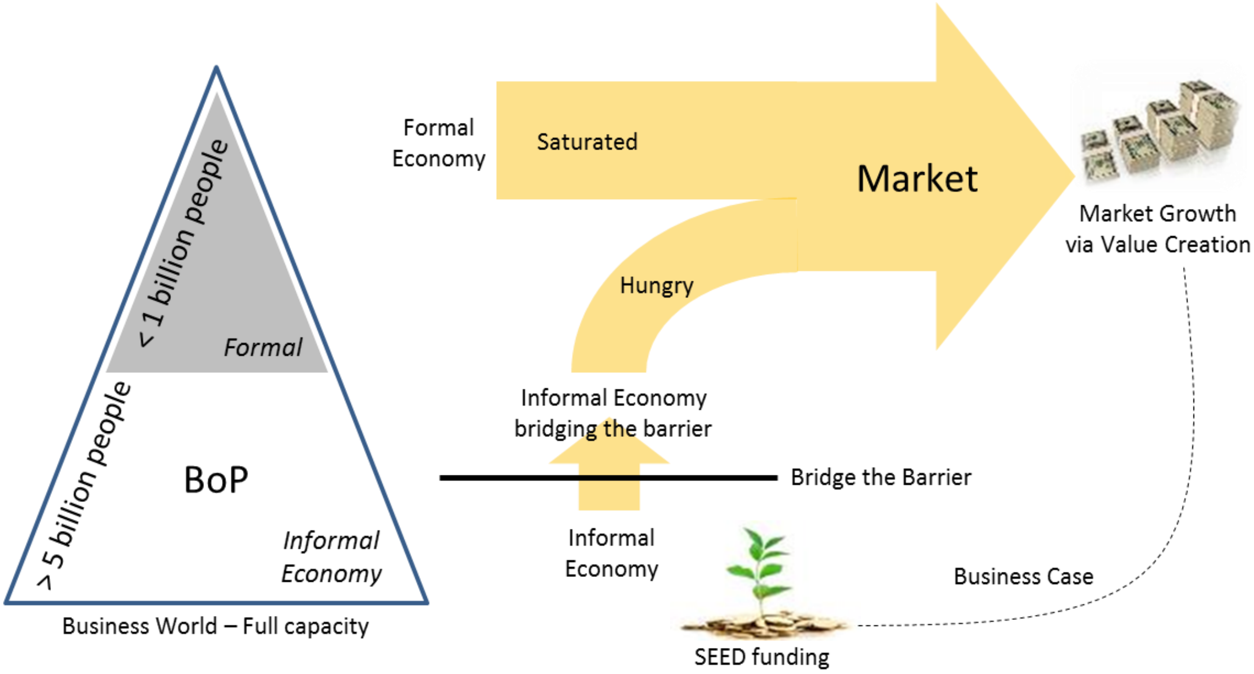

Figure 1: Creating more value for the BoP, creates more markets for organisations investing its SEED funding into social innovation programs (Adapted from [1])

The poor at the base of the corporate ladder primarily transact in an informal market economy, due to the cost, complexity and unfamiliarity of transitioning to the formal economy [1]. In order to address the BoP issues, a more in-depth understanding of this environment is needed. One must keep in mind that the BoP significantly differs from formal business environments as follows:

- customers have a low and irregular income
- markets can be located in extreme geographic locations (e.g. poor physical and informational infrastructure)
- competition is weak or may be too strong for start-up entrepreneurs to enter the market
- lack of support system (e.g. suppliers, distributors)
- corruption is embedded in the society
- formal institutional (e.g. legal enforcement) environment is usually weak

- the informal institutional environment has strong ties within the community and;
- the informal economy is often in conflict with formal institutions

These are just a few, but noteworthy characteristics of the BoP which require significantly different approaches and business models as we know them from the developed (formal) world. Among other, one has to consider the following principles [3]:

- products are to be produced in small sizes with strong local adaptation (flexibility)
- distribution must take into account frequent, small purchases and hard-to-reach areas
- transactions must consider little reliance on contractors
- transactions have strong reliance on informal tie and;
- important to obtain local recognition and legitimacy

Knowing that manufacturing deserves a strong and continuous endeavour to ensure sustainable development, the BoP must be considered not only as a potential market, but also as a producer. According to London et al. [4] BoP producers, which are operating in the informal sector, generate goods for sale (e.g. agricultural products and handcrafts). The challenge is that it is sold almost exclusively in local, informal markets. Also, due to the lack of an industrial culture, one must be aware that there is no adequate knowledge, skills, and resources for manufacturing in the BoP.

Still, there is evidence of undergoing activities related to BoP development. Some case studies [5] show what types of innovation are best to reinforce the value propositions to address low-income consumers´ problems. Other work [6] proposes community desired products to meet the needs of the BoP. Khan [7] proposes a new learning method for BoP people. Therefore, there exists opportunities for introducing the manufacturing of low-tech products in BoP communities.

2.2 Technology transfer

As the lack of knowledge, skills, resources and infrastructure are universally recognised; technology transfer (TT) becomes a key mechanism for introducing manufacturing to the BoP. Several definitions of technology and its transfer in literature exist, with a recent overview given by Wahab et al. [8]. For the purpose of this research we use the following definition of TT: *"Technology transfer is the movement or flow of technical knowledge, data, designs, prototypes, materials, inventions, software, and/or trade secrets from one organization to another organization or from one purpose to another purpose"* [9].

According to Tahmooresnejad et al. [10] companies are the driving force of TT and need to prepare their infrastructure and human skills to be successful. Government's role is to support organisations with policies to accelerate localization and aid them in developing their new products based on transferred technology.

Amesse et al. [11] define two phases of TT: (1) innovation process or technology creation, and (2) reproduction or technology diffusion. The authors also distinguish if these processes are performed within one organization or between organizations. On this basis they define four contexts of traditional TT methods and point out a need for new ways of TT for knowledge based economy.

In the last decade we have witnessed some new emerging approaches to technology creation and transfer. Collective organizational forms emerged such as industrial clusters and networks. Nowadays, the innovation process is even totally opened to global communities in which everybody can participate. The Google Android development and marketing platform is a good example. Everybody can access and use existing design tools and solutions on this platform and co-create even more solutions. Table 1 shows technology transfer contexts in a systematic manner. The left four quadrants (denoted with I – IV) are adopted from Amesse et al. [11] and represent the traditional technology transfer methods. The right four quadrants (V – VIII) represent the novel technology transfer methods.

Table 1: Eight contexts of technology transfer

	Traditional technology transfer methods		Novel technology transfer methods	
	Within organization	Between organizations	Within cluster or network	Open community
Creating technology	I MANAGING INNOVATION	II CONTRACTING OUT R&D AND OUTSOURCING	V COLLABORATION & OPEN INNOVATION	VI OPEN DESIGN & CO-CREATION
Reproducing and diffusing technology	III TRANSFERRING TO DIVISION OR SUBSIDIARIES	IV BUYING OR SELLING PROVEN TECHNOLOGIES	VII BUSINESS ALIANCES AND PARTNERSHIPS	VIII ADOPTING & ADAPTING OF TECHNOLOGIES

Traditionally, TT is considered as a closed system. The creation of technology is performed either within an organization and the main concern is innovation management (I), or between two or more organizations and where the technology creation is contracted or outsourced (II). If reproduction and diffusion of technology is performed within an organization, it is performed as transfer of technology to a division or subsidiary of the organization (III). If reproduction and diffusion of technology is performed to a third party, it is usually executed through buy/sell arrangements and carried out in one of the established forms, such as licensing, turnkey installation, or build-operate-transfer (IV). In all cases knowledge is well protected either through non-disclosure measures or intellectual property rights.

The novel TT methods are more open than the traditional ones. One reason for this lies in the development of information and communication technologies, which enable collaboration in virtual, geographically distributed teams. In such environments, the creation of technologies is performed through collaboration and based on open innovation principles (V).

The next approach to technology creation, which we are facing recently, is the principle of open design performed in open communities. The Internet was the enabler for this approach. It started with the open source software movement and was recently extended to open hardware design. The principles of open design enable co-creation of value through participation of anybody from the global community (VI).

Within clusters and networks the suitable forms for diffusion of technologies are business alliances and partnerships (VII), such as joint ventures and public-private-partnerships. These forms are especially suitable for big technological investments.

The issue of reproduction and diffusion of technologies in open communities is new and not adequately formalized yet. Certainly it is an issue of adoption and adaptation of technology and represents a big potential for the BoP communities. In this paper the proposed concept of open community manufacturing addresses this TT context.

2.3 Open 'X' for Manufacturing

Openness is a feature which has played a vital role in production engineering over the last three decades. Several concepts has been developed which tend to be open. In order to point it out their character, it contains the word 'Open' in their titles. We shall denote these concepts with Open 'X'.

It all started with the issue of connectivity in the early days of computer networking. The International Standard Organization (ISO) recognized a need for standards for communication among different systems in a network and initiated work on the Open Systems Interconnection (OSI). According to [12] the term ''*open*'' was chosen to emphasize that by conforming to OSI standards, a system would be open to communication with any other system obeying the same standards anywhere in the world. The resulting ISO 7498 standard (accepted in 1983) opened a way to integration of systems, such as CAD/CAM and Computer Integrated Manufacturing (CIM).

In the beginning of the nineties a new open initiative was put forward in manufacturing. This time the machine tool controllers (CNC) became a target for being opened up (e.g. LinuxCNC). The CNC controllers offered at that time by a few vendors were closed systems. These closed systems did not allow any adaptation and blocked further development. In order to overcome this situation, Open Architecture Control (OAC) was proposed as a concept for easy implementation and integration of customer-specific controls by means of open interfaces and configuration methods in a vendor neutral, standardized environment [13].

The idea of open architecture was recently extended to Open Architecture Products (OAP) - a new class of products comprising a fixed platform and modules that can be added and swapped. According to Koren et al. [14], customers can adapt OAP's to their needs by integrating modules into the platform. Manufacturers will produce these platforms, while new small companies and customers will develop the modules, thus increasing employment and causing the economy to flourish.

Most software producers consider source code as valuable intellectual property and make it unavailable. The concept of open source software (OSS) is different. OSS programs give any interested party access to the source code, leading to a distributed innovation platform in which users actively participate in the product's development thus enabling co-creation of value [15].

Recently, there are initiatives to also provide open source hardware under the similar propositions as are valid in the OSS community (e.g. Open Source Ecology). The idea here is not only to provide license free product documentation to be downloaded for a do-it-yourself (DIY) realization, but also to enable uploading of new design solutions open to communities.

The open source and open hardware concepts are today considered as one concept called Open Design (OD). OD initiatives can be divided into toolkits (e.g. 3DVIA Cloud, Autodesk 123D), projects (e.g. SketchChair, Wikispeed and OpenStructures), education and learning (e.g. Tinkercad) and enterprises (e.g. Local Motors, Ardiuno and Bug Labs).

The challenge with manufacturing is that in addition to knowledge, equipment and tools are needed to implement the designed solutions. Three solutions can be seen for addressing this issue: (1) rapid, digital manufacturing (e.g. 3D printing), (2) mini factories (e.g. FabLabs) and (3) distributed manufacturing systems composed of various advanced workshops providing professional manufacturing services.

Another concept under the Open 'X' framework is open innovation (OI). One of recent OI definition states that: '*the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation, respectively*' [16]. The basic principle of open innovation is opening up the innovation process through (1) collaboration and co-creation of different actors, and (2) opening innovation outcomes to broader public. Based on this definition, all the above mentioned Open 'X' concepts fit into OI. Pisano et al. [17] explained that OI models can function in the following environments:

- Organisation posts a problem and anyone can submit a solution, while the organisation chooses the best solution
- Organisation chooses participants, posts problem and selects best solution
- A flat network where all peers are equal and anyone can post a problem, or deliver a solution
- Private network of peers that jointly chooses problems, and jointly reaches solutions

OI models that emerged in recent years include idea competitions, customer immersion, collaborative product development and platforming.

2.4 Industrial clusters

"*An industrial cluster is an entity characterized by a social community of people and a population of economic agents localized in close proximity in a specific geographic region. Within an industrial cluster, a significant part of both the social community and the economic agents work together in economically linked activities, sharing and nurturing a common stock of product, technology and organizational knowledge in order to generate superior products and services in the marketplace*" [18].

This definition stresses the geographic proximity of cluster partners which, perhaps, is the main distinction between a cluster and a network. In other words, a cluster is a regional network. Industrial clusters support collaboration and cooperation among partners [19]. They provide a sound basis for competitiveness, innovativeness, agility and adaptiveness by enabling the interconnected partners to (1) form long-term business coalitions, (2) share information, knowledge, resources, competencies and risks, (3) develop mutual understanding and trust, (4) jointly react to business opportunities, and (5) gain synergetic effects by collaboration and cooperation. Thus, they combine good characteristics of large companies with the advantages of SME's and introduce new possibilities and potentials for innovation. Innovation is usually one of the strongest motivation factors for establishment of a cluster. Successful clusters consist of entities from the industry, public bodies, finance, media, universities and formal and informal networks.

Based on the above observation, an industrial cluster may be the best organizational form to support the proposed OCM concept. In the cluster an important role could be played by incubators. Incubators, or more specifically business incubators, are programs which support entrepreneurial or start-up companies via various business support resources and services as shown in figure 2. Young entrepreneurs enrol at these incubators to develop skills. The Department of Public Enterprises (DPE) established a Competitive Supplier Development Program (CSDP), which involves procuring in such a way as to increase the competitiveness, capacity and capability of the local supply base. This program also helps to develop enterprises and sustainable suppliers using these incubators in the clusters.

Figure 2: Key development phases inside an incubator

There are currently approximately 60 privately- and publicly-funded incubators in South Africa. The Department of Trade and Industry (the dti) currently supports publicly-funded incubators via the Small Enterprise Development Agency's Technology Programme, and also has very ambitious plans to establish an additional 250 incubators directly by 2015 under its recently-launched Incubator Support Programme (ISP). These incubators are currently covering industries like chemicals, furniture manufacturing, stainless steel processing, mining and agricultural tooling, construction, jewellery, agro-processing and renewable energy.

3 OPEN COMMUNITY MANUFACTURING MODEL

Considering the Sustainable Development challenges, an innovative development model called Open Community Manufacturing is proposed as shown in figure 3. The model is based on (1) continuous technology transfer based on the Open 'X' principles, (2) mobilization of communities belonging to the base of the pyramid (BoP), (3) co-creation of value through development of low-tech products and educational services desired in communities, (4) transfer of technology and knowledge to spin-out micro enterprises based either on profit or socio-economic principles, (5) interconnection of stakeholders and other interested parties in an industrial cluster, and (6) achieving synergies among individual supporting initiatives provided by the government and public agencies.

The Open Community Manufacturing concept was developed to help grow the formal economy, while not interfering with existent technology transfer mechanisms. The core objective is to mobilize the 'sleeping' BoP communities to help grow the formal market. The OCM value chain also integrates the skill development incubators into a collective support system. The concept uses open design to eliminate the Intellectual Property (IP) barrier and to virtually connect people to develop low-tech and self-replicating high-tech products. This value chain is divided into five core phases – community needs analysis, open design, advanced manufacturing, assembly processes and the incubation of future entrepreneurs. The process is usually driven and managed by volunteers.

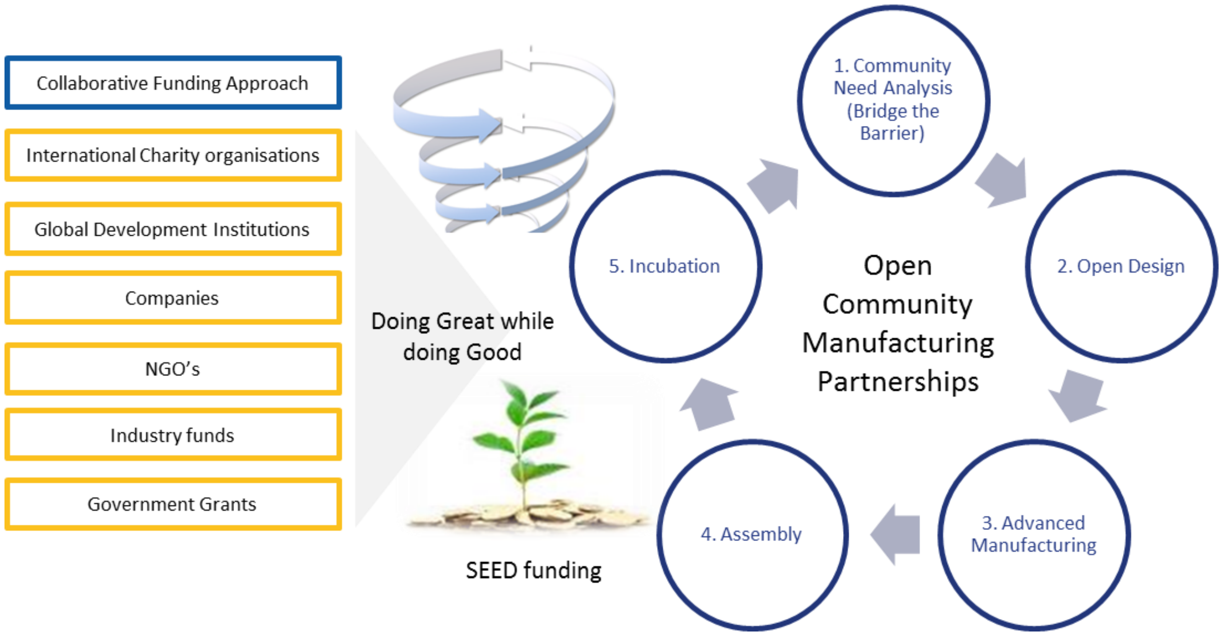

Figure 3: Establishing synergies – OCM development challenge value chain

OCM integrates the knowledge and skills of various global universities and volunteers to solve social challenges. After identifying and understanding the community's needs better, volunteers can either develop their own; or search for possible solutions on the various open design platforms. These possible solutions are then improved through co-creation by students as part of their practical/lectures for various engineering subjects in a Learning Factory. The volunteers then select the best solution from this collection of solutions and identify incubators or workshops that can do the advance manufacturing processes. The winning design is then sent to be manufactured.

The various components are then transported from the incubators to the community as a kit for final assembly. It is important that the community do the final assemble; as it transfers skills and shows the community how to maintain (repair) their innovative solutions. These skilled people can later assist the local municipalities. In order to ensure sustainability (independence), future work will focus on the creation of entrepreneurs with these OCM developed products. These products can include value creating brick, briquette or charcoal making machines, recycling and water filtration technologies or; mini-modular factories in containers as examples. After volunteering for two months to complete an OCM challenge, the program offers the foreign students the opportunity to explore the country, before implementing (assembling) the solutions in the community.

In this cluster designers transform their social developing ideas into physical products, by virtually collaborating with the volunteers and manufacturing specialists. Universities participate by integrating the OCM challenge into their curriculum similar to the learning factory concept. This helps to educate and prepare university students with industrial & social challenges on the platform through collaborative learning. Start-up manufacturers participates and help generate fair work opportunities by creating value through manufacturing of quality products to meet the social demands. At the same time incubators are supported in this cluster to help start-up SMME's with the specialist knowledge on the platform. The OCM development challenge also ensures that social investments are made with a sustainable impact in people, partnerships, infrastructure and technology.

4 CASE STUDIES

4.1 OCM development and manufacturing of a low-tech product

In order to validate the value chain, a low-tech product was manufactured using the OCM platform illustrated in figure 4. Two volunteers from the University of Kassel (Germany) helped to drive the Open Innovation process. Firstly, the community needs of a selected community (Kokstad) were analysed by working closely with various stakeholders in the area (e.g. MCCDO non-profit organization and social workers). It was then decided to develop a stove that could be manufactured by the MSI incubator and assembled by the Kokstad community. The volunteers selected an applicable stove from an open design platform as starting point. The challenge was divided into tasks with clear definitions and the necessary resources were identified. A practical was prepared by the German volunteers for the University of Johannesburg's bachelors Mechanical Engineering Science students as illustrated in figure 3.

Figure 4: The Open Community Manufacturing development challenge platform used to drive the open design phase of the OCM process

As part of a practical, the open design solution development process was divided into four steps: product planning, digital collaborative design, rapid prototyping and refinement. The various requirements of the possible solution and potential risks were communicated to the students as design criteria for the practical. A continuous exchange of information between the community, the volunteers and the Universities was needed to effectively adapt the product to the desired needs of the Kokstad community.

Figure 5: Using open design as part of a University practical to involve students to develop community desired solutions

All the possible solutions were uploaded (published) on the OCM Development challenge platform to ensure continuous knowledge management in the form of a database for duplication in other communities. Thereafter, possible solutions were identified by the volunteers. Rapid prototyping was used inside the Learning Factory as final criteria, before sending the design to the skill development incubators to be manufactured. Only then the selected components were manufactured inside the MSI incubator as shown in Figure 6b. The volunteers worked closely with the MSI incubator to bridge the gap between the design and manufacturing steps; and also to ensure TT to both parties.

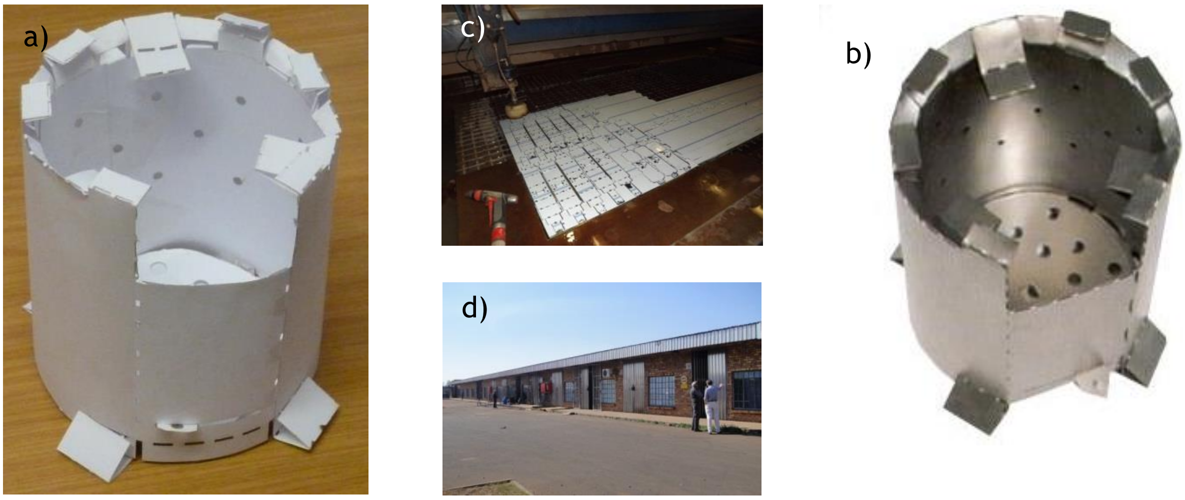

Figure 6: Using FabLab technologies to rapid prototype the student open designed a) product that was then b) produced using c) advanced manufacturing processes inside the d) MSI incubator in Middelburg

The manufactured components were then transported as a kit to the community for final assembly. Final assembly was done inside the selected community to ensure skills transfer. Doing assembly this way also helps to ensure that the people in the community can do maintenance on the manufactured products. None of these designs or manufactured products was sold for a profit.

4.2 Mini mobile robot RoboComp

The mini mobile robot RoboComp is a robotic platform developed at University of Ljubljana for the purpose of the traditional Summer School on Mechatronics. The event is organized annually for third year Bachelor students in Mechanical engineering, with the objective to promote Mechatronics. Using the open microcontroller (e.g. Arduino) students could develop and manufacture their own robots in three weeks. Besides the open design solution they have access to a FabLab (e.g. 3D printer, desktop milling machine and water jet machine). These robots are then used in a competition organized at the end of the Summer school to test the engineering designs. It was found that the students were very excited and motivated to participate on a voluntary basis. They also showed a lot of creativity. Figure 7 shows a robotic kit and an assembled mobile robot.

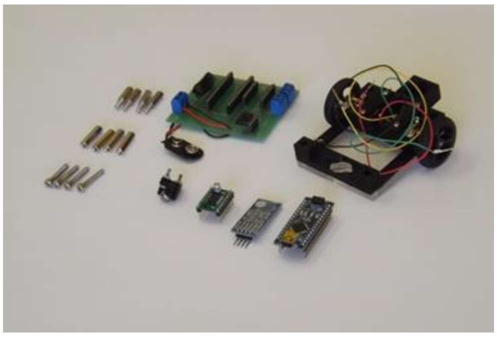
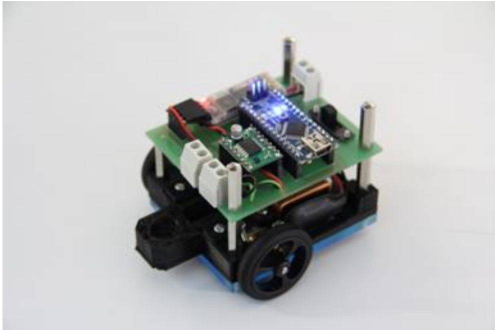

Figure 7: Mini mobile robot – as a kit (left) and an assembled robot (right)

Based on the positive experiences of the three successive Summer schools, the RoboComp action is seen as a comprehensive learning tool to raise technological awareness. Such an event can also help to create a manufacturing culture in BoP communities. The main mission of RoboComp action is to accelerate the transition of basic research concepts performed within the academic environment, into working aspects for the manufacturing industry while educating prospective engineers in the process.

5 CONCLUSION

This contribution introduced the concept of Open Community Manufacturing systems as a new technology transfer mechanism. The concepts of Openness and the BoP were discussed within the context of sustainable development. Several successful open design platforms, projects and toolkits and education packages were reviewed. Both the design and manufacturing of low-technology and high-technology products was evaluated as case studies. Future work will focus on the refinement of the quality management systems for the OCM product development value chain and the sustainable implementation (acceptance) of these products in the community. It will also be interesting to understand the effects of OCM on external stakeholder's production stability and supply chains for formal economies.

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OPERATIONS RESEARCH IN HEALTH CARE: A SOUTH AFRICAN PERSPECTIVE

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ABSTRACT

The use of Operations Research (OR) for decision making and management of health care operations deals with the use of various models that enable decision makers in the health system to make more informed decisions and to plan and manage operations more effectively. Even though the use of OR in health care service delivery in developing countries has increased recently, there are still limited publications available in this field, despite the fact that these countries can significantly benefit from such applications. Considering that the dynamics of the health care system of developing countries differs significantly from those of more developed countries, it is important for customised solutions and decision support models to be generated for developing countries. This paper therefore summarises various OR related research studies and applications in the health sectors of developing countries. It also provides an overview of the South African health sector, its challenges and how OR techniques can be used to support decision making in the country's health system.

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1 INTRODUCTION

After the establishment of the new government in 1994, extensive improvement and restructuring initiatives have been undertaken to improve health care service delivery to South Africans. Even though the restructuring and improvement of the South African public health care sector achieved various accomplishments in the last two decades, some obvious shortcomings are still evident [1].

South Africa's health system performs poorly when its impact on the status of the nation's health is compared with countries with a similar or smaller per capita Gross Domestic Product (GDP) [2]. In 2009, the South African government spent approximately 9.2% of GDP on health, an increase from the 8.5% of GDP spent in 2000. This is slightly less than Botswana's, but more than any of the other upper middle-income African countries' healthcare expenditure in 2009 [3]. Despite this expenditure on health, South Africa's health outcomes are worse than those of many lower income countries [4].

One way in which some of South Africa's health challenges can be addressed is through the use of Operations Research (OR). According to Winston and Venkataramanan [5], OR can be seen as a scientific decision making approach that seeks to find the best way to design and operate a system under conditions that require the allocation of scarce resources. The use OR for health care decision making and management deals with the development and use of various models that enable decision makers in the health care industry to make more informed decisions and to plan and manage day-to-day operations more effectively. Health care OR is not a new field and many researchers, consultants and practitioners have used OR techniques to solve many problems experienced during health care service delivery throughout the world.

Even though OR applications in health systems of developing countries have increased recently, there are still limited publications available in this field, despite the fact that these countries can significantly benefit from such applications. Considering that the dynamics of the health care system of developing countries differs significantly from those of developed countries, it is important for customised solutions and decision support models to be generated for developing countries. In addition, the inefficiencies present in many hospitals and clinics in South Africa also emphasise the importance of generating customised solutions and tools to address the operational and management problems experienced specifically in the South African health system.

1.1 Research aim

The purpose of this paper is to provide an overview of the current South African health care system, identify typical challenges experienced in the country's health sector and highlight opportunities for improvement using OR techniques.

1.2 Research methodology

To obtain a broader understanding of the current health care system in South Africa and to identify potential ways in which OR can be used to address some of its inefficiencies, a comprehensive review of available resources and reports is presented. Specific emphasis is placed on the public health sector, since even small improvements in this sector could result in significant benefits to the majority of South Africans. Thereafter a comprehensive literature review on the use of OR in health care systems of developed and developing countries is provided, followed by suggestions to improve inefficiencies in the South African health care system with the use of OR.

2 HEALTH CARE SERVICES IN SOUTH AFRICA

2.1 Overview of the South African health system

Before 1994 South Africa had a fragmented health system that was designed along racial lines, with a highly resourced system for the white minority and a systematically under-resourced system for the black majority [6]. After the establishment of the new government in 1994, extensive improvement and restructuring initiatives have been undertaken to address the disempowerment, discrimination and underdevelopment of the health sector of South Africa by transforming it into an integrated and comprehensive national service that provided essential health care to all individuals [4].

Even though various successes were achieved many attempts to transform the South African health care sector and introduce financing reforms were unsuccessful, resulting in a two-tiered health system – i.e. public and private health sectors – that still maintains various inequalities in health care [6]. South Africa's public health care sector covers approximately 65% of the country's health care needs with an annual expenditure of 4.2% of GDP [7]. However, other estimates of the country's public health sector coverage are significantly higher [1, 6]. Taking into account that South Africa's spent 9.2% of GDP on health in 2009 [3], it can be deduced that less than 35% of South Africa's health care needs are covered by 54% of the country's health expenditure.

South Africa's public health care sector follows a hierarchical structure divided into primary, secondary and tertiary health services [7, 8].

The primary health care system is mainly a nurse-driven service and focuses on preventative and health promotion services such as maternal and child care, immunisation, chronic illness and minor trauma. This serves as the point of entry to public health care services in the country [9]. Community Healthcare Workers (CHWs) also play an important role in the primary health care system as the provision of home and community based health services are crucial in achieving good health outcomes nationwide [15]. The primary health care system is divided into clinics, Community Health Centres (CHCs) and District Hospitals [7]. Clinics provide a range of primary health care services for eight hours a day, whereas CHCs provide the same services as well as 24 hour maternity, accident and emergency services. In addition, CHCs have a bed capacity of around 30 for overnight patient observations. Clinics and CHCs are mainly serviced by nurses with scheduled visits by doctors to assist with clinical diagnoses [9]. A district hospital is a primary health care hospital that provides out- and in-patient health care services 24 hours a day 7 days a week, including maternal health services, Human Immunodeficiency Virus (HIV) and Tuberculosis (TB) treatment as well as minor and some major surgeries under general anaesthesia [10].

The secondary health care system deals with health conditions and needs that are too specialised or complex for District Hospitals and comprises General Regional and Specialised Regional Hospitals. General Regional Hospitals are hospitals that provide at least five of the following specialty health services; anaesthetics; diagnostic radiology; medicine; obstetrics and gynaecology; orthopaedics; paediatrics; psychiatrics; and surgery. A Specialised Regional Hospital provides a single specialty service such as psychiatric or TB facilities [9].

South Africa's tertiary health care system comprises tertiary or academic hospitals that provide specialist services to the public including specialised medical procedures; complex curative interventions such as oncology; all types of surgeries; Intensive Care Unit services; radiology; pharmacy services; and laboratory services. A full range of medical and paramedical specialists are available 24 hours a day 7 days a week at these facilities [10].

The private health care sector in South Africa provides health services to around 35% of the country's health care needs. The private health care sector is mainly utilized by South Africans with private medical scheme memberships, approximately 16% of the South African population. The rest of the private health care services are typically utilized by South

Africans without medical scheme memberships who pay for private primary health care services out of their own pockets and then use the public health sector for hospitalisations [7].

2.2 Challenges in the South African health system

The South African health system is currently experiencing many different challenges, some of them stemming from the fragmented and biased health system that was inherited by the new democratic government of 1994. In a comprehensive review on the status of the health system in South Africa, the Health Systems Trust classifies the country's health sector challenges into service delivery; structural; resource, pharmaceutical, diagnostics and medical equipment; and information system challenges [10].

2.2.1 Service Delivery Challenges

Service delivery challenges deal with the access, coverage and quality of health care provided to patients. Three key service delivery challenges, as identified by the Health Systems Trust [10], are the large gap between good health policies and their implementation; inequity in health care service access, coverage and quality; and poor supervision of primary health care services.

Coovadia *et al.* [4] state that even though the public health system has transformed into an integrated and comprehensive national service, the inadequate implementation of good health policies in South Africa is still a major challenge. This is mainly due to inadequate human resource capacity and planning; poor leadership, stewardship and management; and increased stress on the public health sector as a result of the burden of disease, especially HIV/AIDS and TB, and restricted spending in that sector.

Despite the progress made towards improved access to quality health care for disadvantaged communities in South Africa, large health inequities still exist. Coovadia *et al.* [4] indicate that there are noticeable differences in the rates of mortality and disease between races, which reflect the differences in access to basic household living conditions and other determinants of health, such as access to health care services. Some barriers to the accessibility of quality health care in the country include unbalanced resource allocation; long travelling distances to health facilities and high travelling costs, especially in rural areas; high out-of-pocket payments for health care; long queues at health facilities; and disempowered patients [11].

The reasons for the poor supervision of primary health care services are similar to those resulting in the inadequate implementation of policies. Coovadia *et al.* [4] assert that a central challenge to the health system is the reluctance to strengthen the management of human resources. This is partly due to limited managerial capacity. However, they also identify limited training support and supervision activities, ill-discipline, absenteeism, and moonlighting as other factors exacerbating the problem.

2.2.2 Structural Challenges

The structural challenges of the South African health sector are a direct result of the challenges experienced in its governance and management. Poor stewardship at policy level, weak management, and weak supportive supervision at the implementation levels are major obstacles to improving South Africa's health system [4]. In the same vein, the Health Systems Trust [10] identifies some of the key structural challenges of the sector as inefficiencies; inconsistent delegation of human and capital resources; an institutional environment that often precludes the implementation of new learning and innovation; and inadequate organisational structures with a lack of lower level management.

The inadequate management and governance at lower levels in the health system, i.e. district and sub-district levels, resulted in a lack of responsiveness to community needs; a general lethargy in the district health system; no prioritising or actions around pressing primary health care needs; a fragmented delivery system implementing multiple un-coordinated interventions and campaigns; as well as the separation of community, home and facility based functions [10].

Mayosi *et al*. [12] also identify the integration of the public and private health sectors, vertical programmes and community outreach programmes as a key challenge in the health sector. They comment that despite many achievements, the coordination of implementation at many levels in the health system remains a challenge.

2.2.3 Resource Challenges

The resource challenges in the South African health sector all result from the shortage of adequate financial, infrastructure and human resources. There are currently major deficiencies in the physical structure and security of facilities, the infrastructure of many existing facilities are inadequately designed, and insufficient maintenance of facilities and equipment impacts negatively on staff retention and morale in the South African health sector [10].

An appropriate, sustainable and trained workforce is a key priority for the health sector in South Africa. Workforce planning is an important process in the management of human resources and massive investments in a country's health sector are focussed toward employing and training health workers. It is therefore important that this *"massive investment in training and employment of the health workforce is well planned, appropriately targeted and properly managed"* [13].

However, various human resources challenges still exist in this sector in South Africa. Some of the human resources challenges in the sector are identified by the Health Systems Trust [10] and include insufficient workforce planning; the maldistribution of human resources; and high attrition rates. In addition, training opportunities provided to staff in the health sector are inadequate, resulting in health personnel that are not sufficiently trained or orientated to understand their responsibilities and the role of social determinants on health outcomes.

This is confirmed by the National Department of Health [13] who states that even though ensuring the appropriate supply and distribution of health care workers in the country is critical, the supply of health professionals in South Africa is not currently actively being managed.

Another key resource challenge in the South African health sector is the availability and efficiency of health facilities. Two international indicators commonly used to assess the efficiency of hospitals are the Average Length of Stay (ALOS) and the Bed Utilisation Rate (BUR) – also known as the Bed Occupancy Rate or Usable Bed Utilisation Rate. According to the Health Systems Trust [14] the ALOS is a measure that determines how much time patients on average spend in district hospitals. This provides an indication of the efficiency of the hospital and the quality of care provided. An extremely long ALOS indicates that patients are kept in the hospital too long. This is typically caused by a shortage of medical personnel and by operational inefficiencies. Conversely, a very low ALOS is also a problem as it may indicate that the quality of care to patients is compromised. The BUR measures the occupancy of usable and available beds in district hospitals [14]. The BUR therefore determines how efficiently a hospital is using its available capacity. A low ALOS and relatively high BUR indicate that a hospital is functioning well.

In 2011 the ALOS in South African district hospitals was 5.6 days and the BUR was 73% [15]. While the BUR is relatively close to the target of 75%, the ALOS is still significantly longer than the target of 3.4 days [16].

2.2.4 Pharmaceutical, Diagnostics and Medical Equipment Challenges

Even though pharmaceuticals, diagnostics and medical equipment are essential for delivering quality health services in South Africa, the management and regulation of these resources are not adequate. These are various guidelines related to pharmaceuticals, diagnostics and medical equipment, such as the Essential Drugs List, but methods to ensure adherence to these guidelines are lacking. To make matters worse, the South African health sector is frequently haunted by pharmaceutical shortages and stock-outs mainly due to weak management systems for forecasting, procurement, warehousing and distribution [10].

This issue is again highlighted in the 2012/13 South African Health Review where the authors caution that the state of many public health systems in South Africa, in particular pharmaceutical supply and delivery systems, threatens the expansion of successful treatment programmes in the country [15].

2.2.5 Information System Challenges

South Africa is often seen as data rich but information poor as the data systems in the country are not adequate to provide good quality, nationally representative information in a timely manner [12]. One of the key challenges acting as a barrier to the establishment and utilisation of an adequate health information system in South Africa is the absence of a culture of information use [10].

This lack of an information culture in the health sector of South Africa is due to, amongst others, the shortage of clear and comprehensive policies and guidelines to support the implementation of health information system legislation; poor alignment in the information system between the measurements and objectives; limited availability of hardware; inadequate technical support; a shortage of human resources; a complex work environment; a distrust of technical solutions; inadequate training opportunities; the lack of governance and standardisation related to health information systems; as well limited buy-in and involvement of managers in data management activities [9, 10].

Further exacerbating the problem is the inadequate investment in health management information systems [10]. However, strategic investments in the South African health information system are essential in developing the ability to prepare, manage and use data for decision making in the health sector [12].

3 USING OPERATIONS RESEARCH FOR HEALTH CARE DECISION SUPPORT

The use of OR in health care is not a new field and many researchers, consultants and practitioners have used OR techniques to solve many problems experienced during health care service delivery throughout the world. A summary of papers presented over 35 years at the European Working Group "Operational Research Applied to Health Services" (ORAHS) is provided by Brailsford and Vissers [17]. They identify various functional areas where OR have been applied, i.e. Finance, policy, governance and regulation; Public health and community service planning; Patient behaviour; Planning system or resource utilisation; Quality management and performance monitoring; Risk management and forecasting; Workforce management; Research; and Other. For the purposes of this paper, these OR application areas in health care service delivery are combined into the five categories discussed in this section.

3.1 Governance, Policy and Strategic Planning

OR is often used at government and institutional levels to assist with the planning and development of legislation, health policies, strategies and management guidelines. Examples of such applications are presented by Hutton *et al.* [18] who integrate various OR techniques to analyse the cost effectiveness of interventions to combat Hepatitis B in the United States and China. The results of their analysis helped to change the US public health policy on

Hepatitis B screening. In addition, it also encouraged policy makers in China to enact legislation that provide access to free Hepatitis B vaccinations for hundreds of millions of children.

Bennet *et al.* [19] provide an overview of similar projects where the Department of Health in England used OR techniques to analyse health policies and guide policy decisions. They comment that even though OR modelling fits into the overall process of policy decision making, the key lies in the ability to understand policy issues in ways that allow for the insightful application of relatively simple models. To this end, they believe that finding a requisite model is a key skill for OR practitioners in government. Such a requisite model could be a dramatic simplification is some respects, but should still capture enough of the full picture to provide practical and insightful guidance for policy decision makers.

OR can also be an invaluable tool in the management of government health programs. To this end, Tao *et al.* [20] present a resource allocation model that can enable improved local sexually transmitted disease control and prevention programs in the United States. Seeing that publicly funded programs usually have insufficient funds available to screen and treat all patients, their model focuses on providing an optimal strategy for screening and treating women with Chlamydia trachomatis and Neisseria gonorrhoea. They conclude that resource allocation models can successfully be used to guide decisions about the effective use of limited resources available for sexually transmitted disease control and prevention.

On a more institutional level, Cabrera *et al.* [21] present a decision support system for the operation of emergency health care departments. This system is developed using agent-based simulation and optimised to find the best staff configuration for the emergency department to minimise patient waiting time and maximise patient throughput. The system can assist managers with the development of strategies and management guidelines for the improvement of emergency health care departments.

Agnetis *et al.* [22] use OR to provide guidance to decision makers on long-term operating room planning policies. They evaluate various approaches to define operating room elective surgical schedules that provide the best balance between stability and flexibility. Their results indicate that introducing a limited amount of flexibility into the structure of surgical schedules can yield significant benefits in terms of the waiting time and due date performance of operating rooms. They conclude that simulation and optimisation models can be profitably used for planning and scheduling on an institutional level, potentially resulting in various benefits, such as better clinical results, higher patient and staff satisfaction, improved patient safety and improved institutional performance.

3.2 Resource Planning

The planning and allocation of resources at health facilities is another area where OR can be invaluable. These types of institutional decisions typically require the planning and allocation of limited resources in a way that will enable the efficient, timely and effective treatment of patients at health facilities. OR techniques can be used to provide decision makers with an indication of the best possible resource allocations that can be achieved under a given set of limitations.

This is illustrated by Stinnet and Paltiel [23] who present a mathematical framework for allocating scare resources efficiently within budgetary, practical and ethical constraints. They comment that the model is a powerful tool that eliminates the need for restrictive assumptions. However, they caution that the usefulness of their model, and all other models of this type, is limited by the need for accurate information of the costs and impacts of decisions. However, as a counterargument they highlight that the use of informed rough estimates is preferable to making uninformed decisions or relying on invalid assumptions.

An application of OR for resource planning at the Department of Veterans Affairs in the United States is provided by Syam and Côté [24]. They present a location-allocation model for specialised health care services, such as the treatment and rehabilitation of strokes or traumatic brain injuries. The primary objective of their model is to provide a mathematical framework, for the assignment of admission districts to treatment units, that incorporates the cost of providing services as well as the service level at which these services are provided. The model is then applied to one of the Department of Veterans Affairs specialised health care services to evaluate the impact of several factors on the objectives of the model. They conclude that most of the major factors considered in the analysis have a significant effect on the assignment of admission districts to treatment units.

Although the use of OR during resource planning, usually focuses on planning resources at an institutional level it also proved to be a useful planning technique on a national level. To this end, Bowers *et al.* [25] present a resource allocation model that can inform strategic resource allocation decisions for a national patient transport service in Scotland. They highlight that their model enabled management to identify a more rational and strategic allocation of resources and examine the trade-offs between service levels and resource requirements. They conclude that their work also illustrates how both simple and sophisticated models offer complementary qualities and that it is possible to achieve a balance with the simpler models built on the foundations of the more complex approaches.

3.3 Patient Planning

Not only can OR be used to efficiently plan the resources of health systems, but also to plan and schedule patients in the health system. This is illustrated by Day *et al.* [26] who present a model of a decision process to improve patient flow in United States hospitals by allocating cardiac diagnostic testing time slots to patients. They ascertain that their model provides a flexible, robust and dynamic network scheduling tool that can be used for patient scheduling in any cardiac diagnostic testing centre. Their model is then applied to a local hospital and the resulting solutions are evaluated using simulation. They conclude that significant improvement in the quality of in-patient service and hospital revenue can be realised with only a minor decrease in out-patient service levels.

3.4 Supply Chain and Inventory Management

Kelle *et al.* [27] state that the field of health care supply chain and inventory management has been given relatively little attention in the past, despite its size and importance around the world. However, various studies dealing with the use of OR to support supply chain and inventory management decisions exist. Most of these studies rightly focus on the development of appropriate inventory management models for various health care facilities as inventory investments in health care is estimated to be between 10% and 18% of revenue, and any measures to control expenditures in this area can have substantial impacts [27].

This is illustrated by Nicholson *et al.* [28] who present two mathematical models for the management of non-critical medical supplies inventories in the United States. The first model determines inventory costs and service levels of an in-house three-echelon distribution network, whereas the second model determines the inventory costs and service levels of an outsourced two-echelon distribution network. These models are compared and results indicate that the two-echelon network results in inventory cost savings without compromising the quality of care. These two models also provide a way for decision makers to investigate strategic inventory decisions within two distribution networks.

In another study, Katsaliaki and Brailsford [29] present a simulation model of the blood supply chain of a typical hospital in the United Kingdom. They ascertain that, in contrast to other inventory models in the literature, their model considers an entire vertical section of the supply chain; include mismatching; incorporate products with different shelf lives; and include the time spent in the assigned inventory stage during the calculation of remaining shelf life. Their simulation model is then used to evaluate various inventory management policies and identify the most suitable one to implement in order to reduce shortages, wastage and costs whilst increasing service levels and safety.

In a more recent study, Baboli *et al.* [30] investigate supply chain and inventory management challenges in a downstream pharmaceutical supply chain and state that traditional inventory models are not ideal for pharmaceutical inventory management as they cannot optimise the total cost of the system. They consequently present centralised and decentralised models for multi-product replenishment policies that focus on the joint optimisation of both inventory and transportation cost for pharmaceutical products. They state that their models can be applied to determine the reorder quantity and replenishment period of a family of products that has a stable demand, low prices and high turnover rates. They also assume a constant deterministic demand rate and order lead time. However, their models don't make provision for any shortages as it is assumed that no shortages are allowed.

While some of these studies include the application of these models to case study hospitals, consideration to the actual implementation of the improved inventory management systems at health care facilities are inadequate. The process of using OR to provide effective supply chain and inventory management decision support is not limited to the quantitative component of inventory modelling and supply chain simulation. Various other factors need to be taken into account.

To this end De Vries [31] investigates the process of reshaping a medicine inventory management system through an explorative qualitative case study in a hospital. He determines that various outcomes in the implementation of a new inventory management system in a hospital are heavily influenced by the dynamics of the relationships and interactions between stakeholders. His study highlights that the process of successfully developing and implementing a new inventory management system at a healthcare facility requires a thorough understanding of the relationships and interactions between different stakeholders at the facility.

In an attempt to improve the current pharmaceutical inventory management policy at the local storage unit of an individual care unit of a case study hospital, Kelle *et al.* [27] present a decision support tool to facilitate improvements of the current inventory management practices. They ascertain that the use of their tool as a decision support system for pharmaceutical inventory management at the case study hospital can reduce its inventory related pharmaceutical expenditures by up to 80%.

3.5 Quality Management

In the context of this paper, health care quality management refers to both the quality of care and the safety of patients in the health system. The availability of OR related publications in the field of health care service delivery quality and safety is limited.

In one study Kanagarajah *et al.* [32] use agent-based simulation to evaluate the complications of health care improvements and its impact of patient safety, economics and workloads. They argue that agent-based simulation has the potential to be a useful tool for studying the quality of health care and analysing the complex adaptive behaviour of health care systems.

A study where OR is used to improve the quality of care to patients in a hospital environment is presented by Van Essen *et al.* [33]. Their study focuses on developing an operating theatre scheduling model that will reduce emergency surgery waiting time and allow hospitals to maintain a high quality of care by scheduling elective surgeries using break-in-moments to compensate for emergencies. The model is then tested by means of simulation and compared to historical data of the operating room for inpatients at the Erasmus Medical Centre in the Netherlands. The results indicate that the use of their model for the scheduling of elective surgeries can reduce the waiting time for emergency surgery by approximately 10%.

4 USING OR FOR HEALTH CARE SERVICE DELIVERY IN DEVELOPING COUNTRIES

Even though the use of OR to improve health care services and operations in developing countries has increased recently, there are still limited publications available in this field. Most of these publications focus on hospital management as health care resources in developing countries are often located at secondary levels [34].

Hani *et al*. [35] present a case study on medical consumables inventory management at a public hospital in Indonesia. They performed a qualitative analysis of problems experienced during medical consumables inventory management by conducting several in-depth interviews with relevant stakeholders as well as various field observations. Key problems identified through this study include a lack of human resources; inadequate information systems; storage space constraints; as well as late supplier payments.

In another study in Indonesia, Rachmania and Basri [36] examine the inventory management practices in a public hospital and identify excessive stock levels, poor demand forecasting and a lack of information technology support as the three major challenges experienced. They investigate the suitability of the basic (r,Q) and periodic review (R,S) inventory models for the management of oncology medicine at the hospital and ascertain that the (r,Q) inventory is the better of the two as it carries less stock while still satisfying demand. They also compare various demand forecasting techniques and determine that trend-corrected exponential smoothing is the most appropriate forecasting technique for oncology medicine.

Hauman [37] presents a South African case study for the Western Province Blood Transfusion Service. She uses simulation to model the blood inventory management policies at the organisation, and examine their effects on blood bank service levels and the associated delivery system. Multi-objective optimisation is then used to identify various improvement alternatives for the current inventory management systems at blood banks.

An application in policy planning in South Africa is presented by Lagarde et al. [38]. They perform cost-effectiveness analyses of various human resource policy interventions to address the shortage of nurses in the rural areas of the country. They conclude that increasing the salaries of nurses is not the most effective intervention and other downstream interventions, such as study leave, can result in better outcomes at a lower cost. However, their results indicate that the best and most cost effective approach to address this problem is to rather focus on upstream measures, such as recruiting more nursing students from rural areas.

In a resource allocation study, Ahmed and Alkhamis [39] integrate optimisation and simulation to develop a decision support tool for decision makers at an emergency department at a hospital in Kuwait. The decision support tool determines the number of staff members required to optimise patient throughput and reduce patient's time in the system subject to budget constraints. The tool is applied to an actual hospital emergency department and results indicate that a 28% increase in patient throughput and a 40% decrease in patient waiting time can be realised with existing resources. The value of this tool lies in its ability to enable decision makers to evaluate various alternatives for the planning of operations in the emergency department.

An interesting application to the area of patient safety is presented by Brent et al. [40] who use the analytical hierarchy process in health care waste management systems in the rural areas of developing countries. Their approach is applied to South Africa and Lesotho to illustrate how the analytical hierarchy process can be used to provide decision support to the health systems of developing countries.

4.1 Opportunities for OR in Health Care Service Delivery in Developing Countries

Despite some studies on the use of OR to improve health care services and hospital operations in developing countries, available research in this area is still lacking. Low-income and developing countries can significantly benefit from the application of OR in health care service delivery [41]. Specific areas where OR can have the biggest impact are as follows:

- *Improved access to medical products and services.*

  Access to medical products can be improved by means of OR applications focussing on improving and informing decisions during inventory and supply chain management. In addition, the use of OR to assist with the planning and development of legislation, health policies, strategies and management guidelines can also enable improved access to medical products and services.

- *Increased hospital or clinic efficiency and quality of service.*

  Every hospital and clinic in developing countries must do more with less. OR can therefore help health facilities to improve their efficiency and quality of service by means of improving quality of operations though quality management applications; designing effective health information systems; planning and scheduling limited resources; modelling resource availability and utilisation; and diagnosing diseases more efficiently [41].

- *Improved emergency medical service efficiency.*

  Emergency medical services, such as ambulances, can rely on OR applications to determine adequate fleet sizes and enable faster response times through better resource planning and management [41].

- *Improved effectiveness of clinical interventions.*

  Ghosh *et al.* [41] indicate that the MDGs for health and nutrition can be accelerated through the application of OR techniques. This can be achieved through the use of OR to assist with the planning and development of legislation, health policies, strategies and management guidelines, as well as through improved resource planning, supply chain and inventory management in health systems.

- *Prevention, control and elimination of communicable diseases.*

  The prevention, control and elimination of communicable diseases can be accelerated through the application of OR techniques [41]. This is possible through OR applications focussing on the planning and development of regulations, policies, strategies and guidelines; supply chain and inventory management; resource planning; patient planning; and quality management.

- *Building equitable and efficient health care systems.*

  Ghosh *et al.* [41] indicate that OR can help with the development of a global health research culture and facilitate the development of effective and equitable health systems through evidence-based policy making, practice and knowledge translation.

Mistry *et al.* [42] identify various OR applications as part of the fight against multi- and totally drug resistant tuberculosis (TB) in India. They suggest the following OR application areas to tackle the challenge of drug resistant TB in Mumbai:

- *Better diagnosis, drug susceptibility testing, classification and definition of cure.*

  OR can be invaluable to this particular application area through modelling the effects of new technologies; network mapping and modelling; improving resource allocation; and modelling of the effects of changes in timing of activities.

- *Better prescribing practices across care providers.*

  The particular usefulness of OR to improve prescribing practices stems in its ability to enable the modelling of the effects of legislation and drug control; modelling of the effects of changing the balance of ambulatory and inpatient management; and modelling of the effects of adverse drug reactions.

- *Better integration of TB diagnosis and treatment with Anti-Retro Viral medicine for patients with HIV.*

  This can be achieved through the modelling of diagnosis and transmissibility; and the modelling of the effects of preventative therapy.

- *Better infection control.*

  The value of OR in achieving better infection control is through the modelling of the effects of changes in infrastructure and routines.

Even though the recommendations made by Mistry *et al.* [42] focus on drug resistant TB in India, most of these OR applications can be be invaluable tools for all developing countries in fighting the global TB pandemic.

4.2 Opportunities in South Africa

The key opportunities for OR to enable improved health care operations and service delivery in South Africa, in addition to those discussed above, are summarised in Figure 1.

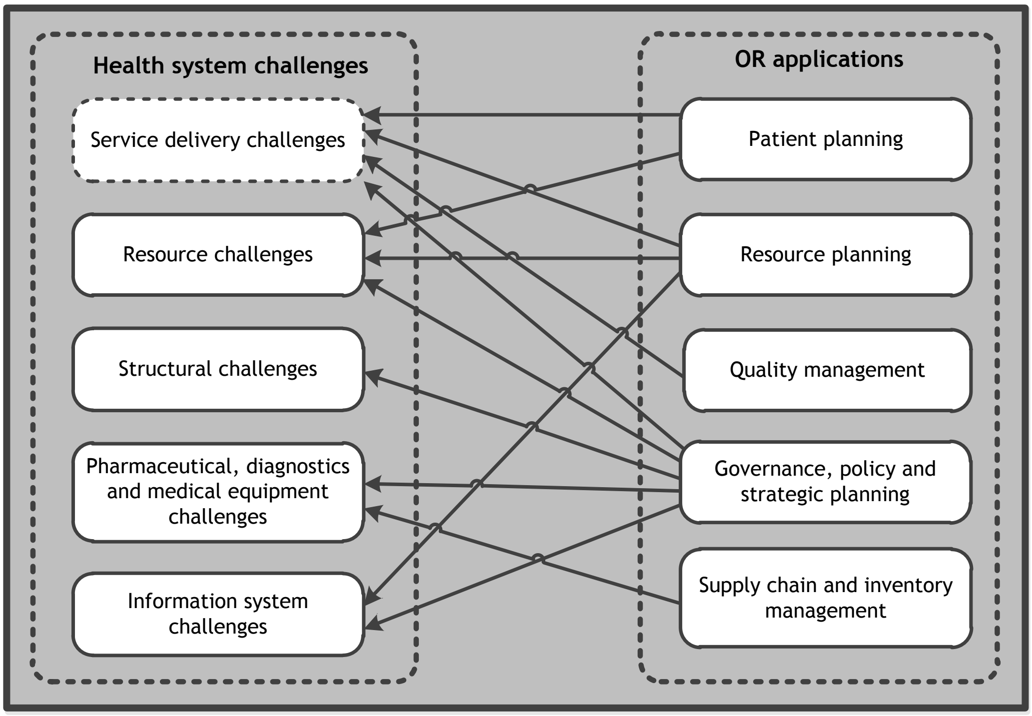

Figure 1: Opportunities for OR in health care service delivery in South Africa

Some of the service delivery challenges in the South African health sector can be improved by means of OR applications focussing on patient planning; resource planning, scheduling and management; and quality management. Improved patient management, resources planning, and quality management will result in improved access, coverage and quality of health services provided to patients. In addition, the use of OR to assist with the planning and development of legislation, health policies, strategies and management guidelines can also enable improved access to health care.

The South African health sector's resource challenges can partly be addressed through the use of OR to manage patients in the system more efficiently; to plan and manage scarce resources more efficiently; and to assist with the planning and development of evidence-based health policies and management guidelines.

Great progress in addressing the structural challenges in the South African health sector can be achieved through the use and application of OR to assist with the planning and development of legislation, health policies, strategies and management guidelines.

Major improvements in the pharmaceutical, diagnostics and medical equipment challenges of the South African health sector can be achieved through OR applications focussing on planning policies, guidelines, and strategies as well as through more effective supply chain and inventory management in the health system.

Finally, many of the information system challenges can be addressed though OR applications focussing on more effective resource planning and management. The use of OR to assist with the planning and development of legislation, policies, strategies and management guidelines related to health information systems can also be invaluable in addressing information system challenges in the South African health sector.

Despite the many opportunities for OR in the South African health sector, merely developing and applying various OR solutions will not be enough to address the challenges in the sector. In order to achieve the best results with these opportunities, it is important for the relevant OR principles to be prioritised, designed, implemented and replicated within national health programmes as well as institutionalised as a critical part of monitoring and evaluation of the health system of the country [41].

5 CONCLUSION

Despite the strides made towards a *"long and healthy life for all South Africans"*, many challenges still exist within the South African health sector, some of them stemming from the fragmented and biased health system that was inherited by the new democratic government of 1994. Failure to address these challenges in the South African health system will result in the country not attaining the health goals it has set for itself.

One way in which these challenges can be addressed is through the use of OR. The use of OR in health care is not a new field, but there is a general lack of OR applications to the health systems of developing countries. Considering that the dynamics of the health systems of developing countries differ significantly from those of more developed countries, it is important for customised solutions and decision support models to be generated for these countries.

This paper therefore focused on providing an overview of the South African health sector, its challenges and how OR techniques can be used and applied to support decision making and management in developing countries', and in particular South Africa's, health systems.

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EFFECT OF MOULD TEMPERATURE ON THE FILLING BEHAVIOR OF MOLTEN RESIN IN PLASTIC INJECTION MOULDING OF HIGH DENSITY POLYETHYLENE (HDPE)

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ABSTRACT

The growth of injection moulding as a manufacturing process has led to the development of more products resulting in an increase in the focus on product quality, as manufacturers try to lower production costs, reduce product weight and eliminate defects. Of particular concern is the flow behavior of molten resin in the mould cavities during the production process. Inconsistencies in the flow of the melt tend to result in uneven or incomplete filling of the mould, resulting in production of defects (short shots). In the paper the Taguchi method is used to determine the optimum values of the injection moulding process parameters for High Density Polyethylene (HDPE.) plastic parts. A moulding processing window in which the process will achieve maximum quality, with major focus being on mould filling is developed.

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1 INTRODUCTION

In recent years plastic products have become more appreciated globally, resulting in a high demand that has made it essential for companies in this industry to improve their processing operations to meet the demand for high quality parts. At the same time, as the companies try to produce high quality parts, they seek to retain a competitive edge and make profits in the present market place by lowering the costs of production. Injection moulding ranks as one of the prime processes for producing plastic parts. According to Shin & Park [1], injection moulding is one of the most commonly used manufacturing processes for the fabrication of plastic parts in net shape with excellent dimensional properties. Thermoplastic injection moulding is a well-known fast process for manufacturing simple and complex shaped products. Understanding the phenomena that govern the production of high quality parts determines resultant output in production of plastic parts.

From past literature survey various techniques have been used to assess the effect of different injection moulding parameters on the process. The flow of molten resin and its filling behavior in injection moulds is one such phenomenon that has been studied by different authors. This has been achieved by application of simulation software such as Moldflow and Moldex 3D, in most cases to understand the development of warpage related defects [1]. In this research the effect of filling behavior is assessed by the application of the Taguchi experimental design approach. The research assesses the effect of mould temperature on the injection moulding process versus other key process parameters.

In previous injection moulding research different control parameters have been used depending on the nature of the investigation being carried out [2]. In this study, mould temperature was considered among other injection moulding parameters to assess its impact on the filling of an injection moulded High Density Polyethylene (HDPE) Coke Light weight crate. The effect of injection pressure, mould temperature, melt temperature, switch over value (injection stroke) and injection speed on the filling behavior of polymer melt was investigated by application of the Taguchi parameter design approach. The experimental results were analyzed using Minitab 16 software.

2 THEORETICAL BACKGROUND

2.1 THE INJECTION MOULDING PROCESS

Spina [3] states that the fabrication process consists of three main phases, necessary to fill the mould cavity with molten polymer resin; the injection step, packing step and the cooling step. Therefore, several process parameters which include melt temperature, mould temperature, injection pressure, injection velocity, injection time, packing pressure (holding pressure), packing time (holding pressure time), cooling temperature, switch over value, cooling time and the injection stroke all influence the quality of the injection moulded parts produced [4]. All injection moulding steps are related to the several factors that govern the behavior of the process and part quality.

Filling behavior of polymer melt is an important aspect of injection moulding. The ability of the polymer melt to flow into the injection mould's cavities, all the way to the micro channels is a very crucial factor in successful injection moulding. In recent studies it has been developed that the nature of the flow of the polymer melt in the mould cavities determines the extent of its penetration into all the crevices of the mould. However with injection moulding being a thermal process the extent of the flow is governed further by the thermal activity of the melt and the mould in as much as the nature of the polymer itself is a key factor.

2.2 Melt flow models

Over the past three decades many authors have developed conjectures on the concepts of injection moulding, particularly on the flow of polymer melt and related defects such as warpage and incomplete filling of the moulds. According to Bolur [5], Galantucci & Spina [6] in the filling phase melt flows evenly in all directions, assuming that the resistance to flow is equal in all directions creating balanced filling. However Mehat et al. [7] argue that this occurs in the most ideal, because wall thickness, holes/slots and variations in the mould surface temperatures introduce flow resistance differences. Therefore in reality, melt moves in a number of streams with different properties with different resistances to flow which create an unbalanced flow [5]. In the most ideal, the flow of molten polymer is modeled as a Newtonian fluid, with the assumptions that the fluid flow and the temperature preserve their shape along the length of the mould. The concept itself is impractical as molten High Density Polyethylene is a highly viscous substance that solidifies as its temperature drops to equilibrium with the mould temperature at the polymer's glass transition temperature [8].

Whale et al. [9] state that in an infinite mould, either the skin thickness reaches an equilibrium level at which viscous heat generation within the plastic balances heat loss to the mould, or the mould closes off the gap. In a finite mould, the solid layer maintains the same shape (time invariant) but may or may not attain a constant thickness. The time variant nature of the polymer melt's flow to its solidification presents a certain level of independence of the flow length from the applied forces on the polymer, to its dependence on its thermal surroundings. Whale et al's [9] theory is further elucidated by that of Thermokinetic asymmetry of polymer flow inside mould cavities brought forward by Bociaga et al.[10] who states that asymmetric flow exists when there is a temperature difference between opposing mould walls. Bociaga et al. [10] link uneven mould filling and warpage defects in injection moulding to asymmetry in flow of the molten polymer.

Young [11] in developing the Microfilling model proposed that melt flow stops when the melt temperature reaches (or goes below) the transition temperature. As the polymer melt temperature reaches transition temperature, the velocity decreases to zero sharply, this is due to increases in the flow length and viscosity increases due to the cooling polymer melt, thereby leading to the reduction in velocity.

2.3 Effect of temperature on High density polyethylene

In general, polymers degrade at elevated temperatures. According to Galantucci & Spina [6] in polymer degradation, weight loss occurs only after the volatile products begin to vaporize from the sample. Before weight loss the sample would have modified due to the heating experience from the melting temperature (or glass transition temperature) to the decomposition temperature.

Rideal & Padget [12] determined experimentally that the molecular structure of HDPE changes during processing with changes in temperature. Later on Bolur [5] confirmed this empirical result that at high melt temperatures, greater than 290°C, decreases in melt viscosity and narrowing of molecular weight distribution is observed while an increase in viscosity is observed at low temperatures. Moeller [13] affirms that in injection moulding of HDPE, the low temperature limit is characterized by excessive injection pressures and/or physical property degradation. The increases in melt viscosity arise from the molecular enlargement reaction which is mainly attributable to the formation of long chain branches (LCB).

Many processes allow for parts to be moulded below the lower limit temperature at which sufficient physical properties are developed with the most common property failure being poor impact strength. The effect of the low melt temperature is highly retained orientation which results in poor impact performance. The high temperature limit is typically characterized by material degradation or moulding problems due to unreliable part, or runner ejection from the mould these failure modes are easily identified [13].

2.4 Quality characteristics of injection moulded parts

According to Yang & Gao [14], the quality characteristics of plastic injection-moulded products can be roughly divided into three kinds:

- the dimensional properties,
- the surface properties and
- the mechanical or optical properties

Kamal et al. [15] showed that product weight is a critical quality characteristic and a good indication of the stability of the manufacturing process in plastic injection moulding. Yang & Gao [14] revealed that product weight is an important attribute for plastic injection-moulded products because the product weight has a close relation to other quality properties; surface and mechanical properties, particularly other dimensional properties for example thickness and lengths (governed by part packing and filling). They also claimed that the performance of a manufacturing process and quality control can be monitored by the product weight. Kamal et al. [15] showed that controlling the product weight is of great commercial interest and can produce great value for production management.

In this research crate weight was used as the quality characteristic to monitor the extent of filling.

3 METHODOLOGY

Spina [3] stated that Taguchi methods are structured and organized Design of Experiments (DOE) methods that are used to determine and understand relationships between factors affecting a particular process and the resultant output .These techniques are applied in different scenarios to statistically quantify indeterminate measurements of factors and their relationships (interactions) by observing methodically forced changes. The main advantage of the technique is the identification of principal factors that govern the output of a particular process and the subsequent development of an understanding on how to achieve desired part quality.

The Taguchi method uses the loss function to determine the quality characteristics. Loss function values are also converted to signal-to-noise (S/N) ratio. Generally, there are three quality characteristics in S/N ratio analysis, namely “Nominal is best”, “Larger is better” and “Smaller is better”, represented below by Equation (1) to (3) [16]. Each level of the process has its own computed value of S/N ratio.

Nominal is best;

$$S/N = 10log\frac{\bar{y}^2}{s^2} \qquad \textbf{(1)}$$

Larger is better;

$$S/N = -10log(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{{y_i}^2}) \qquad \textbf{(2)}$$

Smaller is better;

$$S/N = -10log(\frac{1}{n}\sum_{i=0}^{n}{y_i}^2) \qquad \textbf{(3)}$$

Where

$\bar{y}$ is the mean of the trials for each experiment

y_i is the observed data.

s^2 is the standard deviation of the trials’ results for each experiment.

3.1 Taguchi Experimental Procedure

In Taguchi experimental procedure the process objective has to be defined. In defining the process objective, the factors (design parameters) that affect the process are determined. The number of levels that the factors are varied over should then be specified. Based on the number of factors and levels selected for the experiments, the appropriate orthogonal array is chosen. The factors are then assigned to the columns as is defined by the selected array before conducting the actual experimentation. The experiments are conducted according to the indications by the array and observed data is collected as they are being carried out. Complete data is analyzed to determine the effects of the different parameters on the performance objective. Figure 1 shows the steps on the application of the Taguchi method in experimental design.

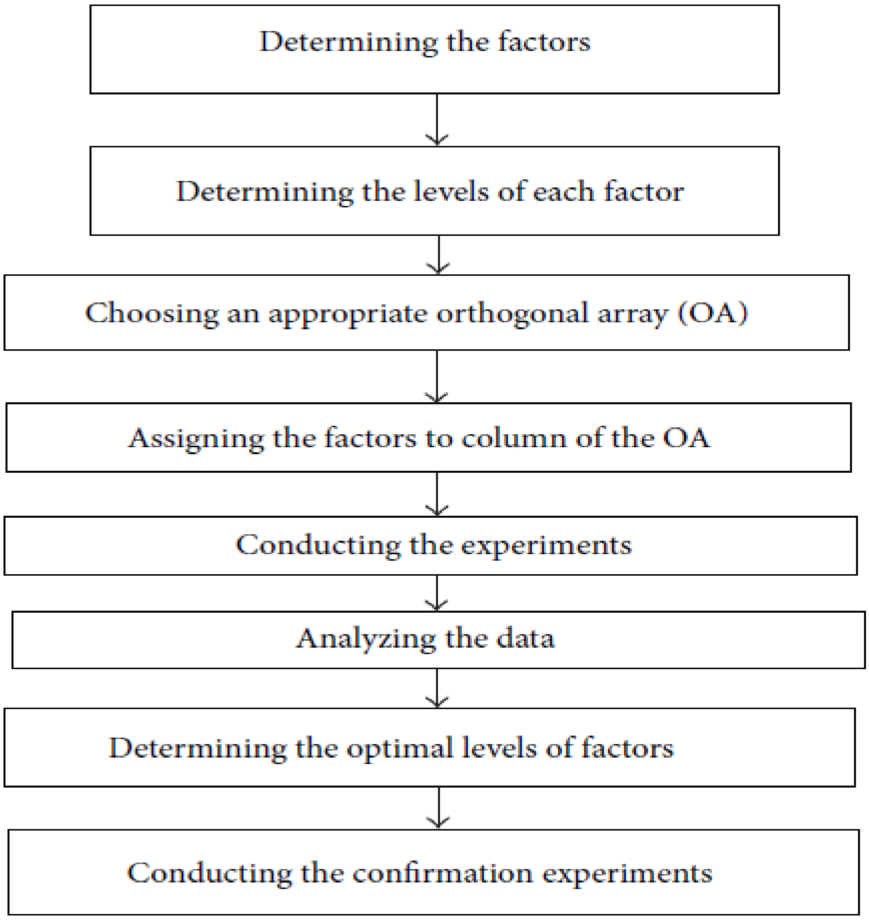

Figure 1: Steps on application of Taguchi Method

3.2 Experimental Set up

The experiments were carried out on an Engel DUO 16050/1000 injection moulding machine shown in Figure 2, running production on the light weight Coke mould. The set values for the injection pressure, injection speed and switch over value were set on the human machine interface on the machine. The melt temperature was achieved by changing the set temperatures on the injection moulder's barrel heaters; these values were set on the human machine interface as well. The actual melt temperature value was then obtained after purging the molten polymer and measuring the temperature using an infrared hand held temperature pyrometer. The mould temperature was obtained by use of the pyrometer as well on the mould cores under monitoring. The Piovan water heater provided the temperature regulation for the heated up sections of the mould, to provide the desired mould temperature for experimentation.

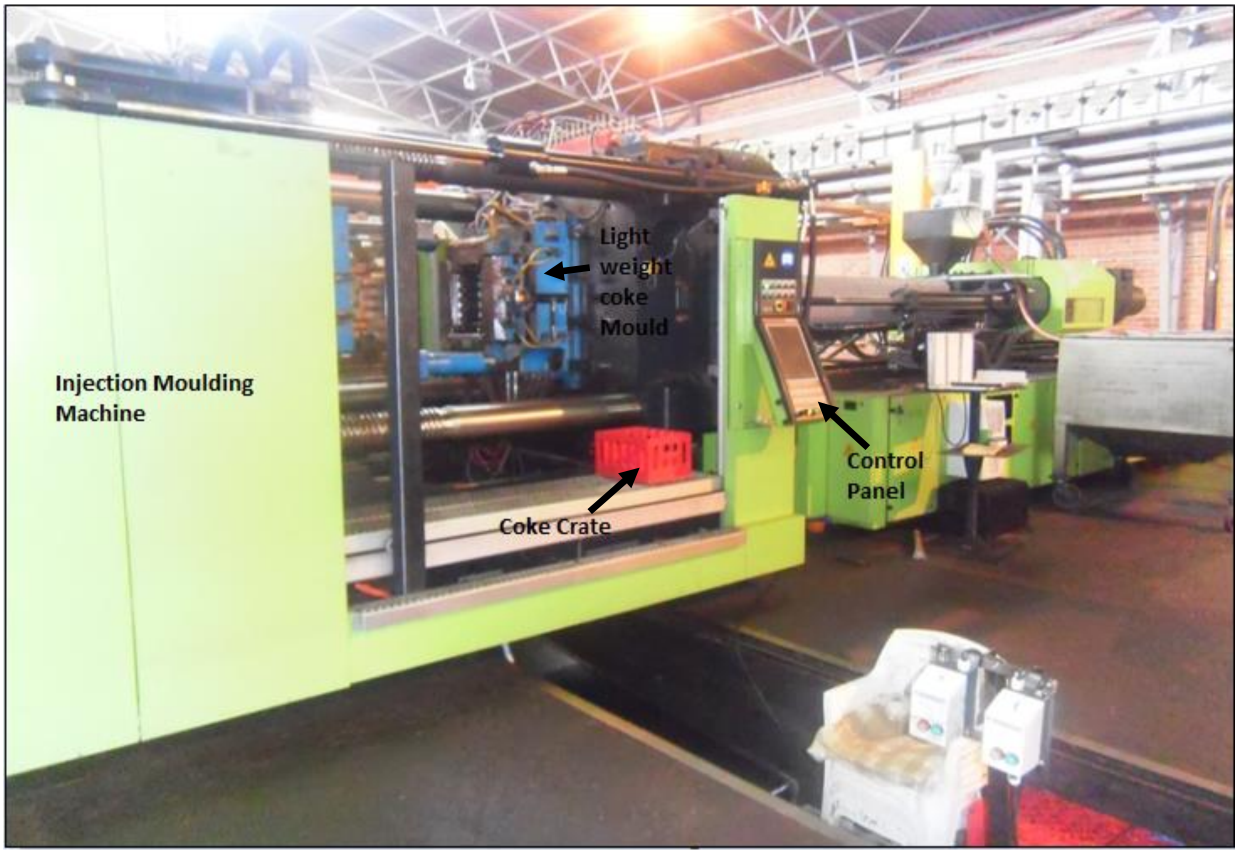

Figure 2: The machine and mould used for the experiments

4 DESIGN OF EXPERIMENT

The experiment focused on determining the effect of injection moulding parameters on the weight of a moulded part. It involved the variation of five (5) parameters (injection pressure, mould temperature, melt temperature, switch over set value and injection speed) over two levels. According to the Taguchi Design of Experiments approach, the samples should be organized into 8 groups; this is the L8 Orthogonal array as shown in Table 1. The numbers 1 and 2 represent the levels of the different factors.

Table 1: L8 Orthogonal array

Experiment	P1	P2	P3	P4	P5
1	1	1	1	1	1
2	1	1	1	2	2
3	1	2	2	1	1
4	1	2	2	2	2
5	2	1	2	1	2
6	2	1	2	2	1
7	2	2	1	1	2
8	2	2	1	2	1

Where:

P1 is Injection Pressure in bar

P2 is Mould Temperature in ˚C

P3 is Melt temperature in ˚C

P4 is Switch over set value in mm

P5 is Injection speed in mm/s

The parameters were tested at two levels due to limitations from the company policies in the organization in which the experiments were executed. The choice of values for injection pressure and injection speed was based on the lowest that had ever been set for that particular product and the highest pressure achievable by the machine. Mould and melt temperature values were limited by the viability of the process and the desire to avoid excessive production of rejects during the experimentation; though the inevitability of this was understood. The switch-over value is indicative of the injection stroke. Increasing it reduces the injection stroke and the opposite is true.

The weight was chosen as the measuring characteristic as it is indicative of filling behavior for a crate. The process parameter settings that were applied are as shown in Table 2.

Table 2: Parameters and levels for the experiment

Level	Injection Pressure	Mould temperature	Melt Temperature	Switch over value	Injection Speed
1	175 bar	35°C	230°C	60mm	60mm/s
2	208 bar	60°C	260°C	75mm	87mm/s

The combination of the parameters and the levels yields are summarized in Table 3 below.

Table 3: Combination of parameters and levels

Experiment	Injection Pressure	Mould Temperature	Melt temperature	Switch over set value	Injection speed
1	175 bar	35°C	230 °C	60mm	60mm/s
2	175 bar	35°C	230 °C	75mm	87mm/s
3	175 bar	60°C	260 °C	60mm	60mm/s
4	175 bar	60°C	260 °C	75mm	87mm/s
5	208 bar	35°C	260 °C	60mm	87mm/s
6	208 bar	35°C	260 °C	75mm	60mm/s
7	208 bar	60°C	230 °C	60mm	87mm/s
8	208 bar	60°C	230 °C	75mm	60mm/s

5 RESULTS AND DISCUSSION

In determining the result the S/N ratio, the nominal is best quality characteristic, represented by equation (1), was the targeted quality characteristic for crate weight. The effects of the level of each factor on the quality characteristic were analyzed using S/N ratios. Table 4 showed the result for the 8 trials and the calculated means and standard deviations. All computations were done on Minitab 16 software.

Table 4: Summary of results for coke crate weight

Expt	P1	P2	P3	P4	P5	Trial 1	Trial 2	Trial 3	Mean	SN Value
1	175 bar	35°C	230 °C	60mm	60mm/s	1.394	1.397	1.398	**1.396**	**56.5316**
2	175 bar	35°C	230 °C	75mm	87mm/s	1.422	1.419	1.420	**1.420**	**59.3680**
3	175 bar	60°C	260 °C	60mm	60mm/s	1.445	1.445	1.442	**1.444**	**58.4201**
4	175 bar	60°C	260 °C	75mm	87mm/s	1.481	1.481	1.484	**1.482**	**58.6458**
5	208 bar	35°C	260 °C	60mm	87mm/s	1.459	1.460	1.459	**1.460**	**63.2871**
6	208 bar	35°C	260 °C	75mm	60mm/s	1.428	1.424	1.427	**1.426**	**56.7162**
7	208 bar	60°C	230 °C	60mm	87mm/s	1.530	1.530	1.529	**1.530**	**63.6938**
8	208 bar	60°C	230 °C	75mm	60mm/s	1.426	1.425	1.426	**1.426**	**63.0824**

Table 5 shows the response for the S/N ratio for the crate weight based on rankings as calculated on Minitab 16. Table 5 shows rankings of the parameters based on their impact on the filling of the mould, with weights as the performance measuring characteristic.

Table 5: Response table of S/N Ratio for part weight

Level	Injection Pressure (bar)	Mould Temperature (°C)	Melt temperature (°C)	Switch over value (mm)	Injection speed (mm/s)
1	58.24	58.98	60.67	60.48	58.69
2	61.69	60.96	59.27	59.45	61.25
Delta	3.45	1.98	1.40	1.03	2.56
Rank	**1**	**3**	**4**	**5**	**2**

The standard weight for a Coke Light weight crate is 1.420 kg +/- 20g. The mean weight for the 8 experiments was 1.448kg. According to the selected quality characteristic, ''the nominal is best'' the optimum combinations for the parameters for crate filling with respect to part weight were selected by them achieving the target part weight of 1.420kg and are shown in Table 6 below. It should be noted however that, factor combinations for experiments 3, 6 and 8 also produce parts that fall within the acceptable quality level of +/- 20g from the target value.

Table 6: Optimum factor combinations

Parameter	Level	Value
Injection pressure	1	175 bar
Mould temperature	1	35°C
Melt temperature	1	230 °C
Switch over value	2	75mm
Injection speed	2	87mm/s

In this study ANOVA was also used to analyze the effects of the injection pressure, mould temperature, melt temperature, switch over value and injection pressure. ANOVA is a tool for determining individual interactions of all control factors. The performed experimental plan was evaluated at a confidence level of 95%. The ANOVA values for the experimental results were computed on Minitab 16 and displayed as shown in Figure 3 below. The significance level of the experiments is represented by R-Sq and is 89.66%.

```
Results for: Experiment one final worksheet data.MTW

General Linear Model: MEAN1 versus Injection Pr, Mould Temper, ...

Factor                          Type   Levels  Values
Injection Pressure (bar)        fixed       2  175, 208
Mould Temperature (Degrees C)   fixed       2  35, 60
Melt Temperature (Degrees C)    fixed       2  230, 260
Switch over value (mm)          fixed       2  60, 75
Injection speed (mm/s)          fixed       2  60, 87


Analysis of Variance for MEAN1, using Adjusted SS for Tests

Source                          DF     Seq SS     Adj SS     Adj MS     F      P
Injection Pressure (bar)         1  0.0012417  0.0012417  0.0012417  1.93  0.299
Mould Temperature (Degrees C)    1  0.0040051  0.0040051  0.0040051  6.23  0.130
Melt Temperature (Degrees C)     1  0.0001967  0.0001967  0.0001967  0.31  0.636
Switch over value (mm)           1  0.0007157  0.0007157  0.0007157  1.11  0.402
Injection speed (mm/s)           1  0.0049833  0.0049833  0.0049833  7.75  0.108
Error                            2  0.0012857  0.0012857  0.0006428
Total                            7  0.0124282


S = 0.0253544   R-Sq = 89.66%   R-Sq(adj) = 63.79%
```

Figure 3: Results of ANOVA for the experiments

The significance of each factor was depicted by the F value of each control factor. Figure 4 shows the S/N response diagram constructed for the part weight based on Table 5 and as plotted on Minitab 16.

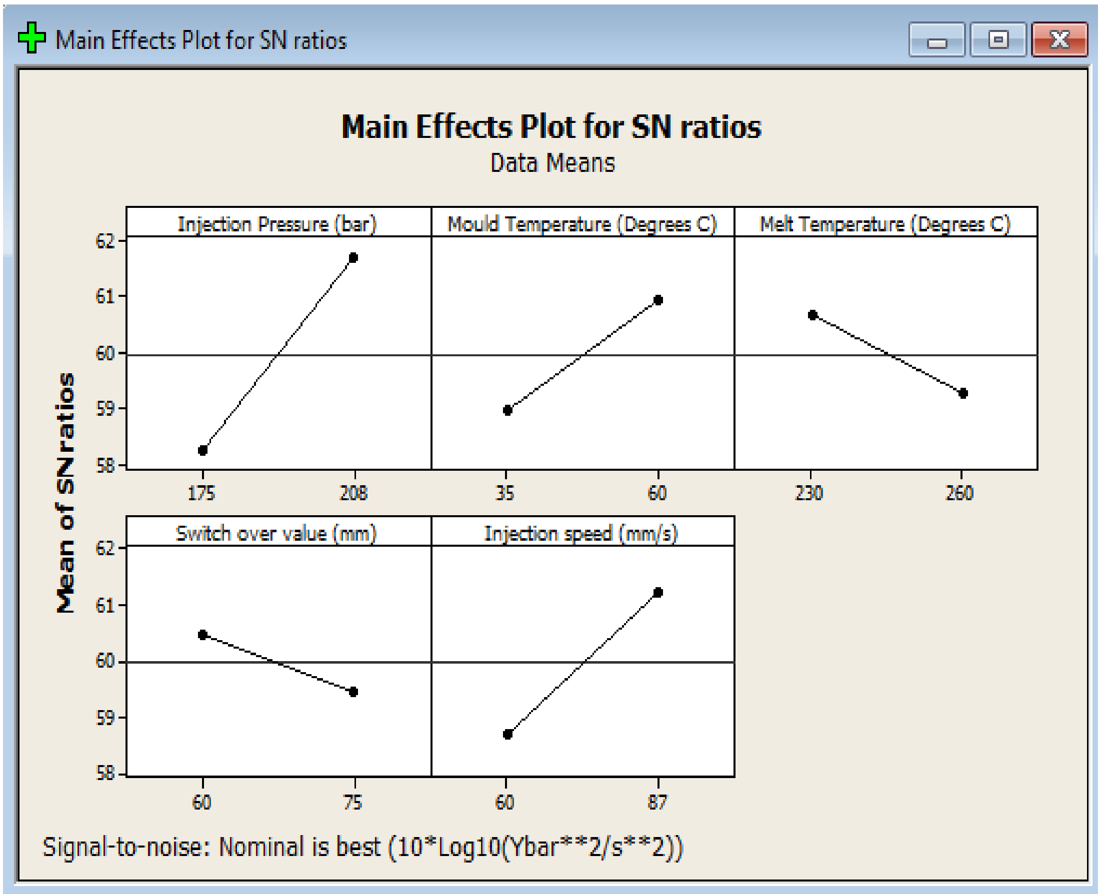

Figure 4: Main effects plot for S/N ratios for the part weight

It was observed that as the mould temperature increase the product weight also increases showing an increase in the filling of the product. Injection pressure increases also showed a direct proportionality increase with the increase in part weight, and so did injection speed. Melt temperature showed inverse proportionality in increase, such that as the melt temperature increased the part weight decreased. It was noted that this decrease was not indicative of reduction in flow; however it was due to the thermal degradation of polymer melt at elevated temperatures as well as the increase in viscosity of the polymer. T

Figure 5: Coke Light weight crate with flash on sides

The mould temperature therefore has a large effect on the filling distance of molten resin. Higher mould temperature will enhance the filling distance process and will result in a larger filling distance. The material of the injection mould is highly likely to play a part in the thermal/flow behavior of polymer melt, as the type of mould material determines the mould's thermal heat transfer coefficient. Low values of heat transfer coefficient result in a slow cooling rate of melt from the mould wall, resulting in a larger filling distance. The opposite is true for moulds with higher heat transfer coefficients. Therefore the effect of mould temperature becomes lower as the values of heat transfer become lower.

6 CONCLUSION

In this investigation on mould filling behavior the results showed that, injection pressure was the most significant factor with a contribution of 33.11%, followed by injection speed which contributed 24.5% then mould temperature which contributed 19%, then the melt temperature contributed 13.49% and least was the switch over value by its contribution of 9.89%.

Taguchi's orthogonal array effectively lowered the number of experimental trials in the investigation of the effect of mould temperature on flow of high density polyethylene. The results from the experimental design were predicted accurately by application of Minitab 16 software, to show the rankings based on importance of the factors on mould filling behavior.

The experiments' scope was limited by constraints due to the case study organization's policies and the need to limit the reject rates. Future work on this area could involve the application of more levels and or more parameters. The research can also factor in different types of base polymer other than High density polyethylene.

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DESIGN OF COTTON GINNING DRYER CONTROL SYSTEM

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ABSTRACT

The most important factor in preserving the quality of cotton during ginning is the fibre moisture content. At higher moisture content, cotton fibres are stronger but trash is harder to remove. Selecting ginning moisture content is a compromise between good trash removal and quality preservation. In the paper, inlet and outlet moisture content of cotton being fed into and out of the dryer are monitored at temperatures given in the dryer manual and literature. A mathematical model for drying cotton is then formulated by analysing the experimental results, cotton dryer historical records and dryer manual. The results show that there is a linear relationship between the initial moisture content, final moisture content and drying temperature. A control system integrating a Barionet controller to regulate and supply of heat to the system based on the initial moisture content is then proposed. The objective of the control system is to enable online monitoring of the dryer as well as giving early warning signs when the system is about to get out of control hence safeguarding from overheating and avoid under-drying of cotton.

1 INTRODUCTION

Ginneries must produce a quality of lint that brings the grower maximum value while meeting the demands of the spinner and consumer. A standardized sequence that includes dryers to obtain the proper moisture level as well as machines to remove the foreign matter is recommended for processing cotton at the gin. Pre-cleaning equipment operates most efficiently with dry cotton, which allows for easier separation of trash. The moisture content of cotton while it is being cleaned and ginned dramatically affects the processing; therefore, one major task of cotton gin is to properly dry cotton. If wet cotton enters the ginning stream it can cause the gin stand to choke, thereby causing considerable problems for the gin operation. The purpose of any cotton drying system is to remove moisture so that cotton cleaning can be more effective. Dryer stoppages average about 15% of the total production time. The current control system is depended on operator's skill and experience. The operator measures the moisture content of the cotton. The incoming cotton parameters such as cotton variety and cotton moisture are recorded manually by the operator for each module entering and the operator uses these values for reference to adjust the dryer temperature. Then the input or feed rate is adjusted to get the desired quality of drying. Cotton ginning dryer control system that will regulate the drying temperature during the drying process is initiated. Dryer operating temperature will be based on the initial moisture content of the cotton. Initial cotton moisture content ranges from 20% to 75% moisture content. Cotton is dried to 6%-8% moisture content which will enhance the cleaning process efficiently. Hughes and Baker [1] found out that many gin operators did not have the recommended dual temperature control systems on their dryers in South-western United States. However, 48% of the dryers surveyed followed the recommendation of using two temperature control systems the primary and maximum control system. The proposed system will constitute of two temperature sensors and two moisture sensors integrated to the Barionet. Related research on cotton drying and cotton drying control is covered in section 2. Experiments and results analysis are covered in the methodology in section 3. Section 4 comprises of linear regression formulation of the relationship between drying temperature and moisture content. The proposed cotton drying system is discussed in section 5, whilst section 6 is the conclusion of the research.

2 RELATED RESEARCH

Drying in cotton industries is an important process, the moisture content of cotton is very important in the ginning process. Overheating of dryers is a common phenomenon if the process is not regulated and properly controlled. This causes severe losses in equipment, cotton and production time as stated by Jackson et al [2]. Cotton with high moisture content will not clean or gin properly and will not easily separate into single locks but will form wads that may choke and damage gin machinery or entirely stop the ginning process .According to Valco et al [3] cotton with low moisture content may stick to metal surface as a result of static electricity generated on the fibres and cause machinery to choke and stop. Research by Nelson and Neir [4] shows that there were developments that were done in West Texas of using a moisture mirror. Moisture mirror is a device that monitors moisture in the ginning process and uses that information to help the ginner to control all of his moisture systems as well as provides valuable feedback to system performance. Swiss researchers Kretzschmar and Ellison [5] have been proactive in developing high volume instrumentation technology applied to fibre analysis in the ginning process. They developed uster intelligin which monitors and control the ginning process through a system of online sampling stations located throughout the gin, information on fiber moisture and trash colour are fed into a main console were a software anlyses fibre value for optimum dryer temperature and lint cleaning practices. All this is designed to help ginners get the most performance and benefit from their moisture control systems.

2.1 Drying Temperature

Cotton should be dried at a temperature around 177°C according to a study by Anthony and Griffin [6]. They further state that cotton fibres will sometimes scorch and discolour at 232°C and will always scorch at 260°C. Cotton will sometimes ignite at 232°C after long exposure and will instantaneously ignite at temperatures over 288°C. Exposure to high drying temperatures (above 177°C) also increases the brittleness of the cotton fibres, which in turn affects lint quality by reducing fibre strength and contributing to fibre breakage. Boykin [7] studied moisture conditioning on fibre quality and gin stand energy requirements and concluded that increasing drying temperature by 50°C decreases lint moisture by 0.81%.

2.2 Cotton Drying Control

Studies on automated cotton drying begun in 1990 the aim was to improve cotton drying in cotton ginning. Byler and Anthony [8] developed a computer based control system which was tested in two gins. The drying temperature set-point was adjusted based on the seed cotton moisture content before and after drying as measured by infrared moisture meters. The control system adjusted the air temperature by opening and closing the modulator valve on the gas line feeding the burner. Scanardo et al [9] computerized the process control system of drying in which infrared moisture meters, video cameras, computers, paddle samplers, pneumatic cylinder were installed in a phased approach over a five year period at two commercial cotton gins. Though the system was partially implemented the components were evaluated and were functioning well for extended period of time. The computer system took reading after every 10 seconds. According to Anthony [10] Dryer temperature sensors should be located as near as possible to the point where cotton and heated air mixed together. Baker,[11] recommended the use of two temperature sensors the primary and maximum control temperature sensors

3 METHODOLOGY

The experiments were conducted so as to determine the relationship between the initial moisture content and the drying temperature. Temperature is the main variable that affects moisture content of the cotton being dried. Cotton is hygroscopic and will gain or lose moisture based on the environmental conditions at which it is stored. Dry cotton placed in damp air will gain moisture and wet cotton placed in dry air will lose moisture. Bales of cotton from the same stack were unloaded into the mixing floor, where the cotton would be mixed and conveyed through the duct to the tower dryer. Initial moisture content was measured and recorded thus the heater was manually adjusted according to the initial moisture content. Two thermocouples were installed to measure the temperature of the heated air before the mix point and the other thermocouple located at the mix point. A mix point is a point where the cotton will first make contact with the drying air. Figure 1 shows the diagrammatic representation of a mix point. Cotton will first make contact with drying air at the mix point at an angle of approach of 30°. The test thermocouples were of 24 gauge wire, twisted and soldered, resulting in a 1.2 mm diameter with a time constant of 3seconds .A thermocouple of this size responds about six times faster than a typical control thermocouple (in flowing air only).These thermocouples were placed in the air and cotton stream, but with an attempt to avoid direct contact with cotton. The final moisture content was recorded using moisture meters, which were inserted at the exit point of the dryer.

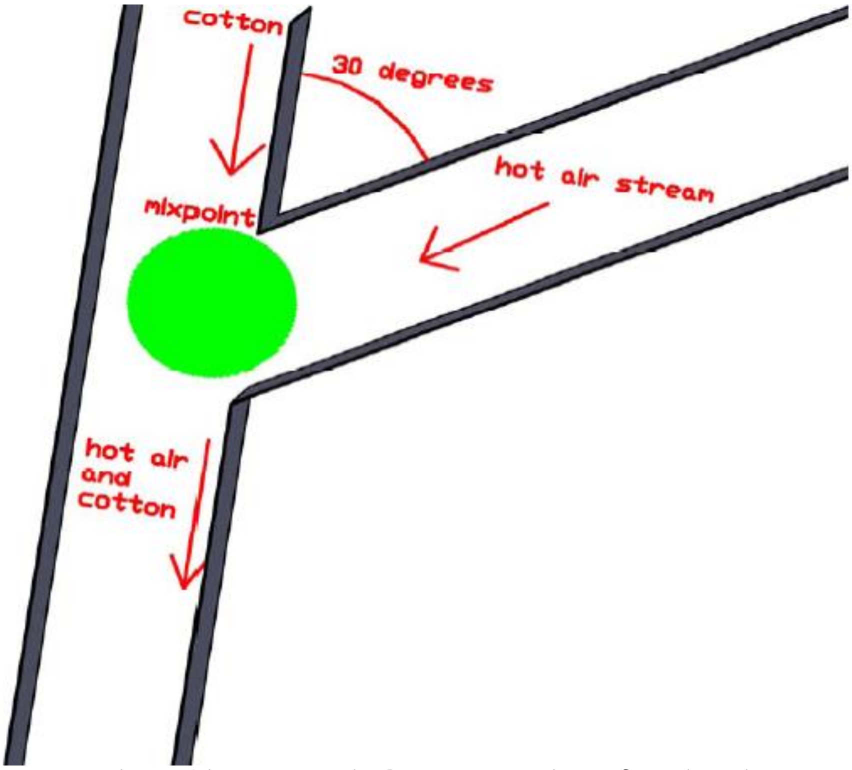

Fig 1: Diagrammatic Representation of a Mixpoint

3.1 Experimental Results

Table 1 shows selected experimental results from the ginning experiments conducted at the ginning depot. The recorded results were recorded at 30 minutes interval starting from mid-morning to sunset.

Table 1: Experimental Results

Initial Moisture content(X_1)	Final Moisture content(X_2)	Drying Temperature (Y)
1) 72 %	7.8%	129°C
2) 49%	6.0 %	92°C
3) 53%	6.7%	105°C
4) 58%	6.0%	101°C
5) 75%	8.0%	127°C
6) 66%	7.2%	102°C
7) 33%	6.2%	91°C
8) 29%	6.0%	90°C
9) 21%	6.3%	91°C
10) 20%	6.5%	90°C

Figure 2 and Figure 3 shows the surface plot and scatter plot for the experimental results.

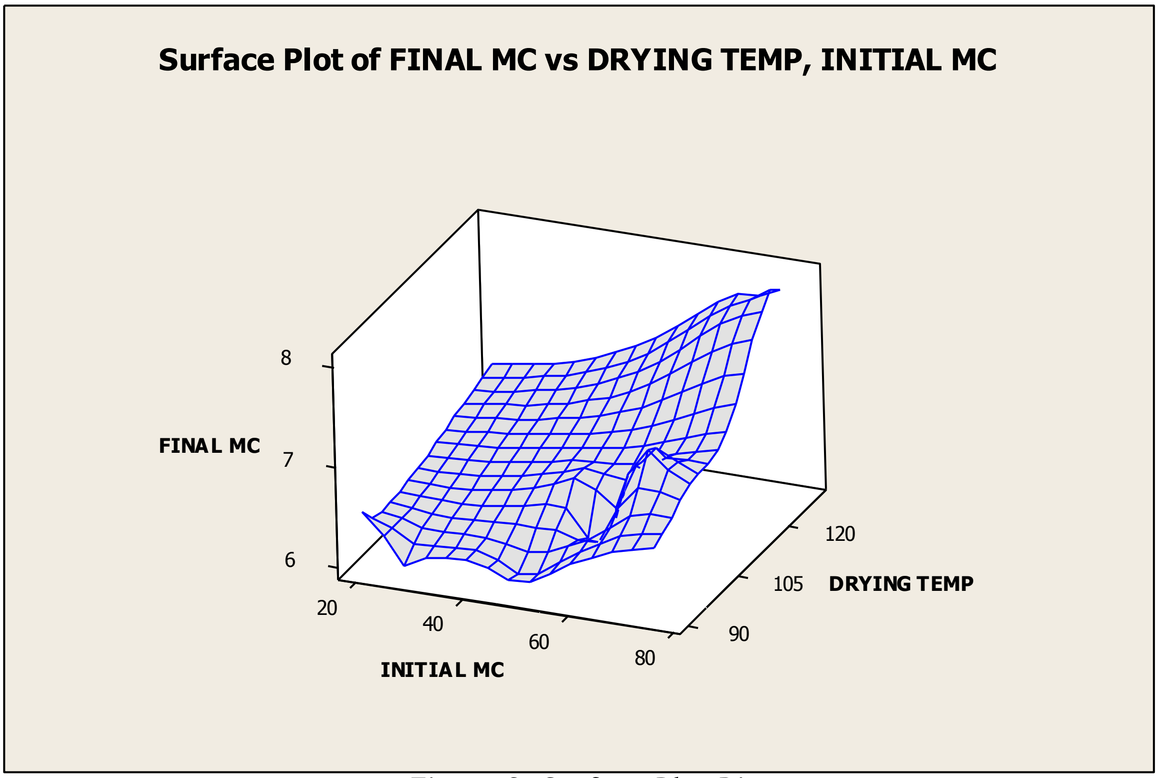

Figure 2: Surface Plot Diagram

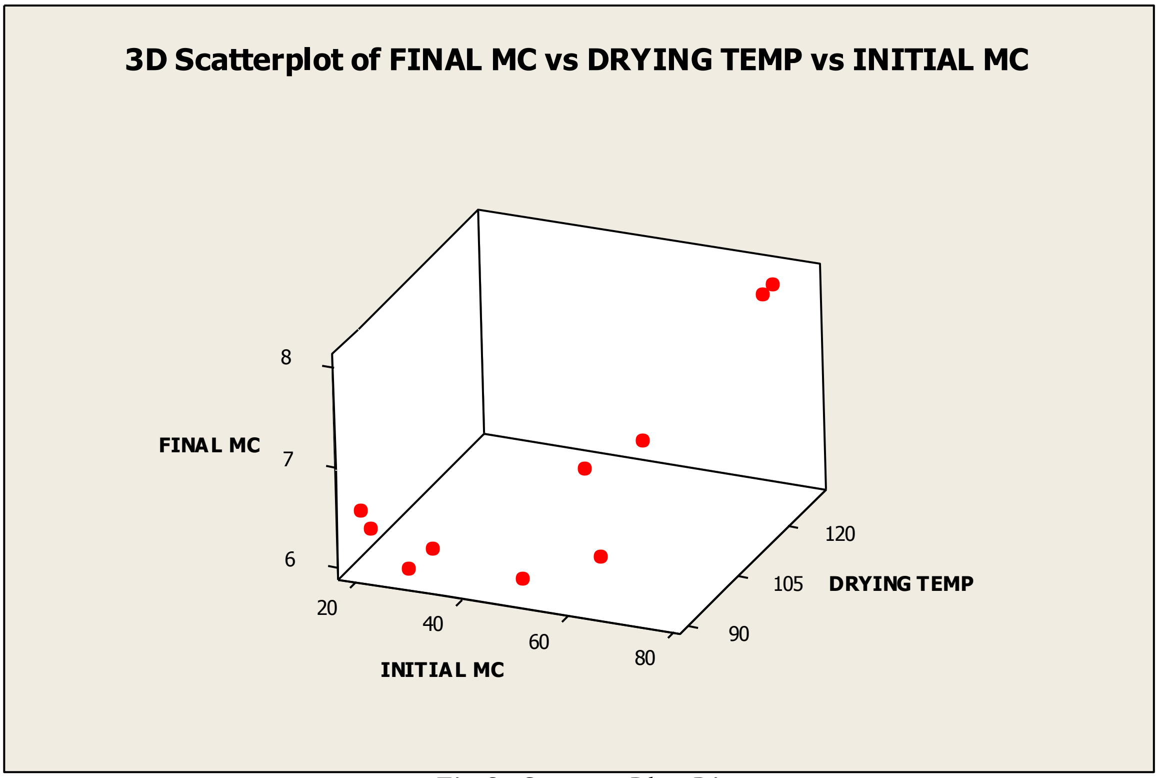

Fig 3: Scatter Plot Diagram

The final moisture content of these selected experiments falls within the recommended range of 6 % -8 % and drying was achieved below the maximum recommended drying temperature of 177°C. According to the drying manuals, the drying temperature should be in the range of 90°C to 177°C, thus our drying temperatures do not exceed the maximum recommended temperature that in turn affects lint quality by reducing fibre strength and contributing to fibre breakage. Cotton drying is a continuous process and the dyer is parallel flow, cotton is moved through the tower dryer by the momentum of the drying air, cotton will take up to 15 seconds in the dryer.

4 MATHEMATICAL DRYING MODEL FORMULATION

Regression analysis is a conceptually simple method for investigating functional relationships among variables. The objective of linear regression is to quantify the linear relationship between explanatory variables and response variables, Amyad and Ahmed [12]. Explanatory variables are the initial moisture content (X_1), final moisture content(X_2) and the response variable is the drying temperature (Y) in this paper.

4.1 Model Summary

Modelling of the data is done mathematically using a matrix notation, so as to solve for which are the coefficients of our variables.

$$Y \text{ is defined as } Y \quad (1)$$

Where

(2)

From the experimental values in Table 1 these matrix are developed as shown in equation 3

$$x= \qquad Y= \quad (3)$$

$\lfloor_1 \quad 5\rfloor \qquad \lfloor \quad \rfloor$

Solving for coefficient of

(4)

Thus

$$) = \begin{bmatrix} 72 & 20 \end{bmatrix} \quad (5)$$

$\lfloor_1 \quad 5\rfloor$

$$= \begin{bmatrix} 476 & 8 \end{bmatrix} \quad (6)$$

Solving for the determinant of X^TX

$$Det \quad of \quad X^TX = 10[(26\,510 \times 449.95) - (3274.8 \times 3274.8)] - 476[(476 \times 449.95) - (66.7 \times 3274.8) + 66.7[(476 \times 3274.8) - (26\,510 \times 66.7)]]$$

$$= 95\,209.82 \qquad (7)$$

Solving for inverse using matrix of co-factors

$$(X^TX)^{-1} = \frac{1}{95\,209.82}\begin{bmatrix} 1\,203\,859.46 & -4252.96 & -209\,412.2 \\ -4\,252.96 & 50.61 & 998.8 \\ -209\,412.2 & 998.8 & 38\,524 \end{bmatrix} \qquad (8)$$

$$(X^TX)^{-1} = \begin{bmatrix} 12.644427829 & 0.044669341 & -2.199481104 \\ 0.044669341 & 0.000531562 & -0.010490514 \\ -2.199481104 & -0.010490514 & 0.404622128 \end{bmatrix} \qquad (9)$$

$$(X^TY) = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 72 & 49 & 53 & 58 & 75 & 66 & 33 & 29 & 21 & 20 \\ 7.8 & 6.0 & 6.7 & 6.0 & 8.0 & 7.2 & 6.2 & 6.0 & 6.3 & 6.5 \end{bmatrix}\begin{bmatrix} 129 \\ 92 \\ 105 \\ 101 \\ 127 \\ 102 \\ 91 \\ 90 \\ 91 \\ 90 \end{bmatrix} = \begin{bmatrix} 1018 \\ 50\,800 \\ 6880.6 \end{bmatrix} \qquad (10)$$

Substituting into Equation 4 to solve for the coefficients

$$\beta = \begin{bmatrix} 12.644427829 & 0.044669341 & -2.199481104 \\ 0.044669341 & 0.000531562 & -0.010490514 \\ -2.199481104 & -0.010490514 & 0.404622128 \end{bmatrix}\begin{bmatrix} 1018 \\ 50\,800 \\ 6880.6 \end{bmatrix} \qquad (11)$$

$$\begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \end{bmatrix} = \begin{bmatrix} 7.3 \\ 0.2957 \\ 12.05313 \end{bmatrix} \qquad (12)$$

The mathematical model according to the matrix notation is represented as follows

$$\boldsymbol{Y = 7.3 + 0.2957X_1 + 12.05313X_2} \qquad (13)$$

Where, X_1 - Initial moisture content
X_2 -Final moisture content
Y - Drying temperature

Using matrix notation allows for a more compact framework in terms of vectors representing the observations, levels of regressor variables, regression coefficients and random errors. The matrix approach offers the author the opportunity to develop her conceptual understanding of matrix algebra and linear regression model. The linear correlation coefficient r is 94.70% and this shows a strong positive correlation. The coefficient of determination R^2 is 89.70% which shows that the drying temperature (Y) is well explained by the initial moisture content (X_1) and the final moisture content (X_2) as shown in Table 3.

Table 3: Model Summary Table

Model	r	R^2
	0.947	0.897

4.2 Hypothesis Testing of the Cotton Drying Model

This is a test of the significance of the drying temperature and the moisture content taken together. Using the F-ratio which is the ratio of the explained-variance-per-degree-of-freedom used to the unexplained variance-per-degree-of-freedom-unused.

$$F = \frac{\textit{Explained variance}/(p-1)}{\textit{Unexplained variance}/(n-p)} \qquad (16)$$

Table 4: ANOVA Table

Model	Sum of squares	Degrees of freedom	Mean Square	F	Significance
Regression	1778.343	2	894.172	30.495	0.000
Residual	205.257	7	29.322		
Total	1993.600	9			

a) Predictors: (Constant), Final moisture content and Initial moisture content.
b) Dependent Variable: Drying Temperature.

Table 4 shows the analysis of variance (ANOVA), it is a statistical methodology for determining information about means. This analysis uses variances both between and within samples. The value of mean square is obtained by dividing sums of squares within the sample by their respective degrees of freedom.
The F test of the significance of the cotton drying equation $Y = 7.3 + 0.2957X_1 + 12.05313X_2$. As shown in Table 4, $p < 0.001$ thus it is reasonable to conclude that our regression equation is a significantly better predictor.

4.2.1 H test

H_0: $\beta = 0$ (There is no linear regression between drying temperature and moisture content.)
H_1 :$\beta \neq 0$(There is a linear relationship between drying temperature and moisture content)
Where H_0 is the null hypothesis

4.2.2 Finding the critical value

F value from the F-Statistics Table is 4.7374 ($F_{critical}$) for the numerator 2 and denominator 7 degrees of freedom intersect.
F calculated as shown in table 4 is 30.495 ($F_{calculated}$) and p = 0.000
Thus if $F_{calculated} > F_{critical;}$ then reject H_0 which states that there is no linear regression between drying temperature and moisture content.
The conclusion is that there is a linear relationship between drying temperature and moisture content since $F_{calculated} > F_{critical.}$

4.3 Residual statistics

The difference between the drying temperature in the experimental results and the predicted drying temperature by the drying model is summarized in this sub-section.

Table5: Model Drying Temperature

	Minimum temperature	Maximum temperature	Number of experiments
Predicted value	88.17	125.85	10

The minimum drying temperature from the drying model as shown in table 5 is 88.17°C and the maximum drying temperature is 125.85°C. From the experimental results in Table1; the minimum drying temperature is 90°C and the maximum drying temperature is 129°C. Hence our percentage error of the model can be calculated.

$$Percentage\ error = 1 - r(correlation\ coefficient)\ \times 100\ \% \quad \textbf{(17)}$$

$$Percentage\ Error = (1 - 0.9479) \times 100 = 5.21\% \quad \textbf{(18)}$$

5 DESIGNED COTTON GINNING CONTROL SYSTEM

Figure 4 shows the hardware wiring of the control system. The model for the system is shown in Figure 5. The power supply is on pin 15 and pin 16.The negative wire being on pin 16 and the positive wire is connected on pin 15. Moisture sensor A is inserted in the conveying duct at the mixing floor to measure the initial moisture content of cotton. The temperature sensor A is located at the mix point where cotton will make its initial contact with drying air. Temperature sensor B is inserted in the dryer, so as to give the reading of the temperature in the dryer. Moisture sensor B finally located at the exit channel of the dryer to measure the final moisture content. The volume of air required to supply a continuous flow of cotton to the dryer is 170m^3/min, thus the fan speed to supply the required volume is 1720 revolution per minute. The unloading separator which sustains such volumetric flow rate requires 22 horsepower. The drying fan to supply hot air to the tower dryer for a five gin stand requires 50 horsepower and a volumetric flow rate of 249m^3/min. As the heated air and the cotton are mixed, the heated air temperature drops significantly due to sensible heat transfer from the air to the cotton and evaporated moisture (the cotton and evaporated moisture warm as the air cools) and due to latent heat transfer (moisture that is evaporated from the cotton causing it to dry and the air to cool). As the cotton and air continue to flow through the length of the drying system, the heated air temperature will continue to drop due to continued drying as well as heat being transferred out through the walls of the drying system. In case of cotton with moisture content of 15% or less, the cotton bypasses the dryer and is fed straight to the cylinder cleaner. In case of cotton with moisture content of 15% or more, the cotton passes through a dryer and from a dryer it is then fed to the cylinder cleaner.

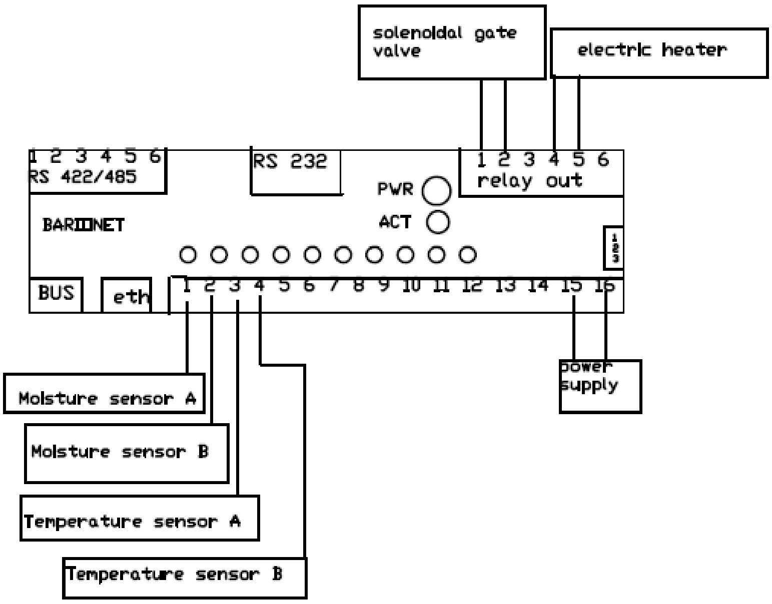

Figure 4: Ginning Control System

6 RESULTS AND DISCUSSIONS

Final moisture content shows that cotton is being dried to the recommended range of 6%-8%. However it have been noted that if dried cotton takes more than 20 minutes to pass through to the next stage of cleaning by cylinder cleaners, there will be a slight change in moisture content at that particular moment. This change is attributed by the following factors

- Environment humidity – If the humidity of the atmosphere is low where the cotton is temporarily stored prior to cleaning, the moisture will slightly decrease. If the humidity of the atmosphere is high the moisture content of cotton moisture will slightly increase. This is mainly due to the hygroscopic nature of cotton fibre, it tends to lose moisture or gain moisture from its surroundings as it tries to achieve equilibrium with environment. The recommendation to the ginners who will implement this system is not to buffer dried cotton prior to cylinder cleaners as storing the dried cotton for more than 20 minutes nullify the whole process of drying.

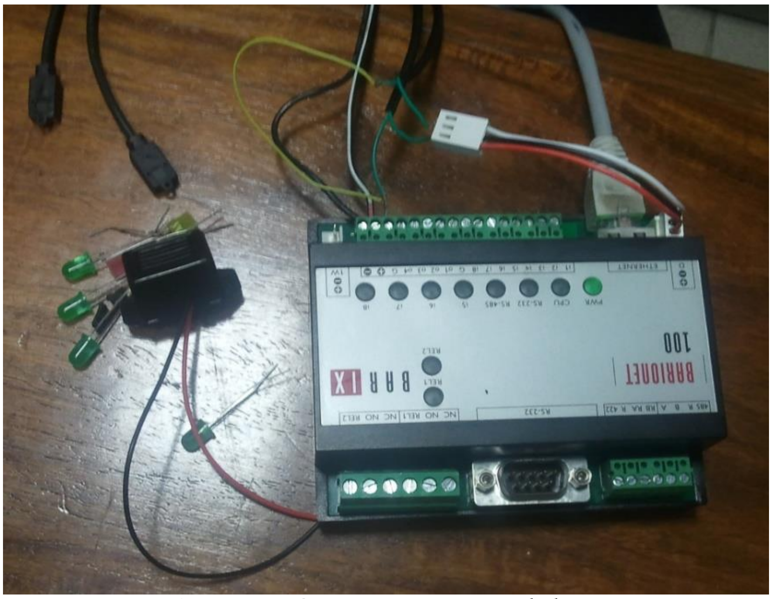

Figure 5: Cotton Dryer Model

- The heat gained by the cotton during the drying phase will still have sufficient energy to continue vaporize moisture in the fibre few moments after drying.

Though the variations in moisture content are observed they are of no effect at all to the final quality of our fibre produced after ginning. The variation range is $\pm 0.05\%$ moisture content.

The drying temperature at the mix point varies to a smaller degree from the set point temperature. This is mainly explained by that the walls of the dryer absorb heat that was intended to dry cotton thus the temperature will decline slightly from the set-point temperature. The walls of the dryer also emit heat to the cotton thus a temperature fluctuating is noted. However the drying system responds very well to cancel out the disturbances thus drying is achieved without any complications.

7 CONCLUSION

In this paper, a drying model is presented. The objective of achieving an optimum drying temperature in the dryer with minimum to no human intervention is achieved. The experiments were conducted so as to determine the relationship between the initial moisture content and the drying temperature. This study confirms that there exists a linear relationship among initial and final moisture content with the drying temperature. There is a continuous monitoring system of the drying temperature, the initial and final moisture content using the Barionet. Used correctly, cotton moisture control systems offer many benefits to growers, gins and textile mills. If the moisture control systems are well chosen, the gin and its customers will reap tremendous dividends.

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ANALYSIS OF A TIME BASED AND CORRECTIVE MAINTENANCE SYSTEM FOR A SUGAR PRODUCING COMPANY

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ABSTRACT

The Southern Africa sugar producers' market is under threat from Brazilian sugar, with the latter's sugar landing in Southern African countries - Zimbabwe in particular – at 75% of the selling price of local producers. This paper outlines an investigation of the current maintenance systems of a Zimbabwean sugar producer and its shortcomings, with a view of optimization. Research has shown that maintenance can contribute between 15 to 75% of production costs, thus playing a critical role in product pricing and consequently competition. Maintenance records and interviews to maintenance personnel from the company were used to extract data relevant to the study. A bottleneck asset in the production line was chosen as a subject to measure the impact of the current maintenance system in cost terms. The study shows that the company is using a hybrid of time based and corrective maintenance. The paper also shows that the current maintenance philosophy resulted in downtime of eighty (80) hours on the subject asset over a four (4) year period, that translated to an equivalent of USD1.9 million in potential revenue lost; which downtime could have been avoided with better maintenance methods. The paper concludes by recommending the introduction of Condition Based Maintenance on the subject asset as an alternative to optimize the maintenance function of the company.

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1 INTRODUCTION

Globalisation has brought competition to the door step of local industry and therefore an increase in pressure to optimise the industry's operations. The Zimbabwean sugar industry is the second largest employer in Zimbabwe after Government [1] making it a major contributor to the national economy. The local industry - like other regional (SADC) sugar industries - has faced stiff competition over the past year from Brazilian sugar that is landing in the region at almost 75% of the local selling price (Brazil's US1.55/unit compared to Zimbabwe's USD2.00/ unit). The direct impact has been a sharp increase in sugar inventory levels due to consumer shift to Brazilian sugar. The purpose of this paper is to investigate the current maintenance systems of a Zimbabwean sugar producer and its shortcomings with a view of optimizing them.

The paper gives a brief description of maintenance types and an outline of the importance of maintenance in any business. It then focuses on a target asset for a local sugar manufacturer to determine the maintenance philosophy being employed and its shortcomings in cost terms.

2 TYPES OF MAINTENANCE

Komonen [2], Mahmood et al [3] and European Standards [4] define maintenance as a combination of all technical, administrative, and managerial actions during the life cycle of an item intended to keep it in or restore it to a state in which it can perform the required function. Dhillon [5] defines it as all actions appropriate for retaining an item, part, equipment in, or restoring it to, a given condition. Maintenance operations can be classified into two large groups namely Corrective Maintenance (CM) and Preventive Maintenance (PM) [6, 7, 8, 9, 10, 11]. Corrective maintenance involves replacement of failed units while in PM the system which is highly likely to exhibit a demobilising fault is replaced before that failure is allowed to occur. The two common forms of PM are scheduled or time based PM and condition-based maintenance (CBM) [7, 8, 9, 10].

2.1 Corrective maintenance

Corrective maintenance is performed to restore a system to a state of functioning after the system has entered a state of failure [8]. No maintenance action is carried out until the component or structure breaks down [9]. It is has no special maintenance plan in place. The machine is assumed to be fit unless proven otherwise. Corrective maintenance should be utilized only in non-critical areas where capital costs are small, consequences of failure are slight, no safety risks are immediate, and quick failure identification and rapid failure repair are possible [10]. The major disadvantage is that of high production downtime and high risk of equipment damage and secondary failure. It has an advantage of not having condition monitoring or maintenance planning costs [9].

2.2 Time based maintenance

Time based or scheduled maintenance is performed at predefined ages of the system in order to reduce the probability of failure of the system [8]. An optimal breakdown window is pre-calculated by the original equipment manufacturer at the time of component design or installation and a preventive maintenance schedule is laid out. Maintenance is carried-out on periodic intervals, assuming that the machine is going to break otherwise [11]. The scheduling can be based on the number of hours in use, the number of times an item has been used, the number of kilometres the items has been used, according to prescribed dates, etc. [10]. The objective of time based maintenance is to prevent failures before they happen and therefore to minimize the probability of failure. It also increases the availability of the production facility [6]. The major advantages of time based maintenance is that it results in fewer catastrophic failures and there is greater control over spare parts and inventory. Maintenance is also performed in a controlled manner with a rough estimate costs well known ahead of time. Its greatest disadvantage is that since it is time based, machines are repaired when there is no fault and there still will be unscheduled breakdowns [11]. Another disadvantage is that the schedule is often not optimal because it is often drawn up on the supplier's recommendation, but made with either only limited local knowledge of the actual use conditions or from past experience [7].

2.3 Condition Based maintenance

Condition based maintenance is a type of maintenance policy that considers the current real state of system degradation [12, 13, 14, 15, 16]. It is based on the principle of using real-time data to prioritize and optimize maintenance resources. Such a system will determine the equipment's health, and act only when maintenance is actually necessary [11]. It is an emerging alternative to time based and corrective that employs predictive analytics over real-time data collected (streamed) from parts of the machine to a centralized processor that detects variations in the functional parameters and detects anomalies that can potentially lead to breakdowns [11]. The major highlight of CBM is that unexpected breakdown is reduced or even completely eliminated. Parts are ordered when needed and maintenance performed when convenient therefore maximising equipment life. Its drawbacks are of the high investment costs and additional skills that might be required.

2.4 Current trends in Maintenance

Eti et al [7] and Marcelo et al [17] highlighted the growth of new maintenance concepts and techniques that include Failure mode and effect analysis (FMEA) and condition monitoring in optimising maintenance operations. Goriwondo et al [18] used FMEA and ABC analysis to analyse and improve the production systems of a pharmaceutical company. In a study of telematics companies, Palem [11] showed that companies saved between 8 and 12 % by changing from traditional maintenance schemes to CBM. Neural networks were recently used successfully as a technique for the system prediction part of condition based maintenance systems [19]. Nguyen [20] used a Montecarlo simulation to evaluate the expected cost of preventive maintenance and a genetic algorithm for optimisation. DeCarlo and Arleo [12] coined formulae that can be used to assess the cost of any maintenance plan.

2.5 The link between maintenance and business

De Carlo and Arleo [12] mentioned planning of maintenance activities as one of the core elements in the design of a production system and that the production process flows regularly if the different systems are available when required by the production plan. Bengtsson [21] and Cortzee [22], agree that the maintenance costs range from 15-70% of the total production cost and that about 5% or more of the total production costs is spent unnecessarily due to bad maintenance. Dhillon [5] gives the cost of maintaining equipment as varying between 2 to 20 times the equipment acquisition costs over its lifecycle. These high figures of maintenance costs signify the importance of the maintenance function in any business. An optimised maintenance system will ultimately allow an organisation to compete effectively in the market. Ramachandra et al [23] notes that systematic maintenance procedures offer tremendous possibilities for saving money and materials. Maintenance activities are a major cost factor in most industries, affecting both return on capital and production throughput [23]. Ramachandra et al [23] and Acherman [24] further compare the benefits of maintenance and effects of poor maintenance to any organisation. Table 1 shows the comparison with factors which directly or indirectly contribute to the company's profit.

Table 1: Effects of poor maintenance vs. benefits of sound maintenance [23,24]

Effects of poor maintenance	Benefits of a sound maintenance system
Increased down time	Reduction in downtime to achieve production targets
Poor efficiency	Reduction in loss of materials in process, thus minimising resource usage
Deterioration of Equipment	Increased equipment life
Poor quality of product	Consistent product quality thus achieving quality objectives
High labour cost	Reduction in overtime
Loss of material in process	Optimum spares inventory
High production cost	Optimum operational cost of the machines
Non compliance with legislation	Compliance to legislation
Increased hazards	Timely replacement of spares and machines
High chances of job and plant accidents	Increased job and plant safety

3 COST OF MAINTENANCE

The cost of maintenance is defined as costs that include lost opportunities in uptime, rate, yield, and quality due to non-operating or unsatisfactorily operating equipment in addition to costs involved with equipment-related degradation of the safety of people, property, and the environment [5, 25].

There are fundamental costs associated with maintenance and are classified into four areas [5]:

- **direct costs** – these costs are related with keeping the equipment in good operating condition and include costs of periodic inspection and preventive maintenance, repair cost, overhaul cost, and servicing cost
- **lost production costs** – these costs relate to the loss of production due to primary equipment breakdown and unavailability of standby equipment
- **degradation costs** – these costs are associated with deterioration in the equipment life due to unsatisfactory / inferior maintenance
- **standby costs -** these costs are relate to costs incurred in operating and maintaining standby equipment. Standby equipment is used when primary facilities are either under maintenance or inoperable [5]

3.1 Factors Influencing Maintenance Costs

De Carlo and Arleo [12] and Dhillon [5] give the following reasons for maintenance costing:

- Compare competing approaches to maintenance
- Determine maintenance cost drivers
- Compare maintenance cost effectiveness to industry averages
- Prepare budget and costs control
- Provide input in the design of new equipment/item/system
- Provide input in equipment life cycle cost studies
- Make decisions concerning equipment replacement
- Improve productivity

3.2 Cost of Maintenance Formulae for Corrective and Planned Maintenance

De Carlo and Arleo [12] evaluated the total cost related to each maintenance type using the main cost and time parameters related to maintenance. Each maintenance type has cost and time items that mainly affect on its average unit cost. Time to retrain system after its unscheduled stop is the critical parameter in corrective maintenance whilst material or spares costs are the major cost drivers for planned maintenance [12]. The following are the costs models as evaluated by De Carlo and Arleo [12]:

i. **Corrective maintenance total cost, C_c**

$$C_c = C_{LP} \times (t_d + t_a + t_r + t_{rs} + t_q) + (C_L \times t_r) + C_M \quad (1)$$

ii. **Planned Maintenance total cost, C_p**

$$C_p = C_{LP} \times (t_r + t_{rs}) + (C_L \times t_r) + C_M \quad (2)$$

Where;

C_{LP} = Lost productivity hourly cost,
C_L = Hourly labour cost
C_M = Material cost
t_d = Time of diagnosis
t_a = Time required for maintenance service activation
t_r = Repair time
t_{rs} = Time for reactivation of production
t_q = Time for system retrain after the unplanned shutdown

4 CASE STUDY

The cost of maintenance models were applied to a particular case study, a sugar factory of one of Zimbabwe's sugar producers. A cane shredding unit, which is an asset within the sugar production line of the company, was used in order to simplify the study.

4.1 Objectives of the study

Traditionally the company has been disregarding lost productivity in their maintenance costing models. The objectives of this study are therefore to;

- Analyse the existing maintenance plan on the shredding unit using the cost models in section 3.2 and compare the costs with those calculated by the company
- Introduce Condition based maintenance (CBM) concepts and assess the likely benefits should it be adopted on the shredding unit

4.2 Methodology

The study was limited to the shredding unit only and a 38 week production / crushing season. Interviews were conducted on eighteen (18) milling section maintenance team. The shredding unit falls under the milling section of the sugar mill. The interviews aimed at extracting information on employment designation of the interviewees, the years experience in the milling section and the maintenance philosophy being applied on the shredding unit. All the personnel in the section were selected since they are responsible for all maintenance actions on the unit. The planning office maintenance records of the company were used to ascertain total downtime hours due to breakdown. Cost of maintenance calculations were done for a period of 4 years (2010 to 2013 inclusive) using the formulae by De Carlo and Arleo [12].

4.3 Cane shredding unit

The purpose of the shredding unit is to complete the preparation and disintegration of the cane, so as to facilitate the extraction of juice by the mills [26]. The disintegration opens the cane cells and liberates the juice, making it more accessible and easily extracted. The schematic below shows the general setup of the shredder, its capacity and the capacities of other equipment along the milling production line. The capacities of the juice extraction unit and the can knives are higher than that of the shredding unit making the latter a bottleneck unit in the production line i.e. 320tonnes cane per hour (TPH) against 290TPH respectively. Figure 1 shows the arrangement of units in the milling production line.

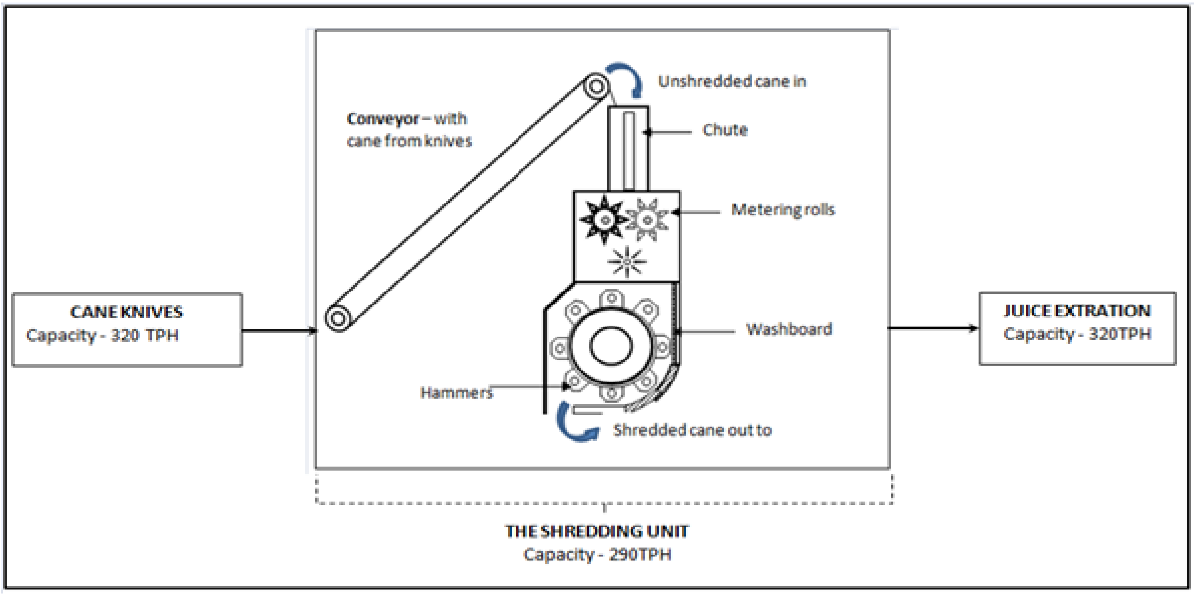

Figure 1: Arrangement of equipment in the milling production line

4.4 Findings from interviews and maintenance records

Based on the responses from the eighteen (18) maintenance personnel through the interviews, and records from the maintenance planning office, the company was found to be employing a hybrid of planned maintenance and corrective maintenance on the shredding unit. Planned maintenance work orders are printed the beginning of every week. Scheduled restoration tasks are carried out 8hrs every fortnight for a *38* week production season and a major scheduled restoration maintenance work is carried at the end of every milling season. This is done on a yearly basis for 14 weeks. Corrective maintenance is done each time a break down occurs. 80.75 hours of downtime due to breakdowns were recorded in the past four years and a corrective maintenance approach was used to attend to the breakdowns. Figures 2 and 3 show the causes of the breakdowns and the repair time in the duration 2010 to 2013.

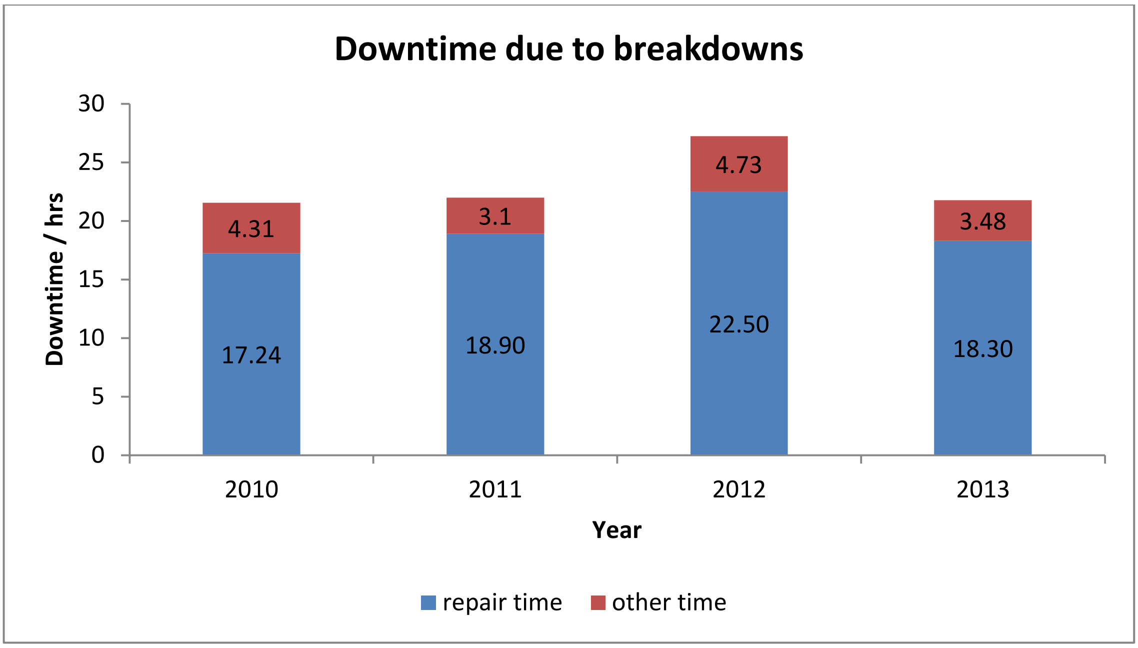

Figure 2: Downtime due to breakdowns

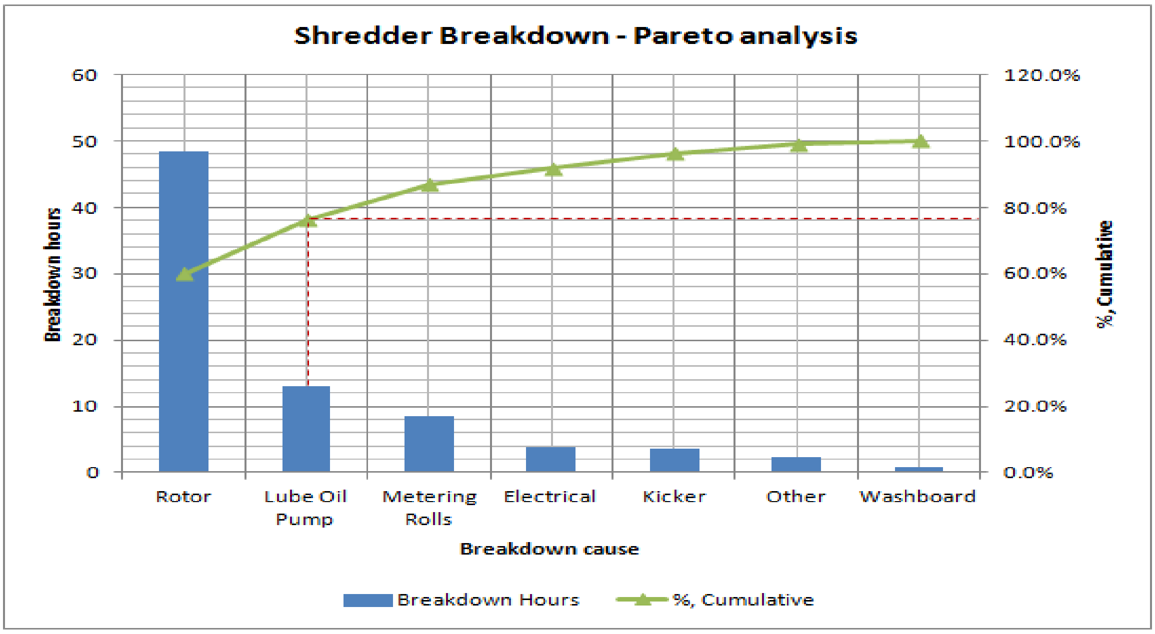

Figure 3: Causes of breakdowns on the shredding unit

4.5 Analysis of breakdowns

Repair time was 80% of the total downtime due to shredder breakdowns. The predominant equipment failures in the period under review were the rotor and lubrication oil pump. The two equipment failed a combined twenty one (21) times to account for 76% of the total breakdown hours.

5 COST OF MAINTENANCE ANALYSIS

The cost of maintenance analysis was done to compare the current understanding of maintenance cost by the company to the maintenance costing model as coined by De Carlo and Arleo [12].

5.1 Cost of maintenance calculation with model by De Carlo and Arleo [12]

Using the equations (1) and (2), the costs of the current maintenance plan on the shredding unit over a four year period was calculated.

5.1.1 Lost productivity hourly cost, C_{LP}

The hourly cost of lost productivity was calculated using an average sugar price per tonne, ***p***, and the output of the production line per hour, *m*. Average price was derived from the prevailing local and world market sugar prices of USD 800.00 and USD 480.00 respectively [14]. The output sugar using a cane to sugar ratio of 8 for a 290 tonnes of cane per hour production line is 36.25 tonnes of sugar per hour (*tsph*). Lost productivity hourly cost becomes:

$$C_{LP} = m \times p \tag{3}$$

$$C_{LP} = 36.25tsph \times US\$640.00$$

$$\boldsymbol{C_{LP} = US\$\ 23,200.00\ per\ hour}$$

- **Assumption**: Since the company does not have a definite sales policy, it was assumed that half of lost production were to be sold in Zimbabwe at the current rate of US*$800.00 per tonne* and half in a European market at the prevailing rate of *$480.00 per tonne*. This gives an average selling price of *$640.00 per tonne*

5.1.2 Hourly labour cost, C_L

The hourly labour cost was calculated using the hourly rate of an artisan and two aides. The rates are ***US$8.52/hr*** and ***US$4.93/hr*** for artisan and aide respectively. For work requiring an artisan and two aides the total cost becomes:

$$C_L = \$8.52 + (2 \times \$4.93)$$

$$\boldsymbol{C_L = \$18.38\ per\ hour}$$

5.1.3 Material cost, C_M

Material cost is the sum of the cost of all spares used in the period under review. Table 2 lists the most significant material used and the associated costs during the period:

Table 2: Material costs

Material	Annual usage in US$	Four year costs
50mm High carbon steel Plate, *EN8*	*$100,183.00*	*$400,732.00*
Welding rods	*$25,375.00*	*$101,500.00*
Bearings	*$29,100.00*	*$116,400.00*
Total	*$154,658.00*	***$618,632.00***

- **Note:** Six (6) bearings were replaced during breakdown or corrective maintenance to imply \$58,200 as C_M for corrective maintenance and the difference from total being C_M for planned maintenance.

5.1.4 *Time parameters for Corrective maintenance,* $(t_d + t_a + t_r + t_{rs} + t_q)$

The ***80.75*** breakdown hours for the period of four years equal the sum of the time parameters used in equation (1). Thus for corrective maintenance;

$$80.75hrs = t_d + t_a + t_r + t_{rs} + t_q \quad \textbf{(4)}$$

- **Note**: From section 4.2, 80% of the downtime is spent as repair time, t_r; thus;

$$t_r = 0.8 \times 80.75$$

$$\boldsymbol{t_r = 64.6hrs}$$

5.1.5 *Time parameters for planned maintenance,* $(t_r + t_{rs})$

Time parameters of planned maintenance equal the product of the number of planned stoppages in a year, *S*, and stoppage hours per planned stop, *N*. Thus;

$$t_r + t_{rs} = S \times N \quad \textbf{(5)}$$

$$t_r + t_{rs} = 19 \times 8$$

$$t_r + t_{rs} = 152\ hrs\ per\ year$$

$$\boldsymbol{t_r + t_{rs} = 608\ hrs\ over\ a\ four\ year\ period}$$

- **Note:** Since most adinimistartive work is down prior to stoppage, 90% of the downtime is spent as repair time, t_r; thus;

$$t_r = 0.9 \times 608hrs$$

$$\boldsymbol{t_r = 547.2\ hrs\ over\ a\ four\ year\ period}$$

5.1.6 *Corrective maintenance cost calculation,* C_c

Using equation (1) and the actual times calculated for the shredder, the cost of corrective maintenance over a four (4) year period are;

$$C_c = C_{LP} \times (t_d + t_a + t_r + t_{rs} + t_q) + (C_L \times t_r) + C_M \quad \textbf{(6)}$$

$$C_c = (\$23{,}200.00 \times 80.75) + (\$18.38 \times 64.6) + \$58{,}200.00$$

$$\boldsymbol{C_c = \$1,932,787.35}$$

5.1.7 Planned maintenance cost calculation, C_p

Using equation (2) and the actual times calculated for the shredder, the cost of planned maintenance over a four (4) year period are;

$$C_p = C_{LP} \times (t_r + t_{rs}) + (C_L \times t_r) + C_M \quad \textbf{(7)}$$

$$C_p = (\$23{,}200.00 \times 608) + (\$18.38 \times 547.2) + \$560{,}432.00$$

$$\boldsymbol{C_p = \$14,676,089.54}$$

5.2 Maintenance cost calculation by the company

The company has been considering direct maintenance costs only in its maintenance costs model such that the total cost of maintenance was given as a summation of the material costs in table 2 of section 5.1.3 and labour costs for both planned maintenance and corrective maintenance as given in section 5.12. The total maintenance cost from the company's perspective was given by:

(8)

($ □□)

5.3 Cost of maintenance summary

The total cost of maintenance on the shredding unit totalled $16,608,876.89 in the four years under review against the company's view of a cost of $629,882.40. $1,932,787.35 which represents almost 13% of the total costs of maintenance was as a result of corrective maintenance.

6 CONDITION BASED MAINTENANCE (CBM) CONCEPTS

Condition based maintenance is a type of maintenance policy that considers the current real state of system degradation [12], [13]. CBM attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviours of a physical asset [15],[27]. CBM recommends maintenance actions based on the information collected through condition monitoring and attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviours of a physical asset [27].

6.1 CBM underlying principle

CBM predicts failure in equipment and optimizes its policy by monitoring the equipment's age and health condition [28]. De Carlo and Arleo [12] indicated that there are many measurable health degradation parameters that can be properly monitored and that different monitoring techniques allow keeping under control the operating parameters that are the most significant for the system degradation, in order to identify the most appropriate time for the execution of maintenance activities dynamically. According to Bengtsson [21] and Mobley [29], condition based maintenance serves the following two functions:

- to determine if a problem exists in the monitored item, how serious it is, and how long the item can be run before failure, and
- to detect and identify specific components in the items that are degrading and diagnose the problem.

Inspection can involve the use of human senses (noise, visual, e.t.c), monitoring techniques or function techniques [30]. The most common techniques are dynamic monitoring (vibration and sound), temperature monitoring, chemical monitoring, particle monitoring, physical monitoring, electrical monitoring and human inspection.

6.2 Condition monitoring for the shredding unit

The analysis in section 4.5 showed that the shredder rotor and lubrication oil pump accounted for 76% of shredding unit breakdowns. Monitoring of the bearing will most likely predict failure or stoppage linked to the rotor, while monitoring the lubrication oil circuit will also most likely predict failure linked to the lubrication oil pump.

6.2.1 Vibration and temperature monitoring for shredder rotor bearing

Vibration measures a rotating shaft's position relative to stationary components in order to guard against changes that would result in catastrophic contact [31]. Vibration is also considered by SKF [31] and Cibulka et al [32] as the best operating parameter to judge dynamic conditions such as balance, bearing stability, and stress applied to components since many machinery problems manifests as vibration. Vibration monitoring on shredder bearing can successfully monitor the behaviour of the rotor thus predicting failure and avoiding unplanned stoppages.

According to SKF [31], temperature measurement is a useful indicator of the mechanical condition of a specific component, such as a bearing. The temperature of a bearing will rise due to friction when it starts to fail. Temperature monitoring on shredder bearing can also successfully monitor the performance of the rotor.

6.2.2 Pressure monitoring for lubrication oil circuit

Pressure monitoring of the lubrication oil circuit by trending the differential pressure across the supply will successfully monitor the lubrication oil pump and oil circuit functionality. Pressure monitoring of the oil circuit should therefore be considered for monitoring performance of the lube oil pump.

6.3 Potential benefits of CBM on shredding unit

If CBM were to be applied on the shredding unit, one direct benefit would be a direct reduction of the corrective maintenance costs due to the failure prediction nature of CBM. Since the CBM system will focus on shredder rotor and the lubrication oil circuit, it can be assumed that the system will likely predict at most 76% of the shredder breakdowns. This will also lead to a corrective maintenance cost reduction of at most 76% of the current costs, translating to potential savings of $1,468,918.39 over a four year period

7 FINDINGS

The following findings were noted on the current maintenance plan:

1. **Planned maintenance -** All maintenance work carried out on the shredding unit is primarily planned maintenance work and cost $14,676,089.54 in the past four years against the company's view of a total cost of maintenance of $629,882.40 . The planned maintenance work was carried out eight (8) hours every fortnight for a 38 week production season. A further 14 weeks was spent on major planned maintenance work every year.
2. **Corrective maintenance -** Corrective maintenance work that was done on the shredding unit cost $1,932,787.35 in same period. An analysis of the breakdowns that warranted corrective maintenance showed that two causes of breakdowns accounted for 76% of the total downtime due to breakdowns. The two were shredder rotor and lubrication oil pump.
3. **Shortcomings of current maintenance plan** – Despite having a comprehensive maintenance plan in time based (planned) maintenance, the sugar producing company was incurring a further 13% of its budgeted planned maintenance costs on the shredding unit due to corrective maintenance (i.e. $1,932,787.35). The added costs on corrective maintenance is an indication of a deficiency in the current maintenance plan

8 RECOMMENDATIONS

The following were recommended in order to improve the maintenance operations.

1. **Adoption of Condition Based maintenance -** Due to the high level of unexpected failure in cost terms on the shredding unit and the likely benefits of CBM, it is recommended that the Zimbabwean sugar producer adopts CBM as a maintenance strategy on the shredding unit. CBM recommends maintenance actions based on the

information collected through condition monitoring and attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviours of a physical asset [27]. The nature of CBM is such that it predicts a failure and thus avoiding unexpected failures and plant stoppages. This will likely reduce the cost of maintenance by at least 13 % through eliminating the current cost of corrective maintenance and also reducing the current cost of planned maintenance. However a feasibility study and cost befit analysis to consider the life cycle costs of implementing CBM against the costs of the existing maintenance plan should be done before changing to CBM. The cost benefit analysis should cover issues like setup costs of a CBM system, operational or running costs, training and support services among other things.

2. **Focus of the proposed CBM system** – the proposed CBM system should focus on the two major causes of breakdowns on the shredding unit i.e. rotor and lubrication oil problems. The CBM system should successfully monitor vibration and temperature of the rotor bearing and oil pressure in the lubrication oil circuit in order to eliminate at most 76% of the breakdown causes.

9 CONCLUSION

The paper has shown that the Zimbabwean sugar manufacturer is employing a hybrid of planned maintenance and corrective maintenance on the shredding unit. The corrective maintenance is resulting in an additional maintenance cost of 13% to the already huge planned maintenance bill. These maintenance cost figures are discouraging in a sugar market that is characterised by diminishing prices and stiff competition from South America. In order to optimize the maintenance operations of the sugar producer, the paper has recommended adoption of a condition based maintenance system on the subject asset.

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DEVELOPMENT OF A CONDITION BASED MAINTENANCE SYSTEM FOR A SUGAR PRODUCING COMPANY

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ABSTRACT

With globalisation taking centre stage in almost every market; traditionally monopolistic manufacturing companies in Zimbabwe are struggling to compete with international companies whose operations are optimised. This paper focuses on maintenance practises of a Zimbabwean sugar manufacturer with an aim to improve the company's asset care plans. The company's current maintenance philosophy and its shortcomings on certain equipment in the plant were identified together with the associated annual maintenance costs. A Pareto analysis on the equipment's breakdown history was used to determine the conditions that can be monitored using Condition Based Maintenance (CBM); and experiments to establish the feasibility of monitoring these conditions were done. The paper then recommends and proposes a CBM system replete with its three main elements of data acquisition, data processing and maintenance decision making to reduce breakdowns on the subject equipment by at most 76%.

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1 INTRODUCTION

The manufacturing sector's contribution to the Gross Domestic Product (GDP) of Zimbabwe fell to 12% from a previous 30% and its contribution to exports dropped significantly by 24% to 26% in 2012 [1]. These figures indicate a huge threat to the continued existence of the manufacturing industry. The sugar industry of Zimbabwe represents a subset of the manufacturing sector that has been the latest victim of competition due to globalisation. Competition from international sugar producing companies has intensified; it has not only affected the international market of the local producers, but has also affected the local sales.

The pressure for optimising operations for this industry in order to at least regain the local market is very high. This study is a follow up on prior work that focused on the current maintenance plan being employed on a cane shredding unit by one of the sugar producing companies in Zimbabwe, with a view of optimisation. The initial study outlined the shortcomings of the current maintenance plan in cost terms and recommended that condition based maintenance (CBM) be implemented on the equipment. The paper lays the ground work for the development of a CBM system. A Pareto analysis on the equipment's breakdown history was used to determine the conditions that can be monitored in a Condition Based Maintenance (CBM) system. Experiments to establish the feasibility of monitoring these conditions were done. A CBM system was proposed using the results from experiments and a cost benefit analysis of the company's customary time based and corrective maintenance to the proposed CBM system on the subject equipment was used to show a probable significant reduction in annual maintenance costs should the CBM be implemented.

2 CONDITION BASED MAINTENANCE

Condition based maintenance is a type of maintenance policy that considers the current real state of system degradation [2, 3, 4, 5]. Jardine et al. [6] describe CBM as a maintenance program that recommends maintenance actions based on the information collected through condition monitoring. CBM recommends maintenance actions based on the information collected through condition monitoring and attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviours of a physical asset [7].

2.1 CBM underlying principle

CBM predicts a failure in equipment and optimizes its policy by monitoring the equipment's age and health condition [8]. De Carlo and Arleo [2] indicated that there are many measurable health degradation parameters that can be properly monitored and that different monitoring techniques allow keeping under control the operating parameters that are the most significant for the system degradation, in order to identify the most appropriate time for the execution of maintenance activities dynamically. According to Bengtsson [7] and Mobley [9], condition based maintenance serves the following two functions:

- to determine if a problem exists in the monitored item, how serious it is, and how long the item can be run before failure, and
- To detect and identify specific components in the items that are degrading and diagnose the problem.

Inspection can involve the use of human senses (noise, visual, e.t.c.), monitoring techniques or function techniques [4].

2.2 Condition monitoring

Borresen [10] defines condition monitoring as a technique that uses equipment to monitor other equipment and can be viewed as a highly sensitive version of human senses. Bengtsson, [7] considers condition monitoring as a central part of condition based maintenance and defines it as an activity - performed either manually or automatically - intended to observe the actual state of an item; and is normally performed in an operating state of the item. The purposes of condition monitoring are to collect equipment condition data thus detecting incipient failure so that maintenance tasks can be planned at a proper time and to increase the knowledge of failure cause and effect and deterioration pattern.

2.3 Techniques for condition based maintenance

There are quite a number of monitoring techniques that can be used to measure equipment condition. These techniques are classified according to the symptoms they are designed to detect [7, 10, 11, 12]:

- **Dynamic monitoring -** monitoring condition such as such as vibration and sound. Amplitude sensors are used for the lower range frequencies, velocity sensors are used for middle range frequencies while accelerometers are used for high frequencies.
- **Temperature monitoring** – monitors temperature rises in the equipment. Measurements are done through thermocouples and / or resistance temperature detectors.
- **Chemical monitoring** – monitoring chemicals released into the environment. Detects elements in fluids, usually lubrication oil. Chemical monitoring can detect wear, leaks and corrosion
- **Particle monitoring -** monitoring particles released into the environment. This type of monitoring will be able to detect wear, fatigue, corrosion and contaminants
- **Physical monitoring** – monitors physical effects, such as cracks, fractures, wear, and deformation.
- **Electrical monitoring** – monitors electrical effects, such as resistance, conductivity, dielectric strength, and equipment used etc.
- **Human inspection -** this is the most basic monitoring technique and is based on human senses

2.4 Setting limits in condition monitoring

Limits for conditions being monitored are set by the equipment user, with guidance from the original equipment manufacturer. Numerous standards also exist to guide on limits for condition monitoring – for instance vibration monitoring and analysis has two ISO standards namely [13]:

i. **ISO/10816 series** – the series consist of six (6) parts on: mechanical vibration – evaluation of machine vibration by measurements on non-rotating parts

ii. **ISO/7919 series -** the series consists of five (5) parts on: mechanical vibration of non reciprocating machines

Where there are no standards or information from the original equipment manufacturer, experiments can be used to determine the limits for condition monitoring.

3 THE CBM SYSTEM

Bengtsson [14] defines a CBM system as an arrangement that uses condition based maintenance to determine and schedule predictive maintenance actions autonomously or in interaction with other systems or humans. Chalwa and Kumar [15], Romesis and Li [3], Zhu et al [16]and Jardine et al[6] summarize a condition based maintenance system as consisting of three main steps namely data acquisition, data processing and maintenance decision making.

3.1 Benefits of CBM

In their case study for gas turbine plants, Romesis and Li [3]estimated savings of 1–3% of operating costs, due to efficient condition monitoring and CBM; which resulted in an overall cost reduction of up to $1 million per annum. The benefits extended beyond cost-efficient plant operation to increased safety, asset reliability and availability. Based on a case study on HVAC system by De Carlo and Arleo [2], corrective maintenance (CM) was found to be the type with the highest cost because of the times and costs due to unscheduled stops. When Planned maintenance (PM) was a potential choice, it was found important to identify the best PM interval time; otherwise there would be a risk of choosing wrong time intervals for the maintenance activities; which would lead to PM being even worse than CM in terms of costs [2]. De Carlo and Arleo [2]further showed that CBM is associated with the lower average unit cost compared to PM and CM. Chalwa and Kumar [15] reckon that if CBM is properly established and implemented, it can significantly reduce maintenance cost by reducing the number of unnecessary scheduled preventive maintenance operations.

Case studies of the application of CBM resulted in the following benefits to institutions:

- **Reduced maintenance costs** – De Carlo and Arleo [2]give a reduction of between 29 – 75% compared to planned maintenance; Bengtsson [7]gives the reduction as 25 - 30%; Taylor [17]gives the reduction as 7 – 60% compared to planned maintenance;
- **Reduction in production losses** – Bengtsson [7] gives a reduction of 20-25%; Besnard [4]gives a reduction of 50% for wind turbines; Taylor [17]gives an increase in production by 2 - 40% compared to planned maintenance; Romesis and Li [3]give a reduction in production costs of between 1 -3 % for gas turbine plants; Telford et al [18]gives an additional production benefits in the range of 5% for oil and gas industry
- **Breakdown elimination** – Bengtsson [7]gives it as 70 - 75%; Taylor [17] gives it as 33 - 45% compared to planned maintenance;
- **Increase in return on investment** – Taylor [17]gives it as 4 – 30 times compared to planned maintenance; Bengtsson [7] mentions that CBM maximises return on investment

4 CHOOSING THE BEST MAINTENANCE PHILOSOPHY – THE METHOD

Despite the apparent benefits and advantages of CBM compared to other maintenance types as outlined by most authors, the decision to adopt CBM should be based on real cost comparison between CBM and its competing maintenance types. In his thesis, Borresen [10] used a Cost-Benefit Analysis to compare costs of maintenance when using either corrective maintenance, planned maintenance or condition based maintenance.

4.1 Cost Benefit Analysis (CBA)

A cost benefit analysis is done to weigh whether a planned action is profitable or not [10]. A CBA is a conceptual framework for the evaluation of an item which tries to consider all gains and losses from for the item; and it expresses costs and benefits in the common metric of today’s money [19]. Costs are subtracted from benefits to obtain the net benefits of the policy, if the net benefits are negative; they are referred to as net costs [20]. The following is the formula for calculating net benefits;

$$- \quad (1)$$

5 CASE STUDY

A feasibility study of implementing a condition based maintenance (CBM) system on certain equipment was done for a sugar factory of one of Zimbabwe's sugar producers. A cane shredder, which is an equipment/unit within the sugar production line of the company, was used in order to simplify the study.

5.1 Background

The CBM feasibility study was a follow up on prior work that focused on the current maintenance plan being employed on the same equipment and its shortcomings. The following were the findings from the initial work;

- Planned maintenance was being employed on the shredder and had cost US$14,676,090 over a period of 4 years
- An equivalent of 13% ($1,932,787.35) of planned maintenance cost was further incurred on corrective maintenance on the same equipment during the same period

Due to these high cost figures of the current maintenance plan and the benefits of CBM in terms of costs reduction; it was recommended that CBM be adopted on the shredder with a view of maintenance optimisation.

5.2 Methodology

A Pareto analysis on the equipment breakdowns was used to determine the most significant breakdowns which would form basis for condition based maintenance. This determined the parameters that needed to be monitored in the CBM system. Experiments to determine the possibility of data acquisition using embedded sensors were carried out while the machine was running. An implementation matrix of the CBM system was developed using experimental results and this was followed by a cost benefit analysis of the CBM system against the existing hybrid of time based and corrective maintenance.

6 THE PARETO ANALYSIS ON SHREDDER BREAKDOWNS DOWNS

A Pareto analysis is a statistical tool in decision making that is used for the selection of a limited number of factors that produce significant overall effect [21]. The purpose of the shredder is to complete the preparation and disintegration of the cane, so as to facilitate the extraction of cane juice by the mills [22]. A total of 80.75 hours were recorded in the period under review. A Pareto analysis of the causes of breakdowns was used to determine the factors or causes that warranted the most attention and those factors which had a relatively smaller effect. The factors were classified into seven major categories according to the part or section on the equipment that is affected whenever the breakdown occurs on the shredder. The diagram below shows the Pareto analysis of the breakdowns;

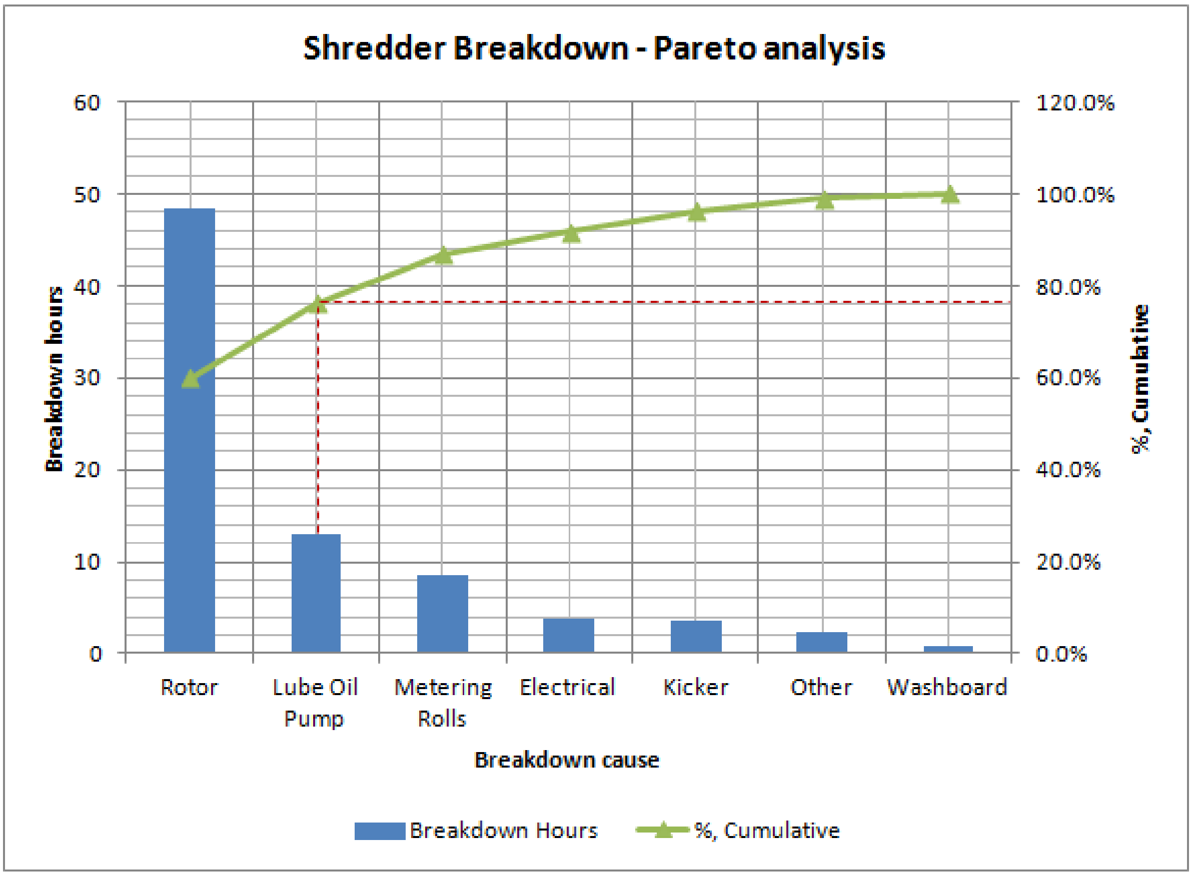

Figure 1: Pareto analysis of shredder breakdowns

6.1 The Pareto analysis summary

The analysis showed that the failures of the shredder rotor and lubrication oil pump accounted for 76% of the breakdowns. The results led to a recommendation to focus condition based maintenance on the two equipment on the shredding unit rather than on low incidence ones.

7 CONDITIONS TO BE MONITORED

The conditions to be used to monitor the rotor and the lube oil pump must be able to detect early forms of degradation or malfunction on the rotor and lubrication oil pump or oil circuit. As noted by Bengtsson [7], the purposes of condition monitoring are:

i. To collect rotor and lubrication oil pump condition data thus detecting incipient failure so that maintenance tasks can be planned at a proper time.

ii. To increase the knowledge of failure cause and effect and deterioration pattern.

7.1 Rotor bearing monitoring

To successfully monitor the behaviour of the shredder rotor, the performance of the bearing was considered. Six bearings were replaced during breakdown maintenance in the period under review. Monitoring of the bearing will most likely predict failure or stoppage linked to the rotor

7.1.1 Vibration monitoring for shredder rotor bearing

Vibration measures a rotating shaft's position relative to stationary components in order to guard against changes that would result in catastrophic contact [23]. Vibration is also considered by SKF [23] and Cibulka et al [24] as the best operating parameter to judge dynamic conditions such as balance, bearing stability, and stress applied to components since many machinery problems manifests as vibration. Vibration monitoring on shredder bearing was thus chosen to monitor the behaviour of the rotor

7.1.2 Temperature monitoring for shredder rotor bearing

According to SKF [23], temperature measurement is a useful indicator of the mechanical condition of a specific component, such as a bearing. The temperature of a bearing will rise due to friction when it starts to fail. Temperature monitoring on shredder bearing was also chosen to monitor the performance of the rotor.

7.2 Lubrication oil circuit monitoring

In order to successfully monitor the behaviour of the lube pump, the oil circuit was considered. Monitoring the oil circuit will most likely predict failure or stoppage linked to the lube oil pump.

7.2.1 Pressure monitoring for lubrication oil circuit

Pressure monitoring of the lube oil circuit by trending the differential pressure across the supply will successfully monitor the lube pump and oil circuit functionality. Pressure monitoring of the oil circuit was chosen to monitor the performance of the lube oil pump.

8 EXPERIMENTS

Experiments were carried out to assess the feasibility of successfully monitoring vibration and temperature on the rotor bearing; and pressure on the lubrication oil circuit. The experiments were based on a temporary periodic monitoring exercise where measurements were taken for the three parameters (vibration, temperature and pressure) at regular time intervals. The overarching objectives of the three experiments were to:

- To determine the normal vibration level for cane shredder bearings
- To determine the normal operating temperature for cane shredder bearings Drive end (DE) and Non – Drive end (NDE)
- To determine the normal operating pressure for lube oil in the bearings of a cane shredder

Figures 2a-c below shows the graphical representation of the experiment results which are further summarised in Table 1. Figures 3 and 4 show the experiments being conducted. Results are for drive end (DE) and non drive end (NDE) rotor bearings and the lubrication oil circuit.

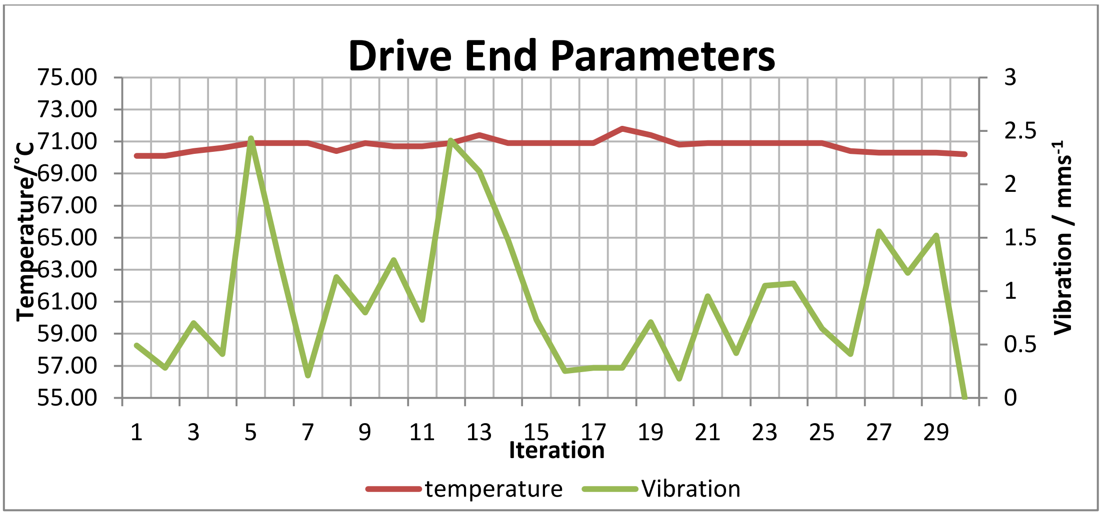

Figure 2a Drive Ends Parameters

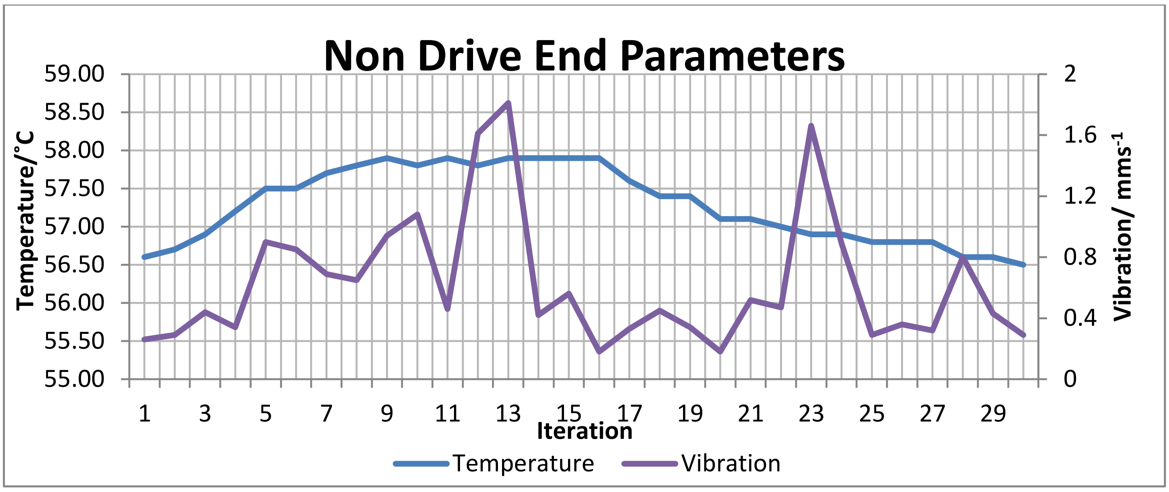

Figure 2b Non Drive End Parameters

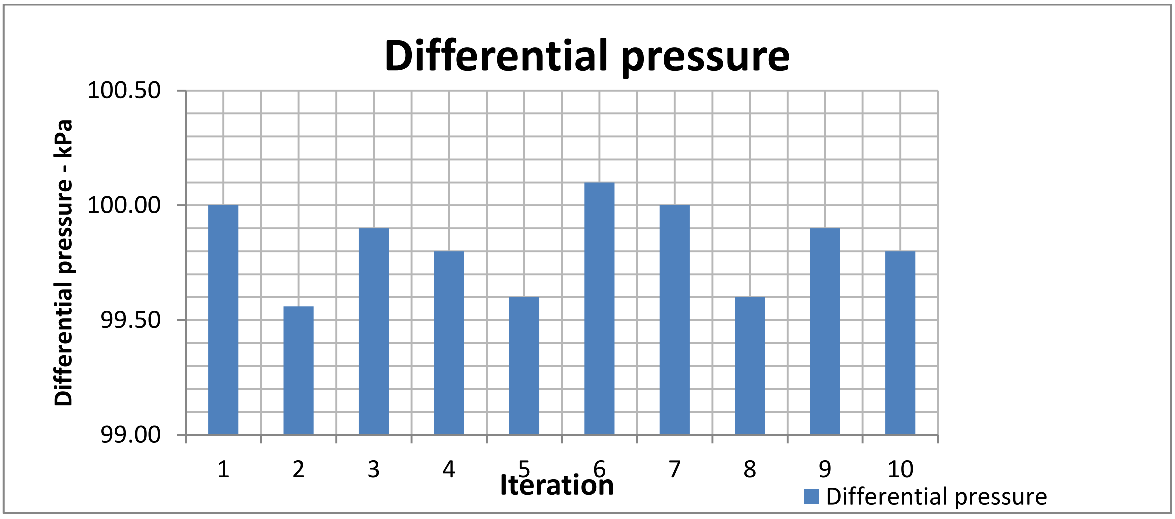

Figure 2c Differential Pressure

Figure 3: Vibration Measurement Using a Handheld Meter

Figure 4: Temperature monitoring using a handheld meter

8.1 Discussion of Results

The normal operating levels for vibration, temperature and pressure for the machine were determined. These values were used for the generation up fuzzy rules for machine health diagnosis in the design stage of the study. Table 1 below is a summary of the three experiments which include apparatus used and the observed results.

Table 1: Experiments results

Experiment	Equipment used	Measurements / intervals	Results		
				DE	NDE
Vibration in mm/s	Handheld vibration meter (velocitometer)	30	Average Standard deviation	0.931 0.63	0.627 0.434
Temperature in °C	Handheld RTD meter (resistance temperature detector)	30	Average Standard deviation	70.75 0.39	57.28 0.49
Pressure in kPa gauge	0 -10 bar Differential pressure (DP) cells	10	Average Standard deviation	99.83 0.189	

8.2 Time period for iterations

Temperature and vibration iterations were done over a time period of 15 hours, with thirty (30) minute intervals from 8am to 10pm inclusive on a single day. Pressure measurements were done over a period of 10 hours, with one (1) hour intervals from 8am to 5pm inclusive.

9 PROPOSED CBM SYSTEM

In identifying the major causes of breakdowns and doing experiments to assess feasibility of condition monitoring on the shredder; the ground work for developing a condition based maintenance system was done. The limits on bearing temperature and vibration and lube oil pressure are determined using manufacturer's catalogues, literature and experiments carried on the shredder. Appendix A with fuzzy rules deduced from experiments should be used as the reference in the design of the CBM architecture for the shredder.

9.1 CBM Modules communication

The concept used in designing the CBM system for the cane shredder will be based on the Open System Architecture (OSA-CBM) by the Information Management Open Standards Alliance [25]. Sensors acquire vibration, temperature and oil pressure data from the shredding unit then they pass the data on to the PLC which analyses it for ascertaining the condition of the shredder. Alarms and other diagnostic decisions will be displayed on the HMI. The shredder lubrication oil and bearings useful remaining life (RUL) can be predicted by algorithms programmed in Microsoft Access VBA.

The data acquisition module is linked to the PLC which does diagnosis. Communication between the PLC and the windows application is facilitated by a lean 7 OPC server. To introduce some flexibility, this system will be designed to be accessed online using custom defined web pages crafted using HTML. The inbuilt web server facilitates access of the CPU data on the web. The proposed condition based maintenance system architecture and link between modules is summarized in Figure 5.

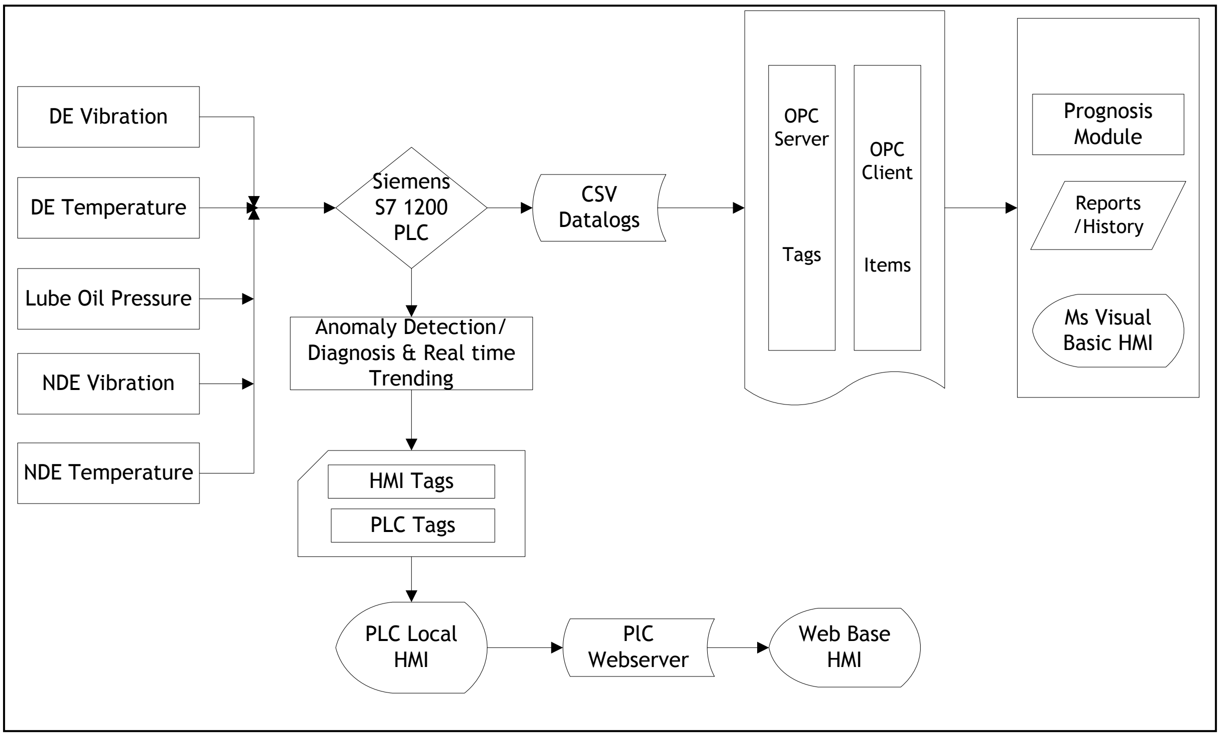

Figure 5: CBM System Architecture for a Cane Shredder

9.2 The anticipated benefits of the CBM system

The anticipated benefits of the proposed CBM system are the difference between the cost of setting up and running the system, to the potential savings realized by adopting the system. Since the CBM system will be in used on the shredder only, with the rest of the production line on planned maintenance; the cost of running the CBM system will be assumed to be equal to that of running the planned maintenance considering overheads such as labour, material and lost productivity due to planned maintenance downtime will still be incurred.

1. **Set up costs of the CBM system**
   Set up costs are those costs associated with purchase of equipment and hardware for the CBM system. Table 2 summarizes the setup costs for the proposed CBM system based on a quotation obtained from an instrumentation equipment supplier.

Table 2: CBM setup costs

Item	Cost in US$
Controller	768.98
Sensors	8,276.65
I/O modules	1,402.88
Total	**10,448.51**

2. **Potential saving – reduction in corrective maintenance costs**
   Given that the proposed CBM will be focusing on 76% of the equipment failures causing breakdowns (i.e. from Pareto analysis); it is assumed that at least half (38%) of the breakdowns will be predicted by the CBM system, thus also reducing corrective maintenance costs by 38%. This gives a reduction in corrective maintence cost over a four year period (CM_{CBM}) of;

9.3 The Net Present value

The net present value (NPV) of implementing CBM is given in table 3. A discount rate of 12.5% per annum reflecting the average lending interest rate charged by local banks in Zimbabwe was used in discounting the potential savings in the four years [26].

Table 3: Net Present Value of CBM implementation

Year	Net Cash flow	Discount factor	PV
0	(USD 10,448.51)	1	(USD 10,448.51)
3	USD 734,459.19	0.702	USD 515,834.16
Net Present Value			**USD505,385.65**

10 CONCLUSION

The study has identified the major causes of breakdowns on the shredder. A breakdown analysis was the basis for recommending the conditions to be monitored. It has also shown - through experiments - the operating levels of three parameters that had been recommended for condition monitoring (vibration, temperature and pressure). Alarm events that warn when defined values of vibration, temperature and pressure have been reached and trips that define thresholds beyond which operation may cause damage to equipment were proposed. The paper has further proposed the implementation of CBM system and summarised how it will work in order to optimize maintenance operations of the sugar producer. The Pareto analysis suggests that the proposed CBM system will be focussing on 76% of the equipment failures resulting in breakdowns. If the CBM system successfully predicts half (38%) of equipment failures, then USD505, 385.65 will likely be saved over a four year period.

Appendix A: Shredder fuzzy rules

SHREDDER STARTING FUZZY RULES	
Situation	**Fuzzy Set**
Oil pressure too low (Below 70kPa)	Prohibit Shredder Start
D.E or N.D.E bearing temperature above 100˚C	Prohibit Shredder Start
SHREDDER CONDITION DIAGNOSIS FUZZY RULES	
D.E Bearing Temperature	**Fuzzy Set**
73˚C	OK
74 - 89˚C	Low level Temperature Alarm
90 - 119˚C	High level Alarm (Shutdown in 10 minutes)
>120˚C	Critical Pressure (Horn + System shutdown)
N.D.E Bearing Temperature	**Fuzzy Set**
59˚C	OK
60 - 89˚C	Low level Temperature Alarm
90 - 119˚C	High level Temperature Alarm (Shutdown in 10 minutes)
>120˚C	Critical Temperature (Horn + System shutdown)
D.E and N.D.E Vibration	**Fuzzy Set**
<1.8 mm/s	OK
1.9 – 4.5 mm/s	Low level Vibration Alarm
4.5 – 8.4 mm/s	High level Vibration Alarm (Shutdown in 10 minutes)
>8.4mm/s	Critical Vibration (Horn + System shutdown)
Oil Pressure	**Fuzzy Set**
98 - 105kPa	OK
81 – 97kPa	Low level Lube Alarm
71 – 80kPa	High level Lube Alarm (Shutdown in 10 minutes)
<70kPa	Critical Pressure (Horn + System shutdown)
SHREDDER FAULT CLASSIFICATION	
Condition	**Fault Class**
D.E and N.D.E vertical, axial and horizontal vibration below 1mm/s	Shredder OK
D.E or N.D.E Excessive Vertical Vibration ≥ D.E or N.D.E Excessive Horizontal Vibration	Rotor Imbalance
D.E or N.D.E Excessive Axial Vibration > D.E or N.D.E Excessive Horizontal Vibration,	Coupling Misalignment
D.E or N.D.E Excessive Horizontal Vibration > D.E or N.D.E Excessive Axial Vibration	Looseness
If oil lube oil pressure is less than 90kPa	Lube oil system faulty

If D.E and N.D.E temperatures are both above 75˚C and 60˚C respectively	Lube oil system faulty
If D.E or N.D.E temperatures is above 75˚C and 60˚C respectively while lube pressure is above 90kPa	Excessive Vibration Wear

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DESIGN OF AN INTELLIGENT FUZZY LOGIC- PID BASED BIOREACTOR CONTROL SYSTEM FOR AN AUTOMATED 50TPD ORGANIC FERTILISER PRODUCTION PLANT WITH AID OF A BM1 ENZYME

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ABSTRACT

Temperature control is crucial for enzyme reactions as changes in temperature can bring a reaction to a complete stop thus killing the enzyme. The greatest challenge on regulating bioreactor conditions is that one has to eliminate percentage overshoot, long rise time and unforeseen transient responds. The main goal of this research was to design a complete control system with aid of hybridized Parallel Structure Fuzzy Logic-PID control algorithm so as to control the enzyme activity in a 50TPD bioreactor for organic fertilizer manufacturing. To achieve this, temperature, pH, pressure and moisture analysis experiments were carried out. Experiments were also done on characterizing the intended raw materials. Process parameters were deduced through modeling and simulation in Matlab and Simulink environments. To a greater extend a process with recommendable rising time; no steady state error and recommendable transient response with no-overshoot was achieved. In comparison with conventional PID controllers the proposed system shows higher control gains when states are away from equilibrium and at the same time retains a lower profile for control signals.

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1 INTRODUCTION

In recent years, fuzzy logic control, mainly fuzzy proportional –integral-derivative controllers have been widely used for industrial applications owing to their heuristic nature associated with simplicity and effectiveness for both linear and non-linear systems [1]. Thus because of the nonlinear property of control gains, fuzzy-PID controllers possess potential to improve and achieve better system performance over the conventional PID controller if the nonlinearity can be suitably utilised.

The paper presents the intelligent control system design of an automated organic fertilizer production plant with an output of 50 tons per day from organic waste with the aid of BM1 enzyme. Section 2 of the paper presents the related literature regarding the design, Section 3 presents the design of the biodigester, Section 4 presents modeling and simulation of the design lastly conclusions and recommendations regarding the design were made.

2 RELATED LITERATURE

This section focuses on the essential theory and critical assessment of the related work needed for the development of the design, it also seeks to present the main arguments and publications by different experts on the subject of automation, fuzzy logic and organic fertilizer production and how it can be used to develop a design which is beneficial and economical.

2.1 Fuzzy Logic Control

In control systems there are a number of generic systems and methods which are encountered in all areas of industry and technology. From the dozens of ways to control any system, it turns out that fuzzy is often the very best way. The only reasons are faster and cheaper. Rajkumar [2] believed that fuzzy logic is a part of artificial intelligence or machine learning which interprets a human's actions. Computers can interpret only true or false values but a human being can reason the degree of truth or degree of falseness. Fuzzy models can interpret the human reasoning and are referred to intelligent systems. Fuzzification is the process of changing a real scalar value into a fuzzy value. This is achieved with the different types of fuzzifiers. Fuzzification of a real-valued variable is done with intuition, experience and analysis of the set of rules and conditions associated with the input data variables.

According to Waznaik [3] fuzzy or multi-valued logic was introduced in the 1930s by Jan Lukasiewicz, a Polish philosopher. While classical logic operates with only two values 1(true) and 0(false), Lukasiewicz introduced logic that extended the range of truth values to all real numbers in the interval between 0 and 1. He used a number in this interval to represent the possibility that a given statement was true or false. Later in 1937, Max Black proposed a concept of “Vagueness; an exercise in logical analysis”. In his defence, he argued that a continuum implies degrees. He accepted vagueness as a matter of probability.

The term fuzzy logic is used in two senses:

- *Narrow sense:* Fuzzy logic is a branch of fuzzy set theory, which deals (as logical systems do) with the representation and inference from knowledge. Fuzzy logic, unlike other logical systems, deals with imprecise or uncertain knowledge. In this narrow and perhaps correct sense, fuzzy logic is just one of the branches of fuzzy set theory.
- *Broad Sense:* fuzzy logic synonymously with fuzzy set theory

Wei [1] acknowledged that fuzzy system was first proposed by an American professor, Lotfi A. Zadeh, in 1965 when he presented his seminal paper on "fuzzy sets". Zadeh showed that fuzzy logic unlike classical logic can realize values between false (0) and true (1).Basically, he transformed the crisp set into the continuous set. Zadeh extended the work on possibility theory into a formal system of mathematical logic, and introduced a new concept for applying natural language terms, and he became the "Father" of fuzzy logic. Fuzzy sets thus have movable boundaries. The elements of such sets not only represent true or false values but also represent the degree of truth or degree of falseness for each input.

Fuzzy control systems interpret the expert human and replace them for performing certain control and regulation tasks. Fuzzy controllers apply decision rules (if-then rules) by making use of critical variables to interpolate the output between the crisp boundaries. Cox [4] developed a more realistic ideology which stated that fuzzy logic is not logic that is fuzzy, but logic that is used to describe fuzziness. Fuzzy logic is the theory of fuzzy sets, sets that calibrate vagueness. It is based on the idea that all things admit of degrees. In other words, fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership.

Fuzzy logic reflects how people think. It attempts to model our sense of words, our decision making and our common sense. As a result, it is leading to new, more human, intelligent systems. As opposed to the modern control theory, fuzzy logic design is not based on the mathematical model of the process. The controller designed using fuzzy logic implements human reasoning that has been programmed into fuzzy logic language (membership functions, rules and the rule interpretation). It is interesting to note that the success of fuzzy logic control is largely due to the awareness to its many industrial applications.

2.2 Fertiliser processing techniques

The processing of organic fertilizers can be categorized into either anaerobic or aerobic processing.

2.2.1 Anaerobic

In anaerobic decomposition, the breakdown of the organic material is caused by enzymes, bacteria and fungi that thrive in low or no-oxygen conditions. It is the type of decomposition that takes place in closed containers. This type of system is more complex and difficult to control and requires complex equipment for larger scale decomposition of organic matter. Salminen and Rintala [5] stated that advantages of the process are, among others, production of biogas and its use in energy production as well as production of a solid end product which can be used as fertilizer, soil improvement material. Thus Hessami [6] subdivided the process of anaerobic digestion into three separate steps each of which is performed by a different group of microorganisms:

- *Hydrolysis*

In the hydrolysis stage the non-air breathing bacteria, (hydrolytic bacteria) use enzymes to breakdown and liquefy insoluble organic polymers such as carbohydrates, cellulose, proteins and fats. The insoluble organic polymers except proteins are then hydrolyzed to sugars which further decompose to form carbon dioxide, hydrogen, ammonia and organic acids. The latter decomposes to form ammonia, carboxylic acids and carbon dioxide.

- *Acidogenesis*

During this stage the organic acids formed during hydrolysis are converted to acetic acid by acetogenic micro-organisms. At the end of acidogenisis carbon dioxide and hydrogen concentrations start to decrease.

- *Methanogenesis*

The final stage produces 60% Methane and 40% carbon dioxide from the organic acids and other derivatives produced during acidogenesis of the digestion process. The methane is a useful source of fuel and methanogenic bacteria plays a further role in maintaining broad breakdown processes.

Anaerobic disintegration can be very useful to treat arising organic waste such as sewage sludge, organic farm waste, municipal solid wastes, green /botanic wastes, organic and industrial wastes.

2.2.2 Aerobic

In aerobic decomposition, bacteria and fungi which thrive in high oxygen conditions are responsible for the decomposition. This form of decomposition occurs in open organic waste heaps and organic filled containers that allow air to enter. With open heaps and more ventilated containers, organic fertilizer can be formed in a matter of a few months, and even faster if the organic material is turned regularly [5].

2.3 Developed designs and existing systems in organic waste processing

Some of the ideas that have been implemented in organic waste processing include *composting, vermicomposting* and *bio-digestion.* The paper will acknowledge the existence of other waste processing techniques such as composting and vermicomposting however only bio-digestion was considered.

2.3.1 Bio-digestion

Bio-digesters are natural systems that use organic waste, primarily manure, to produce biogas (fuel) and biol (natural fertilizer) by means of anaerobic digestion. Biol is a by-product which consists of a mixture of manure and water that has fermented in the bio-digester. Biol is a liquid fertilizer that can completely replace chemical fertilizer. Biogas as the main product can be used for industrial or domestic purposes to release energy. The process can be wet or dry digestion catalyzed by enzymes or bacteria.

- ***Wet*** – involves dilution of organic matter with a large volume of water.
- ***Dry***–does not involve any dilution with large volume of water. Such systems do not use agitators but may have a slow-speed turner to encourage release of the biogas generated within the mass.

Digestion of manure with other substrates such as food industrial wastes, animal by-products (slaughterhouse waste), or sewage sludge can be highly advantageous which is termed Co-digestion. Acording to Braun and Wellinger [7] some of the benefits include improved balance of total organic carbon, nitrogen, and phosphorous nutrients, which results in a stable and maintainable digestion process and good fertilizer quality.

The typical dairy farm biogas contains approximately 55% to 70% CH_4 and approximately 30% to 45% CO_2. The theoretical CH_4 to CO_2 ratios of various substrates were determined by Jewel [8] using the following equation, developed by McCarty [9]:

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right)H_2O \rightarrow \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right)CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right)CH_4 \qquad (1)$$

Readily degradable substrates (urea, fats, and proteins) yield the highest percentages of CH4. However Salminen and Rintala [5], augured that, the fats and proteins available from industrial wastes such as slaughterhouse and rendering operations may, in high concentrations, inhibit the anaerobic digestion process through the accumulation of volatile fatty acids and long chain fatty acids.

2.4 Digester catalyst (Enzyme)

The catalyst can either be a bacteria or an enzyme, however this paper presents a design based on the enzyme although a benchmark was done using a bacteria.

Bacteria are organisms which are single—celled, meaning that they do not have organelles such as a nucleus, where its cells are enclosed in a cell wall which is rigid. They contain all genetic material to reproduce through cellular division. They also show energy-related metabolism and a wide range of nutrient requirements in which some require only minerals and a carbon source such as sugar, while others require more complex growth nutrients. Bacteria play a role in recycling nutrients in the environment during waste digestion. They break down organic matter into simple compounds like carbon dioxide, water, and they cycle important nutrients such as nitrogen, sulfur and phosphorus during the same process. They have a capability of migrating to areas that are rich in specific nutrients for their growth if need be. They are also able to attach themselves to surfaces and form communities. These communities are known as biofilms.

Bacteria can be classified into:

- *Mesophilic anaerobic bacteria*- It means bacteria which can develop in the absence of oxygen and at room temperatures in the range 20°C to 40°C.
- *Thermophilic anaerobic bacteria* - It means bacteria which can develop in the absence of oxygen and at room temperatures in the range 45°C possibly up to 85°C.
- *Heterotrophic anaerobic bacteria* – means bacteria which can assimilate organic carbon-containing sources using oxygen as an energy source which consequently can develop on such sources.

When used in processing of organic waste the type of bacteria used are thermophilic anaerobic bacteria, at a temperature in the range 45°C to 85°C preferably in the range 50°C to 75°C. By use of such a temperature, it eliminates pathogenic germs which include bacteria, yeasts, protozoa, or viruses present if any in the organic waste when it is introduced into a digestion reactor, while allowing the thermophilic bacteria to develop and decompose the organic waste.

According to Stedman's medical dictionary, an enzyme is defined as a macromolecule that acts as a catalyst to induce chemical changes in other substances, while itself remaining apparently unchanged by the process.

BM1 is a white natural blend of healthy bacteria with high heat tolerance capable of acting as powerful enzymes that break down the waste.BM1, which includes keratinase, lipase, cellulose and thermophilic aerobic micro-organisms that accelerates the decomposition and fermentation process, is loaded into a digester along with the waste at a rate of 1 kilogram of BM1 per ton of waste according to Biomax Technologies the manufacturer of the enzyme.BM1 accelerates Thermophilic Digestion Process (TDP). BM1 is able to reduce fermentation time (24 hours or less) by activating fermenting microorganisms at high temperature region (thermophilic process). It is non-genetically modified.

3 DIGESTER INSTRUMENTATION AND PROCESS VARIABLES

Anaerobic processes are still largely dependent upon "manual laboratory analysis" and the adaptation of the system by a "qualified operator." Chromatography, electrochemistry, spectrometric, titrimetric, observers, and some other principles have all been explored as sensing options for anaerobic digestion [10]. In contrast with manual control, where an operator may periodically read the process temperature and adjust the heating or cooling input up or down in such a direction as to drive the temperature to its desired value, in automatic control, measurement and adjustment are made automatically on a continuous basis.

In automatic control a controller compares signal from instrumentation measuring devices with the signal of a process variable, that is desired (set point- The set point is a value for a process variable that is desired to be maintained.) and actuates the final control device. A process variable is a condition that can change the process in some way. In the case of automatic temperature controllers, several types can be used for a given process variable. Achieving satisfactory temperature control, however, depends on;

- The process characteristics

- How much temperature variation from the set point is acceptable and under what conditions (such as start-up, running, idling), and
- Selecting the optimum controller type and tuning it properly.

With digesters, instrumentation measuring devices are used to maintain adequate environmental conditions against possible changes in influent characteristics (temperature level, moisture level, pH, flow rate or composition, reactor pressure) or the conditions inside the reactor. The control of these complex bioprocesses is a difficult task because of the great variety of microorganisms, as well as the long reaction periods [11, 12]. A suitable system to control digesters should maintain the process variables inside the reactor such as temperature, pressure material flow and pH.

3.1 Temperature

Temperature is one of the major important parameters in anaerobic digestion. It determines the rate of anaerobic degradation processes particularly the rates of hydrolysis and methanogenesis. This is a classic measurement, typically with a thermistors or thermocouples. It is a rather important variable for anaerobic digesters where temperature control is often implemented. Moreover, it not only influences the metabolic activities of the microbial population but also has a significant effect on some other factors such as gas transfer rates and settling characteristics of bio solids [13].

3.2 pH

Although pH is a variable that is important in all biological processes, its value is especially critical in anaerobic digestion and nitrification where important quantities of protons are released, eventually leading to acidification and process failure. A low pH value often induces damage in pipes, valves and other metallic components. A measurement of pH at several points in the inlet area is required to ensure efficient plant operation and to monitor the effect of the influent water on the concrete structures and channels. The pH measurement can be done by actual probes. Stronach [13] urged that alkalinity and pH in anaerobic digestion can be adjusted using several chemicals such as sodium (bi-) carbonate, potassium (bi-) carbonate, calcium carbonate (lime), calcium hydroxide (quick lime) and sodium nitrate. The optimal pH values for the acidogenesis and methanogenesis stages are different. During acidogenesis, acetic, lactic and propionic acids are formed and, thus the pH falls. Low pH can inhibit acidogenesis and pH below 6.4 can be toxic for methane forming bacteria (the optimal range for methanogenesis is between 6.6 and 7) an optimal range for all is between 6.4 and 7.2

3.3 Flow rate of fluids

Instruments for the monitoring of gas and liquid flows are ubiquitous in waste treatment. Harremoës *et al* [14] give an extensive overview of liquid flow measurement techniques and point to the importance of proper installation for guaranteed accuracy. For gas flow measurements recurrence is made to Rota meters and, less common, thermal mass flow meters. One of the most important measurements on the entire plant is the accurate measurement of flow at the main pump station inlet. This signal is fed to other parts of the plant as part of the control signal.

3.4 Gases

The Carbon/Nitrogen (C/N) ratio is the relationship between the amount of carbon and nitrogen present in organic materials. For anaerobic digestion an optimum range from 20-30 of C/N ratio is considered to be the best. If the C/N ratio is of high value, it means the nitrogen is consumed rapidly by methanogens for meeting their protein requirements and will not react with the left over carbon content of the material. As a result, this produces very little amount of gas. In a case were the C/N ratio is very low, nitrogen will be released and accumulates in the form of ammonia (NH_4). Ammonia will increase the pH value of the contents in the digester. According to Karki et al. [15] if the pH increases to a pH higher than 8.5, the condition in the digester will start showing toxic effect on methanogen population.

4 DESIGN OF THE FUZZY-PID CONTROL SYSTEM

The design was based on the fact that the pH and the temperature control sub-systems will act as inputs to the proposed bioreactor system. Thus there will be individual controllers fuzzy logic controllers for each parameter (pH and temperature). When the control problem is to regulate the process output around a set-point, it is natural consider error as an input, even to a fuzzy controller, and it follows that the integral of the error and the derivative of the error may be useful inputs as well. In a fuzzified PID controller, however, it is difficult to tell the effect of each gain factor on the rise time, overshoot, and settling time, since it is most often nonlinear and has more tuning gains than a PID controller. Therefore a controller with parallel structure was adopted and the design was derived as follows.

Initially the error and the change of error are defined as;

$$e(k) = r(k) - y(k) \tag{2}$$

$$\Delta e(k) = e(k) - e(k-1) \tag{3}$$

The inputs to the fuzzy are normalised error ($\omega_{e*}e$) and for normalised change in error ($\Delta\omega_{e*}\Delta e$) where $\omega_{e*}$and $\Delta\omega_{e*}$ are weighting factors. Considering the triangular shape there are three inputs of which one is a zero crossing therefore we will consider only the non-zero terms thus *Positive error (P_e)*, *Positive change in error ($P_{\Delta e}$)*,*Negative error (N_e)* and *Negative change in error ($N_{\Delta e}$)*.The corresponding membership functions are defined as follows;

$$\mu_{P_{e1}} = \begin{cases} 0, & \omega_{e1}.e < -1, \\ 1/2 + \frac{1}{2}\omega_{e1}.e, & -1 \le \omega_{e1}.e \le 1, \\ 1 & \omega_{e1}.e \ge 1, \end{cases} \tag{4}$$

$$\mu_{N_{e1}} = \begin{cases} 0, & \omega_{e1}.e < -1, \\ 1/2 + \frac{1}{2}\omega_{e1}.e, & -1 \le \omega_{e1}.e \le 1, \\ 1 & \omega_{e1}.e \ge 1, \end{cases} \tag{5}$$

$$\mu_{P_{\Delta e1}} = \begin{cases} 0, & \omega_{\Delta e1}.\Delta e < 1, \\ 1/2 + \frac{1}{2}\omega_{\Delta e1}.e, & -1 \le \omega_{\Delta e1}.\Delta e \le 1, \\ 1 & \omega_{\Delta e1}.\Delta e \ge 1, \end{cases} \tag{6}$$

$$\mu_{N_{\Delta e1}} = \begin{cases} 0, & \omega_{\Delta e1}.\Delta e < 1, \\ 1/2 + \frac{1}{2}\omega_{\Delta e1}.e, & -1 \le \omega_{\Delta e1}.\Delta e \le 1, \\ 1 & \omega_{\Delta e1}.\Delta e \ge 1, \end{cases} \tag{7}$$

The following membership functions are for the temperature control;

$$\begin{cases} 1/2 & - \end{cases} \quad (8)$$

$$\begin{cases} 1/2 & - \end{cases} \quad (9)$$

$$\begin{cases} 1/2 & - \end{cases} \quad (10)$$

$$\begin{cases} 1/2 & - \end{cases} \quad (11)$$

Therefore there are nine rules used for the control system including the zero regions as illustrated in Figure 5. The fuzzy labels of the control outputs are singletons defined as P=1, Z=0 and N=-1.Implementing methods such as Larsen's product inference method with Zadeh fuzzy logic AND Lukasiewcz fuzzy logic OR, using the traditional centre-of-gravity (COG) deffuzification, and for simplicity considering $\omega = \omega_{e1} = \omega_{e2}$ and $\omega = \omega_{\Delta e1} = \omega_{\Delta e2}$, the control output of each FLC can be obtained , in the universe of discourse as follows;

$$^{(F)} \quad \frac{}{x(\omega_{e1}|e|, \omega \quad |e|)}(\omega \qquad e) \quad \frac{}{}(\omega \qquad e) \quad (12)$$

$$^{(F)} \quad \frac{}{x(\omega_{e2}|e|, \omega \quad |e|)}(\omega \qquad e) \quad \frac{}{}(\omega \qquad e) \quad (13)$$

Where

$$x(\omega \quad |e|, \qquad |e|) \qquad x(\omega \quad |e|, \qquad |e|) \qquad x(\omega_e|e|, \qquad |e|) \quad (14)$$

The overall fuzzy control output will be;

$$^{(F)} \quad \sum^{k} \quad ^{(F)} \quad ^{(F)} \quad (15)$$

Therefore

$$^{(F)} \quad \sum \frac{}{}\left(\Delta \quad \frac{}{e/\omega} e\right) \quad \frac{}{}\left(\Delta \quad \frac{}{e/\omega} e\right) \quad (16)$$

If we however chose,

$$^{(F)} \quad \frac{}{} \quad (17)$$

$$^{(F)} \quad \frac{}{} \quad (18)$$

$$^{(F)} \frac{^{(F)}}{^{(F)}} \quad \frac{}{} \quad (19)$$

Then the fuzzy control output derived from the above equations can be combined in a fuzzy-PID as follows;

$$u_{PID}^{(F)} = \sum_0^k K_c^{(F)} \left(\Delta e + \frac{\Delta t}{T_i^{(F)}} e\right) + K_c^{(F)} \frac{T_d^{(F)}}{T_i^{(F)}} \left(e + T_i^{(F)} \frac{\Delta e}{\Delta t}\right) \qquad (20)$$

Considering the fact that the constants of the bioreactor plant are sufficiently large compared with sampling interval, which is common and reasonable in process control, such that;

$$\dot{e} \approx \frac{\Delta e}{\Delta t} \qquad (21)$$

Therefore the overall control output can be approximated as;

$$u_{PID}^{(F)} = \int_0^{k.\Delta t} K_c^{(F)} \left(de + \frac{e}{T_i^{(F)}} dt\right) + K_c^{(F)} \frac{T_d^{(F)}}{T_i^{(F)}} \left(+T_i^{(F)} \frac{de}{dt}\right) \qquad (22)$$

$$u_{PID}^{(F)} = \int_0^{k.\Delta t} K_c^{(F)} \dot{e} dt + \int_0^{k.\Delta t} \frac{K_c^{(F)}}{T_i^{(F)}} e dt + \frac{K_c^{(F)} T_d^{(F)}}{T_i^{(F)}} \left(e + T_i^{(F)} \dot{e}\right) \qquad (23)$$

Thus equation (23) represents the fuzzy-PID for a parallel fuzzy control system.

The designed Simulink model was as shown in Figure 1.0 below. The main goal was to achieve a cascaded system for the PID Controller and the Fuzzy Controller, with the output crisp value of the Fuzzy controller being an input to the PID controller.

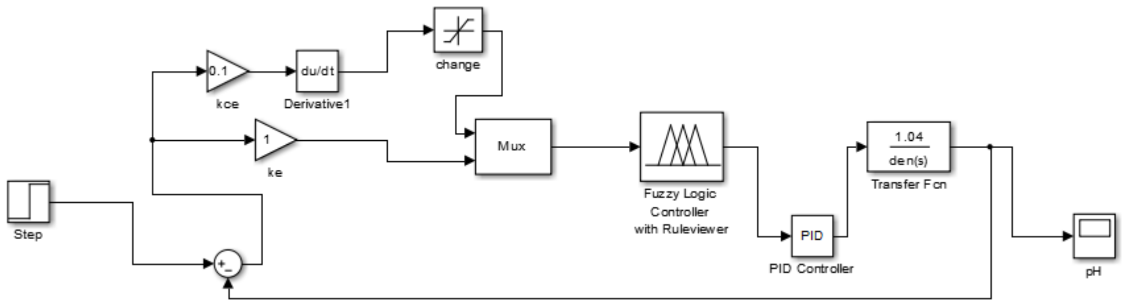

Figure 1: The proposed Simulink Fuzzy-PID Model

The design reflected challenges on the system Transfer Function, after testing several values and tuning the final system transfer function was as shown in equation (24).

$$G_{(s)} = \frac{1.04}{0.2s^2+1.5s+1} \qquad (24)$$

4.1 Development of the fuzzy controller

Fuzzy inference can be defined as a process of mapping from a given input to an output, using the theory of fuzzy sets. The most commonly used fuzzy inference technique is the so-called Mamdani method. In 1975, Professor Ebrahim Mamdani of London University built one of the first fuzzy systems to control a steam engine and boiler combination [16]. He applied a set of fuzzy rules supplied by experienced human operators. The Mamdani-style fuzzy inference process is performed in four steps: fuzzification of the input variables, rule evaluation, aggregation of the rule outputs, and finally defuzzification.

4.1.1 Fuzzification

The first step is to take the crisp inputs, x_1 (error) and x_2 (error change), and determine the degree to which these inputs belong to each of the appropriate fuzzy sets. The crisp input is always a numerical value limited to the universe of discourse. In our case, values of x_1 and x_2 are limited to the universe of discourses X_1 and X_2, respectively. The ranges of the universe of discourses were determined by expert judgements. Once the crisp inputs, x_1 and x_2, are obtained, they are fuzzified against the appropriate linguistic fuzzy sets.

4.1.2 Rule evaluation

The second step was to take the fuzzified inputs, and apply them to the antecedents of the fuzzy rules. If a given fuzzy rule has multiple antecedents, the fuzzy operator (AND or OR) is used to obtain a single number that represents the result of the antecedent evaluation. This number (the truth value) is then applied to the consequent membership function. To evaluate the disjunction of the rule antecedents, we use the OR fuzzy operation. Typically, fuzzy expert systems make use of the classical fuzzy operation union. The rules were developed and the correlations between inputs were derived as shown in Figure 2. A linguistic variable carries with it the concept of fuzzy set qualifiers, called hedges. Hedges are terms that modify the shape of fuzzy sets. They include adverbs such as very, somewhat, quite, more or less and slightly. Hedges can modify verbs, adjectives, adverbs or even whole sentences.

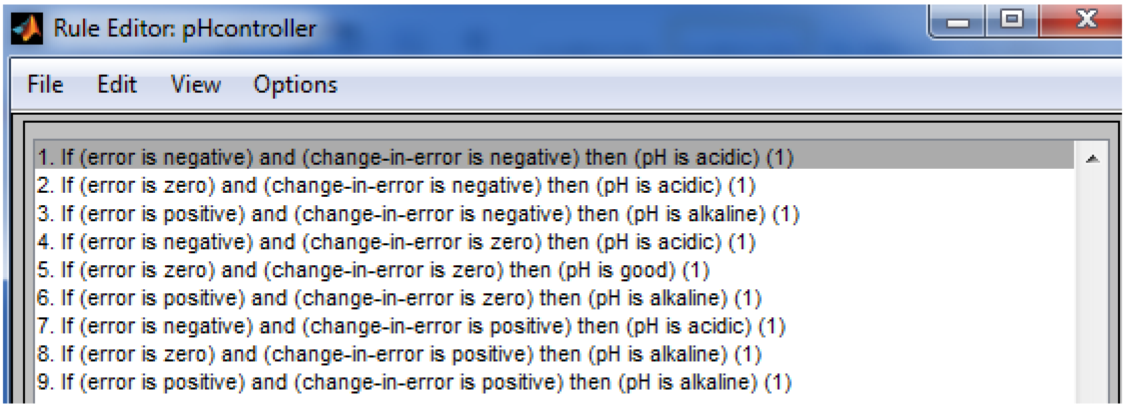

Figure 2: The proposed Simulink Fuzzy-PID Model

4.1.3 Aggregation of the rule outputs

Aggregation is the process of unification of the outputs of all rules. In other words, we take the membership functions of all rule consequents previously clipped or scaled and combine them into a single fuzzy set. Thus, the input of the aggregation process is the list of clipped or scaled consequent membership functions, and the output is one fuzzy set for each output variable.

4.1.4 Defuzzification

The last step in the fuzzy inference process is defuzzification. Fuzziness helps us to evaluate the rules, but the final output of a fuzzy system has to be a crisp number. The input for the defuzzification process is the aggregate output fuzzy set and the output is a single number. There are several defuzzification methods as stated by Cox [4], but probably the most popular one is the centroid technique. It finds the point where a vertical line would slice the aggregate set into two equal masses.

5 SIMULATION RESULTS

To achieve the set objective the system was initially tested without a fuzzy controller so as to justify the need for the fuzzy controller in cascade with the PID controller and the results were displayed as shown in Figure 3.

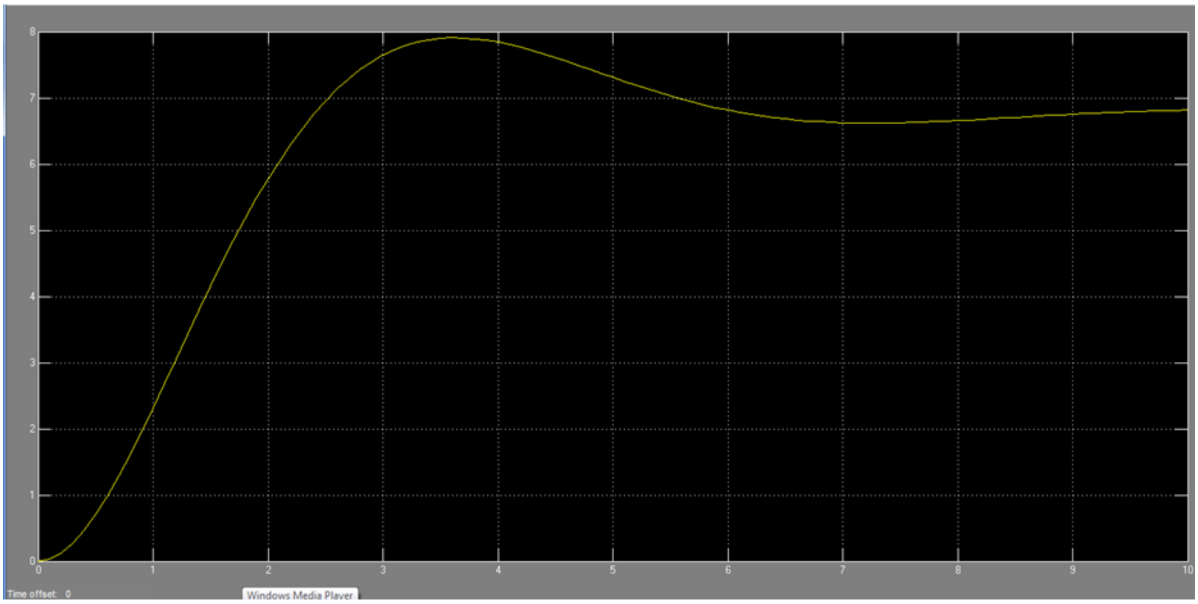

Figure 3: The system output for a PID Model

The motive for this research was to develop a system which will be able to operate without any percentage overshoots above the recommended range of 6.6≤pH<7.0; the results shown in Figure 3 were not favourable for the operation of the enzyme. The enzyme requires an acidic environment and any deviation towards the alkaline environment will result in sudden death of the active enzyme. Although the results in Figure 3 shows a system operating in acidic condition, the fact that the system has an overshoot close to pH=8 reveals that the bulk of the enzyme would have been destroyed between the 2sec≤t(s)≤7sec. This has motivated the inclusion of a Fuzzy controller which has the capability to reason with imprecise or partial data, the results are shown in Figure 4.

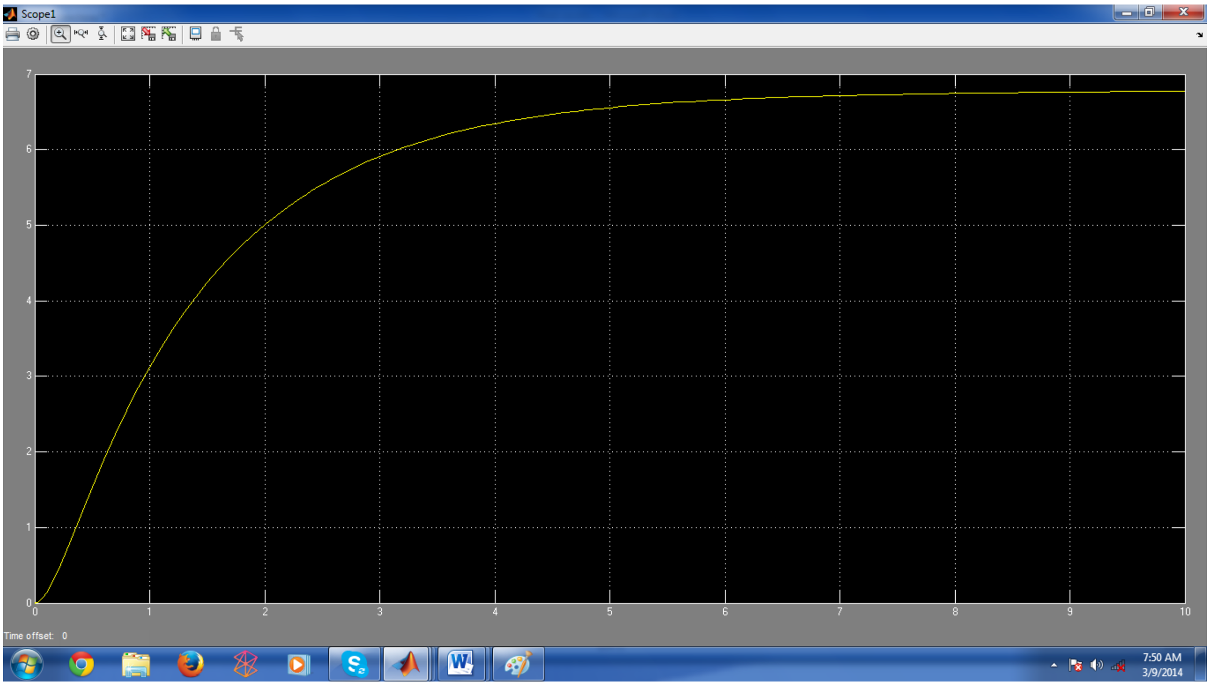

Figure 4: The system output for a Fuzzy-PID Model

The final results revealed that the design is achievable with no percentage overshoot. There was need to have a trade-off between having a short rise time and achieving a system with no percentage overshoot. The fuzzy logic result illustrated in Figure 5 below, shows that the system has an average output of pH=6.8 under wide range of variable system disturbances.

The optimum operating range for the BioMax1 enzyme is between 6.6 and 7.0 thus the stable value of 6.8 is acceptable for optimum enzyme performance.

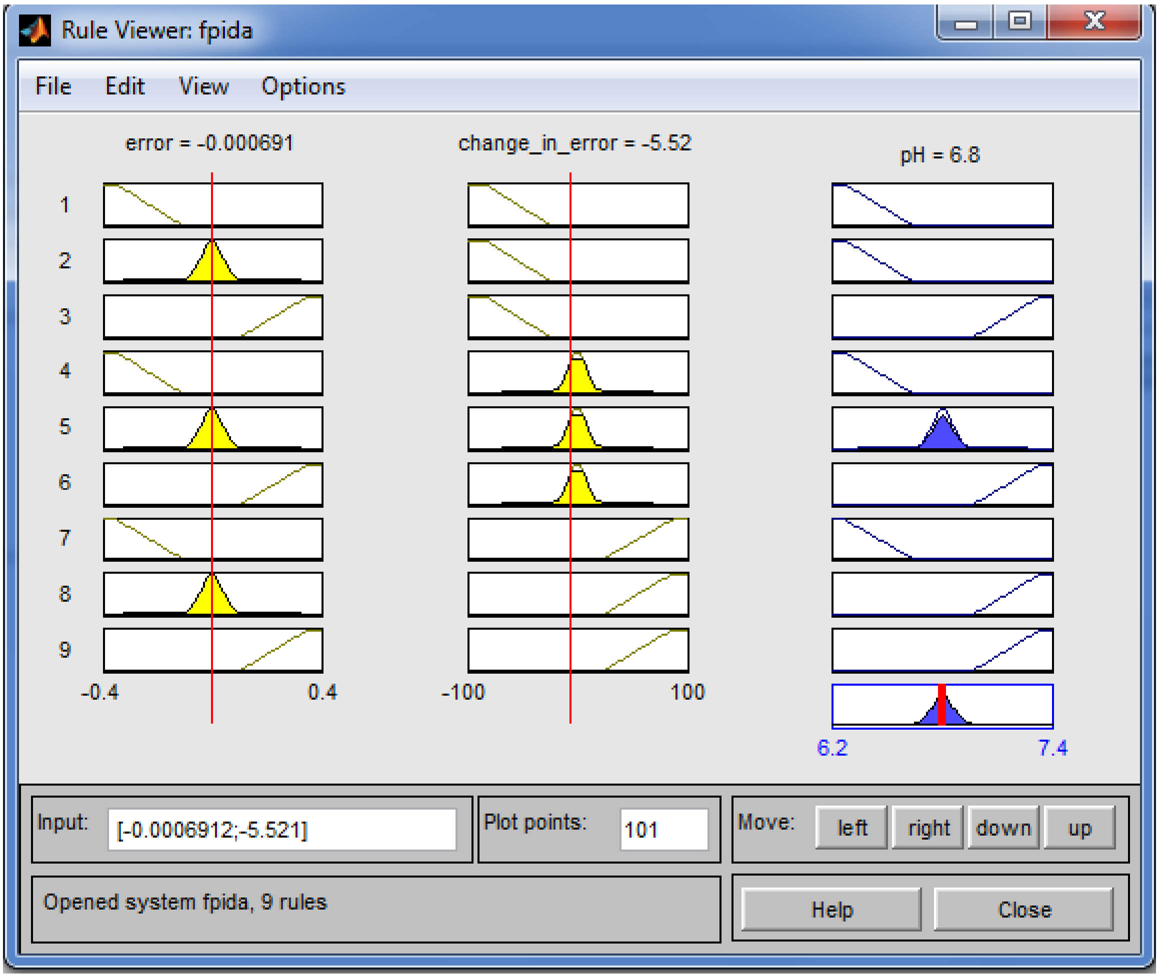

Figure 5: The system Fuzzy-PID rules

6 CONCLUSION

In a nutshell the main objective of this project was to come up with a suitable controller which is capable of minimizing overshoots, reduce rise time and transient response under non-linear conditions. The set objective was achieved. A sensitivity of the fuzzy logic controller to design parameters, different shapes and superposition of membership functions was tested. It was also concluded that since fuzzy logic is determined as a set of mathematical principles for knowledge representation based on degrees of membership rather than on crisp membership of classical binary logic if used in cascade with a PID controller complex systems can easily be modeled without the aid of mathematical modeling.

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AN INTERNET-BASED POINT-OF-BETTING (IPOB) FOR LOTTO PUNTERS

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ABSTRACT

In this research an Ethernet-based lotto betting machine is developed, tested and deployed as an embedded web-client in a network. The device's hardware mainly comprises a microcontroller, an Ethernet network interface shield, a keypad for input and an LCD screen output. The web-client sends requests to a remote Windows-Apache-MySQL-PHP (WAMP) server using PHP scripts. The Apache webserver serves the requests by querying the MySQL database where user identification, player-tokens and winning number records are stored and sends bet receipt SMS messages directly to users. To access the system a player enters a pre-purchased token number that allows them several chances via keypad. The remote server checks the token for authenticity, allows the user to enter a 6-digit number and registers the number in the database. It then sends a bet acknowledgement SMS while the LCD displays system transaction messages. This system eliminates the use of paper in betting slips, receipts and associated spoilt paper. It also replaces most human processes with inherent machine speed-up and continuous service availability. The system also reduces customer loitering and queuing, consequently eliminating crowding and associated environmental hazards. The system therefore potentially exhibits some positive sustainable environmental impact.

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1 INTRODUCTION

The Internet-based Point-of-Betting (IPoB) system is an Ethernet embedded microcontroller lotto betting console that could eventually be implemented in Zimbabwe. The study's targeted system is LOTTO™ and is the most popular in the country as it offers the highest jackpot payouts. LOTTO™also features the majority of gaming outlets in the country with live draws held every Saturday on national television. To play the game a punter picks up a betting card with numbers 1 to 45 from a betting clerk's counter typically located at the entrance of a major supermarket. The player then selects and crosses out any 6 of the 45 numbers, as shown in Figure 1, and submits the betting card to the clerk together with the payment.

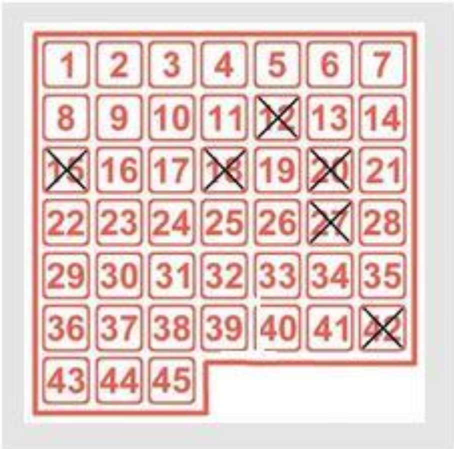

Figure 1: Sample LOTTO™ Betting Card

The card is electronically scanned and the system automatically prints out the receipt showing the selected numbers. The system in its current form is laborious, time consuming and environmentally hazardous as spoilt betting cards are often thrown away by punters and, furthermore, some paper is rejected by the scanner system as it effectively works with flat surfaces. These factors are also unfavourable for business growth as new clients are discouraged by long queues and poor service time. The number of customers also directly impacts on community development in the long term. This is mainly because the Lotteries Gaming Act Chapter 10 (clause 45) of Zimbabwe [1] prescibes that the lotto business, must contribute some 25% of its revenue toward social service, public welfare or relief of distress within Zimbabwe.

This research seeks to improve the whole system performance and offer a sound return on investment over a reasonably short period of time. This will be made possible by introducing an interactive betting console that connects to a database over an Ethernet network.

This paper briefly examines similar systems in form of patent applications and states the main aim of the study and system objectives. This is followed by the methodology section which describes system hardware and software development that then leads to the system integration and testing section, culminating in deployment and concludes with some sample results. The research is of a practical nature and hopes the system may eventually be implemented or some of the ideas adopted in similar or different systems.

2 SOME RELATED RESEARCH

The authors examined some of the research and developmental work in the field of lottery technology to determine the trends and possibly identify any gaps in them that they could fill. Work by Piper and Smith [2]; drew many technological similarities with that of De Cuba

[3], Choi and Park [4] and several other researchers. The following section briefly describes the work by these three teams of researchers.

2.1 Lottery System

The project by Piper and Smith [2], aptly named Lottery System, describes a computer based system which allows entries to be sold over the telephone, or by using other systems such as an ATM or POS machine, an email, and, via kiosks. The Lottery System participants are invited to choose at least one unique number from a defined range of numbers, for example a number between one and one million. The participant can register their selection with an entry-logging engine. This engine records the details of the participant (for example telephone number or email address), the number selected, the date and time of the entry, and, an optional receipt number. The engine then passes each entry in turn to a lottery engine, which allows the competition to run until a winner is determined.

2.2 SMS Messaging System Accommodation Variable Entries for Lotteries System

In this system by De Cuba [3], an SMS lottery gateway server obtains one SMS message from a mobile phone and parses it. There are various ways in which the SMS message can be parsed such as looking for a number (which indicates the number of entries) and an associated pick. Lottery winnings can be credited to a prepaid or post-paid account.

2.3 Lottery Business System and the Working Method Using the Personal Unit on the Wire/Wireless Network

In their patent documentation, Choi and Park [4] propose the use of an existent IT infrastructure to run a lottery business system. The two indicate that use of the IT backbone secures both domestic and international competitiveness, resulting in improved investment efficiency. Their system uses a personal terminal or a versatile TV terminal (which has a two-way function) to access a public switched telecommunication network or a broadcasting network. The punters have to access the network to purchase a lottery ticket and check the winning ticket.

3 AIM AND OBJECTIVES

3.1 Aim

The aim was to design a functionally lightweight embedded web client system that could be used as an automated standalone lotto booth, allowing users to submit their bets over the Internet and receive bet acknowledgements without filling in any paperwork and with minimum or no human assistance.

3.2 Objectives

The objectives were to deliver a system that easily fits into the existing system network with the following major features:

- The system should be easy to operate and maintain such that it can be easily installed.
- The system should be user friendly and fully interactive guiding the user step-by-step as they log in data in order to reduce operational error and enhance its life cycle.
- The system should send data in the correct Hyper Text Transfer Protocol HTTP/1.1 format, conform to IEEE802.3 Ethernet standard and to Internet Engineering Task Force (IETF) technical recommendations, Fielding et al [5]
- The system should be robust such that it can smoothly handle errors and exceptions.

- The system should be loosely coupled from the main LOTTO™ system so that local maintenance does not affect the main system.
- The system should be extensible so that any changes to the LOTTO business rules will not shut the system down but involve minor or no software adjustments.

4 SYSTEM ARCHITECTURE

The system development strategy is aimed at replacing the current manual system without disrupting normal business processes, thus the new system's functionality should map to the existing system. The keypad represents the LOTTO™ betting card and the number selection is done by keying in the keypad number keys. The customer and betting clerk's interactions are replaced by a Liquid Crystal Display LCD display of, among others, a welcome screen; the echo of the pressed keys; step-by-step user instructions and error reporting; all these displays providing real-time feedback driven by events within the local system or from the remote server responses.

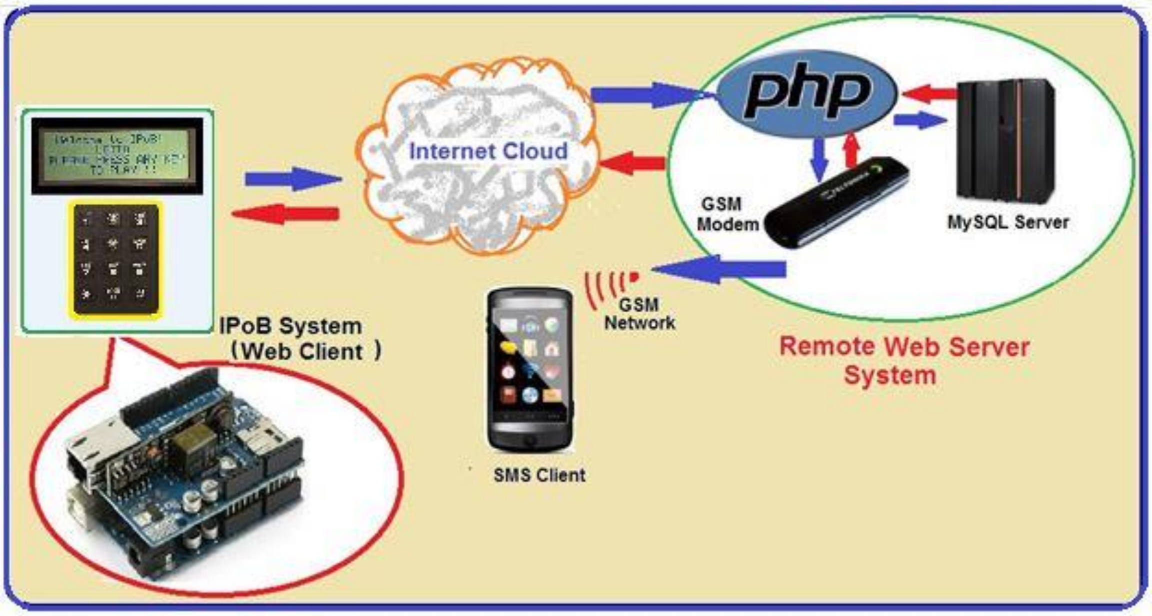

Figure 2: Overall LOTTO™ System Deployment Diagram.

The deployment diagram in Figure 2 illustrates the IPoB system's location within the LOTTO™ system. The current system serves many different web clients from different devices including mobile phones, using web browsers like Google Chrome among others. A bet placed by a client is a request to the server for some file, which the server pushes back to the client through his or her browser for viewing. The IPoB will send a keypad input formatted as a client request to the server and when the response arrives back the system will be configured to interpret and display the information on the console screen. The IPoB will thus emulate a low level web browser through which punters can place their bets and get SMSes from the remote system as shown in Figure 2. The remote engine still remains the lotto draw centre access the system as any other player.

4.1 IPoB System Hardware Components Description

The IPoB system's architecture is represented by the stacked hardware model shown on the left hand side in Figure 3. The magnified illustration of the WIZnet® W5100 Ethernet controller block diagram is shown on the right with numbers indicating the applicable hardware component drawn from the hardware side to show where each hardware application approximately fits into the W5100 block stack diagram, extracted from the datasheet [6].

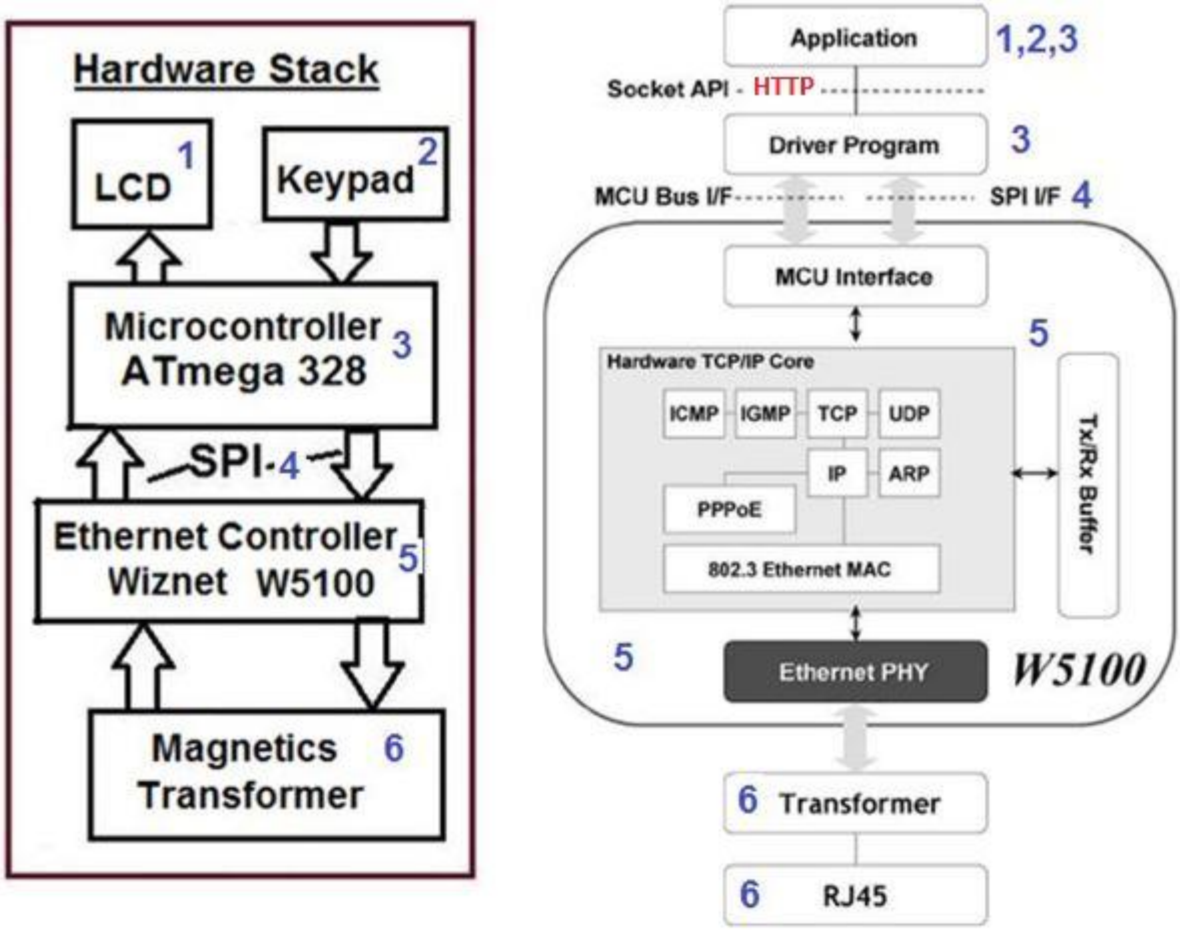

Figure 3: System Hardware Stack WIZnet W5100 Protocol Stack [6]

4.1.1 Microcontroller

The microcontroller used the Atmel AVR® ATmega328 which is housed on an Arduino™ board prototyping platform. According to Banzi [7], the Arduino hardware and software are available as open source under the Creative Commons (CC) licensing agreement that allows for free circuit reproduction. Under this licensing agreement individuals can make Arduino-compatible boards, which can be exact copies of the original, free of charge using freely downloadable printed circuit board templates.

Creative Commons has been described by Broussard [8] as being at the forefront of the “copyleft” movement, which seeks to support the building of a richer public domain by providing an alternative to the automatic "all rights reserved" copyright, and has been dubbed "some rights reserved”.

The IPoB system used the Arduino Uno Revision 3 (or R3) shown in Figure 4. The Arduino Uno Revision 3 (or R3) board features an ATmega328 microcontroller on board, like other Arduinos, but differs from all preceding boards in that its USB-to-Serial converter chip uses the more powerful ATmega16U2 instead of the 8U2, has a highly sensitive RESET circuit and input output reference (IOREF) that allows external shields to adapt to the voltage provided from the board automatically.

The top two headers have fourteen digital input/output (IO) pins marked on the board as pins 0 to 13, six of these digital pins numbered 3, 5, 6, 9, 10, and 11, and marked “~” can, through software configuration, also be turned into six analogue output pins using pulse-width modulation (PWM) in which rapid pulses can be output to control motors at various speeds, or play music (by varying the pulse frequency). The right bottom header has six Analogue input pins (marked as pins A0 to A5) which are dedicated analogue input pins that take analogue values (such as voltage readings from a sensor) and convert them into a number between 0 and 1023. The rest of the pins are used for powering external devices during development, or other Arduino accessory boards called shields which have pins that have the same form-factor as the basic Arduino development board. Figure 6 shows an Ethernet shield connected on top of the Arduino via the pins-to-headers coupling. The In Circuit Serial Programming (ICSP) pin terminal block on the right edge of the board provides the Serial Peripheral Interface (SPI) bus interface for connecting with the Ethernet Controller and, can also be used for programming the Arduino from an external programmer.

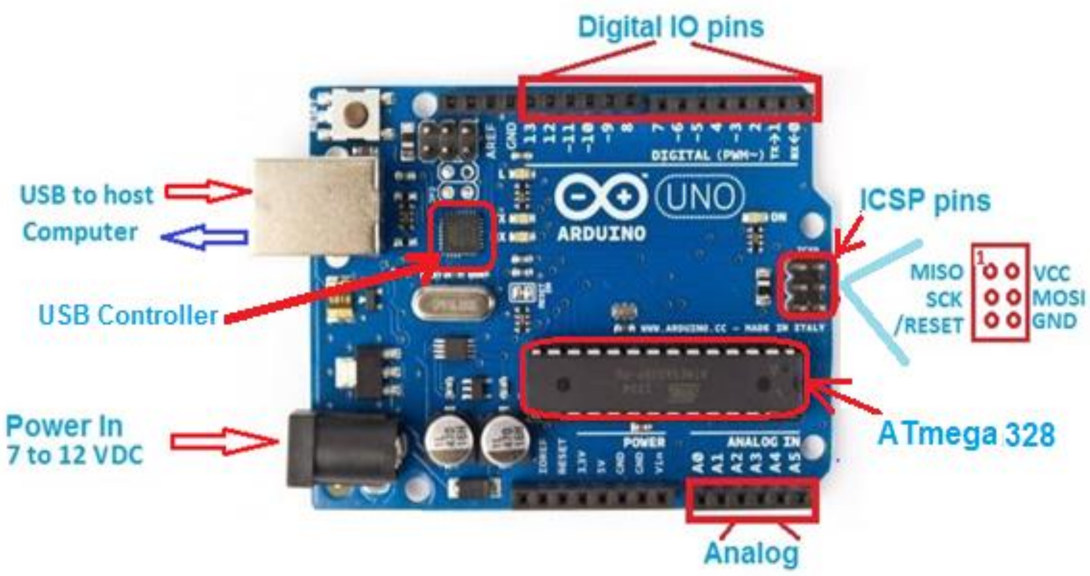

Figure 4: Arduino™ Uno R3 System [9]

The board can be powered from the host computer's USB port, or from most USB chargers, or an AC adapter (9 volts is recommended). Banzi [7] describes how the power to the Arduino can be connected via USB. He concedes that in the absence of a normal power supply plugged into the board's power socket, power will be derived from the USB input and the board automatically changes over to the mains input when it becomes available.

4.1.2 The Keypad

The IPoB system's input device is a 4x3 keypad with a construction similar to the ones used on telephone systems whose digit '5' key is marked to assist the blind and visually impaired people to locate the numeric keys by the sense of touch. The keypad is a matrix of switches that connect at the intersection of row—column conductor lines as shown in Figure 5. To use the keypad the rows and column pins must be identified using the manufacturer's datasheet or manually by depressing each key and testing for circuit continuity between the pins using an ohmmeter. It must be noted that the keypad layouts in Figure 5 only serves as an illustration others may differ from it.

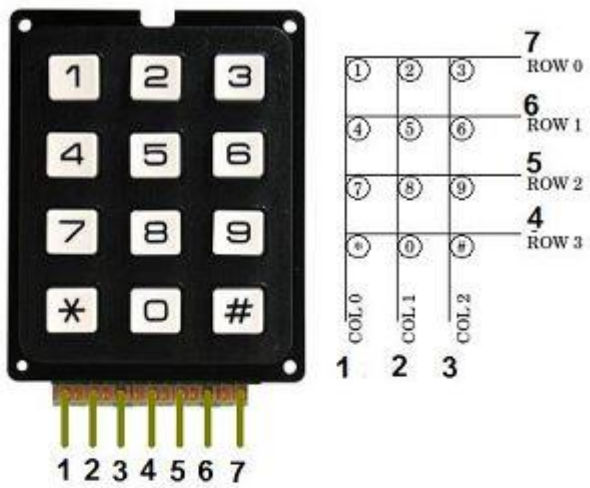

Figure 5: Keypad

4.1.3 The LCD Display

The LCD used in the project is a 20 x 4 alphanumeric display. An example by Margolis [10] was used as reference to determine the LCD pin assignments which are VIN and Vout (used for the contrast), Read/Write (R/W), Reset (RS) and enable (E) and the data pins D4 to D7. The data connection uses the 4-bit mode (which excludes data pins D0 to D3) instead of the 8-bit in order to use fewer pins on the Arduino. The display module is used in conjunction with the keypad above to echo each key value as it was entered. The LCD also echoes instructions, transaction acknowledgements and errors generated by the remote server.

4.1.4 The Serial Peripheral Interface

The microcontroller links with the Ethernet Controller via the SPI bus. SPI is a four-wire synchronous serial bus protocol developed by Motorola and integrated in many of their microcontrollers. SPI bus consists of four signals: master out slave in (MOSI), master in slave out (MISO), serial clock (SCK), and active low slave (or chip) select (SS). As a multi-master/slave protocol, communications between the master and selected slave use the unidirectional MISO and MOSI lines, to achieve data rates in full duplex mode. With SPI the maximum number of devices that the master can connect to is limited by main microcontroller’s available pins. Sandya and Rajasekhar [11], in their paper on the design and verification of SPI, also demonstrate that using SPI ensures that the speed of data transfer is much faster.

4.1.5 Ethernet Shield and Magnetics

The WIZnet™ W5100, whose internal structure is shown in Figure 3, is the main component of the Arduino Ethernet Shield. The W5100 implements the Transport Control Protocol/Internet Protocol (TCP/IP) protocol suite in hardware for fast response. The Arduino Ethernet shield connects to the Arduino Uno using an SPI interface via the In Circuit Serial Programmer (ICSP) header as shown in Figure 4. The shield module and the Uno have the same number of pins and headers thus it fits directly on top of the Uno as shown in Figure 6. The Magnetics part is made up of a transformer, an RJ-45 socket and link establishment LEDs thus the meshing of the Arduino to Ethernet shield completes the hardware stack in Figure 3.

4.2 System Software Architecture and Components

The software architecture closely follows the protocol stack model shown in Figure 3 illustrated by the W5100 block diagram. The application at the top can be viewed as the Arduino microcontroller system’s data, for example bet number entries, which it encapsulates within an HTTP GET request as a socket (that is a host destination address/ port number pair).

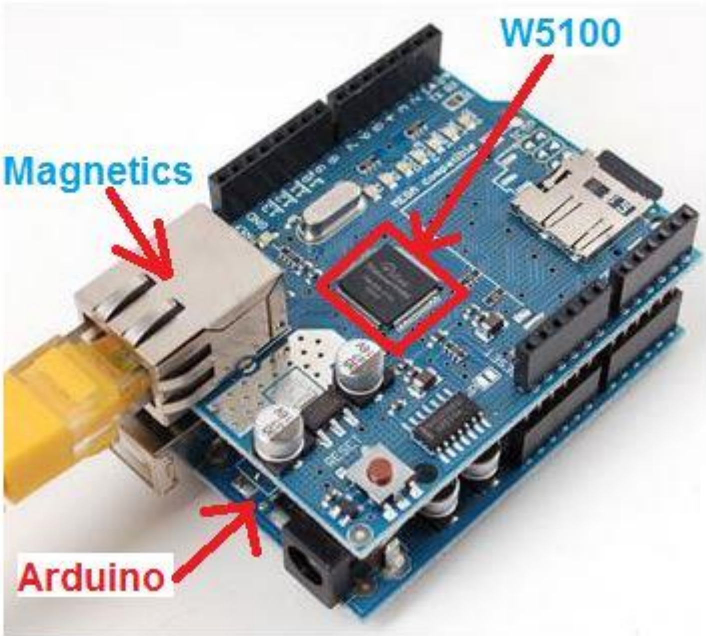

Figure 6: Ethernet Shield Top View [9]

The driver section is accomplished by the Arduino-SPI messages to W5100 that enable flow of data under the control of the Arduino. In the W5100 module the data are further encapsulated within TCP/IP, MAC using the data from the Arduino. Other networking information is added at the physical or PHY layer level where physical receive/transmit negotiation takes place as the data are sent as electrical pulses in packets according to IEEE802.3 standards.

The software development is carried out using the Arduino Integrated Development Environment (IDE) to write program code, compile, debug and run all under the same environment. The software for programming the Arduino is, according to Igoe [12], easy to use and also freely available for Windows, Mac, and Linux computers, at no cost.

4.2.1 The Arduino Sketch

The basic Arduino program is called a sketch (shown in Figure 7) and is written using a programming language called Wiring. The Arduino Integrated Development Environment (IDE) is used to create the sketches. A sketch is written and compiled (or verified in Arduino language) to check for any syntax errors and uploaded onto the Arduino board to run. One very useful IDE tool is the Serial monitor which print out the Arduino board's output on the screen, this can be used for debugging by example embedding some printing routine at some point within a loop to verify that it executes.

The anatomy of a sketch is in three parts namely the declaration of variables and constants; then two functions namely setup () and loop() function. During program execution the setup() runs once during start up or upon reset then the loop() follows and runs for as long as the Arduino is powered on.

Wiring is a version of the C++ language which the Arduino developers have simplified by the inclusion of libraries called Hardware Abstraction Libraries (HALs). The HAL is basically a class that has been prewritten with the generic features for Arduino hardware accessories to ease the process of interfacing the hardware to the Arduino platform.

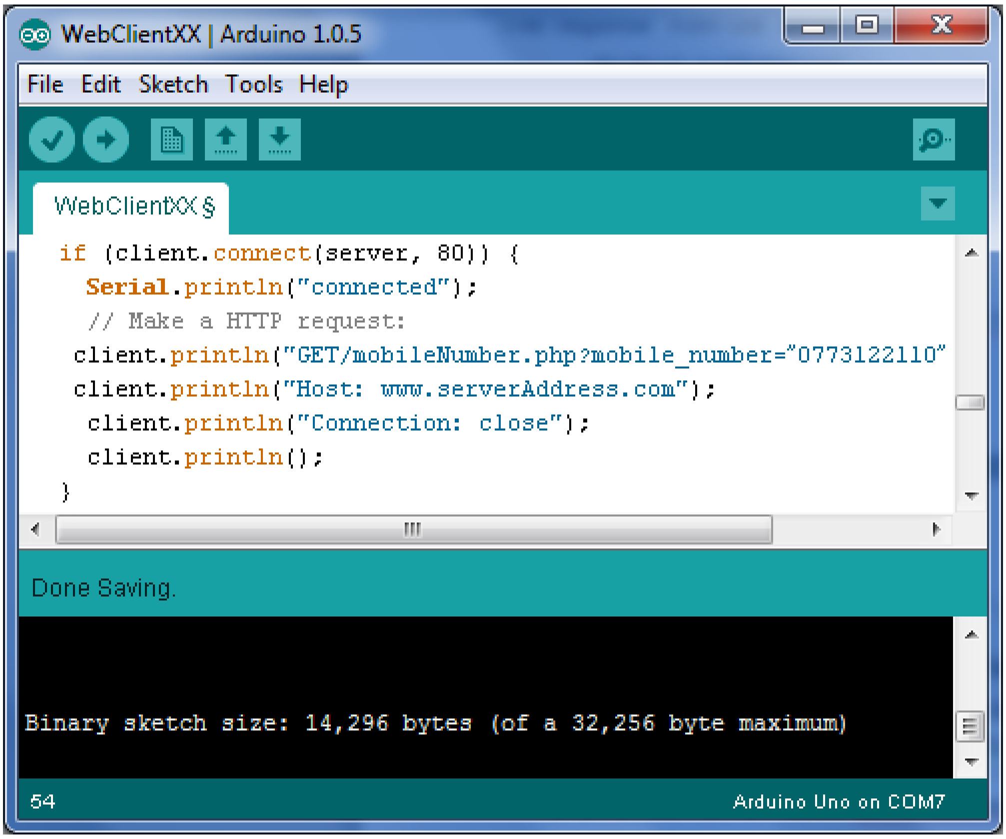

Figure 7: The Arduino Sketch

HALs provide software code wrappers that hide the low level software implementation details of the hardware turning the implementation into that of any ordinary C++ class. The HAL is usually implemented in a sketch as a header file (with an .h extension) by importing it into the sketch. In this project four libraries were used and these are briefly described below.

4.2.2 The Keypad.h Library

The Keypad.h library contains the keypad's generic key layout description in terms of rows and columns. The user must consult the manufacturer's information about the key-to-pin mapping or test it with an ohmmeter. The developer programmatically maps the keypad pins to the Arduino digital pins as inputs. Once configured and declared the keypad object can then be used like any other C++ class to trigger events such as when a key is pressed.

4.2.3 The LiquidCrystal.h Library

The LiquidCrystal.h library is used with the LCD which connects to the Arduino digital pins in the output mode. Its configuration includes the number of characters columns and rows; the bit mode, that is the number of data pins whether 4-bit or 8-bit. The implementation includes the cursor starting position, blinking, outputting a message using an lcd.print ("a message") function.

4.2.4 The SPI.h Library

The SPI.h library is used to control data between the Arduino (as the master) and any other devices (as the slaves) using chip select and MISO/MOSI routines. In this project it is used to transfer HTTP-bound data from the Arduino (master) to the W5100 Ethernet controller which is the slave.

4.2.5 The Ethernet.h Library

The Ethernet.h library contains both several network-related classes including the EthernetClient and EthernetServer this paper is confined to the EthernetClient class. The EthernetClient instance is configured to transfer TCP/IP sockets to a server by assigning a mac address which comes with the hardware, setting up the server IP address, and, if a router is used, the gateway and subnet addresses. Once configured the EthernetClient object can use the EthernetClient.connect (server, portnumber) method to connect to the server. If the connection is established the EthernetClient object can then just use a println method to send HTTP requests using a GET method such as:

```
EthernetClient.println("GET /search?q=arduino HTTP/1.1");
EthernetClient.println("Host: www.google.com");
```

5 IMPLEMENTATION - PUTTING IT ALL TOGETHER

5.1 The Keypad Implementation and Testing

The keypad's pins Figure 5 were checked to identify which ones of them were rows and columns using a continuity tester. After identification the four row pins were connected to the Arduino digital pins 8,7,6,5 and the three columns to pins 4, 3 and 2. The Keypad.h library described in 4.3.1 above was imported to the IDE Arduino sketch and the IDE's Serial.print() used to output any key press on the monitor window. An excerpt of the code (with comments after the "//")is as follows:

```
//The Keypad class constructor initialises a keypad object to create a virtual keypad
//that maps the physical hardware rows (ROWS) and columns (COLS)

// to the Arduino pins rowPins array and colPins array of digital pin numbers

Keypad keypad = Keypad( makeKeymap(keys), rowPins, colPins, ROWS, COLS );

char key = keypad.getKey();//get the key face value

if (key != NO_KEY){

Serial.println(key); // show the face value key that was pressed }
```

5.2 The LCD Implementation and Testing

The LCD display connections were obtained from the examples by Margolis [10] and the program was implemented using the LiquidCrystal.h library to create a "4x20"character lcd object using the 4-bit mode to save pins as described in 4.3.2 above. The following code snippet displays the message *" To PLAY!!!"* on the forth row starting from the sixth column:

```
// initialize the library with the numbers of the interface pins

LiquidCrystal  lcd(A0, A1, A2, A3, A4);//These are the Arduino Analogue Out pins

// which  will connect with LCD for RS, E, D7, D6, D5, D4 respectively

void setup() {// set up the LCD's number of columns and rows:

 lcd.begin(20, 4);// 20 Columns or characters, 4 Rows }

void loop() {lcd.setCursor(5, 3);//cursor set to the sixth column and fourth row

 lcd.print(" TO PLAY!!! ");

delay(500); }
```

Figure 8: The IPoB Console

Figure 8 shows the implementation of the above program code displayed on the fourth row.

5.3 The Input Console Integration and Testing

One of the objectives outlined in subsection 3.2 that the system must be fully interactive meant that the keypad inputs must be echoed on the LCD display. This was solved by combining the LCD and keypad sketches, then modifying the lcd object to print the value of the pressed key using the following sample code:

```
char key = keypad.getKey();//get the key face value

if (key != NO_KEY){

lcd.println(key); // show the face value key that was pressed on LCD display }
```

5.4 Ethernet Implementation and Testing

The Ethernet shield comes with a Media Access Control (MAC) address which is a unique hardware address for initial identification on the network. This address is then mapped to the more universal IP address, the datasheet WIZnet [6] provides more detail. To set up a network connection the Ethernet.h library imported to a sketch with. The network test was done within a local area network (LAN) environment through a router thus MAC, IP, subnet and gateway parameters were required to initialise the link, some code sample is listed below:

```
Ethernet.begin (mac, ip, subnet, gateway);

EthernetClient client; // client object is the main communicating object
```

Connecting to a server whose IP address is already assigned requires the:

```
client.connect(serverAddress, 80); //this is a TCP socket to an HTTP port address
```

The message that is sends a user’s mobile phone number could be coded as an HTTP request of the general form:

```
client.println("GET/mobileNumber.php?mobile_number=”0773122110” HTTP/1.1");

client.println(serverAddress);// remote server name
```

The response from the server is read then printed to the LCD in the form:

```
If(client.available()){

char in_msg = client.read();

lcd.print(in_msg);}
```

5.5 IPoB HTTP GET Request and Server Side Implementation

In this project the embedded web client sends keypad input data as HTTP GET requests to the remote server to be processed by a targeted PHP file. The following example shows the implementation of the token number for validation request from a client object called *client* to a remote server called *serverAddress:*

```
client.print("GET/ serverAddress /validat_token_number.php?

token_number="number");

client.print("HTTP/1.1 ");
```

The above request sends the parameter *token_number* and its value *"number"* to the remote WAMP server called *serverAddress* and then passed on to the *validat_token_number.php* file where it is assigned to the PHP $_GET variable. The PHP file processes the value by executing a database query checking through the MySQL database for token number records. The result is returned with a PHP echo of "Y or "N" or "S" (as listed in Table 1), embedded in HTML.

5.5.1 Server Response Implementation

The server's response to an HTTP request consists of a header with some code for example HTTP/1.1 200 OK for a successful request or HTTP/1.1 404 Not Found for an unsuccessful web page request. The header also contains many other server description parameters and an HTML body, as given in the reference documentation by Fielding et al [5]. In this research the system analysed the content of a successful request otherwise displayed an error and a retry message giving the user two more chances. (Table 1 provides a list of messages).

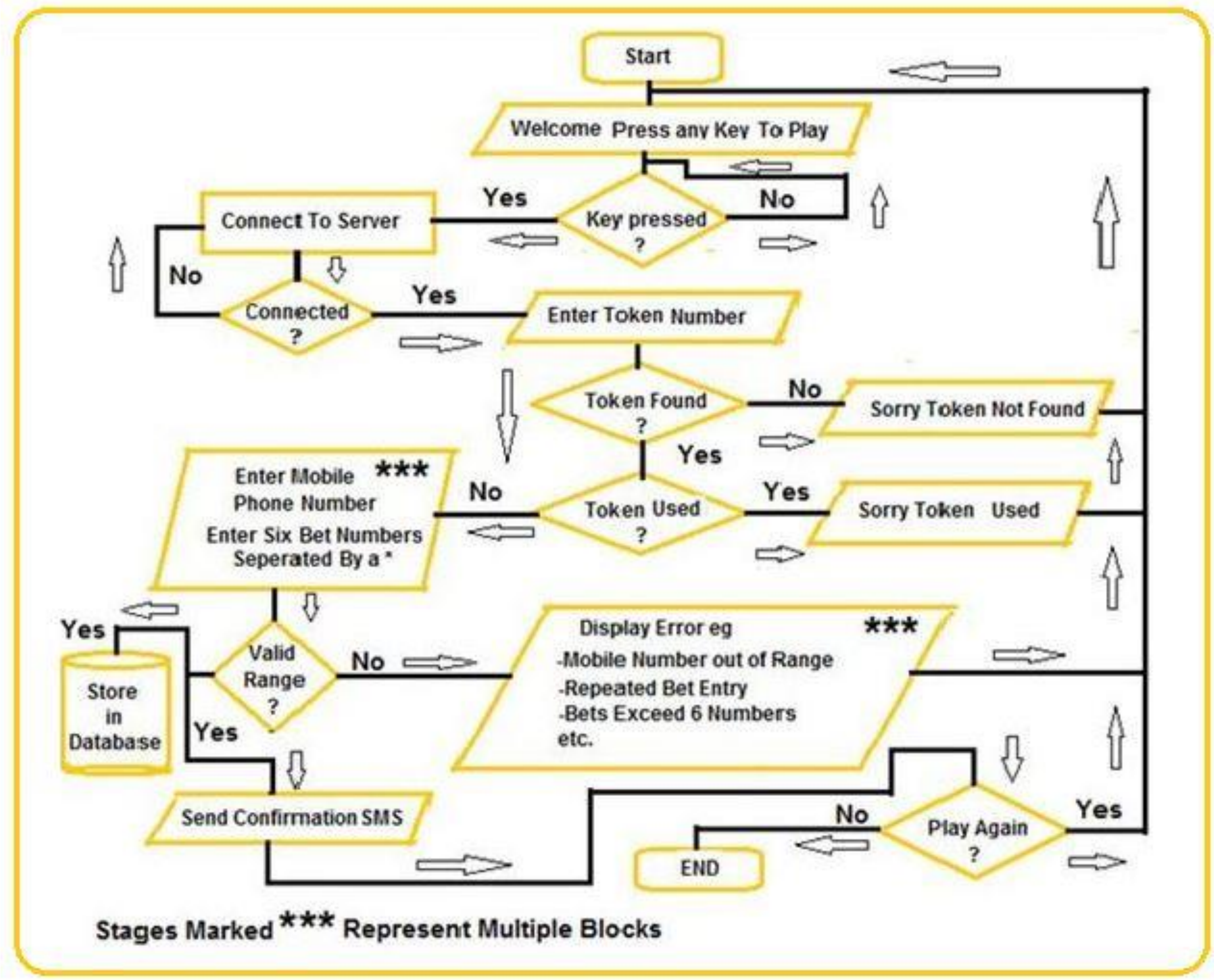

Figure 9: A Sample Flow Chart

6 DEPLOYMENT

The prototype was assembled and connected via Ethernet to a laptop that had a WAMP server with PHP scripts prepared by a colleague and a GSM modem. A five-field MySQL database table was created with a filled in token number field and blank fields for mobile phone, bets, DateTime and transactionID numbers. To test the system users were given a piece of paper with a copy of the token number and asked to place a bet, the system responded well and upon success users received an acknowledgement SMS on their mobile phones. The system test scenario was further extended to scores of high school students during the university open Day and proved quite popular with a virtual queue forming up as more students learnt about it. The downside was that some of the acknowledgements SMSes were delivered days after the bets.

7 RESULTS

In order to verify that the system was running according to specification tests were undertaken. Hardware tests were carried out to ensure that the system delivered the appropriate responses from the server as shown on the table below. Erroneous entries were also made to the system to carry out limited stress testing.

Table 1: Remote System Response Codes

Server HTML Response Message	Meaning	IPoB LCD Message Display
"Y"	12 digit scratch or token number valid	"Enter Mobile Phone Number"
"N"	token number invalid (User is given 3 chances)	"Sorry Token Not Found"
"C"	Database record update failure because token already used. (User is given 3 chances)	"Sorry Token Used "
"A"	Mobile number not valid for network.	"Mobile Number out of Range"
"M"	Lotto first number entered is out of the 1 to 45 range.	"First bet out of 1 to 45 range"
"H","D","E", "F","G"	As above for lotto second to sixth number entries respectively out of the valid range.	"Second [third...up to sixth] bet out of 1 to 45"
"J"	Repeated number entries detected	"Repeated Bet entries please check"
"S"	Successful transaction.	"Bet successful SMS to be sent shortly"

8 CONCLUSION

The system console shown in Figure 8 was successfully tested by scores of "clients" comprising groups of high school students and teachers during university open Day. From that exposure the authors draw the conclusions that:

- The system proved easy to set up, operate and is user-friendly. Users got a fully interactive step-by-step guidance as they logged in data and the main problems encountered such as undelivered SMSes or network disruptions were not attributable to the system.
- The system was constructed using Arduino components which conform to IEEE802.3 Ethernet standard. It was also able to send data in the correct Hyper Text Transfer Protocol HTTP/1.1 format as per Internet Engineering Task Force (IETF) technical recommendations, Fielding et al [5] implementation
- The system was robust enough as it could inform users of errors and what they should do as shown by the Table 1 and the flow chart in Figure 9.

- The system design was such that it behaved like any web client that sends standard HTTP requests thus it can be used as a browser that submits HTML web form data thus it can be easily be ported to other systems and is loosely coupled from the main LOTTO™ system so that local maintenance does not affect the main system.

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THE APPLICATION OF SOFT SYSTEMS METHODOLOGY TO SUPPLY CHAIN RISK MANAGEMENT IN SMALL AND MEDIUM ENTERPRISES

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ABSTRACT

The persistent failure of small and medium enterprises has put the South African government under severe pressure, considering the increased unemployment rate. These enterprises, which are crucial in job creation, fail to overcome supply chain challenges due to the lack of resources and poor management. The failure of these enterprises has increased the need for sound frameworks and approaches to be developed.

Supply chain risk management is one of the strategies that assist enterprises in the identification, assessment and control of supply chain risks. With the increased dynamics and complexity of supply chain risks for small and medium enterprises, an innovative approach in analysing these risks is required. The purpose of this research is to assess supply chain risk management in a small and medium enterprise case using soft systems methodology.

The systems thinking approach will assist in the analysis of the dynamics and complexity of supply chain risks for small and medium enterprises. A qualitative approach will be utilised to obtain insight into current issues that small and medium enterprises, in the manufacturing sector, face within the supply chain.

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1 INTRODUCTION

Small and Medium Enterprises (SMEs) are one of the drivers of economic growth. These enterprises contribute to the economy through job creation, generation of higher production volumes and increased exports [20]. With South Africa facing an unemployment crisis, nearly 40% of the population being unemployed, the survival of these enterprises has become vital. Unfortunately, due to the lack of resources and proper management, most of these enterprises fail to survive in the supply chain [27].

Numerous tools are available in the supply chain management (SCM) discipline that assist enterprises within the supply chain to deliver competitive products and/or services to their customers. The effectiveness of some of these tools is mainly dependent on resources and good management structures. The implementation of these SCM initiatives becomes exhaustive and expensive for SMEs [29]. SCM has introduced concepts such as supply chain risk management (SCRM) to assist enterprises within the supply chain in anticipating and managing risks associated with the supply chain. Since the foundation of this concept is from SCM principles, it also becomes problematic in terms of its implementation in SMEs [16]. With the dynamic behaviour of the supply chain, the complexity of the supply chain increases. More complexity in the supply chain leads to newer risks, which create a need for innovative ways to manage complexity. A framework for managing the complexity associated with the risks involved in supply chains of SMEs, will assist in obtaining insight that will ensure the survival of SMEs and thus benefit the South African economy.

The purpose of this research is to examine supply chain risks and SCRM specifically in SMEs, using the soft systems methodology. The theoretical framework will assist in the understanding SCRM for SMEs, considering their limitations.

This paper is structured as follows: a review of studies in SCRM is presented; the SCRM review will explore the SCRM process and its challenges; a brief setting of challenges experienced in SMEs; a review of the soft systems methodology is then presented prior to its application in one SME in the manufacturing sector.

2 SUPPLY CHAIN RISK MANAGEMENT

SCRM is a management strategy that utilizes the practices of risk management in SCM. Recent events, which affected supply chains, have increased interest in the application of risk management in supply chains. The management of risks in the supply chain, through a co-ordinated approach amongst supply chain members, in order to reduce supply chain vulnerability as a whole is called SCRM. This management approach has become vital for the survival of supply chains.

Risk management is a concept that has gained recognition and been applied in most areas. This concept involves a process of identification and analysis of risks in order to set up a strategy to manage those risks [21]. This risk management process has received attention in the management of supply chain disruptions. The economic impact of recent supply chain disruptions has increased the importance of SCRM [32].

2.1 Supply Chain Management

A supply chain is a linkage of enterprises that turn materials, products and services into finished products for the customer [Beamon, 2]. Each enterprise within the supply chain has a customer but in the objective of the supply chain, the end user is the main customer. The process of planning, implementing, managing and improving the operations of the supply chain and its value in the entire network, depicted in graph 1 below, is called SCM [1].

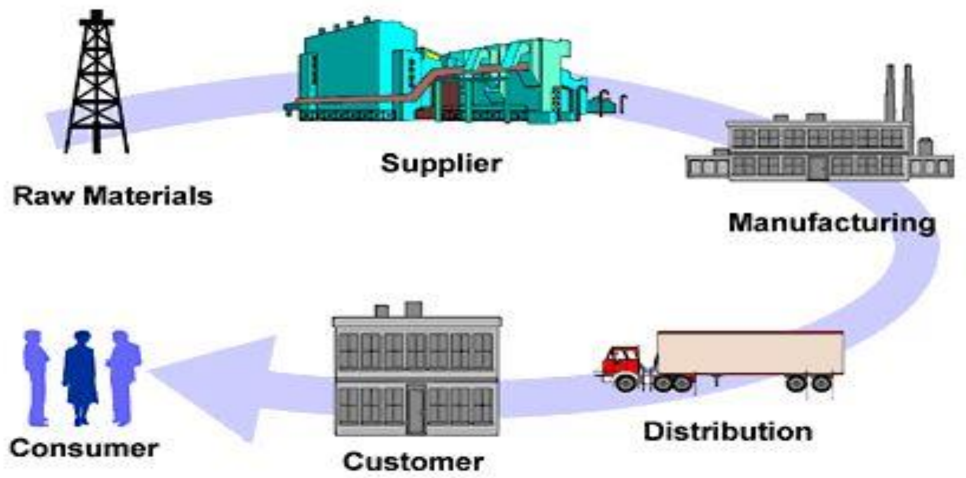

Figure 1: Components of the Supply Chain [26]

Effective SCM produces a competitive advantage for enterprises and prevents them from conducting their business in isolation. This approach allows all the parties in the supply chain to have a long-term objective of working together to deliver added-value products and/or services to the consumer. SCM concepts, such as lean manufacturing and just-in-time inventory, have boosted supply chain efficiency. Even though enterprises become more agile and responsive, the application of these concepts has presented new supply chain challenges such as limited expertise, higher costs and lack of cooperation from other parties in the supply chain [1].

The value-added in the application of SCM makes it vital for enterprises to overcome these challenges. Any disruptions to the supply chain can reduce an enterprise's revenue, cut into its market share, inflate cost, damage its credibility, and threaten production and distribution [6]. These disruptions can affect all the parties in the supply chain [30]. Enterprises need to manage supply chain risks in order to reduce or eliminate the impact of any disruption.

2.2 Risk Management in Supply Chains

Disruptions to supply chains are a major risk to the survival of any supply chain. Supply chain risks are defined as *"any risks to the information, material and product flows from original supplier to the delivery of the final product for the end user"* [17]. These risks can be divided into supply risks, internal risks, demand risks, external risks and environmental risks [26]. This classification of supply chain risks covers all the aspects of the supply chain. The process involved in the management of these supply chain risks was adopted from basic risk management principles [3]. Figure 2 below, adopted from the Orange Book [15], depicts the phases involved in the risk management process.

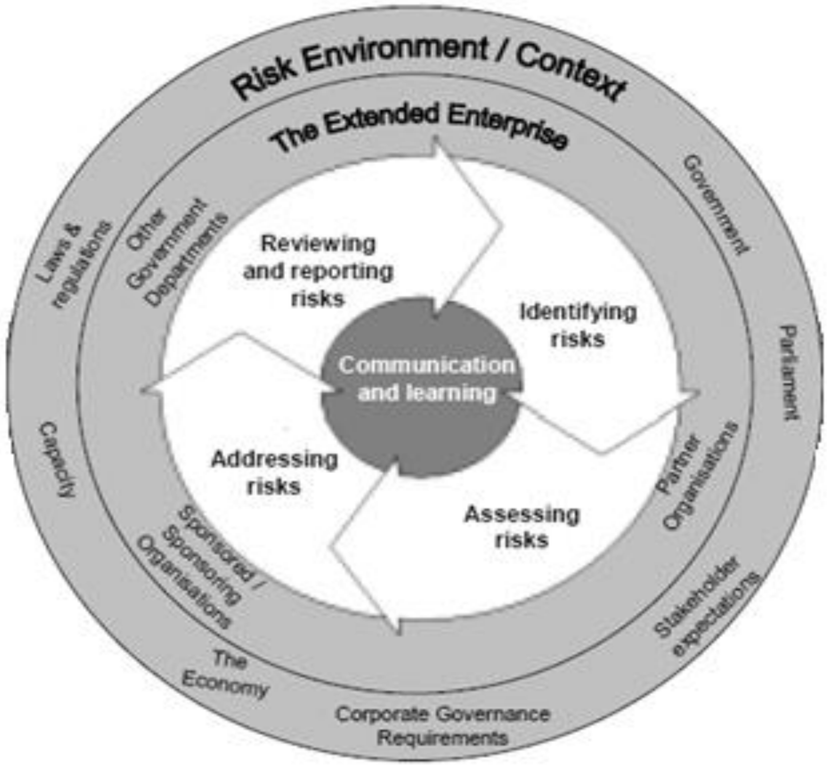

Figure 2: Risk management process [adopted from 15]

The effectiveness of this process requires a balance of the main phases and is not a linear process. Communication with all stakeholders is vital throughout this process, especially in the first phase. The risk identification phase is essential as it might misguide other phases of the risk management process, if done inaccurately [18]. An accurate and well-defined risk identification phase will ensure that stakeholders select the best solutions to address the risks.The phases involved in the risk management process are as follows:

Table 1: Phases in the Risk Management Process [15]

Context Definition	Identifying the areas of risk
Risk Identification	Identifying all possible sources of risk in the specified context
Risk Assessment	Analysing all risks based on probability and consequences of occurrence
Risk Evaluation	Analysing and prioritizing the risks, based on the results from the risk assessment
Risk Treatment	Involves transferring, excluding, reducing or accepting the risks
Monitoring and Reviewing	The effectiveness of risk treatment is reviewed

SCRM has evolved from an emerging topic to an established one [11, 12] but there are still gaps within this research. The management of supply chain risks is a process that presents difficulties in its application due to the complexity and dynamics of the risks. Some research papers have suggested a more holistic approach to the application of SCRM [23, 12]. A more holistic approach will assist in obtaining an insightful understanding of SCRM and thus fill the gaps in this research area.

3 SMALL AND MEDIUM ENTERPRISES

Small and medium enterprises (SMEs) are essential for the economy as they play a major role in any industry. For the purpose of this research, the term SMEs will be used instead of small, medium and micro enterprises as defined in the National Small Business Act. SMEs in the manufacturing sector will be defined according to table 2 below, adapted from the National Small Business Act.

Table 2: Classification of SMEs in the Manufacturing sector [adapted from *28*]

Sector	Size of Class	Total full-time equivalent of paid employees	Total Turnover	Total gross asset value (fixed property excluded)
Manufacturing	Medium	<200	<R51m	<R19m
	Small	<50	<R13m	<R5m
	Very Small	<20	<R5m	<R2m
	Micro	<5	<R0.20m	<R0.10m

SMEs in the manufacturing sector also assist in job creation, forming 44% of the manufacturing sector's employment rate. SMEs, being smaller players in any supply chain, are under enormous pressure to overcome supply chain disruptions. 74% of the SMEs in the manufacturing sector found it hard to run in the year 2012 [7]. This number is not surprising considering that most SMEs spend 62% of their turnover on input materials and labour only, which yields a small profit margin. With limited resources and current economic constraints, these enterprises are still expected to deliver competitive products and services at lower costs.

SMEs exist in an environment that requires constant changes in order to survive in supply chains. The South African environment presents increased pressure on these enterprises. There is increased pressure on these enterprises to 'go-green' and abide to Black Economic Empowerment (BEE) requirements. There is also pressure within supply chains for SMEs to align the management of their operations with those of larger enterprises. SMEs are then required to comply with any safety, environment and quality system requirements, which require increased resources. This constant battle to ensure compliance with the requirements of the supply chain (or of large enterprises) and still offer a competitive advantage increases the complexity within its supply chain.

4 SYSTEMS THINKING

There has always been a need for the analyses of complex problems. In the traditional analyses of problems, individual parts (systems) are isolated from the whole entity (system) being studied. The problem with this approach is that the interactions between systems are ignored. Systems thinking focuses on how individual parts (system) are studied and their interactions with other parts of the system. The system thinking approach is very useful in analysing dynamic and complex systems [5].

The system thinking approach views a whole system as an entity that adapts to the changing environment. This system, which may contain subsystems or may be seen as a subsystem in a larger system, has communication processes, control processes and 'emergent properties'. These 'emergent properties' are properties that the system has a single whole. This systems thinking forms the basis for the soft systems approach [5].

4.1 Soft Systems Methodology

The soft systems methodology (SSM) stems from systems thinking and attempts to give a holistic approach to solving problems. This methodology is based on the work of Peter Checkland, which was produced in the 1970s at the Department of Systems, University of Lancaster. The essence of Checkland's approach is to identify one or more problem areas in a system and then model only those business processes which are relevant to that problem area [19]. Checkland's SSM has proved to be powerful as a systemic approach to defining and solving problems in enterprises [22]. This methodology has been defined as soft as it focuses on understanding a problematic situation while hard system methods focus on solving well defined problems.

SSM involves seven stages, which address both the real world and the conceptual world. The first two stages involve developing a deeper understanding of the problematic situation, 'the real world'. The next two stages involve developing an understanding of the ideal situation, 'the conceptual world'. The fith stage involves the comparison of the two worlds, while the last two stages involves the improvement of the problem situation [34].

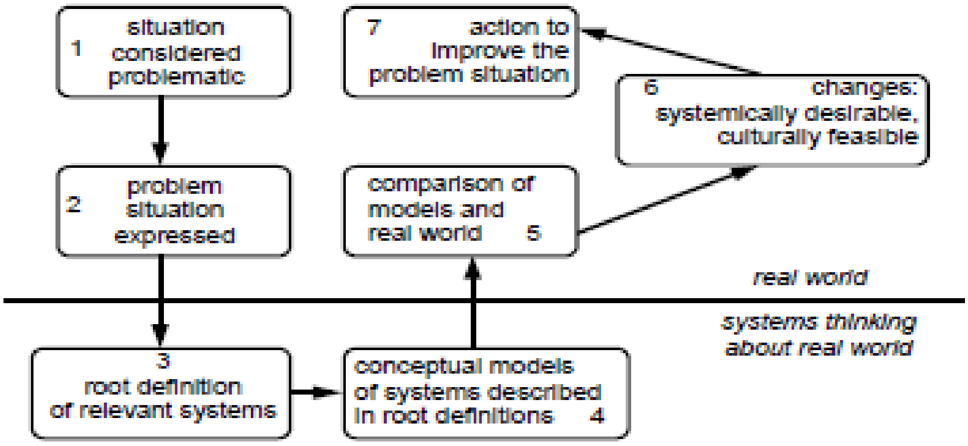

Figure 3: Stages in Soft Systems Metholody (Adapted from [8])

In stage one of the methodology, the problem situation is defined while the second stage involves building a rich picture of the problem situation. As a guideline, Checkland recommends that a rich picture should include the system structures, processes, climate, people and conflicts. The rich picture should capture all the elements that affects and is affected by the problem stuation. In the third stage, the 'root definitions' of the relevant systems are defined. Checkland presented the mnemonic 'CATWOE' as a quideline for this stage. This mnemonic describes six elements: C - customers of the system, A - actors within the system, T - transformation process, W - weltanchauung or worldview, O - owners of the system and E - environment within which the system exists. In the fourth stage, the 'root definitions' are used to draw up a conceptual model of the system. In stage 5, this conceptual model of the system is then compared with the problem situation depicted in stage 2. The last two stages of the methodology involve generating and implementing changes that will improve the problem situation [Defence Acquisition University,10]. The application of this methodology offers a structure to the understanding of a loosely-defined problem situation.

5 CONCEPTUAL FRAMEWORK OF SCRM FOR SMES

This research paper will explore SCRM in one SME in the manufacturing sector. The risk management phases will be explored with respect to the risk classes identified in the supply chain literature. These supply chain risk classes will form the risk areas in the risk management process and thus define the context of the process. Each class of risks consist of dynamic risks that also impact or are impacted on by other classes of risks. The SSM will be utilised explore the complexity and dynamics of the risks in the SME case. Figure 4 below represents the conceptual framework for SCRM in SMEs. This framework will be explored using SSM.

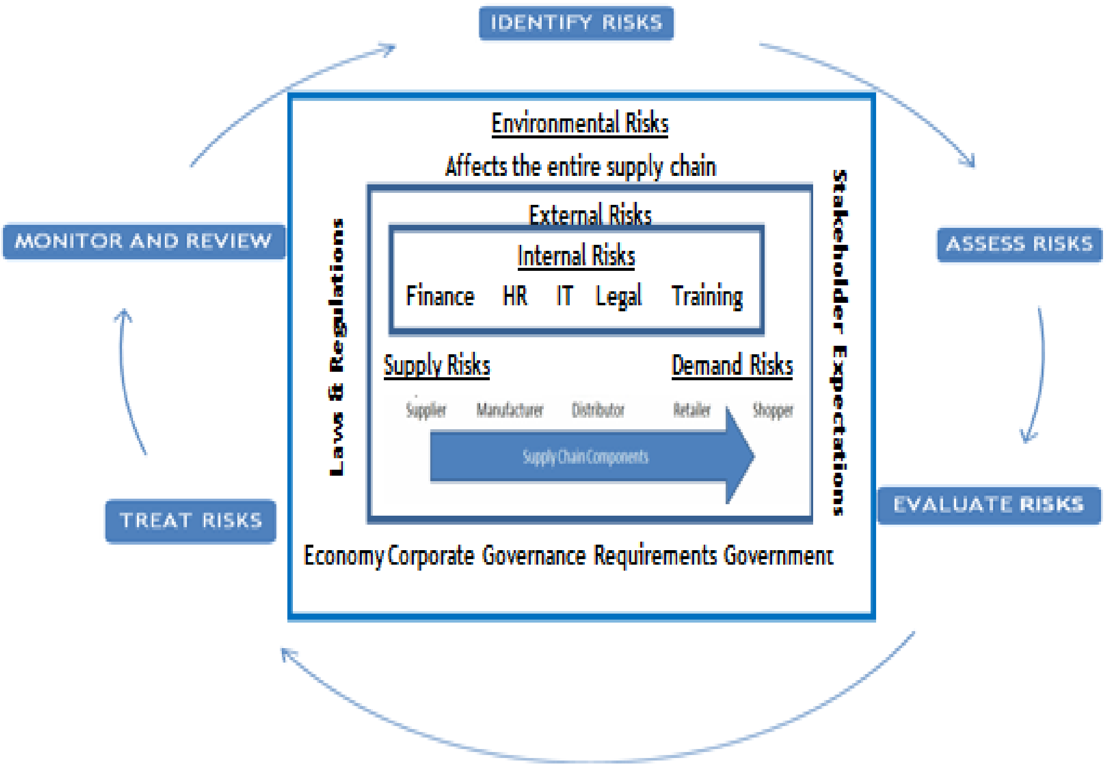

Figure 4: Conceptual Framework for SCRM in SMEs

In this conceptual framework, the environmental risks are those external forces that affect the entire enterprise. These risks are the main reason for increased complexity in the supply chain. The external risks are those risks that are external to the SME and can include risks associated with outsourcing. Internal risks are tied to the enterprise's operations. These risks also include risks associated with any business function that supports the enterprise [30].

6 RESEARCH METHOD

This research paper will explore SCRM utilising SSM in a case study. This research design was selected because of the type of information desired, the availability of resources and the capability of the researcher [31]. SCRM will be explored in one SME case in the manufacturing sector. The first five stages of SSM will applied in order to obtain a better understanding of SCRM in SMEs. The research objective and the characteristics of the study population determined the type and size of the sample [14]. For the purpose of this research paper, a combination of purposeful and selective sampling will be exploited. Purposeful sampling is the selection of information-rich cases for in-depth study. Information-rich cases are those from which one can learn a great deal about issues of importance to the purpose of the research. Selective sampling refers to a decision made prior to beginning a study, this decision is based on preconceived but reasonable initial set of criteria [9]. The exploration of one SME should be adequate for this research, considering the depth of SSM. The case selected satisfied the SME criteria, which has been defined in the literature. Table 3 below presents the details of the SME case under study. Sun Engineering (not real name), based in Gauteng is a manufacturing enterprise that produces drill bits.

Table 3: General Information of SME under study

	Sun Engineering
Sector	Manufacturing
Product/Service	Drill Bits
Age of Creation	1993
Number of Employees	17
Turnover	~R20 million
Production Volume	100 000/month
Key Customers	Atlas Copco, Afrox, Transnet, AEC, ISE

6.1 Data Collection Techniques

Qualitative methods were used to collect data for this research paper. The qualitative method is suitable for small-scale analysis, in which first-hand information about the problem is analysed [35]. Interaction with Sun Engineering was achieved through semi-structured interviews, written documents, a questionnaire and field notes. A member of the management team filled in the questionnaire with the help of the researcher, through an interview, by email and by telephone. A voice recorder was utilised to capture all the information obtained during the interview. The interview approach allowed the researcher to obtain insights and a deeper understanding of the current study. The interview was conducted at the SME's premises and it lasted approximately an hour. The interview questionnaire was based on SCRM and SSM concepts. Prior to the interview, a telephone interview was obtained with the General Manager (GM) of the enterprise to obtain general information of the enterprise and the company profile was emailed to the researcher. This information assisted the researcher in drawing up a questionnaire for data collection purposes.

6.2 Validity and Reliability

Validity and reliability are criteria that were used to evaluate the quality and trustworthiness of the research study. These criteria will ensure that this research paper is trustworthy and is of good quality [13]. The validity criterion was divided into internal and external validity. Triangulation was used to verify internal validity of the data obtained by using multiple sources within the enterprise as well as information obtained from the SME's website and profile. The findings of the research were also taken back to the interviewee for evaluation. These criteria ensured that the study was observing what it is intended to observe [24]. Thick description and purposeful sampling were used to address external validity, which is concerned with the extent to which the findings of the study can be applied to other situations [4].These criteria ensure that transferability and generality of the study is addressed. The reliability of the study will be ensured by audit trial [33]. This will allow for the evaluation of the dependability or consistency of the study by keeping a detailed record (recordings of the interview) of the data collected.

7 SUN ENGINEERING CASE

Sun Engineering, the case under study, will allow this research paper to evaluate SCRM from the perspective of an SME. The first five stages in SSM will be applied and thus assist in obtaining a better understanding of how this SME views and manages risk management in its supply chain.

7.1 Stage 1 and 2

In the first stage of the methodology, the problematic situation is defined. In this case, the problematic situation can be viewed as ‘SCRM in Sun Engineering, an SME in the manufacturing sector’. The second stage of the methodology involves depicting a rich picture of the dynamics and complexity involved in Sun Engineering. Figure 5 below illustrates all the dynamics involved in this SME.

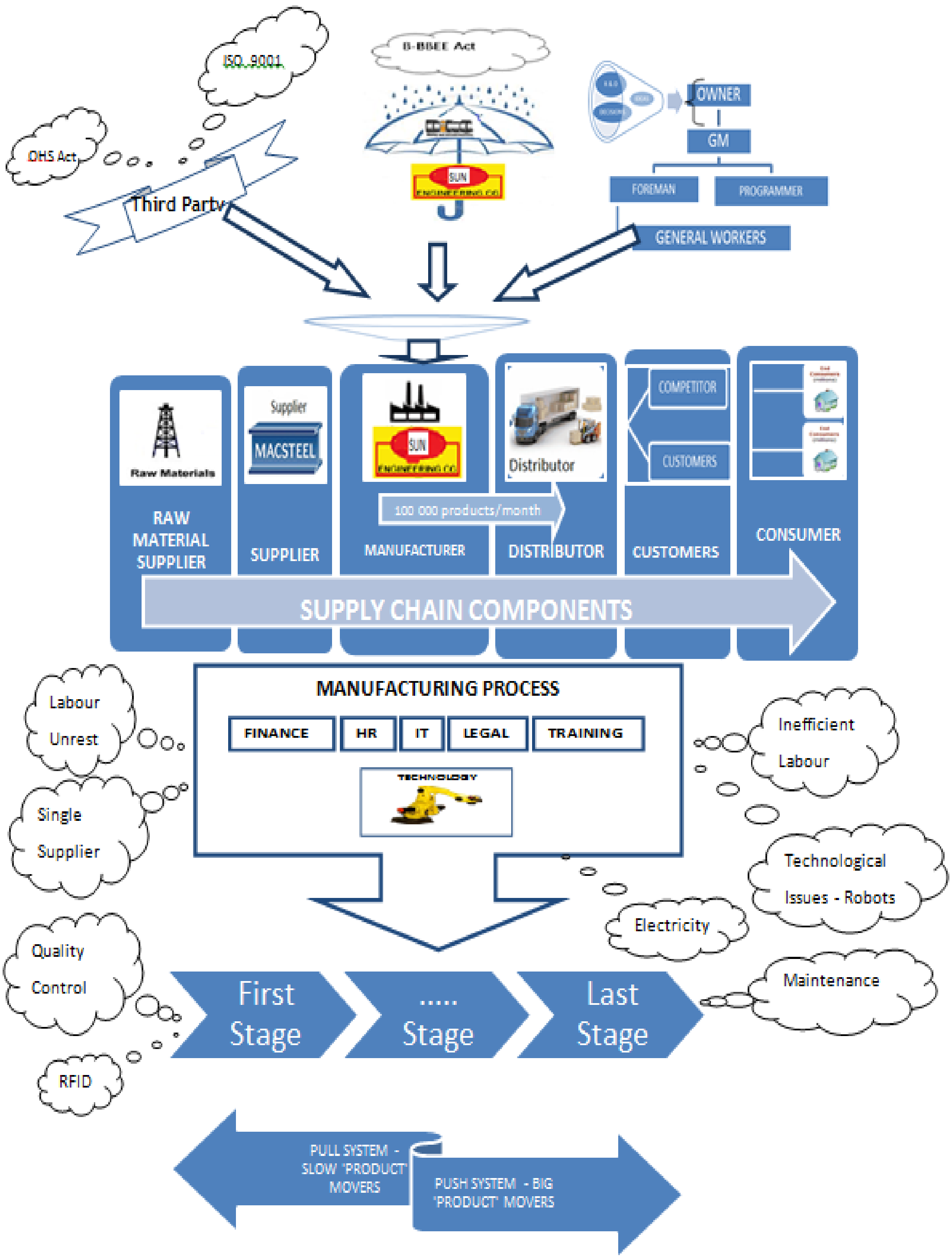

Figure 5: Rich Picture for SUN Engineering

In the rich picture above Sun Engineering receives materials from Macsteel, who supplies them with materials specially designed for this specific industry. These materials, which arrive in different sizes, are delivered in batches, which are linked to this SME's Radio Frequency Identification (RFID) system. These materials then undergo various processes before being dispatched to the customer, who also includes some of Sun Engineering's competitors. In the hierarchical management structure, the CEO of the SME, together with the GM, is responsible for the management of the enterprise. The supervisor, who reports to the GM, leads the general workers who do not require specialised skills to run the production line. Most of the processes within this SME have been automated in order to improve productivity and efficiency of the production line. This enterprise also highlighted the following risks, as their top ten risks and the solutions they have adopted:

Table 4: Top Ten Risks in Sun Engineering and their Treatment

Top Supply Chain Risks	Treatment of Risk
Disruption from single supplier	Sourcing of Alternate Suppliers & excess stock
Quality Issues	Assignment of quality checks & complete traceability of products (RFID)
Machine/Robot Failure	Sourcing of Local Replacement machines and regular maintenance by third party
Robot Programming Issues	Easy-to-follow resetting procedure & Employment of Programmer
Labour Unrest/Inefficient Labour	Automated processes
Technological Issues (Robots)	Re-designed system to accommodate new technology
Power Cuts	Acceptance of Risk
B-BBEE regulations	Creation of Dino (not real name), as a BEE brand name of Sun Engineering
Safety Requirements	Sourcing third party for compliance
Quality Requirements	Sourcing third party for compliance

Sun Engineering management have identified these top risks as those that may have a huge impact to the objective of their operations. These risks have been identified through experience. Although there is no formal process of the management of the risks, plans have been put in place for addressing these risks.

7.2 Stage 3

The root definitions of the relevant systems are defined in the third stage of the methodology. In this case study, two systems were identified: Sun Engineering and the entire supply chain. Exploring these two systems will assist in determining conceptual models of Sun Engineering, as well as of the supply chain. Table 5 below reveals the CATWOE models of the systems identified.

Table 5: CATWOE Models of Sun Engineering and its Supply Chain

Root Definition Element	Sun Engineering	Entire Supply Chain
C – Customers	Atlas Copco, Afrox, Transnet, AEC, ISE and competitors	End consumer
A – Actors	CEO, GM, Foreman, Programmer, general workers and machines within Sun Engineering	CEOs/Owners, employees and machines of the supply chain enterprises
T- Transformation	Raw materials from suppliers are used to manufacture products	Resources are used to fulfil customer demands
W – Weltanchauung or Worldview	Supply customers with the highest quality products in a timely manner and at a competitive price	Deliver competitive products and/or services to customers by improving the flows of material and information between suppliers and customers
O – Owners	CEO	CEOs/Owners of the enterprises within the Supply Chain
E - Environment	Supply Chain	World

7.3 Stage 4

From the root definition above, the following conceptual model for Sun Engineering was determined:

'Sun Engineering is a system owned by the CEO, who together with his employees and machines, uses raw materials from the supplier to manufacture products. This is undertaken with the understanding that customers will be supplied with the highest quality products in a timely manner and at a competitive price in its supply chain'.

The following conceptual model for the supply chain was also determined from the root definition:

'The supply chain is a system owned by the CEOs or owners of the enterprises within the supply chain, who together with their employees and machines, use resources to fulfil customer demands. This is undertaken with the understanding that customers will be supplied with competitive products and/or services by improving the flows of material and information between suppliers and customers'.

7.4 Stage 5

This part of the research paper covers a comparison of the 'real' world with the 'conceptual' models produced in the stage 4 of the SSM. From the previous stages, it is evident that the perception of supply chain risks to Sun Engineering management differs to those depicted in the 'conceptual' model of the enterprise. This comparison has been depicted below in Table 6.

Table 6: Comparison of 'Real world' with 'Conceptual world'

Risk Area	'Real' World	'Conceptual' World	
		Sun Engineering	**Entire Supply Chain**
Supply Risks	Disruptions to direct supply of products from Macsteel	Delivery disruptions of raw materials from suppliers in the SC	Delivery disruptions of resources utilised in SC
Internal Risks	Disruptions to resources (labour, equipment and money)	Late delivery and low quality products	Disruptions to flow of material and information
Demand Risks	Statutory (quality, safety, health, environmental & BEE) requirements from direct customers	Late delivery, low quality and/or expensive products	Lack of customer fulfilment , uncompetitive products/services
External or Environmental Risks	Tax compliance, electricity disruptions and natural disasters	Any SC disruptions (demand, internal and supply)	Any SC disruptions (demand, internal and supply)

The table above shows that Sun Engineering views supply chain risks as those risks that directly affect their enterprise. Supply risks are viewed as those that affect the supply of products required internally, while demand risks are viewed as those risks that are linked to the direct customer satisfaction. This includes any customer requirement (quality, safety, health, environmental or BEE) that is imposed onto Sun Engineering. Internal risks are those risks linked to the actors within Sun Engineering. On the other hand, the external or environmental risks are viewed as those risks that cannot be controlled. This view of supply chain risks is different from the 'conceptual world'. Supply, internal, demand and external or environmental risks are similar in the 'conceptual model'. These risks are those that threaten the worldview of the 'conceptual model'.

8 CONCLUSION

The following conclusions were made from the findings of this study:

- There are limited research frameworks of SCRM that are suitable for SMEs. In the findings of this paper, it is evident that the view of SCRM from a conceptual point of view is different from what is currently happening in the 'real' or SME case in the study.
- SMEs practice risk management. Although this study was based on one case study, it is evident that the owner of the SME does apply risk management practices. This management of risk within the SME is conducted informally and is based on the owner's experience or perception of the risks and their impact. The perceived impact of the risks by the owner affects the risk treatment chosen for those risks.
- SSM is an effective tool in the analysis of SCRM in SMEs. SSM assisted in obtaining insight into the perception of SCRM as a concept and actual practices conducted in SMEs. The difference in both views reveals existing gaps. These gaps can be further studied to determine an ideal SCRM framework for SMEs.

9 ACKNOWLEDGEMENTS

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MEASURING EFFECTIVENESS AND EFFICIENCY IN SOUTH AFRICAN POST OFFICE MAIL CENTRES OPERATIONS: AN INTEGRATED ENERGY MANAGEMENT SYSTEM APPROACH

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ABSTRACT

The integrated energy management system for the mail operations and buildings is aimed at addressing aspects that contribute to the high energy consumption of the Post Office buildings. The approach to the system emphasises on effectiveness and efficiency as tools that are capable of managing energy use in buildings. The South African Post Office's study on "Measuring effectiveness and efficiency in mail operations and buildings: An integrated energy management system approach" was used to determine the scope and benchmarking of the energy management system for mail operations and buildings.

This study follows up on the assembly of quantifiable data that will enable identification of opportunities on effective and efficient energy usage. Historical data on 27 mail centres was collected to determine the baseline and tracking trends of energy usage within buildings. A survey was sent to employees occupying the mail centres to determine their behaviour towards energy usage.

The implementation of the system will focus on high energy using buildings (mail centres) and later phased out to other buildings such as depots and retail outlets. This continual improvement system will guide the efficiency and effectiveness indicators through measurable tools which will focus on occupation and utilization of energy in buildings.

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1 INTRODUCTION

The world greenhouse gas (GHG) report by the World Resources Institute indicates that electricity and heat contributes 24.9% of the GHG emissions (Herzog [1]). The South African Post Office operates over 2000 buildings. "The electricity generation in South Africa had a greater share of 92% from coal fired stations in 2004" (Harald and Andrew [2]), which leads to high GHG emissions. The buildings are categorised according to the type of operations and this paper focuses on mail centres which has a common operation of mail sorting and dispatch. The organisation's mail centres range from 700 square meters to 64 240 square meters in size.

The International Organisation for Standardization (ISO) developed an energy management system framework which gives guidelines on energy management in organisation [5]. The framework is the ISO 50001:2011-Energy Management System and can be utilised by postal sectors to develop their energy management system. The framework follows the Plan, Do, Check, and Act (PDCA) cycle which is continuous for improvement of the system. The framework will assist in further improving the system and also integrating the effective and efficient usage of energy in the buildings.

Literature on energy usage has shown that providing employees with information does not necessarily encourage them to change their behaviour. For many types of behaviour including the ones related to energy consumption. An organization should consider focusing on providing employees with feedback on their energy usage including comparing their consumption with similar buildings or departments which may influence the behaviour to the best towards energy usage [6].

The South African Post Office approach to energy management will address the effectiveness and efficiency of energy use. The effective energy usage refers to technology of energy using components in the building and human behaviour towards energy usage. The efficiency on energy usage in mail operations and buildings are evident in the energy consumption data. This approach provides an integration of using energy correctly (effective) and saving energy (efficiency), i.e. the approach fuses technological capabilities and user capabilities as proxies for energy conservation.

Energy management literature focuses on cost effectiveness with respect to technology. For example, heating and cooling equipment are targeted to improve energy efficiency in residential and commercial buildings. The latter encourages upgrades from old and non-viable technology and less focus on the consumer. This commonplace practise yields good results for organizations focusing on energy management; however it remains prejudice to the user. The inclusion of personnel relations to technology in this paper draws attention to the fact that technology will continue to change; similarly the human element will still hold a pivotal role in ensuring effectiveness and efficiency in energy conservation systems.

2 METHODOLOGY

2.1 Study area

The study of the effectiveness and efficiency in mail operations and buildings was conducted on 27 mail centres of the South African Post Office. The buildings location and sizes are on the table below:

Table 1: Buildings location and size

Mail Centres	Address	Size m^2
Northern		
Tshwane Mail	23 Potgieter Street, Pretoria, 0100	28600
Polokwane	36 Nikkel Street, Superbia, Polokwane	3461
Nelspruit	2 Loco Street Industrial Site, Nelspruit,	1400
Wits		
Witspos	Corner Northern Parkways and Roeland Street, Ormonde, 2091	34000
Germiston	27 George Street, Germiston,	7858
Krugersdorp	36 Industria Road, Baltania, Krugersdorp	3687
Vanderbjilpark	Corner FW Beyers & General Hertzog Blvd, Vanderbjilpark,	4305
JHB int.	Corner Jones & Super South Gate, Jetpark,	8003
JetPark	8 Rudonell Road, Jetpark,	3831
KZN		
Durmail	98 NMR Avenue, Durban , 4001	21600
Pietermaritzburg	21 Wilton Road, Pietermaritzburg, 3201	4940
Port Shepstone	Corner Robison & Durban Willy Streets, Port Shepstone,	2018
Ladysmith	36 Progress Street,	1411
Richards Bay	Ceramic Curve Alton, Richards Bay,	1493
Central		
Bloemfontien	Boemmark Fresh Market, Bloemfontein, 9300	4679
Welkom	Bok Street, Welkom	2678
Kimberly	Market Square, Kimberley	2766
Potchestroom	Corner Wolmarans & Greyling Street, Potchefstroom,	1136
Mafikeng	Corner Carrington & Martin Street, Mafikeng,	1661
Upington Industria	Tin Street, Upington industria,	2566
Eastern Cape		
Port Elizabeth	259 Govan Mbeki Avenue, Port Elizabeth,	5000
East London	Corner North & Oxford Street, East London,	3900
Umtata	Vulindlela Heights no. 21 Southern Wood, Umtata,	4900
Western Cape		
Cape Mail	Mail Street, Good Wood, Cape Town,	64240
Beaufort West	15 Bird Street, Beaufort West,	603
Worcester	Krone Street, Worcester,	1163.05
George	Corner Laing & Industria Street, George	715.15

2.2 Study Design and Protocol

The effectiveness of the energy management system was assessed on two factors which is technology of energy using components in buildings and the human behaviour towards energy usage in operations and buildings. The efficiency of the system was assessed from the historical data on energy usage compared with the current usage.

2.3 Data analyses

Information was gathered on the recommended energy efficient technologies and existing technologies in Lighting, HVAC, Hot Water Systems and Sorting Machines. The information received on the technology was used to compare the existing technology in buildings with the recommended technology which showed if the organisation is effectively using energy in terms of technology.

The questionnaire that was given out consists of two options which were 0-Not Applicable; 1-No; 2-Yes. The number for Not Applicable as an answer indicates that the question does not apply to the individual; number representing No indicates that the activity represented by the number is applicable but the individual does not do it; the number for yes indicates that the question apply to the individual and it is practised. The answers received gave the impact the human behaviour has to energy efficient and ways of using energy.

During the analysis of the data the 0 represented the response No and 1 represented the response Yes. The results of the questionnaire are displayed on a bar graph for the responses that were yes. The graph represents the number of individuals that responded with yes to all the questions and the difference from the number of individuals that responded will represent the No.

The historic data of energy usage and cost was used to indicate the change in usage from 2011 to 2013. The data was analysed by comparing the usage and cost through the years as the progress and the following formula was used to determine the efficiency of each year:

If Year 1 (KWh used) > Year 2 KWh used then Year 2 was energy efficient (1)

If Year 1 (KWh used) < Year 2 KWh used then Year 2 was not energy efficient (2)

The formula was used on the basis that energy efficiency is seen from the reduction in energy used.

3 RESULTS

The energy using components that were identified for this study are: Lighting, Heat Ventilation and Air Conditioning (HVAC), Computers and Machine (sorting and stamp cancellation). The tables below indicate the technologies found in sampled buildings and the recommended technology by Eskom [3].

3.1 Lighting

Table 2: Lighting technology comparison

Type of lights	Existing Technology	Recommended technology
Mercury vapour High Bays	400 Watts mercury vapour	350 Watts Induction High Bay
CFL 2 pin	9 Watts CFL	6 Watts LED
T5/T8 adapter fluorescents	58 Watts CFL	36 Watts LED T5
T5/T8 adapter fluorescents	36 Watts CFL	28 Watts LED T5

3.2 Hot Water Systems

Table 3: Hot Water System technology comparison

System	Existing technology	Recommended
Boilers	36 kW ; 3000 litres	Heat Pumps
Geysers	3kW ; 150 litres	Solar Geyser

3.3 Computers, HVAC and Sorting Machines

Computers that are energy star rated are recommended as energy efficient and there is no specific recommended energy efficient technology for the HVAC and sorting machines. The energy efficiency of these systems is based on the usage and demand side management in the building.

3.4 Human Behaviour

The human behaviour towards energy technology usage in buildings yielded a total of 3353 responses. Figure 1 and figure 2 indicate the general and technology specific responses, respectively.

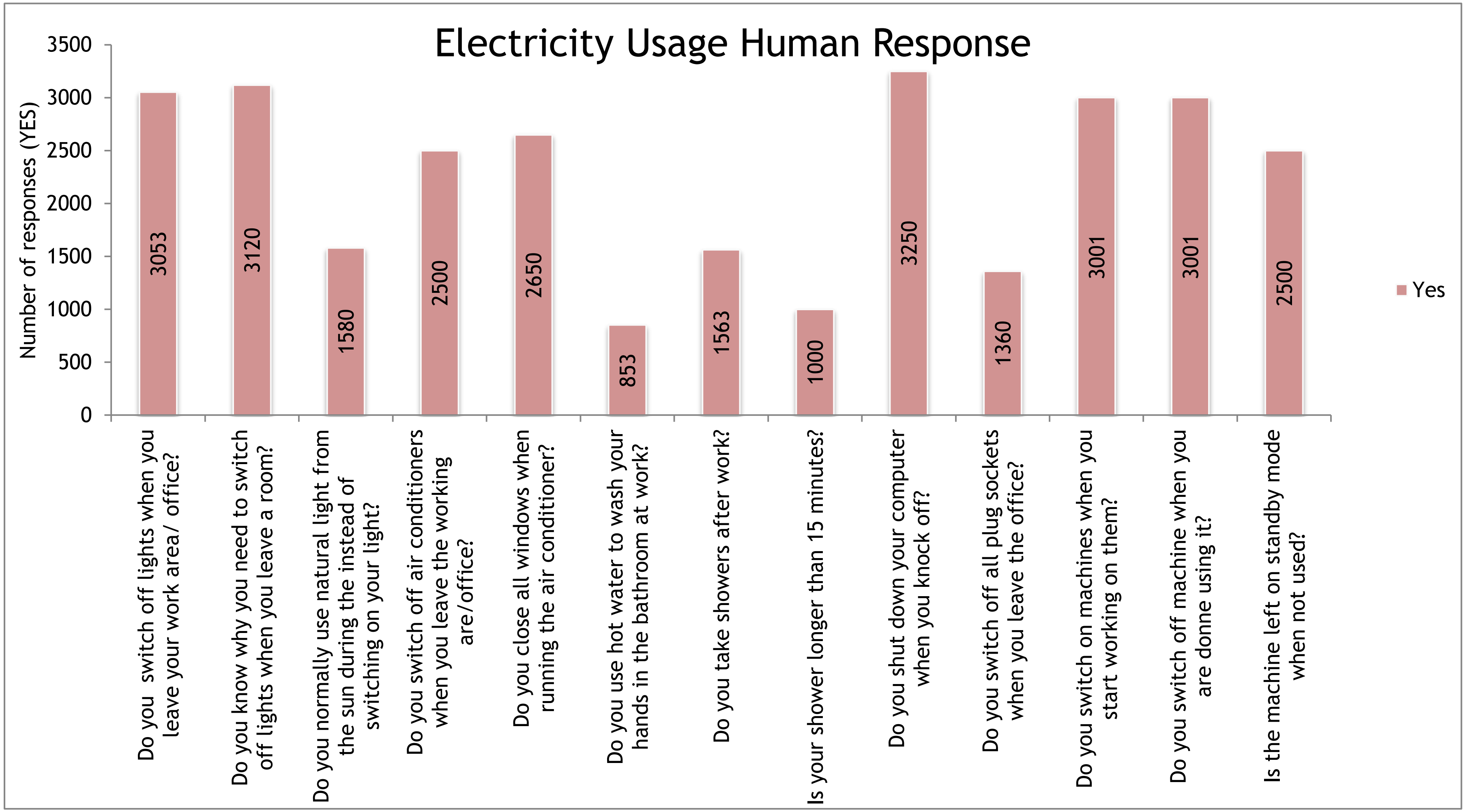

Figure 1: Overall responses from employees

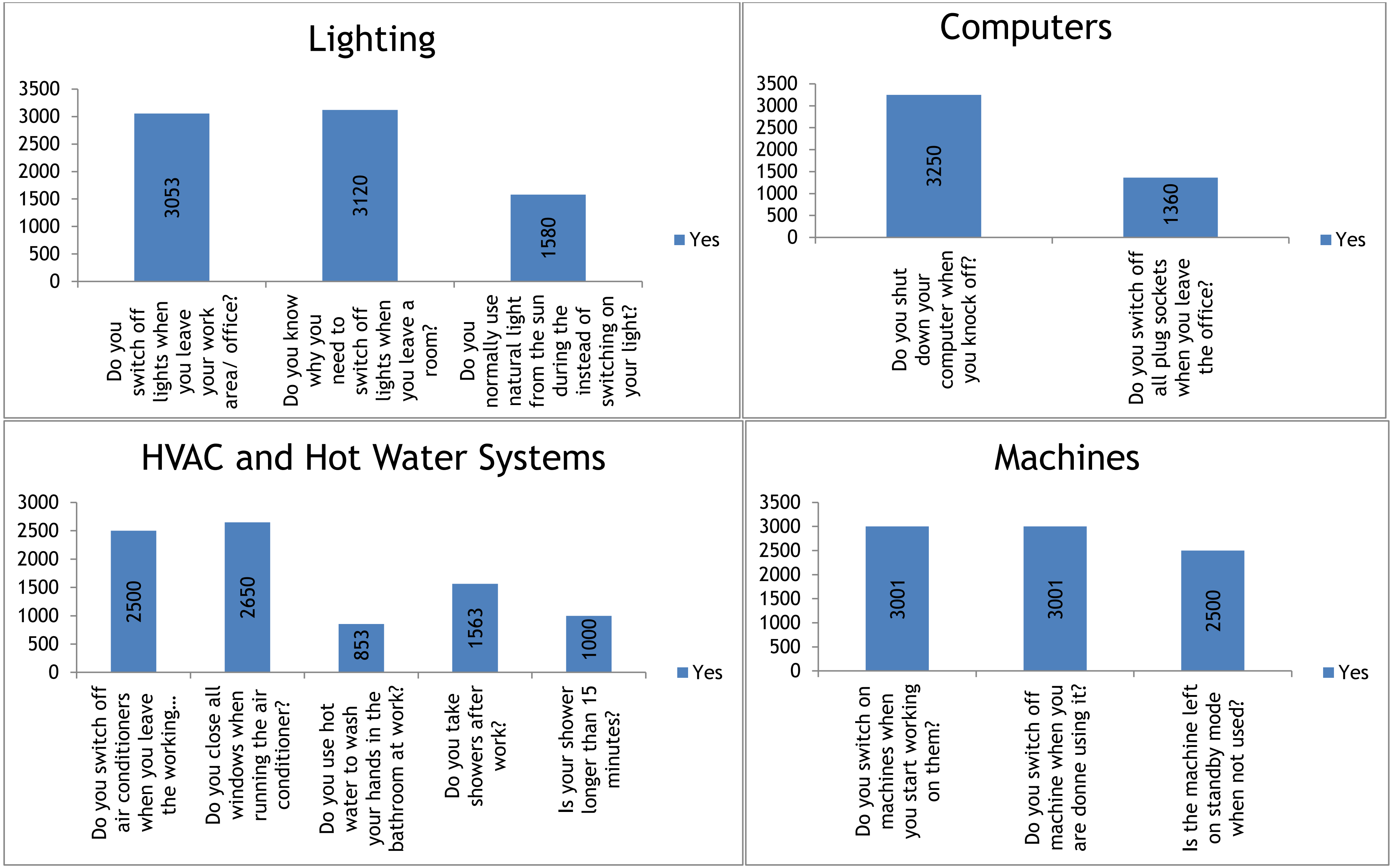

Figure 2: Responses per user category of technology

3.5 Efficiency

The SA Post Office energy efficiency is measured using the historical energy usage data for the 27 mail centres buildings with the current usage. The baseline set for this study is 2011; the data is populated up to 2013; efficiency is a result of reduction in usage and is based on the threshold set. The South African Post Office has a threshold of reducing 3% of the electricity usage in buildings annually. The threshold is based on each previous year's consumption. The graphs indicate the performance of the 27 mail centres were studied in terms of electricity usage.

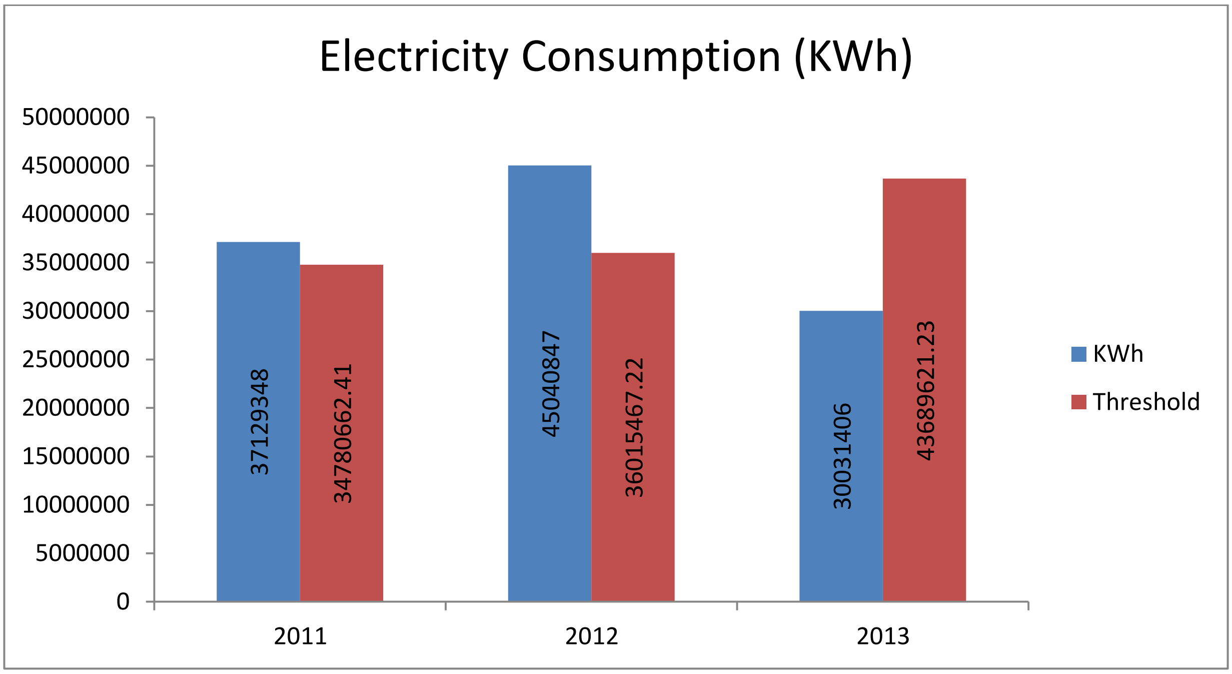

Figure 3: Mail Centres annual electricity consumption

4 DISCUSSIONS

The results of the study of effectiveness and efficiency was based on the technology of electrical components that are being used, human behaviour towards energy usage in buildings, efficiency of the sampled buildings over the three years (2011 to 2013).

The lighting technologies that are used in SA Post Office buildings are less efficient as compared to the recommended energy efficient lighting by Eskom Standard Offer Product Toolkit. The boilers which consume 36kW are less efficient as compared to the heat pumps and solar geysers are more efficient as compared to electric geysers. The Computers, HVAC and sorting machines do not have any specific efficient technology to replace with as they are managed through demand side management where the time and manner of usage of the components is managed to reduce energy usage.

The response shows the total number of 3, 353 people employees responded from the total of 4, 785 people that occupy the 27 mail centres. The figures' representing the results reflects the response of people who responded with affirmative. The results of the questionnaire indicates the role of human behaviour in energy usage and shows that with sufficient training and awareness on effective and efficient energy usage the impact can be reduced.

The human behaviour toward lighting indicates that employees are aware of the controlling usage in lighting; they also show to be aware of the reasons of switching off the lights. The results of switching off computers off when knocking off shows 96% of the respondents that respond with affirmative which means employees are practicing energy saving with their computers.

The Hot water usage in the buildings indicate that even though hot water usage is not part of the main operations, the buildings still have 3000 litre boilers and the human behaviour results also shows that 25 % of the people use warm water to wash their hands after using the bathroom. The results show the type of technology as inefficient especially when the operations do not fully depend on hot water and the usage of hot water is low and indicates that employees are aware of using warm water only when necessary.

The use of machinery indicates that 89 % of the employees switch off their machines when done using them and on only when they are operating from then. The percentage shows that with further training and improvement in technology the buildings can reach a fully energy efficient and effective energy usage state.

The energy efficiency of the buildings from the baseline year 2011 shows an increase in energy used in 2012 as compared to 2011 by 21% followed by a decrease in 2013 as compared to 2011 and 2012 by 19% and 33% respectively. The result indicates 2012 to be energy efficient as compared to the year 2012 and the baseline year 2011.

5 CONCLUSIONS

The study has indicated that there is a need to integrate the effective usage with the efficient usage in managing the buildings energy usage. The change of technology and human behaviour to energy efficient technology and energy conscious behaviour will lead to reduction in energy. Since energy management system is a continuous improvement system there will be continuous reduction and improvement in usage and cost which will lead to cleaner and greener technologies of energy.

The South African Post Office needs to implement an energy management system that is integrated with effective and efficient energy usage. The current state of energy management indicates that with proper training and awareness to the employees on using electricity and change of technology to efficient technology the management system will be effectively implemented. The South African Post Office is currently changing the buildings lighting technology to energy efficient technology which shows that with continuous change and adopting the tool of integrating effectives and efficiency in the system will lead to the company reducing their energy usage.

6 ACKNOWLEDGEMENTS

This paper is made possible by the help and support of everyone from the South African Post Office: Employees, Supervisors and Managers.

Especially, please allow us to dedicate our gratitude to toward the South African Post Office Sustainability Unit (Coordinators, Specialists and Head) for the encouragement and support.

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ENERGY MANAGEMENT SYSTEM: THE BEST TOOL FOR ENERGY MANAGEMENT IN THE POSTAL SECTOR

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ABSTRACT

ISO 50001:2011- Energy Management System (EnMS) was developed to specify requirements for establishing, implementing, maintaining and improving energy management systems with the purpose to enable organizations to follow a systematic approach in achieving continual improvement on energy efficiency, energy use and energy consumption.

The paper will focus on testing two hypotheses which are as follows: Hypothesis 1- Energy Management System is the best tool for energy management in the postal services. Hypotheses 2- Energy Management System is not the best tool for energy management in the postal services. The hypotheses will be tested by assessing the current energy management for mail centres and fleet in the South African Post Office as a benchmark, and comparing it to the projected outcomes of implementing the ISO 50001:2011-EnMS.

Historical energy (electricity and fuel) data will be analysed to establish the baseline, the significant energy users and drivers will be derived from the current operations and also be used to determine the suitability of the system to operations. The outcomes of the data analysis will determine the final result of the two test hypothesis.

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1 INTRODUCTION

South Africa is faced with an energy crisis, where the demand does not meet the supply, it is imperative as outlined by the government and the energy provider being Eskom for every individual and businesses to conserve and use energy efficiently [2]. The SA Post Office as a state owned company acknowledges the need to adhere to this call by the government. The approach to this call was based on which system recommended to assist the company to manage their energy usage and implement energy efficiency projects, the ISO 50001:2011 Energy management system is the system that the this study will be based on.

The International Standards Organization (ISO) developed the 50001:2011- energy management system (EnMS) framework which gives guidelines on energy management in an organisation [5]. The framework follows the Plan, Do, Check and Act (PDCA) cycle which is continuous improvement of the system. The system is embedded in the UNIDO guidelines of implementing Energy Management System Toolkit [3]. The framework and toolkit will assist in further improving the systems and integrating energy efficiency in the system.

The same as other ISO standards such as quality (ISO 9001) and environmental management (ISO 14001), ISO 50001 is an internationally accepted energy management standard. It comprises of sustainable energy management systems, baseline energy consumption verification and commitment to energy performance improvement. Even though ISO 50001 and other management systems are effective to identify methods and opportunities to achieve energy savings, when applied solely they will not offer sufficient mechanisms to ensure that energy performance improvements are achieved [6]. The synergies within systems is of high importance in ensuring that the systems work best with other aspects such as human behaviour towards energy usage

The need for energy management is required but the paper assess whether the EnMS is the right tool by testing two hypotheses: EnMS is the best tool for energy management in the postal sector (hypothesis 1) and/or EnMS is not the best tool for energy management in the postal sector (hypothesis 2) using the United Nations industrial development organization (UNIDO) EnMS tool kit to assess how applicable the tool kit is and what are the benefits and differences [3].

The South African Post Office currently operates in +/- 3000 buildings which uses electricity and has approximately 1450 vehicles that utilize petrol and diesel. From the buildings, the study is going to look at mail centres as a benchmark. These two resources of the Post Office consume energy directly and indirectly on a daily basis.

The study relates with the research UNIDO has been conducting regarding the processes of ISO 50001 energy management systems in the developing countries. This tool serves to better understand the potential opportunities and challenges that may arise when implementing the EnMS into the respective companies in the emerging economies and developing countries [4]. This was conducted in the South African Post Office to assess the loop holes in the current system of energy management. The aim is to assess the current system from the planning to the corrective actions following the PDCA cycle; the assessment will enable identification of the need to implement the system or not as part of testing the hypothesis.

2 METHODOLOGY

2.1 2.1 Study Area

The study of Energy Management System: Best Tool for Energy Management in the Postal Sector was conducted in mail centres and fleet across the South African Post Office footprint. The buildings are located in all South African provinces and the vehicles from the fleet are used for mail operations and delivery within the provinces. The buildings locations and sizes are as displayed on Table 1 below:

Table 1: Buildings location and sizes

Mail Centres	Address	Size m^2
Northern		
Tshwane Mail	23 Potgieter Street, Pretoria, 0100	28600
Polokwane	36 Nikkel Street, Superbia, Polokwane	3461
Nelspruit	2 Loco Street Industrial Site, Nelspruit,	1400
Witwatersrand		
Witspos	Cnr Northen Parkways and Roeland Street, Ormonde, 2091	34000
Germiston	27 George Street, Germiston,	7858
Krugersdorp	36 Industria Road, Baltania, Krugersdorp	3687
Vanderbjilpark	Cnr FW Beyers & General Hertzog Blvd, Vanderbjilpark,	4305
JHB int.	Corner Jones & Super South Gate, Jetpark,	8003
JetPark	8 Rudonell Road, Jetpark,	3831
Kwa-Zulu Natal		
Durmail	98 NMR Avenue, Durban , 4001	21600
Pietermaritzburg	21 Wilton Road, Pietermaritzburg, 3201	4940
Port Shepstone	Cnr Robison & Durban Willy Streets, Port Shepstone,	2018
Ladysmith	36 Progress Street,	1411
Richards Bay	Ceramic Curve Alton, Richards Bay,	1493
Central		
Bloemfontien	Boemmark Fresh Market, Bloemfontein, 9300	4679
Welkom	Bok Street, Welkom	2678
Kimberly	Market Square, Kimberley	2766
Potchestroom	Cnr Wolmarans & Greyling Street, Potchefstroom,	1136
Mafikeng	Cnr Carrington & Martin Street, Mafikeng,	1661
Upington Industria	Tin Street, Upington industria,	2566
Eastern Cape		
Port Elizabeth	259 Govan Mbeki Avenue, Port Elizabeth,	5000
East London	Cnr North & Oxford Street, East London,	3900
Umtata	Vulindlela Heights no. 21 Southern Wood, Umtata,	4900
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Beaufort West	15 Bird Street, Beaufort West,	603
Worcester	Krone Street, Worcester,	1163.05
George	Cnr Laing & Industria Street, George	715.15

2.2 Study Design and Protocol

To test the two hypotheses, historical data for the two resources (electricity and fuel) was used to assess the trends and also the current situation by filling in the data in the United Nations industrial development organization (UNIDO) energy management system tool kit. The toolkit outlines the current situation of energy based on the input of data in order to identify the gaps and opportunities that may be implemented.

2.3 Scope of work

The Post Office has around 3000 buildings and vehicles that are operating in both the company and the subsidiaries. Table 2 depicts the scope of work which covers only the company and excludes the subsidiaries.

Table 2: Study Scope of work

Included	Excluded
Mail Centres	Other Buildings (Depots, Retail Outlets, Data Centres and Warehouses)
SAPO Fleet	Subsidiaries fleet (CFG, Docex and Speed Services)

The study is based on the big mail centres taking one of the biggest mail centre; the Tshwane mail centre as an example in assessing the SEUs in the buildings. For the fleet, we took the SA Post Office fleet that consumes both diesel and petrol. The scope of work depicted in table 2 was chosen based on the reasons that mail centres are big in size with high electricity consumption, while SAPO also constitute the highest in terms of fleet as compared to the subsidiaries fleet.

2.4 Data Analysis

The study looks at the energy used in buildings and in fleet. Mail Centres were used to study buildings and vehicles (diesel and petrol) were studied. The litres that were consumed over the three calendar years (2011 to 2013) were converted into Kilowatt Hours using the DEFRA conversion factors [1]. The data of consumption is displayed in graphical forms on figures 3, 4, 5 and 6, where it shows the previous consumptions and cost of electricity and fuel respectively.

The acquisition of the energy consumption from electricity and fuel gives a clear picture of how much energy is used by the organization. The following step was to identify Significant Energy Users (SEU); these are components that play the most important roles within operations and require energy to be operated. SEUs usually utilize more electricity especially in buildings, for each SEU the power output and number of hours they operate were used to calculate the KWh. The assessment and distribution of the SEU was studied only at Tshwane Mail Centre with the aim to show how the calculations will be carried out and how the toolkit assesses the SEUs. The following equations were used:

Power requirement *: Power = Voltage (V) * Current (I)* **(1)**

Energy Usage *: Energy Used = Power (Watts) * Operating Hours (h)* **(2)**

The UNIDO tool was used to assess the trends of the consumption and also in evaluating the current working system of energy in the organisation. The toolkit assisted in identifying the loopholes within the current system from the self-assessment to the documentation that is generally expected for an energy system. The usage of the toolkit is more of fact finding and assessment in order to identify the improvements that are required within the energy management system and also within the organisation's energy usage.

3 RESULTS

Figure 1 depicts the self-assessment which is designed to indicate the organisation's current state in terms of energy management.

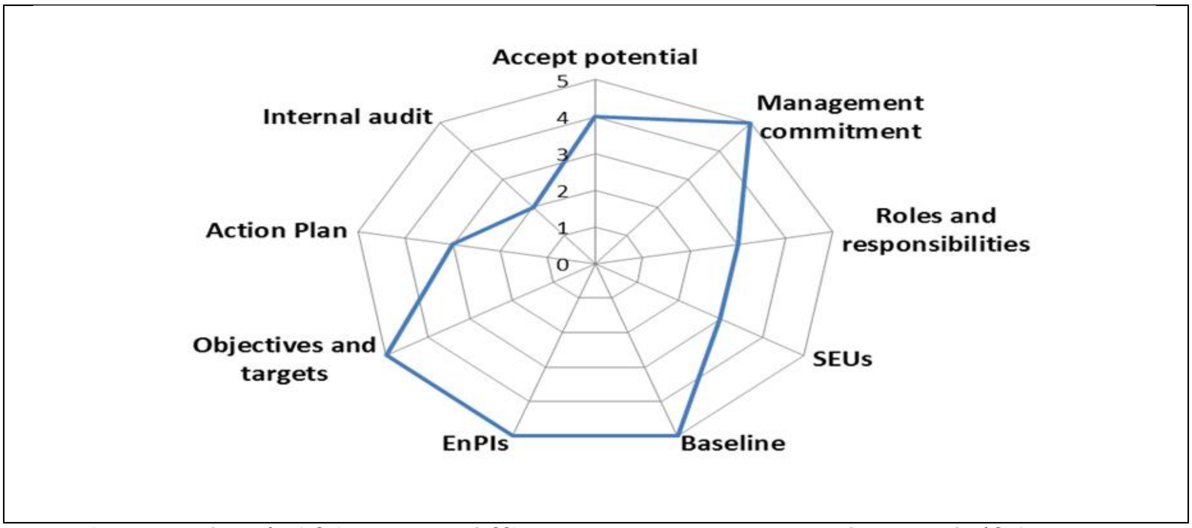

Figure 1: South African Post Office Energy Management System Self-Assessment

Figure 2 show the distribution of SEU list within Tshwane Mail Centre examples how the SEUs are assessed and applicable in buildings using the UNIDO tool Kit.

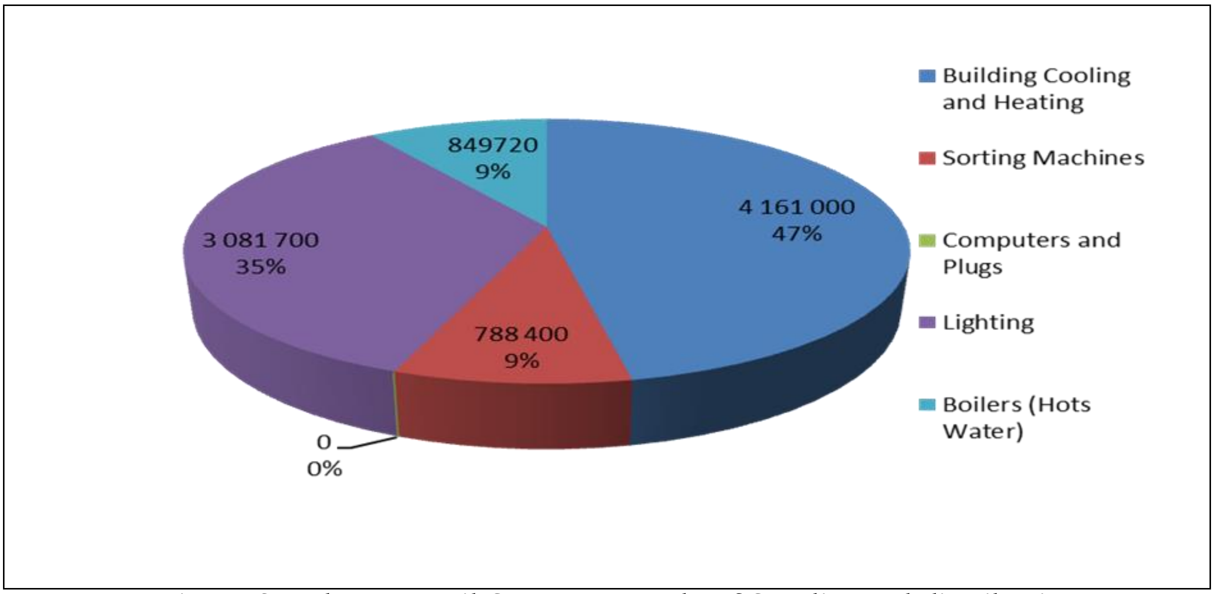

Figure 2: Tshwane Mail Centre example of SEU list and distribution

The distribution list indicates the highest energy users in the building, in Figure 2, the building's cooling and heating is the significant energy user constituting 47% of the Mail centre's energy use.

Figure 3 and Figure 4 below indicate the trend for buildings electricity usage and cost over three years (2011– 2013)

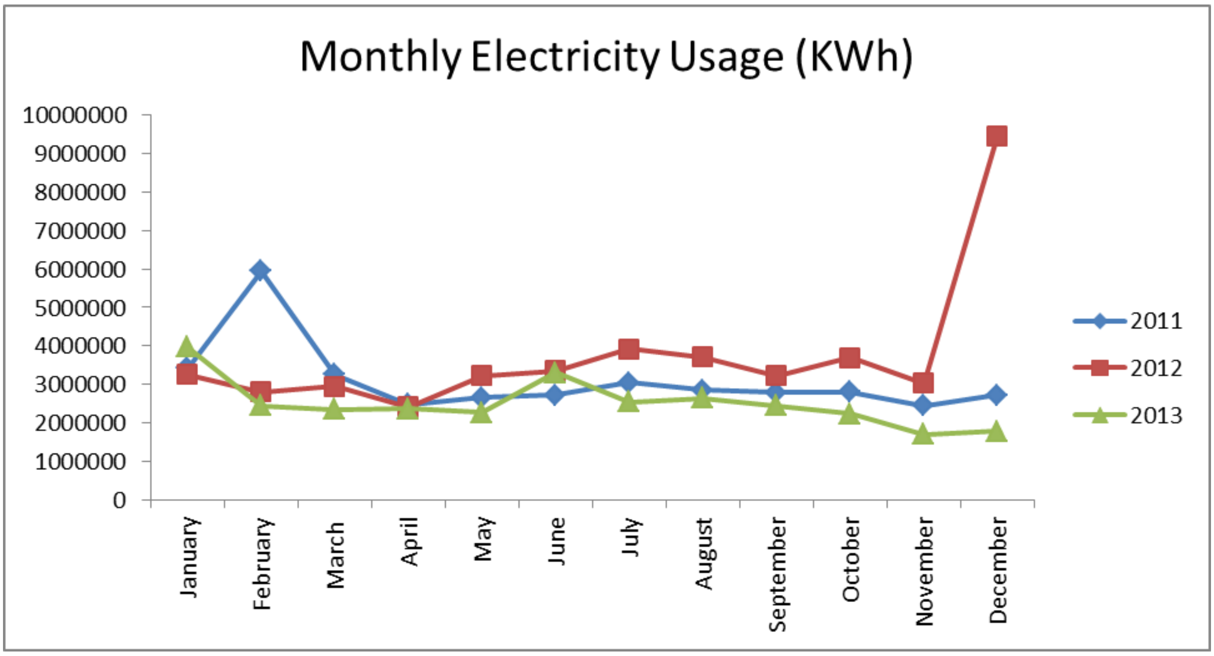

Figure 3: Monthly electricity usage trend analysis over three years (2011-2013)

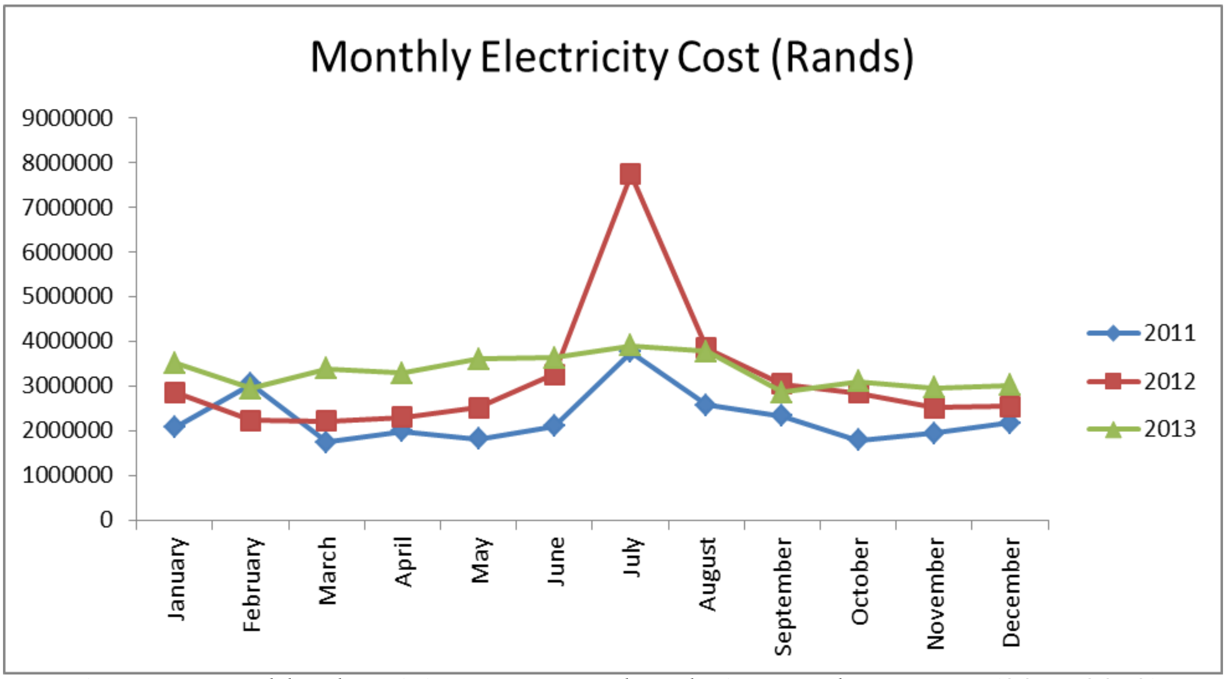

Figure 4: Monthly electricity usage trend analysis over three years (2011-2013)

Figure 5 and Figure 6 below indicate the fuel usage and cost by SAPO fleet over three years (2011- 2013).

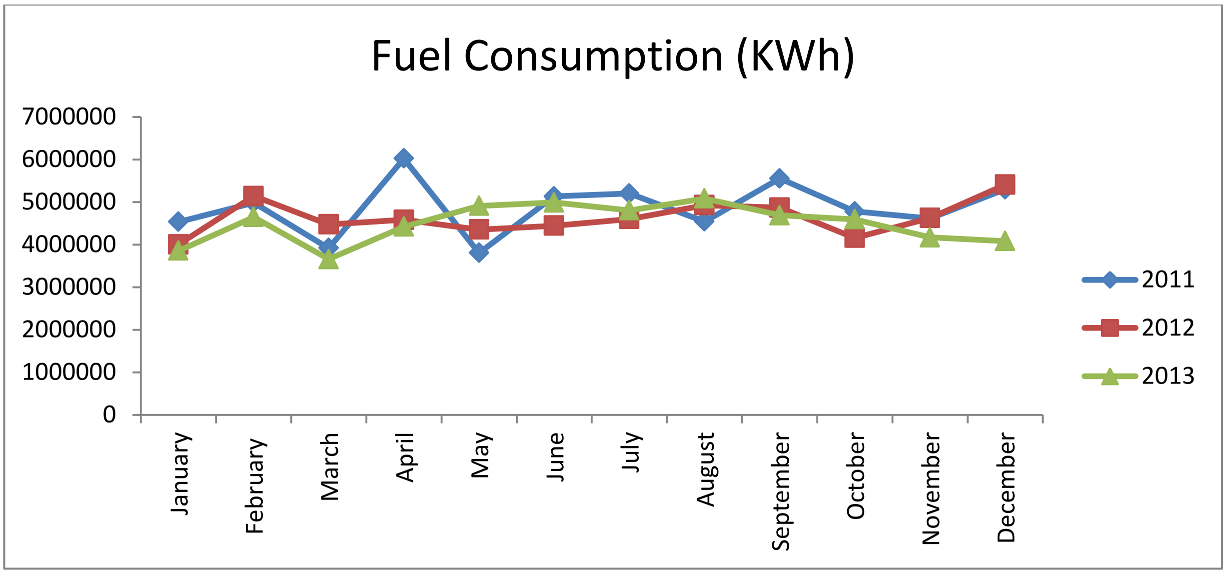

Figure 5: Monthly fuel usage trend analysis over three years (2011-2013)

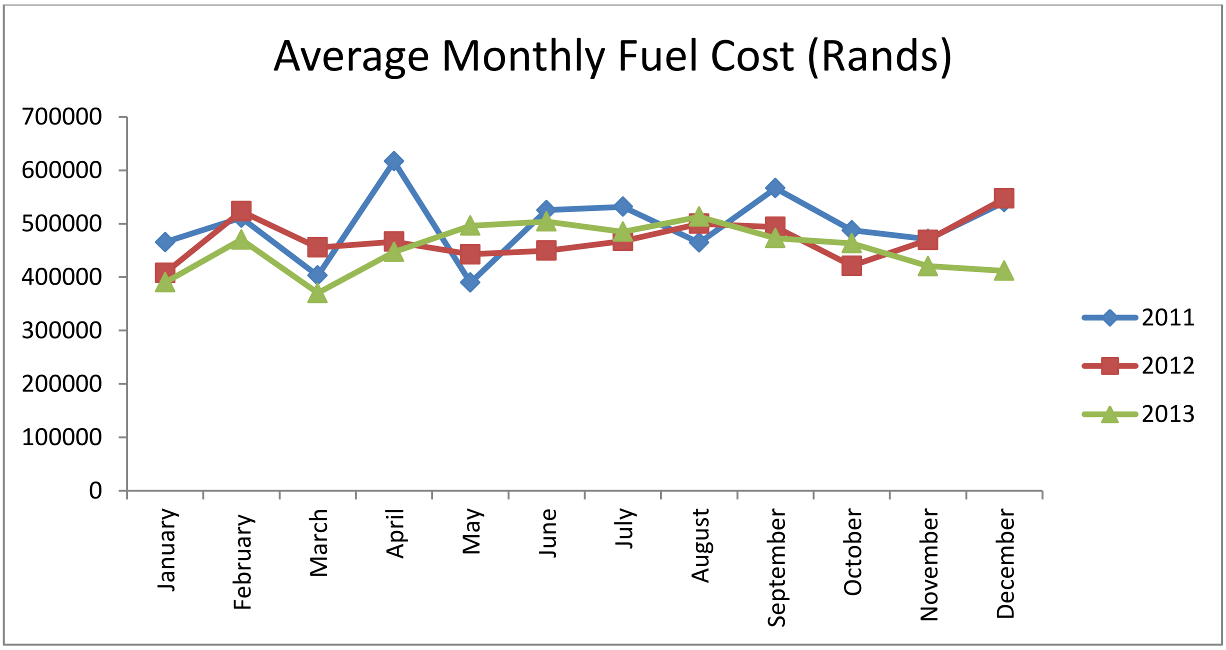

Figure 6: Monthly electricity usage trend analysis over three years (2011-2013)

4 DISCUSSIONS

4.1 Organization's self-assessment

The self-assessment is used to illustrate the state of an organisation where an energy management system is meant to be implemented; in this case the assessment was conducted for the South African Post Office Mail Centres and the fleet; the assessment is for 28 mail centres and 1500 fleet.

The results of the assessment indicate that there is currently no balance in the energy management system being operated on in the organization. There is currently accepted potential on energy savings in the buildings but the low cost measures associated to energy efficiency have not been exhaust hence the rank is not at level five for that particular aspect as shown in Figure 1.

Management commitment on energy management is included in the organizational environmental policy but the roles and responsibilities have not been identified and documented for the organization as a whole, the roles and responsibilities are documented for the Sustainability Unit which is the energy team. The significant energy users (SEU) in the mail centres have been identified but not quantified and documented as significant energy users. The basic significant energy users in the buildings would be mail sorting machines, Heat, Ventilation and Air Conditioning system (HVAC), Hot Water Boilers and Lighting. The SEUs are not quantified and documented mainly because there are no meters that measure each SEU's usage.

The baseline year for energy usage in buildings and fleet is 2009/2010 at a consumption of 472, 046, 220 KWh. The indicators were to set to measure consumption and performance against the baseline. The target was set to reduce 3% of the energy usage in buildings and fleet over prior year. The opportunities and projects that may assist in reducing energy have been identified although they have not been approved and adequately resourced to commence. The current energy management system is not evaluated and has not been improved in a formally documented manner.

4.2 Significant Energy Users

The significant energy users are vital in the EnMS as they assist the company to develop work flow plans of opportunities to implement in ensuring that the energy is efficiently used. The data displayed on the pie chart is extracted from Tshwane Mail Centre which is the second biggest Mail Centre and also one of the high consuming Mail Centre. The average annual energy usage of the building is 9, 510, 996 KWh [2]. The total usage for the SEUs is 8, 880, 820 KWh and non SEUs are 63, 017 KWh which are 93% and 7% of the total consumption respectively. Building Cooling and Heating system constitutes 47% of the total which means they contribute more to the maximum demand of the building.

The lighting of the building also has a high contribution of 35% because of the technology that is used such as 400 Watts Mercury Vapour and T8 CFL lights which is not deemed energy efficient. The hot water systems that are mainly used in the bathrooms and kitchens uses 9%; the same as the sorting machines. The 7% of non SEU is for the computers and plugs that are in the building [2].

4.3 Energy usage and cost trends

Compiling the energy used for both mail centres and fleet enables us to see the discrepancies in the organisation's energy usage and also report on the overall energy uses from the two energy types.

Figure 3 represents the amount of electricity used per month for three calendar years (2011, 2012 and 2013) in the 28 mail centres. The figure indicates the highest consuming month and the lowest over the three years, this assists in going further into the tool kit by determining the cause of the high consumers of energy and opportunities to reduce the consumption. Figure 4 compares the amount of money spent on the electricity, this figure should correlate with the consumption (Figure 3). Assessing Figure 3 and 4, it is evident that the cost of the energy used does not match with the consumption i.e. December 2012 has the highest energy consumption and a fairly lower cost.

Figure 5 indicates the amount spent on fuel for the three years, which was compared with Figure 6 to see if the cost corresponds with the consumption. Both consumption and cost correlate in case of fuel, therefore we are able to see the pattern and the trend.

The UNIDO EnMS tool kit has 26 tools that are able to assist the company in having a complete energy management system, out of the total tools, only 19 are applicable to the South African Post Office, this is 73% of the system. With the current situation out of the 19 applicable tools, twelve tools were completed; which is 63% from the 19, this gives us the potential to complete more and ensure that the self-assessment web reaches the balance of all five marks being ranked.

Toolkit	Applicability to SAPO	Currently completed
1. Self-Assessment	Y	Y
2. Roles and Responsibilities	Y	Y
3. Scope	Y	Y
4. Policy	Y	Y
5. Data	Y	Y
6. Trends	Y	Y
7. SEU list	Y	Y
8. SEU - Motors	N	N
9. SEU - Heat Users	N	N
10. SEU - Lighting	Y	Y
11. Drivers	N	N
12. Energy Performance Indicators	N	N
13. Measurement Plan	Y	N
14. Maintenance Criteria	Y	N
15. Critical Operating Parameters	N	N
16. Technical Audits	Y	Y
17. Opportunities List	Y	Y
18. Training	Y	N
19. Documents	Y	Y
20. Operational control	Y	N
21. Procurement	Y	N
22. Design	N	N
23. Non-conformities	Y	N
24. Legal	Y	N
25. Internal audit	Y	Y
26. Info-finance	N	N

Figure 7: The UNIDO EnMS tool kit [3]

Figure 7 is a representation of the UNIDO tool kit; it highlights the applicability of the tools to the company and the ones that have been completed.

5 RECOMMENDATIONS

Identifying the SEU's in buildings will enable us to increase the scope of work further by including the maintenance criteria tool to list the activities of the SEU's, the tasks they perform and the frequency of their usage. This also includes the responsible people to perform the tasks and ensure that the maintenance of the SEU's are conducted as required by the system.

The inclusion of other tools in the EnMS such as the technical and internal audits will assist in evaluating the SEU's and plans that were implemented The evaluation will cover the checking of the system as outlined on the PDCA cycle before review and management commitment; continuous improvement and evaluation is necessary, hence the inclusion of the audits will result in the self-assessment web reaching the full marks.

6 CONCLUSION

Based on the toolkit and what the toolkit consist of, the first hypothesis applies; the energy management system is the best tool for energy management in the postal sector. The study has indicated that the current situation of the company does have gaps that needed to be filled in order to ensure that the energy management system is fully operational and there is potential for improvement as part of energy efficiency in buildings and fleet.

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ASSESSMENT OF ENTERPRISE RESOURCE PLANNING IMPLEMENTATION IN ZIMBABWEAN COMPANIES AND READINESS TOOL TOWARDS A STRATEGIC SUCCESS FRAMEWORK

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ABSTRACT

Enterprise Resource Planning (ERP) was a great leap of technology that received astounding welcome in the business world. However, with time problems began to surface, from complexity to inflexibility. Consequently, companies implementing ERP software are not attaining full benefits due to several reasons. Studies have been carried out in different countries to evaluate the causes of failure and provide solutions. This paper aimed at assessing ERP implementation from Zimbabwe's perspective. Questionnaire surveys were done focusing on major project stages namely pre-implementation, implementation and post-implementation. The survey also targeted all parties involved in ERP implementation, comprising top management, Information Technology department, end users and consultants. From the findings analysed, a conceptual success model was designed and simulated using System Dynamics Software. Application software was developed using Visual Basic 200x to measure companies' readiness level for ERP implementation. Based on these results, recommendations were made on ways to tap the full potential embedded in the Enterprise Resource Planning technology. Therefore, the resulting model and software was used as a tool for companies that intend to optimize their systems and to manage ERP projects in future.

1 INTRODUCTION

Research has attributed closure of most companies to decision making on inadequate, incomplete, inaccurate and obsolete information. As a result, the most popular trend in corporations nowadays, is to rely more and more on Enterprise Resource Planning (ERP) systems as they move towards increased integration and team-based work processes. These ERP systems allow companies to work as a whole instead of relying on islands of information. However, most companies have not been able to fully benefit from their very expensive ERP implementations. The failure of ERP projects remains a major concern for all organisations thinking of adopting ERP systems [1].

Pouransafar et al [2] shows 70 percent of all ERP projects fail to be fully implemented even after three years. Jahanyan et al [3] added that the management team has to concentrate not only on economic and formative objectives but also on the other aspectual objectives which are more qualitative and intangible for the success of ERP implementation. ERP project failure is a major threat to organisations and has influenced other companies' decision in adopting ERPs. In order to cope with this challenging threat in the industry, Zimbabwean industry needs to explore the key factors influencing ERP project failures in order to help reduce the chances of failure. It is not the first time that attempts are made to solve this problem, previous attempts have tried to capture the cause of failure in different countries and different economic situations [4, 5, 6, 7, 8, 9]. The aim of this paper was to look at ERP implementation failures from a Zimbabwean perspective. This will allow companies, through their project managers to identify critical success factors to avoid failure in the future and reduce the level of threat for organisations thinking of adopting ERP systems. This paper can also be used as guidance for the ERP project managers in order to acknowledge previous failures and to understand the missing gap that they must fill in order to attain successful projects in some ERP implementations.

2 RELATED LITERATURE

Section 2 gives a brief on the ERP implementation stages, followed by the ERP implementation failure areas. Systems Dynamics was discussed introducing the tool used to support strategic framework of the paper.

2.1 ERP Implementation stages

According to Rashid [4], ERP implementation stages can be classified into:

a) Pre-implementation or setting up stage

This phase considers incorporation of the risk and quality management plans in the change management plan; breakdown of the project into natural phases or subsystems for modular planning and development of cross-functional communications.

b) Implementation stage

Implementation stage involves formulating a network for collecting user requirements, and setting-up monitoring network for collecting control information at each stage of the implementation process. In this stage preparation to handle expected or unexpected crises through a strong leadership with concern for the welfare of people and resource commitment are some of the strategies to consider. The top management support, client consultation, user participation are some more strategies to be considered.

c) Post implementation or evaluation stage

Post-implementation activities are critical for the acceptance of ERP systems. Requirements of IT systems and structures tend to change continuously even after the completion of a project. Post project evaluation strategy could be followed in measuring the effectiveness of an ERP system, where some of the questions could be used for further improvement:

i. Whether the objectives of the ERP system were realized fully
ii. Whether the scheme options were considered adequately
iii. Whether the estimates and project information were accurate
iv. Whether or not the agreed practices and techniques were complied with

2.2 Factors Leading to ERP Implementation Failure

Ligus [5] defines twelve (12) cardinal sins of ERP implementation and some of the factors are discussed are lack of top management commitment leading to lower management levels missing scope, size, time and resources required for successful implementation; Inadequate requirements definition; poor ERP package selection due to inadequately developed functional requirements definitions; inadequate resources in terms adequate skills and individual workloads; resistance to change and lack of buy-in caused by failure to build a case for change, lack of involvement by those responsible for working with changed processes, inadequate communication, lack of visible top management support and commitment and arrogance; miscalculation of time and effort; misfit of application software with business processes; unrealistic expectation of benefits and Return On Investment (ROI); inadequate training and education; poor project design and management by short-cut critical events in the project plan, such as time for documentation, redefining and integrating processes, or testing before going live; poor communications begin with announcing the reason for the up and coming effort, and continuing to advise the organization of the progress and importance of the ERP implementation to the company while good communication allows different parts of the organization to assess how they will be impacted by changes in processes, policies, and procedures and ill-advised cost cutting as seen in an effort to avoid temporary conversion costs, some companies take a very risky route and go live at multi-plant sites simultaneously, subjecting all plants or some plants to a total shutdown

Some of the other work that looked at the critical success factors for ERP projects was Wong and Tein [6]. Aarabi et al, [7], and Saini et al [8] analysed critical success factors in ERP implementation with a focus on small and medium enterprises in developed an country which gave a basis of comparison of recommendation to Zimbabwe for some of the small to medium organisations considered.

2.3 Types of success in ERP systems

Success in ERP implementation can be categorised as follows [9]:

i. Correspondence success: when there is a match between IT systems and the specific planned objectives.
ii. Process success: when the project is completed within time and budget.
iii. Interaction success: is when users' attitude towards IT is positive.
iv. Expectation success

2.4 Systems Dynamics

System Dynamics is a study of information feedback characteristics of industrial activity to show how organisational structure, amplification in policies and time delays in decisions and actions interact to influence the success of the enterprise. Real world processes are represented in terms of stocks, for example, material, knowledge, people and money, flows between these stocks and information that determines the value of the flows [10].

According to Sterman [11] large scale projects belong to the class of complex dynamic systems and such systems. These are extremely complex, consisting of multiple and interdependent components, highly dynamic, involve multiple feedback processes, involve non-linear relationships and involve both hard and soft data. To manage such complexity properly, a model must be capable of representing systems with these characteristics and it must be understandable and usable by the managers of the projects

3 METHODOLOGY

Purposive sampling was used in terms of the companies that had implemented ERP systems from the past work by Mhlanga et al [12]. Thirteen (13) companies were targeted of different products and employee sizes. Questionnaires were designed to interrogate the critical success factors and project management in three main ERP implementation stages namely pre-implementation, implementation and post implementation. The target groups such as Top management, Companies' Information Technology Department, End-users and Consultants were selected based on the five main pillars of ERP implementation [13] for which questionnaires were designed.

Table 1 shows a summary of the companies using ERP systems and consultants.

The second stage of the methodology involved strategic analysis of ERP implementation through the application of systems dynamics using Vensim software. The motivation was to evaluate the effect of the different stages of implementation. The final stage involved the development of an ERP implementation readiness tool using Visual Basics programming which could give indication to the company on their position in ERP readiness.

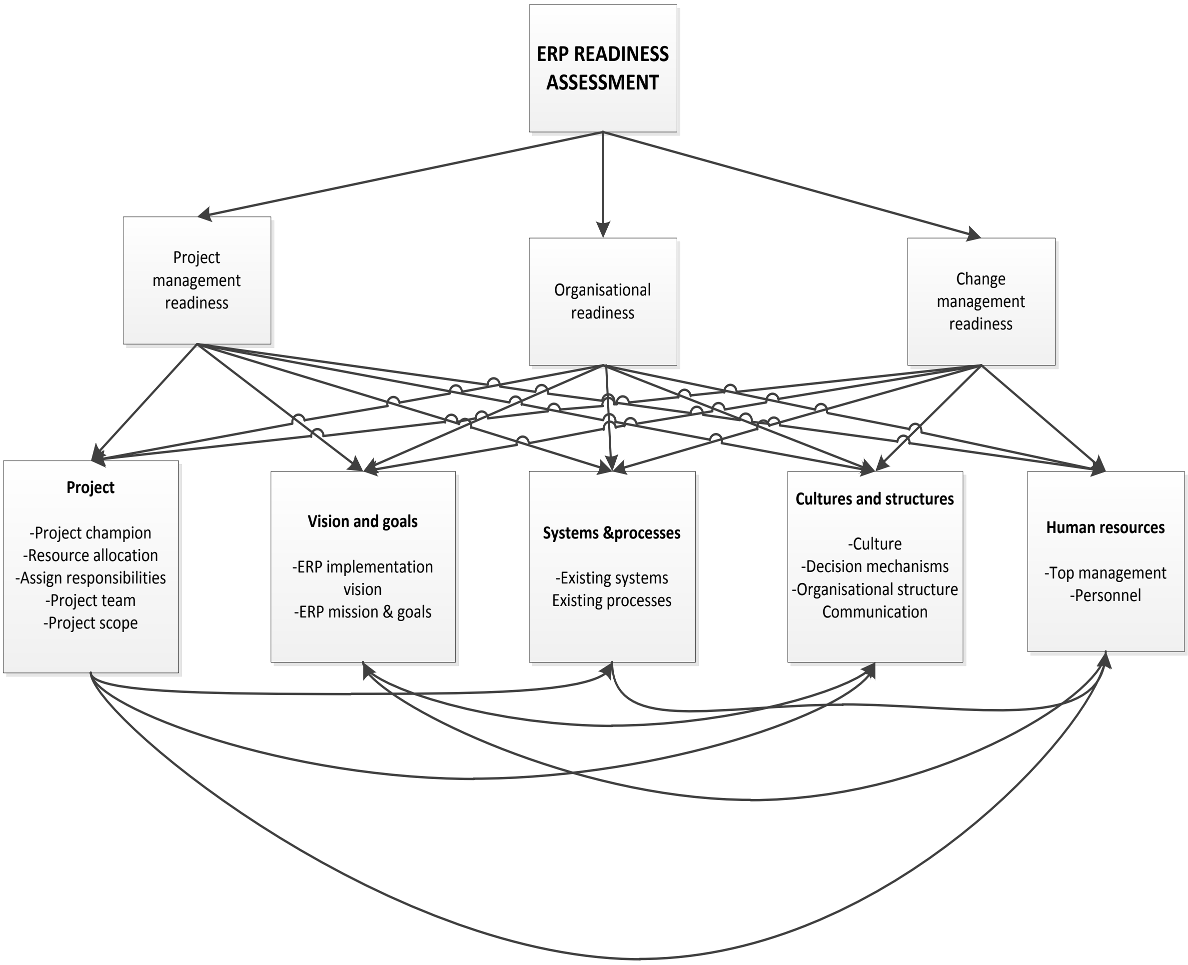


Figure 1: ERP Readiness Assessment framework

4 FINDINGS

4.1 TOP MANAGEMENT AND PROJECT MANAGEMENT FINDINGS

The following are the findings gathered from top management and project management concerning their roles in ERP implementations.

Table 1: Companies using ERP Systems and Consultants

Company	Business	Company Size	ERP software	Company	Business	Company Size	ERP software
Cafca	Power cables	150	Sage	Unilever	Fast moving consumer goods	360	SAP
Coca cola	Beverages	4000	Syspro	Victoria Foods	Foodstuffs	300	Microsoft Navision
Dairibord	Dairy products	800	SAP	ZESA Enterprises	Transformers	300	SAP
Delta Beverages	Beverages	1134	Syspro	Zimtile	Roof tiles	300	Microsoft Navision
Dunlop	Tyres	200	Syspro	23rd Century systems	ERP Consultants	-	SAP
Monarch Steel	Steel products	400	Sage	Chips Enterprise	ERP Consultants	-	Sage
Natpharm	Pharmaceuticals	180	Microsoft Navision	Pinsoft Consultants	ERP Consultants	-	Microsoft Navision
Schweppes	Beverages	700	Microsoft Navision	West Chase Consultants	ERP Consultants	-	Microsoft Navision
Turnall Fibre Cement	Roof sheets	500	Microsoft Navision				

4.1.1 Software selection factors

One of the factors that affect success in the implementation of ERP systems is the choice of software used. The types of ERP software used are shown in Table 1. Table 2 summarises selection factors such as vendor reputation, compatibility with existing system, ease of use, cost efficiency and consultants' suggestion were used in choosing the software packages. There is diversity of software selection factors chosen by companies but an average of 3 factors are used by each company in selecting a software package to use, that is, 36.9% of factors are considered.

Table 2: ERP selection factors

	Vendor reputation	Compatibility with system	Ease of use	Cost	Efficiency	Consultant's Suggestion
Companies	A, C, F, J, L	E, F, I	A, B, F, I, J, L, M	A, F, I, J,	A, D, F, I, L	G
% CONTRIBUTION	**30**	**30**	**38**	**30**	**30**	**8**

4.1.2 Objectives behind ERP implementation

Table 3 shows the companies objectives behind implementing ERP systems. Table 3 shows that companies implement ERP systems mostly to improve productivity, efficiency and customer service.

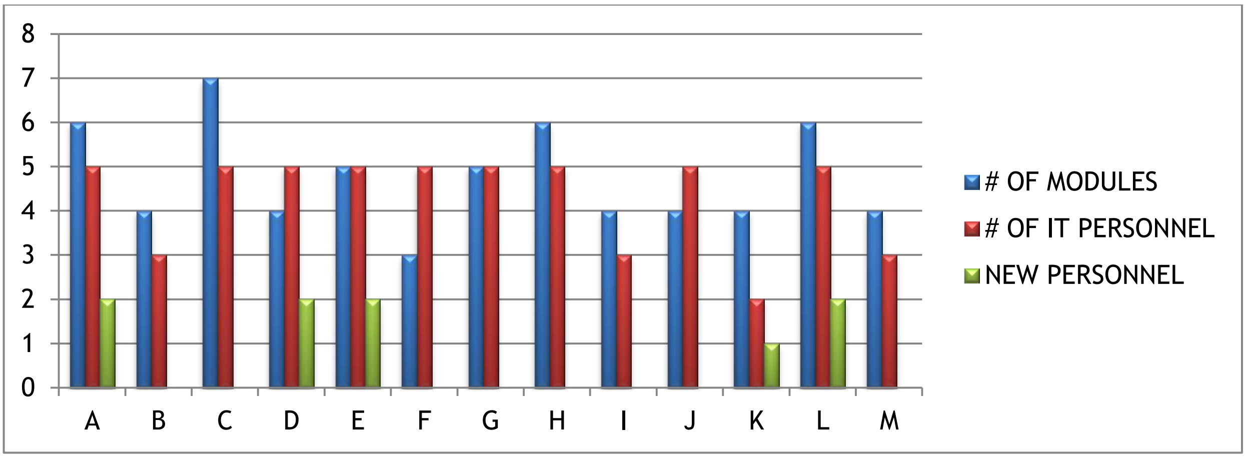


Figure 1: Personnel

Table 3: Objectives behind ERP implementation projects

	Increase Revenue	Increase Productivity	Facilitate Growth	Economic recovery	Merger	Customer Service	Improve Efficiency
COMPANIES	A, F, L	A, F,H, I, J, K, M	A, F, L			A, C, D, E, F, I, J, M	A, B, C, F, G, H, I, J, K,
% CONTRIBUTION	**15**	**38**	**15**	**0**	**0**	**53**	**61**

4.1.3 Other strategic decisions

The other strategic decisions made by the top management are based on the number of modules in the software, the number of IT personnel on the ground to support the system and the number of additional personnel needed after implementation of the systems. Figure 1 shows an average of 5 ERP modules were being used in companies. The IT departments have an average of 5 personnel while only about 30% of companies employ new people as a result of ERP projects.

4.1.4 Total costs of ERP projects

The cost of ERP implementations are summarised in Figure 2 which support the great need for planning for success of the project comparing the investment that goes into the project. ERP projects cost small companies an average of US$100 000 while large companies spend up to US$1Million on ERP implementations. This information was given to give a guide to the price of products. Thus companies can purchase products that are in their budget reach and still get the full benefits. The cost of the product should also be related to the usage of the package which is mentioned in sections below where some companies would pay for packages but do not fully utilize them.

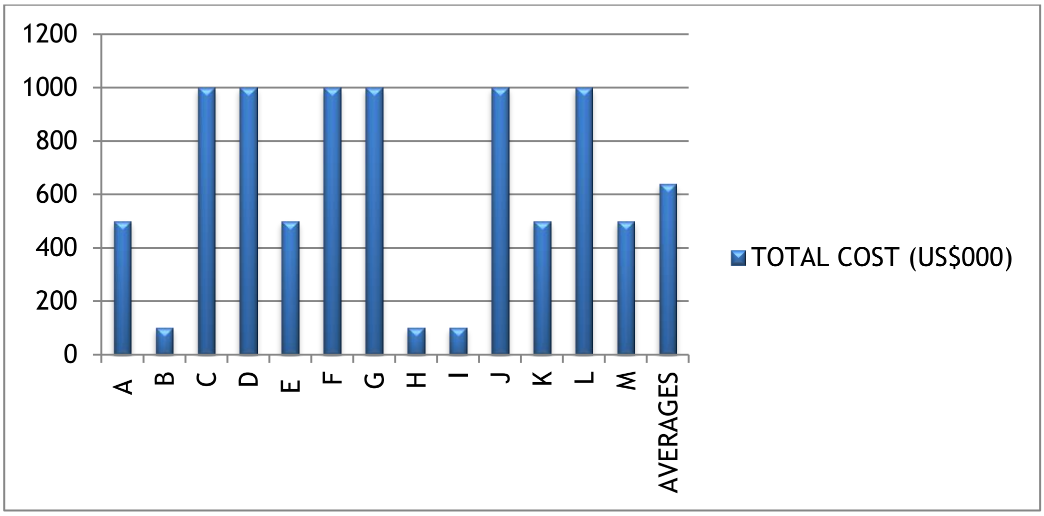


Figure 2: Total cost of ERP Implementation projects

4.1.5 Pre-implementation stage

The main strategies used in the pre-implementation stages are as shown in Figure 3. Figure 3 highlights that there was more than 75% support from top management although in some companies it is as low as 50%. Of the key critical success factors in ERP implementation, companies are considering an average of 60% of them, with some recording as low as 20% consideration of the critical success factors.

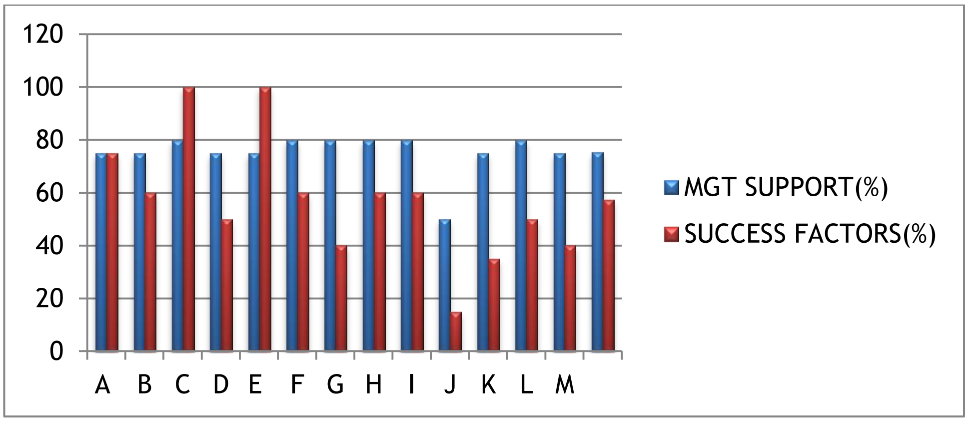


Figure 3: Pre-implementation stage: Strategic Decisions

4.1.6 Implementation stage

The implementation activities and their variations are shown in Figure 4. Figure 4 highlights that ERP projects take an average of 13 months to be completed. There is satisfactory top management support (over 75%) during implementation while 60% of companies carryout basic computer training during ERP implementation and most of these carry out a one-off training. Averages of five (5) ERP training were carried out during ERP implementations. Of the common challenges faced in ERP implementations, companies surveyed face an average of 37% of them and over 75% of the problems have been solved to date.

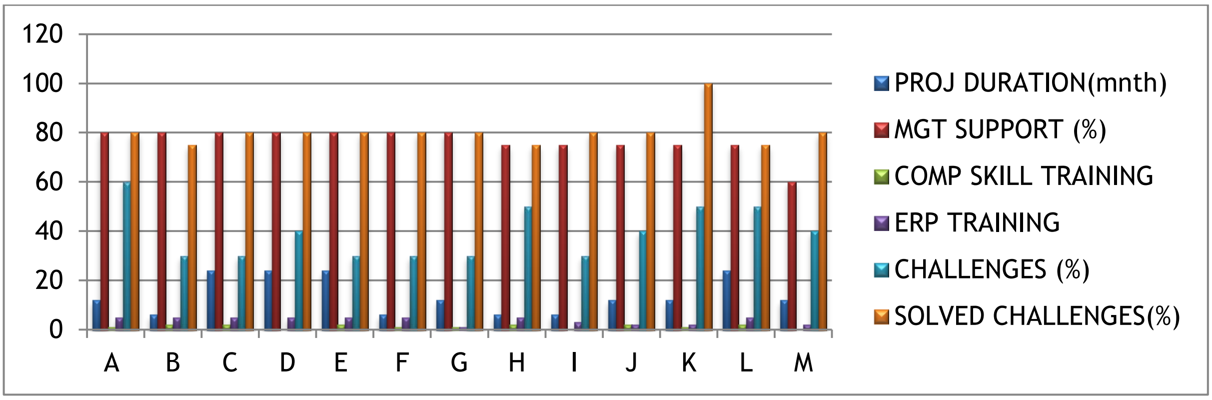


Figure 4: Implementation Factors

4.1.7 Post implementation (overall)

The post implementation benefits as they are realised in the organisations are summarised in Figure 5.

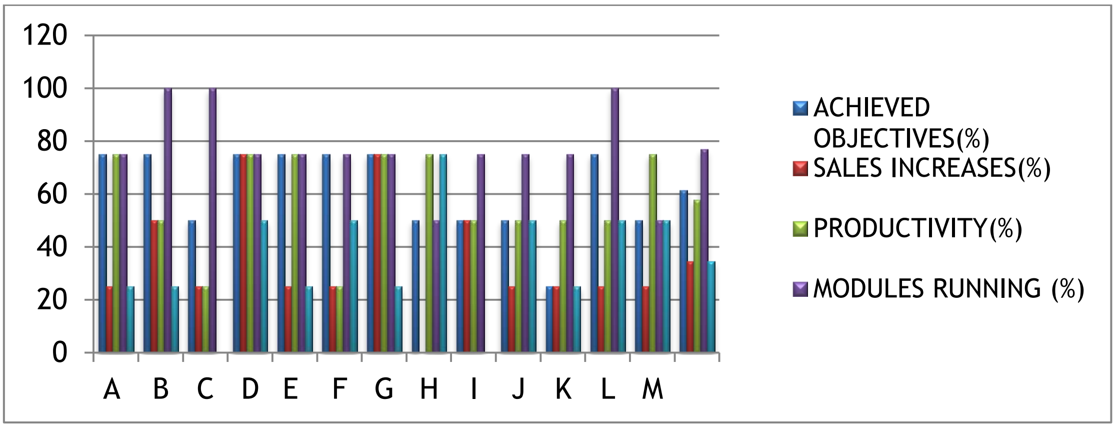


Figure 5: Post-implementation stage (overall)

Figure 5 highlights that Averages of 65% set objectives have been achieved. There have been about 39% sales increases from the ERP implementations, with 58% productivity improvements. Companies exceeded set project time frames by 32%. Eighty percent (80%) of implemented ERP modules are running or in use while 20% is not in use.

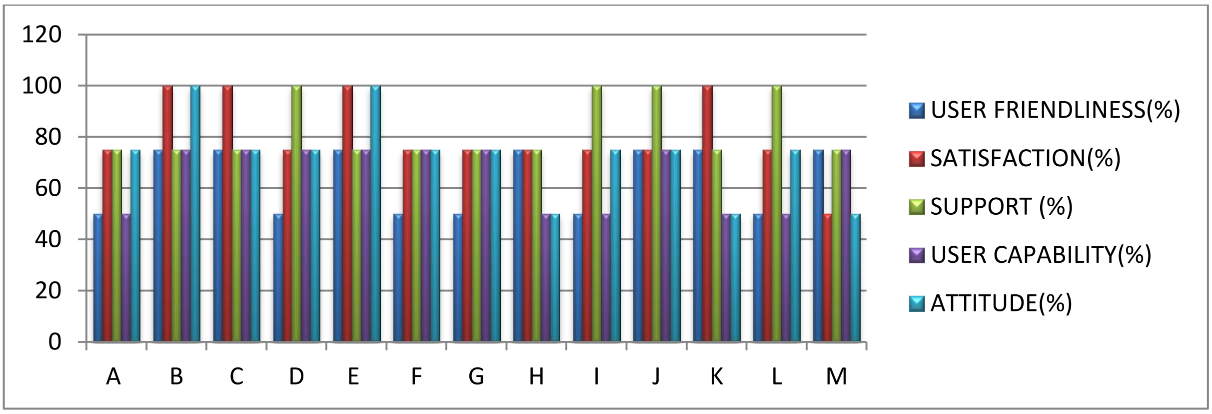


Figure 6: Post-implementation: User Evaluation

4.1.8 Post implementation (user)

The findings in Figure 6 show that ERP systems have 62% user friendliness, while overall satisfaction is 82%. Continuous support was found to be 83%, ERP user capabilities was at 67% while there was 77% measure of positive user attitude towards ERP systems.

4.2 TECHNOLOGY MANAGEMENT FINDINGS

The findings from IT departments were as follows:

4.2.1 Pre-implementation stage

Figure 7 shows IT changes that take place in the pre-implementation stage.

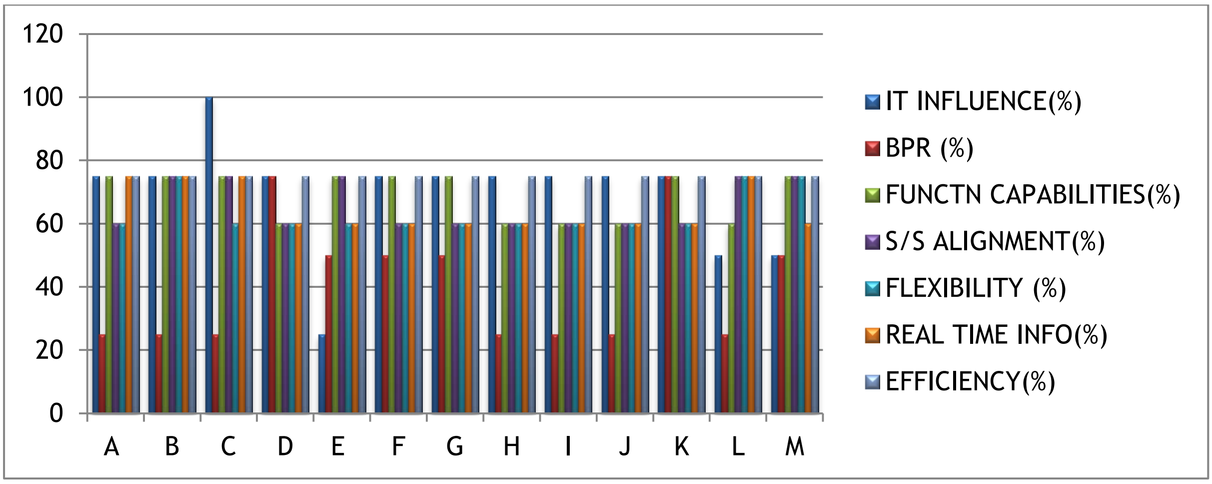


Figure 7: Pre-implementation stage: IT Function

Figure 7 shows the IT departments had an average of 73% involvement and influence during ERP implementation whereas there is 41% Business Process Re-engineering in companies for ERP projects. ERP systems have 70% functional capabilities and about 64% system-software alignments were achieved. Flexibility of ERP system was found to be 60%, real time information achievement 65% and efficiency was estimated at 75%.

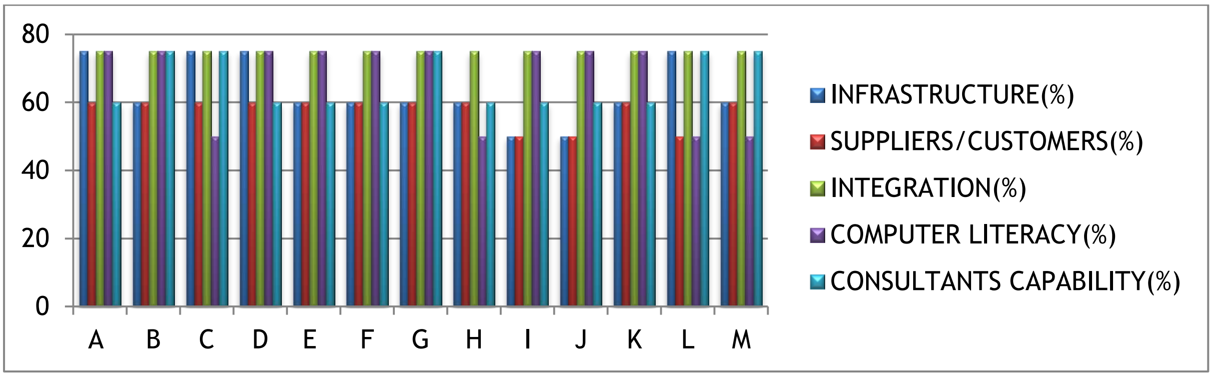


Figure 8: Implementation stage: IT Implementation

4.2.2 Implementation stage

In the implementation stages, the IT department recorded 62% of the infrastructure required for ERP systems as shown in Figure 8. There was 58% capability to link with suppliers and customers and over 75% of organisational integration due to ERP implementation. Computer literacy was between 50% and 75% while Consultant capability was estimated at 64%.

4.2.3 Post-implementation stage

The IT departments handle the day to day running of the ERP system in the following ways shown in Figure 9 and their frequencies of occurrence. On IT post-implementation 52% of faults were dealt with internally as summarised in Figure 9 while 43% of faults were fixed by an external support team. About 13% of faults remained unsolved; there are about 27% system changes after ERP implementation while there was 36% further training after ERP implementation.

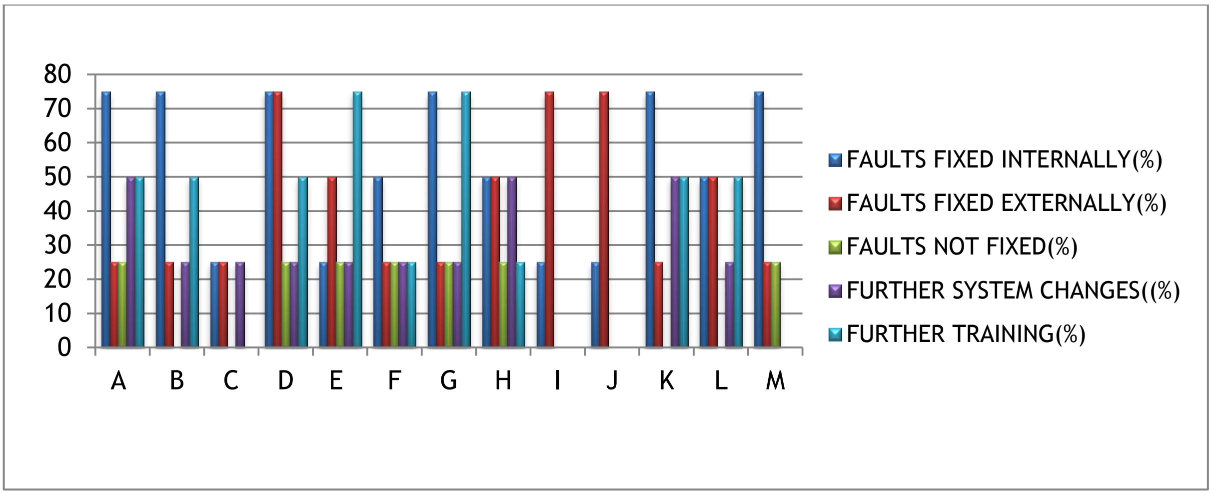


Figure 9: Post-implementation stage: ERP Faults

4.3 CHANGE MANAGEMENT FINDINGS

Findings from ERP end users are summarised in Figure 10. End-user ERP background, involvement of end users in implementation, ERP user friendliness, ERP speed capability, reporting capability and overall performance were 32%, 42%, 62%, 63%, 65% and 65% respectively.

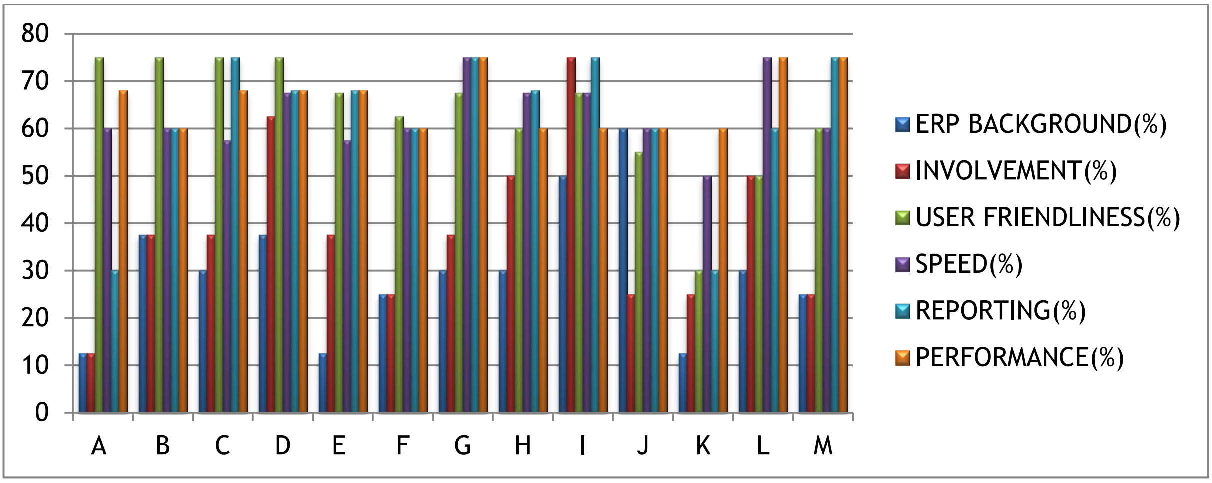


Figure 10: Change management: End User

4.4 PROCESS MANAGEMENT FINDINGS

Consultants as the major influencers and drivers of the ERP implementations provided the following information.

4.4.1 Companies input

Figure 11 show that company information compactness was found to be 50% while about 75% of the information was quantitative. Business Process Re-engineering was carried out 42%

although system-software alignment was 58%. There was 50% top management involvement with computer literacy at 50% in organisations.

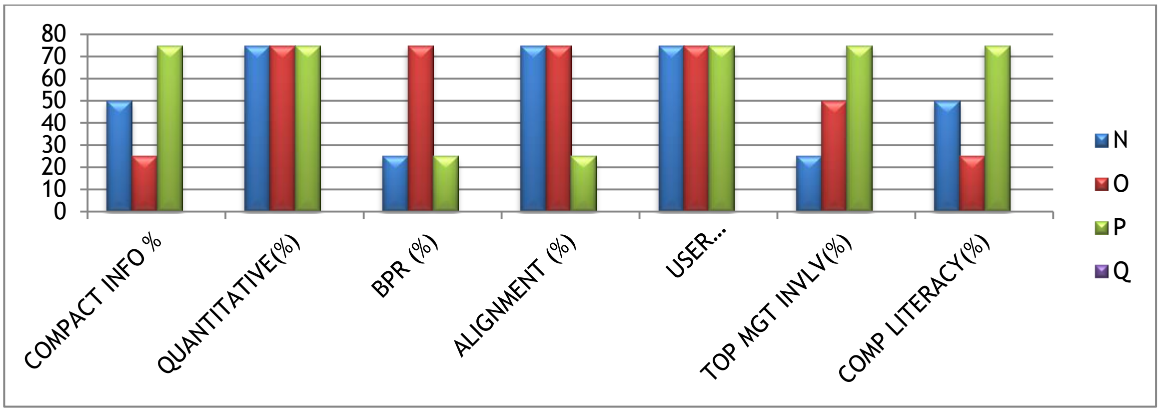


Figure 11: Consultant Finds

4.4.2 Consultants input

The consultants' contributions were rated as shown in Figure 12. ERP projects took from 6 months to 24 months to complete while some project reversals ranged from 0-5 reversals per consultant history. Averages of six (6) test runs are carried out to come up with the best quality ERP system and Consultants ran an average of 5 training sessions in organisations during ERP implementation.

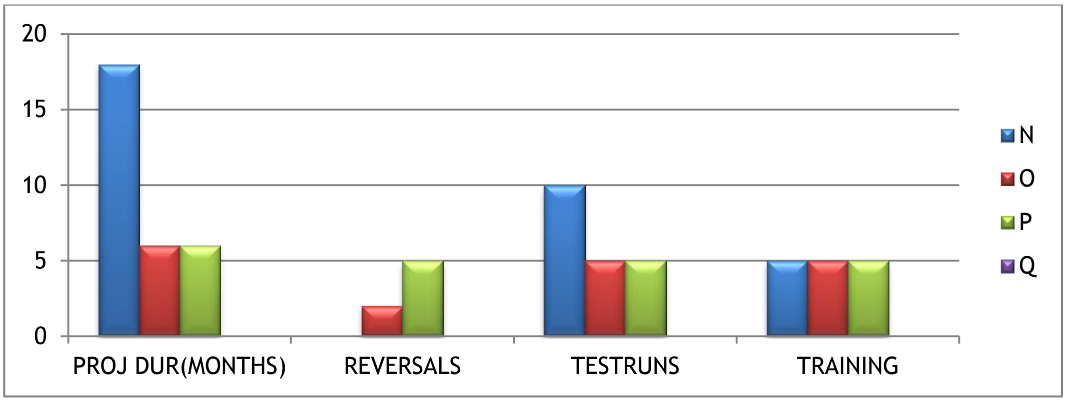


Figure 12: Consultants' input: Implementation

4.5 OPEN RESPONSES

4.5.1 Challenges faced by Top management in ERP projects

The following challenges were sighted by top management: upgrading to newer versions, infrastructure constraints, staff adaptation to new environment (culture change), aligning ERP software package to the existing company systems (BPR), network speed and reliability, end user resistance to change, budget constraints, implementation clashing with normal duties, skills deficiency, high turnover of consultants, limited consultant knowledge, changes in the business trading procedures, funding for training and training to make end users competent.

4.5.2 Challenges faced by IT in ERP projects

The following challenges were sighted by IT departments regarding ERP implementations: low computer literacy of users, users' resistance to change, hardware upgrade, infrastructure robustness, maintaining link-up connection, delays in performing tasks, Business Process Re-engineering, infrastructure compatibility, inventory grouping, budget constraints, identification of assets into the system, poor network systems, power outages, lack of backup information, customisation of the Dispatch function.

4.5.3 *Challenges faced by End Users in ERP projects*

The following challenges were sighted by end-user regarding ERP implementations: network fluctuations, low system response speed, reports do not give the correct on the ground situation, strong knowledge base required, user congestion, non-user-friendly system, too much centralisation, budget constraints, limited user licences, limited storage capability, little communication between management and end-users, poor integration with other existing systems e.g ONKEY, hierarchical decision making deems process slow, low computer literacy and bar coding.

The challenges the consultants faced in implementing ERPs in companies were lack of commitment and resistance to change from users, lack of adequate funding, high turnover of top management in companies and lack of adequate support resources.

4.5.4 *Major Business Process Re-engineering*

The major process changes made in companies are barcoding for stocktaking, procedure changes in Quality Management System, purchase of new hardware and process planning changes.

4.5.5 *Means of addressing end user complaints*

End- users face challenges such as faults and constraints and the channels used in solving the problems are call centre system, key users in each department, change request form to track user positions, back-end/ consultant support and centralised IT support system.

5 SYSTEMS DYNAMIC MODELS

The developed strategic success framework is shown in Figure 13. It shows the critical success factors as they affect success of ERP implementations in Zimbabwean companies at each stage of implementation project. The importance ratings are quoted with the factors to guide the project managers in managing ERP projects. It also shows interactions of factors between the three implementation stages.

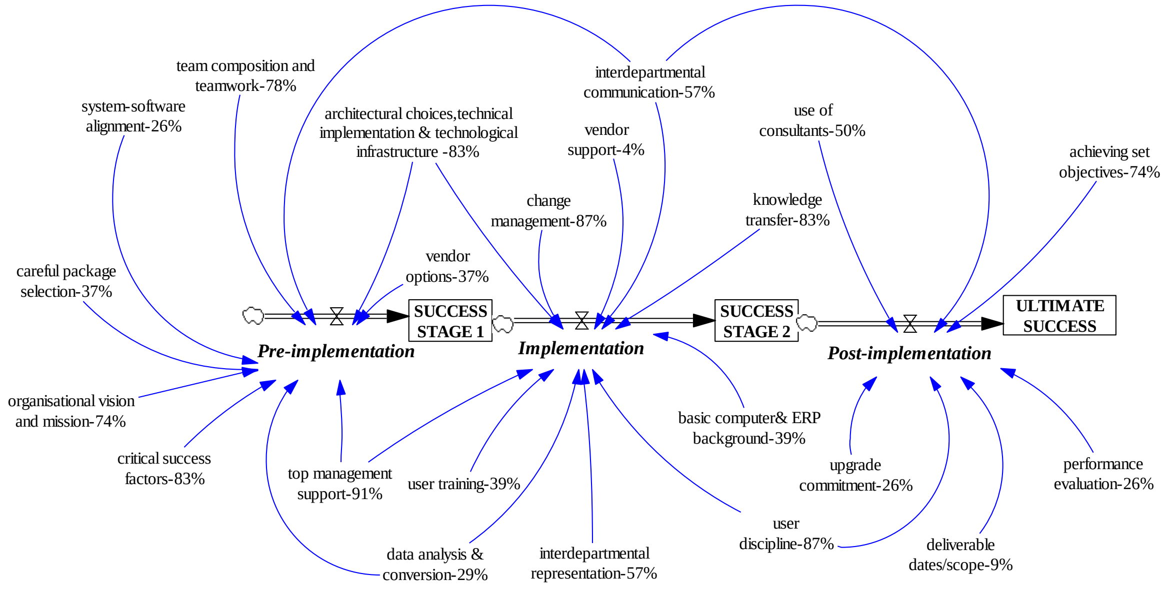
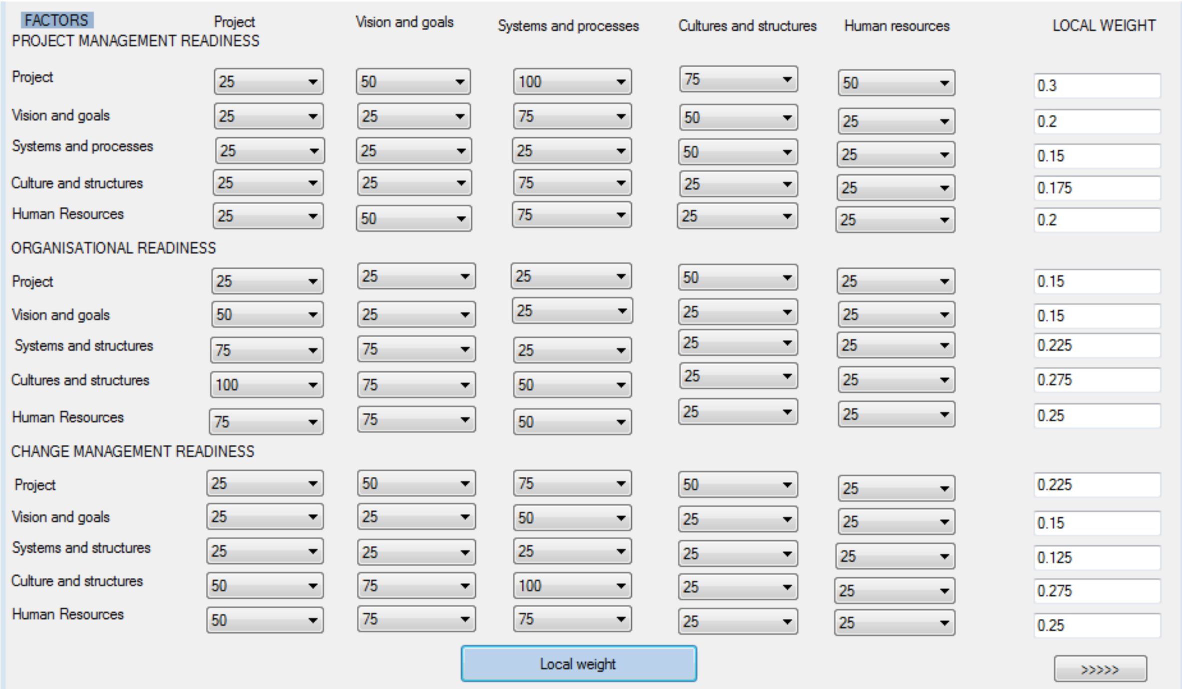


Figure 13: Selected concept

6 READINESS ASSESSMENT TOOL

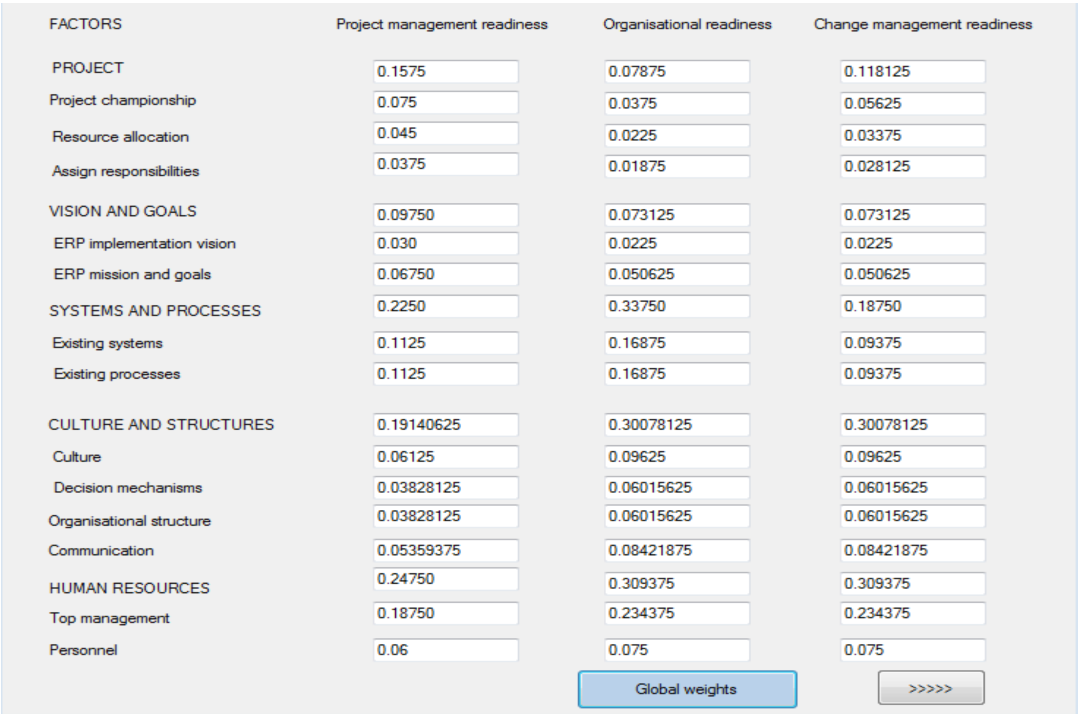
The user rates the local weights by selecting a suitable value between 1 and 100. The {Local weights} button calculates the local weights and the results appear in the {Textboxes} adjacent as shown in Figure 15. The {Save} button appears on each of the subsequent forms thus each instance of the assessment can be saved to a Microsoft Excel spread sheet for tracking and reporting purposes. The {>>>>>} button navigates user to the next stage.



FACTORS	Project	Vision and goals	Systems and processes	Cultures and structures	Human resources	LOCAL WEIGHT
PROJECT MANAGEMENT READINESS						
Project	25	50	100	75	50	0.3
Vision and goals	25	25	75	50	25	0.2
Systems and processes	25	25	25	50	25	0.15
Culture and structures	25	25	75	25	25	0.175
Human Resources	25	50	75	25	25	0.2
ORGANISATIONAL READINESS						
Project	25	25	25	50	25	0.15
Vision and goals	50	25	25	25	25	0.15
Systems and structures	75	75	25	25	25	0.225
Cultures and structures	100	75	50	25	25	0.275
Human Resources	75	75	50	25	25	0.25
CHANGE MANAGEMENT READINESS						
Project	25	50	75	50	25	0.225
Vision and goals	25	25	50	25	25	0.15
Systems and structures	25	25	25	25	25	0.125
Culture and structures	50	75	100	25	25	0.275
Human Resources	50	75	75	25	25	0.25

Figure 15: Local weights-factors/ sub-goals

Figure 16 calculates global weights based on the previously calculated local weights.



FACTORS	Project management readiness	Organisational readiness	Change management readiness
PROJECT	0.1575	0.07875	0.118125
Project championship	0.075	0.0375	0.05625
Resource allocation	0.045	0.0225	0.03375
Assign responsibilities	0.0375	0.01875	0.028125
VISION AND GOALS	0.09750	0.073125	0.073125
ERP implementation vision	0.030	0.0225	0.0225
ERP mission and goals	0.06750	0.050625	0.050625
SYSTEMS AND PROCESSES	0.2250	0.33750	0.18750
Existing systems	0.1125	0.16875	0.09375
Existing processes	0.1125	0.16875	0.09375
CULTURE AND STRUCTURES	0.19140625	0.30078125	0.30078125
Culture	0.06125	0.09625	0.09625
Decision mechanisms	0.03828125	0.06015625	0.06015625
Organisational structure	0.03828125	0.06015625	0.06015625
Communication	0.05359375	0.08421875	0.08421875
HUMAN RESOURCES	0.24750	0.309375	0.309375
Top management	0.18750	0.234375	0.234375
Personnel	0.06	0.075	0.075

Figure 16: Global weights

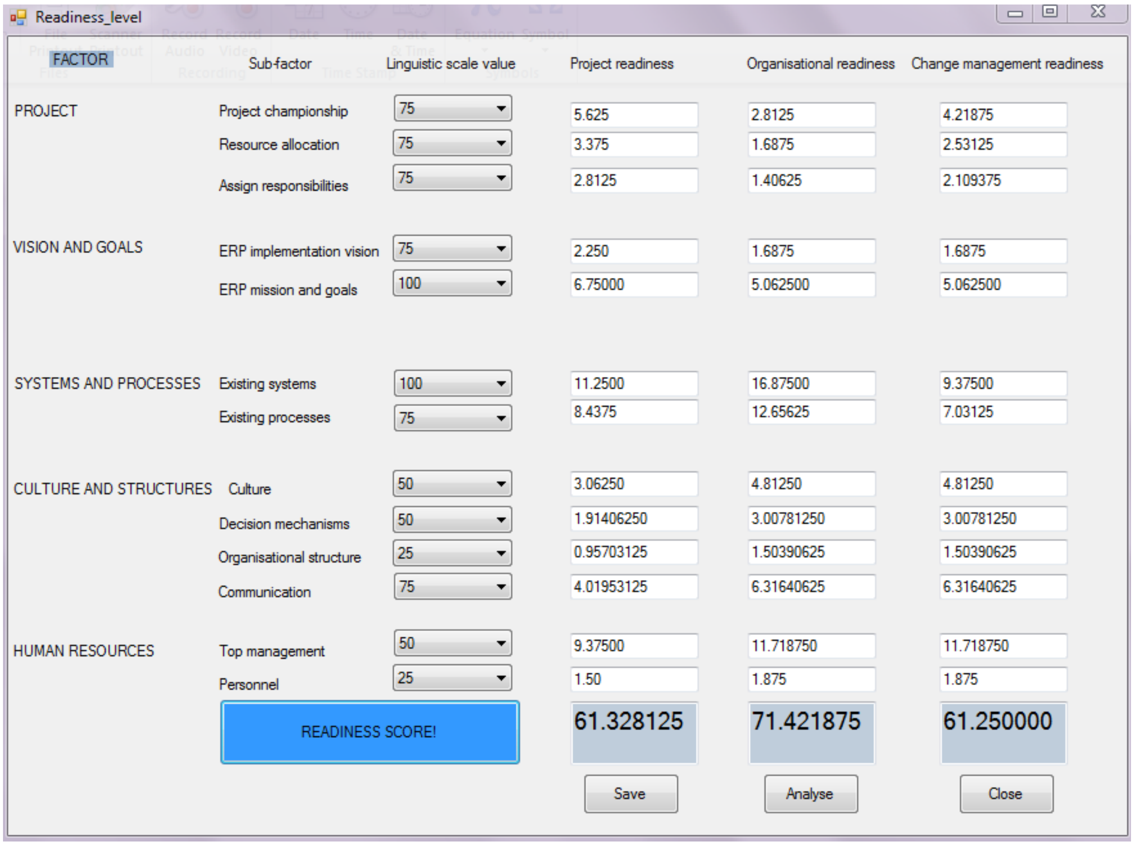


Figure 17: Readiness level

Figure 17 calculates the readiness level for Project management, Organisational management and Change management. The {Save} button saves the results on Excel Spreadsheets and can be used for reporting and tracking. The {Analyse} button navigates the user to Analysis form that shows the factors that need improvement to increase readiness level. The {Close} button terminates the Readiness Assessment. From the calculations project readiness is 61%, organisational readiness is 71% while change management readiness is 61%.

7 RECOMMENDATION AND CONCLUSIONS

The following recommendations were derived from research and analysis of findings:

a) Top management support remains a highly rated factor fundamental for the success of any project in general and ERP projects in particular

b) Process management: There should be informed decisions regarding the selection of the software vendor and the consultant for the achievement of implementation vision and goals. Choose a vendor with knowledge of the local trading environment.

c) Technology management: Proper budgets and allowance for additional indirect costs should be made for the acquisition of adequate infrastructure for the efficiency of the ERP system.

d) Change management: There should be continuous involvement of end users through all project stages and culture change activities such as training should be carried out.

e) Benefits evaluation: Companies should carry out project evaluation and introduce continuous improvement activities such as software upgrades and end user training.

In conclusion the paper set to highlight the background on ERP systems and factors affecting the success and failure of implementation depending on the stages and the different people involved from top management, IT personnel, end users and consultants. Questionnaire survey was used to gather data on success of ERP implementation in Zimbabwe companies as to give an insight to other companies that are hesitating of facing challenges in the implementation so that they learn from those that have implemented. Adopting the recommendations outlined in this paper will optimise the success levels of ERP implementations and will result in companies tapping full benefit from this huge investment.

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IMPROVING FORGE CHANGEOVER PERFORMANCE AT AN AUTOMOTIVE COMPONENT SUPPLIER

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ABSTRACT

A manufacturer of aluminium parts for the automotive industry is currently constrained by its forging process. Tool changes are required on the forge to produce different part types. This paper describes a project that was undertaken to reduce changeover time and improve the quality of tool changeovers. A study of current practices revealed high variability in the changeover times and showed that changeover performance could be improved by reducing the effort required to perform changeover tasks, reducing the need for making setting adjustments, removing opportunities for making errors and standardising the procedure. The design solution includes changes to tools and equipment, improvements to tool handling and fastening methods and the use of a changeover trolley. A new, standardised process is provided, focusing on task quality and not time. Changes to the organisation's strategy, culture and performance measures are also required for improvements to be sustainable. The resulting improvements will allow more tool changes to be performed, reducing batch sizes and the amount of work in progress required in the plant, ultimately enabling the company to plan production closer to customer demand.

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1 INTRODUCTION

1.1 Background

An automotive component supplier produces five unique suspension struts on a 1600 ton forging press. Changing between parts is a lengthy process ranging from 3 to 5 hours. Forge changeovers produce significant part defects at the start of a run whilst setting adjustments are made. This has resulted in the company adopting a policy of long batch runs to reduce the production downtime and defects caused by forge changeovers. Consequently the company is required to keep a large amount of work in progress inventory to feed subsequent processes and finished goods inventory to meet customer demand.

Figure 1 shows the company's inventory levels of finished goods and work in progress over the last year.

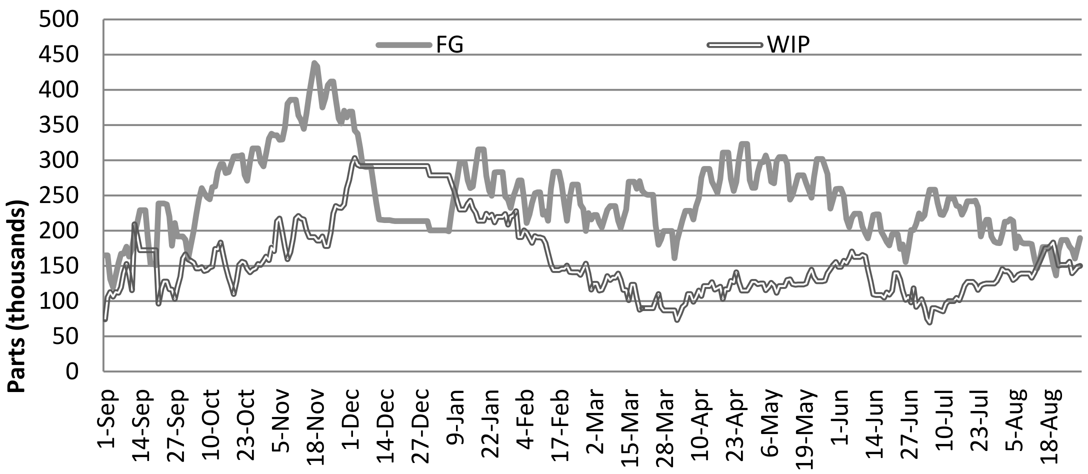

Figure 1: Company inventory of finished goods and work in progress

The inventory levels are high and variable as a result of the company's forge, which is characterised by long changeovers, frequent stoppages and occasional occurrences of severe breakdowns.

Lean theory suggests that by reducing the changeover times of key equipment within a process, smaller batch runs can be used which can in turn lead to less reliance on high inventory levels [1]. This philosophy inspired this study which aimed to reduce the need for inventory by reducing changeover times on the company's forge.

1.2 Forge Process Overview

Struts are formed from pre-heated aluminium bar, then forged in four stages before proceeding to a heat treatment and a calibration process. Parts are then shot blasted, inspected and transferred to a work in progress storage area, for parts that require further machining, or to finished goods storage.

Currently, five different strut types are produced at the forge. Changing between types requires a change of the bending, pre-form, final form and de-flash dies as well as the gripper and tongs on the transfer arms.

The forging process is shown in Figure 2 followed by a brief description of the different elements within the process.

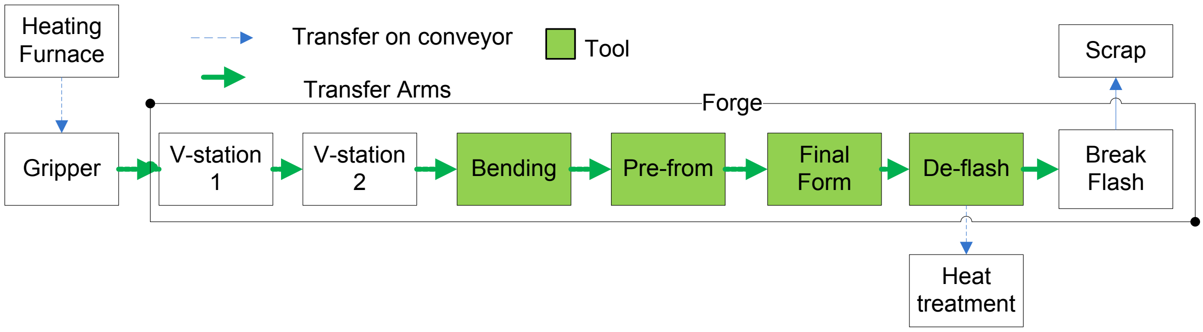

Figure 2: Forging process

- Tool - The forge has a top and bottom tool, the tool is made up of a large steel jig to which the forming dies are attached.

- Dies - The top and bottom tools each have four dies, namely bending, preform, final form and de-flash. The first three consecutively convert the aluminium bar into the final shape and the de-flash separates the final part from the flash that has formed around it during the forging process.

- Gripper - A gripper picks the bars up from the conveyor and places it into the V-station at the entrance to the forge.

- Transfer arms - The transfer arms move in conjunction with the forging motion and are used to pick up and place aluminium as it moves from bending to de-flash.

- Tongs - Tongs are connected to the transfer arms and hold the part as it moves from one die to the next. Tongs are bolted to a tong barrel which is in turn bolted onto the transfer arm. Tongs are adjusted to ensure the correct placement of a part. Incorrectly set tongs will result in incorrect forming and subsequently a part will be scrapped. A V-station transfer is used to transfer the bar between V-stations and pre-form.

- Lubrication - Lubrication nozzles spray an oil ‘mist’ on the top and bottom die before each press. Oil is used to prevent the part from sticking to the dies. Too much oil will however result in unwanted marks on the part, while too little may result in parts sticking to the dies. Both cases result in scrapped parts.

The forge is operated by a forge operator and a forge assistant. Together they are responsible for constantly monitoring the forge, loading bars into the heating furnace, making adjustments, and ensuring parts produced are not defective. The forge is a demanding piece of equipment and requires constant attention and adjustments.

It takes approximately 11 seconds for the part to move from the gripper to the exit of the forge with the forge having a design cycle time of 3.24 seconds per part. This cycle time translates to a potential of 1 110 parts per hour, if the forge runs seamlessly without stopping. The current production target is 1 000 parts per hour and 21 000 parts are planned for the forge per day. Three hours a day are set aside for breakdowns, stoppages and other problems with the forge system. The historic, average daily production is however only 19 500 parts per day. The variability of this average is an important consideration as the forge does not produce 19 500 parts per day, every day. Instead it has good days, where it produces up to 26 000 parts, and bad days when no parts are produced.

1.3 Objective

The project objective is to improve the changeover performance of the 1600 ton forge. This will enable the company to improve their planning, run smaller batches, increase their flexibility and responsiveness to customer demand, shorten their lead time and ultimately reduce inventory in the plant. Improved changeover performance includes:

1. Reducing changeover time
2. Reducing run-up time to full production after changeover
3. Reducing stoppages for setting adjustments and breakdowns during production

1.4 Method

The improvement of changeover performance was based on an integrated approach where improvements were required from a design and an organisational point of view. This is based on McIntosh, Culley and Owen's matrix methodology for improving changeover performance [2]. Their design improvement approach focuses on making improvements to machinery and methods of performing a tool change. Improvement focuses on system influences, such as; training, scheduling and operating procedures. The matrix methodology suggests investigating opportunities for improvement within four broad categories:

1. On-line activity
2. Adjustment
3. Variety or Variability
4. Effort.

This approach was supplemented with methods of improvement from Shingo's work on single minute exchange of dies (SMED) [3].

2 INVESTIGATION

In order to understand the current state of the forging process, detailed analyses of the company's historical data and observations of processes, operations and equipment were performed.

2.1 Analysis of Historical Performance

Company data was analysed to determine reasons for forge downtime as any increase in forge uptime would allow for more frequent changeovers. The cumulated forge downtime is presented in Figure 3 for a period of 1 year, showing breakdown categories.

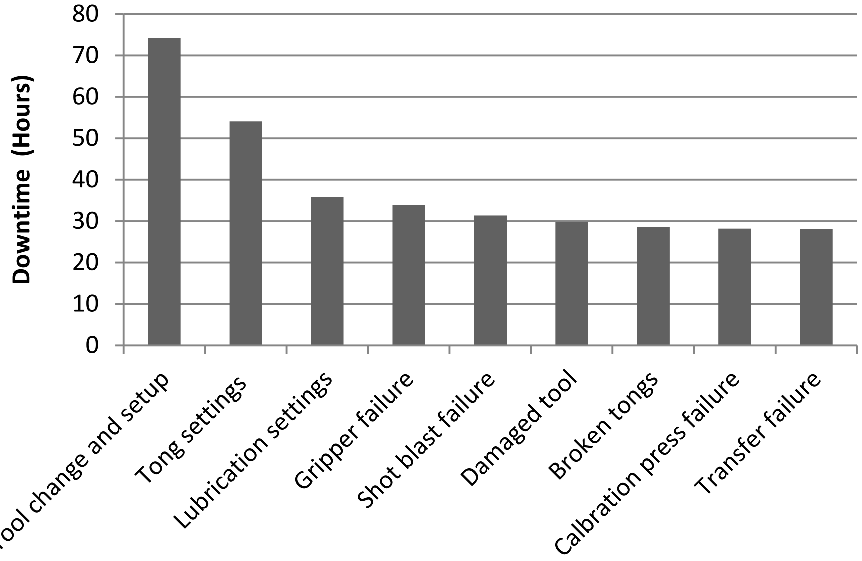

Figure 3: Analysis of forge downtime

The tool change and setup is the most significant reason for forge downtime amounting to a cumulative downtime of 74 hours, an average tool change time of 1 hour and 48 minutes. Tong and lubrication settings were also a major reason for downtime cumulatively 54 and 36 hours respectively. The company's data system does not record reasons for stoppages that are less than 5 minutes meaning that often setting adjustments go unrecorded. It was also observed that the majority of setting adjustments take place in the period following the tool change in order to get the forge running properly. Using a Pareto analysis it can be concluded that setting adjustments together with the tool change and set-up have the most potential for improvement.

To determine the total changeover time, (the time from the end of production until normal production commences on a new part) data was extracted manually using a sample of 14 changeovers. Figure 3 shows the total changeover time from stopping the forge until the start time of normal production (normal production was defined as the forge running at, at least 90% of capacity for at least 30 minutes). The figure also shows the proportion of time which is spent on tool change and set-up time, and that which is spent on adjustments.

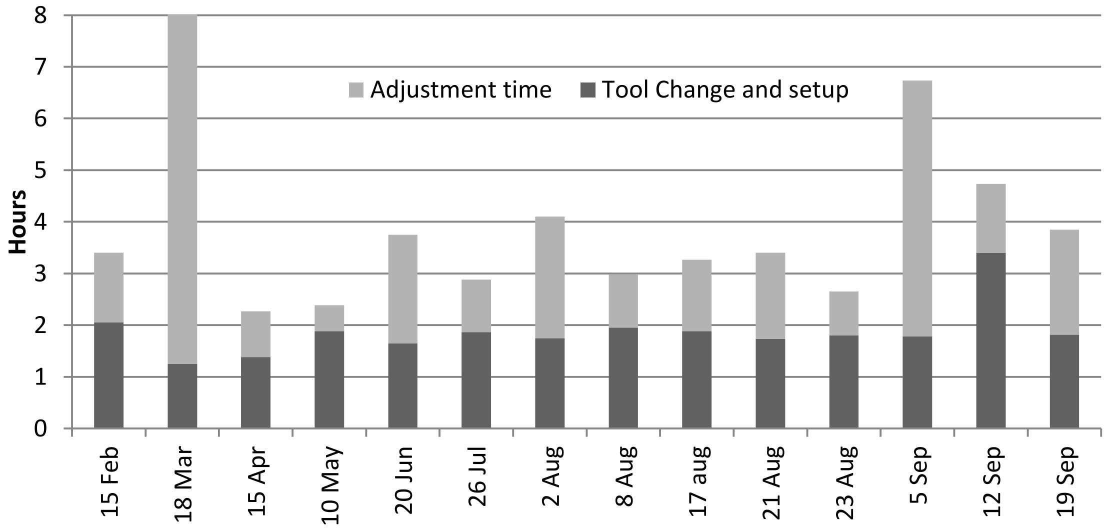

Figure 4: Total changeover time

Figure 4 shows that while average tool change and set-up is 1 hour and 46 minutes, it takes longer when the total adjustment time is considered as part of the changeover. The sample average for total changeover time is 4 hours and 20 minutes. This is, however, skewed by the lengthy times in March and September caused by breakdowns during the changeover. With the outliers removed the changeover average is 3 hours and 18 minutes with a standard deviation of 43 minutes. This represents an average adjustment time of 1 hour and 35 minutes. Almost the same amount of time is required to change the tool as is required to make the necessary adjustments for normal production to continue after the machine has been started.

2.2 Performing a Tool Change

In order to understand the tool change procedure tasks were separated into four categories:

1. Changing and adjusting the tongs and transfer arms.
2. Removing and installing the bolts
3. Handling the tool
4. Installing and adjusting the lubrication system

Time studies were completed on the total changeover and tasks on the critical path in each of the four categories are compared in Table 1.

Table 1: Categorised task time analysis

<table>
<tr><th>Time(min)</th><th>Tong and transfer</th><th>Bolts</th><th>Tool handling</th><th>Lubrication</th></tr>
<tr><td>0:00</td><td rowspan="2">Record tong settings</td><td>Remove de-flash</td><td rowspan="2">Grab top tool & remove</td><td rowspan="2">Disconnect lubrication</td></tr>
<tr><td>0:02</td><td>Loosen top bolts</td></tr>
<tr><td>0:04</td><td rowspan="2">Remove tongs</td><td rowspan="2">Remove top bolts</td><td rowspan="2">Transfer to tool room and return to forge</td><td rowspan="2">Insert bottom Lubrication</td></tr>
<tr><td>0:06</td></tr>
<tr><td>0:08</td><td rowspan="3">Set tongs</td><td rowspan="2">Loosen bottom bolts</td><td>Remove bottom</td><td rowspan="2">insert top Lubrication</td></tr>
<tr><td>0:10</td><td>Transfer to tool room</td></tr>
<tr><td>0:12</td><td rowspan="2">Remove bottom bolts</td><td rowspan="2">Remove new top then bottom from oven</td><td rowspan="2">Connect Lubrication</td></tr>
<tr><td>0:14</td><td rowspan="4">Fit new tongs</td></tr>
<tr><td>0:16</td><td>Raise press</td><td>Transfer & place in forge</td><td></td></tr>
<tr><td>0:18</td><td rowspan="2">Insert bottom bolts and tighten</td><td rowspan="2">To tool room, collect & transfer top to forge</td><td></td></tr>
<tr><td>0:20</td><td></td></tr>
<tr><td>0:24</td><td>Set transfer</td><td rowspan="3">Insert top bolts and tighten</td><td>Place in forge</td><td></td></tr>
<tr><td>0:26</td><td rowspan="2">Disconnect transfer</td><td></td><td></td></tr>
<tr><td>0:28</td><td></td><td></td></tr>
<tr><td>0:30</td><td rowspan="5">Changeover V-transfer</td><td>Install de-flash</td><td></td><td></td></tr>
<tr><td>0:32</td><td></td><td></td><td></td></tr>
<tr><td>0:34</td><td></td><td></td><td></td></tr>
<tr><td>0:36</td><td></td><td></td><td></td></tr>
<tr><td>0:38</td><td></td><td></td><td></td></tr>
</table>

Thus, to shorten the total time of the tool changeovers the tasks in each of these categories must be reduced, moved to external activities or eliminated entirely. Detailed observations are made for each of the changeover categories.

2.2.1 Tongs and Transfer

At the start of the tool change, the current settings on the tongs are recorded using digital vernier callipers. These will be used to check the setting specification for the next time a particular part is run. Once recorded, tong settings can then be changed for the new part. This is done by adjusting 2 bolts to lengthen or shorten the tongs.

Once settings are recorded and re-set, the tongs are removed. A pneumatic tool is available but is not always used, the correct attachment was missing and a pneumatic pipe was broken. New tongs for the new part are then installed at the end of the tool change.

2.2.2 Bolts

The top and bottom tools are each fastened to the press by four bolt pins. The nuts on the bolts are loosened and tightened using a ring spanner and a steel pipe to provide leverage. This is a difficult task as the nuts require substantial effort to loosen and tighten, the floor is slippery due to oil and grease spillage and the bolts are hot. The bolts and nuts are also caked with oil and grease during a run, making them harder to turn. The required torque on the nut is 2500 N.m but no torque wrench is used and operators just make the nut as tight as they can. Sometimes two people pull on the pipe to ensure the nut is 'tight'.

Once the nuts have been loosened, the bolt pins are removed by sliding them from the tool using a bolt puller. During operation, the slot which the bottom bolts are seated in, becomes filled with oil and grease. This makes it harder for the bolts to be removed. A copper hammer is sometimes used on the bolt puller when the bolt is stuck. A rag is also used to cover the bolt to prevent hot grease from spraying and burning operators.

The top 4 bolts each have 2 nuts, the purpose of the second nut is meant to create a locking effect to prevent loosening from vibrations and ensures that there is a back-up if the first nut fails. It is doubtful whether a locking effect is achieved without the correct torqueing of bolts. There are a total of 12 nuts which have to be loosened and tightened during a tool change, and 8 bolts which have to be removed and replaced. The lack of space between the tools and the high torque required makes it difficult to use standard power tools to assist in the loosening of the bolts.

2.2.3 Lubrication

The lubrication hoses need to be disconnected before the tool is removed and reconnected after the new tool has been placed, for both the top and bottom tools. Lubrication hoses are covered in oil and while each pipe has a quick release system there are a total of 40 hoses to disconnect and reconnect. It is also unclear which pipes must go where. The lubrication hoses can be seen in Figure 5.

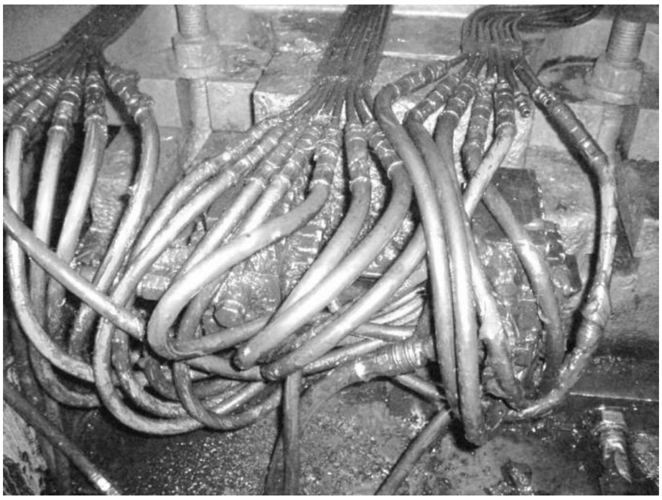

Figure 5: Cleaned and connected lubrication hoses

2.2.4 Contributing Factors and Areas of Concern

Several other issues were noted that affect the people and processes of a tool change and pose opportunities for improvement.

- Working conditions – Operators have to wear cumbersome gloves to protect themselves from the hot forge, there is a limited space available to move forge and everything is covered in grease and oil. The required tasks are physically tiring.
- Inability to communicate - The environment is too noisy for operators to be able to speak to one another unless they are standing together. Operators communicate by shouting '*whoooh'* which has several meanings, including: 'Close the forge gate for lockout',' I need help', 'I need a tool/ to tell you something', or 'be careful'.
- Tools – Manual tools are used throughout, all of which are different sizes. Tools were missing from some toolboxes, ratchet wrenches did not always work smoothly and bolt pullers were often bent meaning operators had to share the one working tool. The pneumatic Allan key, the only power tool used, was initially broken but once fixed was still not used out of habit.
- Motivation – As changeovers are such hard work they are dreaded by all operators.
- Following correct procedure – The required procedure is not followed during a changeover. A standard procedure does exist, all the operators were aware of a formal procedure but none knew the procedure or thought that it was important. It is thus not possible to optimise operator work process until all teams are performing the same tasks using the same sequence and technique.
- Previous improvement initiatives - Many good ideas have been implemented to improve changeovers but implementation of ideas has not been sustained.
- Time - Changeovers are usually performed at the start of the morning (6am) or afternoon (2pm) shift, this was done so that a team would be responsible for the changeover and then running the forge for the rest of the shift. The main problem is that teams arrive at work, with the forge already stopped and immediately need to start the changeover, but have not had time to adequately prepare. Previous shifts also stop the forge early in anticipation for the tool change.
- Safety – Protective equipment such as gloves and face shields are often removed during the tool change as it is difficult to perform tasks with them on. The risk of burning is extremely high during a tool change, by accidentally touching the tool or press bed and from hot oil dripping or spraying from the forge. There is also a risk of slipping.

3 DESIGN IMPROVEMENTS

The investigation of current changeover practices showed that the tool change and setup time as well as adjustment time were contributing to the overall long changeover times. Improving setup time in isolation can often lead to increased adjustment times, if the overall quality of the changeover is not improved in conjunction with reducing the time [4]. Improvements to the changeover were therefore focused on improving the overall quality of the entire tool change process as well as reducing the time.

3.1.1 Tong Settings Gauge Blocks

Gauge blocks are suggested to replace the use of vernier callipers to set the tongs. Gauge blocks are permanent spacers between the tong adjuster and transfer arm, during a tool change the spacers are changed, changing the tong settings. Gauge blocks and their placement is shown in Figure 6.

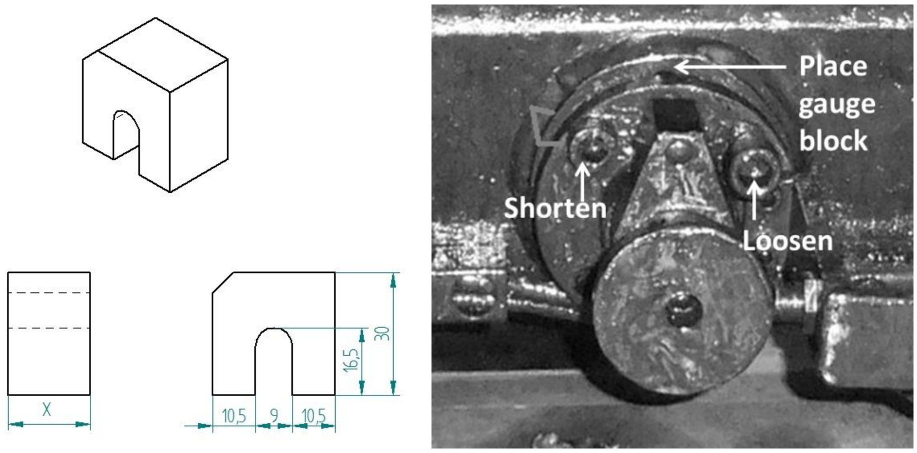

Figure 6: Gauge Block

3.1.2 V-station Transfer

Changing the V-station transfer is a challenge because the operator has to lean far into the forge to remove 8 bolts and then replace them. In order to make this easier for the operator and reduce the time it takes. Slots in the V-station transfer will be cut to allow the operator to complete only half a turn on each bolt and then slide the plate up and over the bolts without removing them. Slot dimensions are shown in Figure 7.

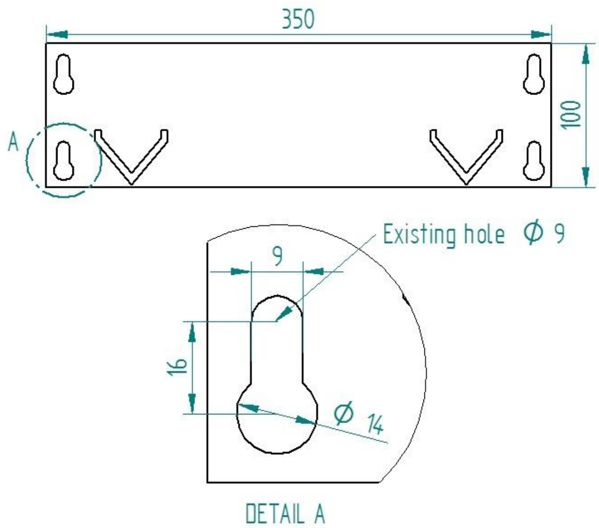

Figure 7: V-station transfer slots

3.1.3 Hydraulic Torque Wrenches

The lack of work space around the forge and the high torque requirements makes it difficult to specify a power tool that will be suitable for this application. Of all the tools investigated, a limited clearance hexagonal torque wrench is the most suitable. This tool will decrease bolting time, ensure bolts are torqued to the correct specification and reduce the workload on operators.

3.1.4 Bolt Covers

Bottom bolts are difficult to remove as grease gets stuck in the slots. A bolt cover was designed to protect bolts and slots from grease during operation. A sample bolt cover, Figure 8, was manufactured and implemented to test the design. The bolt cover successfully kept the bolt and the bolt slot clean, significantly reducing time and effort to remove the tested bolt.

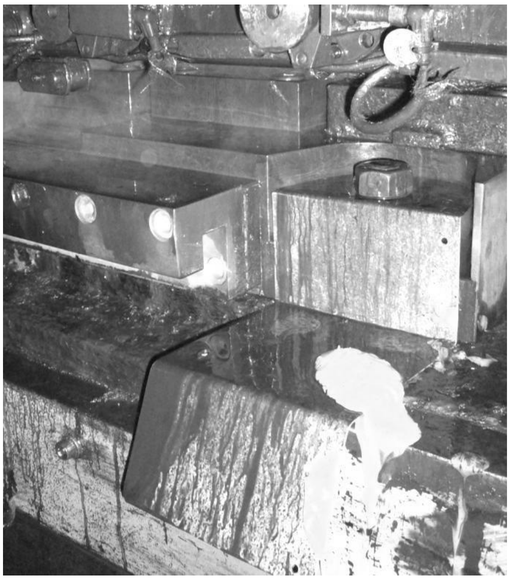

Figure 8: Bolt Cover in position

3.1.5 Clean Bolts

During a run, bolts and nuts get covered in grease. Grease also fills the threads making it difficult to turn the nut on the bolt by hand. It was also noted that damaged bolts go unnoticed as cracks are covered by grease. Moreover bolts have lost temperature by the time they are re-fitted to the tool resulting in incorrect torqueing.

In future, a clean set of bolts must be placed in the oven with the tool and brought to the forge resting on top of the top tool in two containers, one for the front and one for the back of the forge. Each container should have the bolts with the nuts in the correct position so that they can be immediately inserted into the bolt slot.

The top bolts should be tightened before the bottom bolts to reduce the risk of mismatch problems.

Bolts and nuts removed from the tool must be sent to the tool room for cleaning, inspection and preparation for the next tool change.

3.1.6 Lock Nuts

The locknuts on the top tool are safety redundancies against nut failure and vibration loosening. It is however possible to ensure safety without having the second nut. The risk of vibration loosening is eliminated by correctly torqueing nuts, to the specified 2500 N.m which will be possible with a hydraulic torque wrench. The risk of nut failure can be reduced by using longer nuts on the top of the tool. Currently a standard M30 nut is used. This must be replaced by a longer nut with more thread to prevent thread failure and more material to reduce the risk of cracking. Finally by using clean bolts and nuts when the tool is replaced nuts can be thoroughly inspected after every run and damaged nuts or bolts can be detected and replaced before failure.

3.1.7 Lubrication Hose Multi-coupling System

To remove the need to disconnect and reconnect 40 lubrication hoses during a tool change a commercially available multi-coupling systems needs to be adapted and installed. A multi-coupling system will reduce the 40 connection points to only two, one for the top and one for the bottom of the forge.

3.1.8 Oven Shelf for Top Tool

The tools are currently placed on top of one another in the oven, the bottom tool is however required first meaning the top tool has to be removed from the oven, placed on steel blocks so the fork lift can move the bottom tool. A second shelf was designed for the oven so the tools can be pre-heated separately. Besides the savings from reducing tool handling time, the second shelf has the added benefit of keeping the top tool hot while the bottom tool is being transported and installed.

3.2 Process Improvements

3.2.1 New Procedure

Before improvements can be made in the tool changeover process time, the procedure first needs to be standardised between all teams and operators. A new process will also ensure that bad habits and personal preferences and methods are eliminated. It is essential that all teams follow the exact same procedure even if it initially seems slower.

The new procedure is broken down into three sections that are not interdependent. If an operator finishes a task they may move onto the next task provided it is in the same section of the process, if an operator finishes a section before other operators they must wait for everyone to catch up before continuing. The completion of a section is important as historically one operator would stop doing an 'unimportant tasks' halfway through so the 'important tasks' can continue, only to delay the changeover at a later stage. The time it takes to complete sections is secondary to quality. Operators must complete tasks in order, slowly and correctly rather than keeping within the time frame.

Team leaders should note the start and end times of completing each section but should not focus on keeping to any time target until all teams are achieving similar times and issues and imbalances within the procedure are resolved. Once production samples have been made and the settings checked all operators must meet again at the front of the forge and the tool change declared over. The forge can then be started in its automatic cycle. Any adjustments made after this point are a reflection of the changeover quality.

3.2.2 Changeover Trolleys

A changeover trolley was designed to hold all the tools and parts required to perform a changeover. The changeover trolley serves three main functions:

1. To reduce operator movement by providing all the necessary tools and equipment in the right place.
2. To improve tool change preparation, by ensuring the trolley is prepared
3. To assist the operator in following procedure, by using the items on the trolley from left to right.

Three changeover trolleys are required; one for the front, one for the back and one for the left of forge, for the three operators who perform a tool change. Each trolley should have its own unique layout based on the tasks each operator needs to perform. The required layout for the forge operator's trolley at the front of the forge is shown in Figure 9.

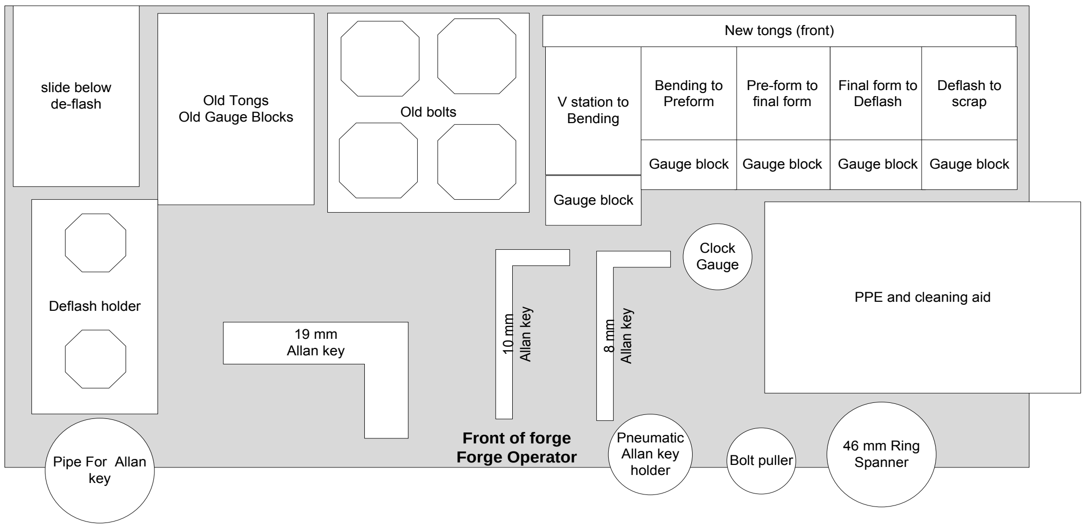

Figure 9: Forge operator's changeover trolley lay-out

3.3 Strategic Changes

3.3.1 Scheduling Changeovers

Changeovers are scheduled for the beginning of the morning or afternoon shifts (6:00 or 14:00), in future, this should be moved to one hour into a shift (7:00 or 15:00). This is important as its means operators do not arrive at work and immediately have to start with the tool change usually meaning they are unprepared and not in the correct mind-set. It will also make the entire changeover, a single team's responsibility including changing bars at the loading bay as well as the production samples at the end of the previous run. The shift before a changeover also often stop the forge before the end of their shift in anticipation for a changeover resulting in a longer amount of forge downtime which is not included in the changeover time.

More changeovers should also be scheduled per month. Doing more changeovers before changeover time is reduced may create an initial decrease in plant performance but it will raise the importance of improving changeover performance and make it a priority in the organisation. Performing more changeovers will also change employee perception that changeovers are unimportant and only performed occasionally to something that is part of everyday work. While this will initially be difficult to accept, eventually changeovers will just be the norm and will not be dreaded by operators, team leaders and management.

3.3.2 One Attempt Adjustments

Currently when the forge goes down or there is a defect due to an incorrect setting there is an informal company protocol that the forge operator has 15 minutes to solve the problem. If he does not resolve the problem in 15 minutes the team leader must be involved. Together the operator and team leader have a further 15 minutes to resolve the issue. If after half an hour the problem persists a forge specialist must be contacted and involved in resolving the situation. It is suggested that a new protocol is introduced.

When the forge is stopped or goes down due to a defect on the part, a forge failure or a problem with settings the forge operator has one attempt to resolve the problem. One attempt means that once the forge is stopped the operator can make the changes or adjustments they think necessary but once they set the forge to run again the one attempt is over.

If after one attempt the problem persists the team leader must be involved and the operator and team leader, working together, have one attempt to resolve the problem. If after a total of two attempts the problem is unresolved the forge specialist must be involved. When the forge specialist is involved he must work with operators and the team leader until the problem is resolved.

This protocol is designed to encourage the operators to follow a troubleshooting process before making an adjustment based on a guess. Currently operators know that time is essential and thus make quick adjustments to get the forge running again. This results in many minor stoppages where one longer stop would be far faster overall.

Operators and team leaders must be trained in troubleshooting, such as inspecting everything first for cracks, loose bolts, broken equipment or any abnormality before making any changes. A white board should be placed next to the forge to facilitate trouble shooting. Team leaders and operators should be encouraged to record problems and the steps they followed to resolve it. This can allow lessons and knowledge to be shared between teams.

3.3.3 Performance Measuring

The current changeover performance measures do not give changeovers enough importance and do not adequately represent whether a changeover was good or bad. Three performance measures should be recorded and charted after every tool change. Forge performance charts should be reported on in the production meeting by the team leader the day following the changeover.

1. Tool change and set-up time - which is recorded automatically on an Overall Equipment Effectiveness (OEE) system. This measure is currently recorded and is the time it takes to replace the actual tools. The target for changing the tool should be to reduce the time from 90 minutes to 60 minutes in 6 months.

2. Scrap produced during a changeover - which is already measured and should be continued to ensure the defect rate continues to remain low.

3. The time between full production - This new measure will need to be calculated manually by team leaders. The time between full production is measured from the time the forge is stopped at the end of a part run until the time when a production run of more than 500 parts are produced at a production speed of at least 900 parts per hour. This means that the machine has to run for at least half an hour non-stop before the changeover can be considered complete. Figure 10 shows how to calculate the time between full production. The target for the time between full production should be to reduce the time from 200 minutes (3hours and 20 minutes) to 120 minutes in 6 months.

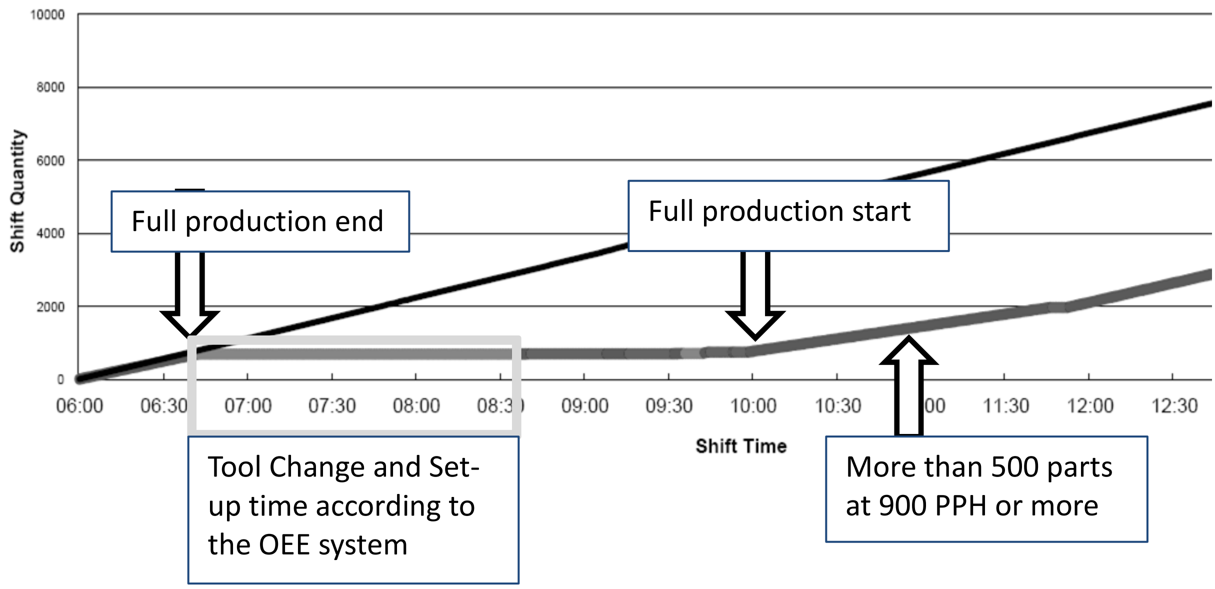

Figure 10: Determining production to production changeover time

4 BENEFIT ANALYSIS

This section summarises the expected benefits associated with the presented design solutions.

4.1 Time Savings

4.1.1 Changing the Tool

While reducing the time it takes to change the tool should not be the initial focus, based on the solutions presented it is possible to reduce the time it takes to change the tool from 1 hour 43 minutes to 1 hour. Estimated time savings on the critical path is detailed in Table 2.

Table 2: Estimated Time Savings

Improvement	Estimated time saved (min)
Tong gauge block	4
Changing V-station	2
Torque wrench	4
Removing bolts	1
Lock nuts	3
Oven shelf	1
Relocate oven	4
Multi-connect	4
Lower lubrication	1
Changeover trolley	4
Standard process and co-ordination	12
Total	**40**

4.1.2 Reduction in Adjustment Time

While it is hypothetically possible to eliminate the adjustment time by gaining complete control of the forge settings, the forge is over 33 years old and will always present some adjustment difficulties. The average adjustment time based on a conservative estimate is currently 1 hour and 35 minutes. By proactively managing settings and adjustments and changing the focus of the tool change from speed to quality this time can be reduced to an average of 45 minutes per tool change.

This suggests that the total production to production changeover time can be reduced from 3 hours 20 minutes to 1 hour 45 minutes. A total time estimated saving of 90 minutes.

4.2 Reduced Inventory

The time reduction of 90 minutes means that the total production to production changeover time which is currently 3 hours and 20 minutes can be halved. Theoretically this equates to being able to do twice the number of changeovers in a month without losing any production time. Being conservative, the company can move from doing an average of five changeovers in a month to eight. With eight changeovers, the required inventory needed within work in progress to sustain downstream processes can be reduced by 24%. This will free up a significant amount of working capital, and space in the plant.

4.3 Increased Capacity

Instead of using the reduction in changeover time to perform more changeovers, the same number of changeovers could also be performed which result in an increase in the overall forging capacity by over 7000 parts per month, equivalent to an extra shift per month. The spare capacity presents an opportunity to make more sales or removes the need for running overtime shifts when behind schedule.

5 CONCLUSION

The need to improve the forge's changeover performance is highlighted by the large amount of inventory in the plant, the difficulties in planning production and the large variation in changeover times. By improving changeover times, smaller batch runs can be considered, shorter internal lead times will be possible and ultimately inventory levels can be reduced. This means that the manufacturer will be able to supply existing customer orders in a more efficient and cost effective manner.

The design solutions presented will each provide small benefits to improving the forge's changeover quality, and reducing the changeover and adjustment time. If the company wishes to sustain these gains, a unified approach is required. This can be achieved by implementing the designs as part of an incorporated changeover project.

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AN INVESTIGATION INTO WHETHER ORGANIC FARMING IS A MARKET ENTRY ENABLER FOR SMALL FARMERS IN SOUTH AFRICA

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ABSTRACT

The objectives of this research were to identify system-wide factors that enable or constrain market entry for small organic farmers relative to conventional farmers and to identify the problems that these farmers face once they have gained market entry. Critical market access factors were identified through secondary research and subsequently investigated within the context of a case study. Nine farmers from an organic farmer's cooperative were interviewed, the transcripts organised thematically into the critical market access factors and the results compared to secondary research.

It was found that the organic sector is a better market opportunity for small farmers due to price premiums, market growth and reduced use of external inputs. However, the current organic enabling environment is not conducive to supporting small farmers during the organic conversion period in which there is high capital investment, a steep learning curve and an initial increase in production inputs. The main environmental deficiencies identified were extension and advisory services and reasonably priced and easily available production inputs. The lack of a national organic policy is the main reason for this underdeveloped enabling environment.

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1 INTRODUCTION

The South African food industry can be divided into two sectors, the informal and formal sectors. The formal food sector is dominated by a few, large retailers while the informal food sector consists of fresh produce markets, green grocers and other informal role players. The rise of urbanization, population growth and a growing middle class with a higher per capita disposable income has stimulated the expansion of supermarkets and their various retail formats [1]. To adapt to the ever-more competitive market dynamics, retailers have re-organized their supply chains into more centralized systems consisting of a few, large distribution centres and a few preferred suppliers. This centralized system procures less produce from fresh produce markets (FPMs) [2], which is where the majority of small farmers sell their produce [3]. Furthermore, market entry into these formal supply chains is difficult for small farmers because they do not have the resources to deliver the consistent quality and volume requirements demanded by large retailers.

In parallel to these supply chain changes, the size and marketing of the organic sector has been growing [4]. This form of farming has traditionally been practiced in South Africa by small farmers who do not have the resources to procure expensive non-organic fertilizers and pesticides. The potential benefits of organic farming are the price premiums, the reduction in input costs and access to an organic market that is growing both domestically and internationally. However, the organic sector in South Africa is underdeveloped as there are insufficient support mechanisms such as legislation and economical certification systems [5]. In addition, farmers do not always receive price premiums as retailers stand accused of not passing on premiums to farmers [6].

The organic sector is still comparatively small and there are not many accounts of certified, small organic farmers who have accessed formal supply chains. This paper therefore presents a case study of a small organic farmer's cooperative that has managed to access formal markets through a contract with a major retailer.

2 LITERATURE REVIEW

Organic farming is a sustainable, low-input production system that uses the surrounding natural resources to its advantage [7]. It emphasizes the use of management practices as opposed to the use of chemical inputs which are believed to negatively impact the environment and health of those consuming the produce [8]. It focuses on maintaining soil fertility through the use of crop rotation, composting, manure, cover crops, mulches and green manures [9]. With the limited use of pesticides and herbicides in these systems, there are conflicting arguments as to whether yields decrease or increase. Rundgren claims that traditional rural farmers may see an increase in yields and profit [10]. The Institute of Natural Resources also supports this but identifies the conversion to organic farming as the period when farmers may temporarily see a decrease in yields as the ecology of the system adjusts [12].

Due to a lack of financial resources, many small farmers naturally use traditional methods which are in fact similar to organic farming. Organic agriculture is seen by many as a market opportunity for small farmers to use their more traditional farming methods to access high value, niche markets [1]. It is seen to have the potential to improve the productivity of resource-poor farmers, increase sustainable agricultural practices and reduce the reliance on expensive external inputs. The requirement for crop diversification in organic systems reduces the risk of changes in market demand [12] and there are also employment opportunities due to the increased reliance on human labour and natural systems [13].

Thamaga-Chitja assessed the production potential of organic agriculture for three small farmers [14]. The study was location specific and focused on the suitability of growing certain organic crops in a specific region under certain climatic conditions. It was therefore a production focused study with little consideration for the end market opportunities.

Thamaga-Chitja recommended that the sustainability and economic viability of organic farming be investigated within the context of South Africa [14]. Niemeyer & Lombard focused purely on the organic conversion process and surveyed 93 farmers to determine the motivation for converting to organic methods [15]. They found that protecting the environment and improving the soil fertility were the two major motivations for converting. This study, like Thamaga-Chitja [14], was production focused and considered only the immediate enabling environment such as extension and financial services. Production advantages and constraints were identified but their effects were not translated into market access opportunities or constraints.

Thamaga-Chitja & Hendriks did focus on both sides of the value chain and presented a synopsis of the issues in smallholder organic production and marketing [16]. This wider analysis of the opportunities and constraints identified market factors such as price premiums, policies, marketing channels and certification regulation as well as many of the production factors identified by Thamaga-Chitja [14]. Although the paper was only a review of literature, it was comprehensive and identified the effect of direct and indirect market access factors throughout the organic supply chain.

Svotwa *et al* surveyed 246 small farmers in Zimbabwe to determine the perceived advantages and disadvantages of organic farming [9]. 57% of the farmers believed that organic farming was a less costly strategy. The problems identified were inadequate production inputs (seeds and fertilizers), lack of technical expertise and high labour requirements. Mushayanyama investigated the problems faced by an organic farmers' cooperative in Kwazulu Natal [17]. This study is unique as it is one of the few that looks at problems faced by small farmers once they have been able to access formal markets. The focus, however, was more on management, communication, trust and cooperation between the farmers and the study did not investigate the advantages or disadvantages of organic farming compared to conventional farming methods. The top 10 constraints that the farmers faced were climate uncertainty, unavailability of the tractor or draught power when needed, delays in payments for crops sent to the pack-house, lack of affordable inputs (labour and manure), a lack of cash and credit to finance inputs, lack of affordable transport to market crops, more work than the family can handle and a lack of crop storage facilities and telephones.

Of the studies reviewed, most have focused on either the production side or market side opportunities and constraints of organic farming. There is a need to include both perspectives and evaluate all factors in a system-wide analysis.

3 RESEARCH OBJECTIVES

1. To identify factors that enable or constrain market entry for small, organic farmers relative to conventional farmers.
2. To identify the problems that small, organic farmers face once they have gained market entry.

4 RESEARCH FRAMEWORK

4.1 Value Chain Analysis Framework

A value chain analysis was chosen to assess the organic supply chain environment as well as the South African and global markets in which the organic chain operates. The framework consists of the following four elements:

1. End market opportunities
2. The enabling environment (regulatory and legal, infrastructure and extension support factors)

3. Horizontal linkages (partnerships between enterprises in the same level of the chain)
4. Vertical linkages (cooperation among vertically linked stakeholders in the chain)

The value chain framework was chosen because it is a diagnostic tool that helps to identify barriers to entry as well as constraints and opportunities for target groups in the value chain [25]. It is also useful in identifying systemic chain-level issues instead of only enterprise-level problems. This framework is therefore applicable to small farmers because the constraints they face extend beyond the immediate farm production to the policy, regulatory and financial environments in which they operate.

4.2 Value Chain Target Group

The focus of the research will be on farmers operating in informal markets, the objective being to investigate the possibility of their advancement to formal markets. These are farmers who have not been able to access formal markets but who have sufficient resources to grow and sell crops for a living. The nature of these informal markets includes open markets (e.g. National Fresh Produce Markets), informal local markets, green grocers and hawkers. Figure 1 shows the target range of farmers and how they can become more commercially orientated.

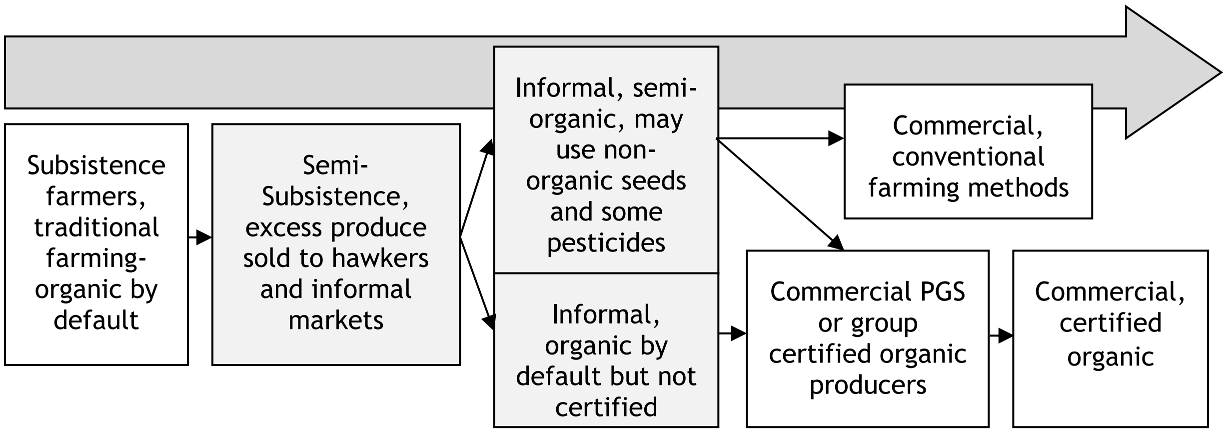

Figure 1: Categorization of small-scale farmers

As discussed in the literature review, it has been found that collaboration through farmer groups, such as cooperatives, improves market access. For this reason, the research will focus on the market access of organic and conventional farmer groups.

5 SECONDARY RESEARCH-VALUE CHAIN ANALYSIS

5.1 End Market Opportunities

The spread of urbanization, a growing middle class with a higher per capita disposable income and changing consumer preferences (a higher demand for processed and quality fresh food) has resulted in supermarkets acquiring a larger market share in the food industry [1]. As these retailers have increased their size and market share, the sector has consolidated into four major players who control 55% of the food retail industry [18]. With an ever more competitive environment, retailers have embraced supply chain management principles and restructured their supply chains to reduce transaction costs and optimize procurement processes. This restructuring has resulted in vertical integration, increased coordination and a more concentrated wholesaling system which takes the form of large, centralized distribution systems.

Retailers previously procured their produce from National Fresh Produce Markets (FPMs). The increased emphasis on food safety and traceability has lead retailers to initiate contracts with a few, large primary producers [19]. With these decreasing markets, small farmers are left with the daunting task of entering retailer supply chains which are already dominated by large, commercial farmers.

The need to include small conventional farmers in formal retailer markets stems from the diminishing market share of their open markets which are their primary market channels [3]. In contrast, organic open markets are growing and may be a sustainable market opportunity. Van der Heuden claims that there are more than 30 such markets in Gauteng although they are still a relatively small part of the food chain, and that other alternative niche marketing channels such as box schemes, specialty grocers, delis and health shops are also on the rise [3]. With an increasing variety of market opportunities, organic farmers may be better positioned to reduce the risk of market changes through channel diversification.

Further factors enabling or constraining market entry for small farmers have been identified through the end market analysis. These factors are given in table 1.

Table 1: End-market factors

<table>
<tr><th>Factors contributing to the market entry of organic farmers relative to commercial farming</th><th>Factors hindering market entry of organic farmers relative to commercial farming</th></tr>
<tr><td>Organic certification provides access to price premiums. [20].</td><td rowspan="2">Primary organic producers are not always guaranteed premiums. Retailers accused of not translating benefits to producers. [22].</td></tr>
<tr><td>Continued international growth, better price premiums and an undersupply of organic produce in South Africa’s main export market (the EU) may see large farmers continuing to export. Domestic opportunity for small farmers. [21].</td></tr>
<tr><td>In contrast to conventional fresh produce markets, organic open markets are growing [3].</td><td rowspan="2">Behind the corporate social responsibility campaigns, retailers do not provide any meaningful developmental support to organic farmers. [23]</td></tr>
<tr><td>Increasing variety of market opportunities may mean that organic farmers are better positioned to reduce the risk of market changes through market channel diversification.</td></tr>
</table>

5.2 Horizontal and Vertical Supply Chain Linkages

5.2.1 Horizontal Linkages

Van Tilburg *et al* claim that the nature of access to formal markets is a critical factor and that horizontal coordination is an important market entry enabler [24]. Mitchell *et al* claim that it is the initial step in a sequence of interventions that facilitates market entry through reduced transaction costs, economies of scale and increased bargaining power [25]. Cooperatives are an important mechanism for the transaction of goods between stakeholders in a supply chain. They redress market failures such as the exploitation of individual farmers through market intermediaries [26]. Furthermore, support provided to a cooperative is more effective than targeting individual farmers one at a time. Haggblade identifies the concept of leveraged intervention as “intervention points that affect a large number of vulnerable people at once”, and identifies cooperatives as one of these interventions [27].

The Department of Agriculture, Forestry and Fisheries (DAFF) has recognized the insufficient functionality of current small-scale cooperatives and is in the process of developing an Integrated Cooperative Strategy for the sector. Part of these plans is to establish secondary cooperatives to support primary cooperatives. This was based on the fact that current primary cooperatives operate at a production level and lack the resources to link produce to markets [26]. The secondary cooperatives would provide assistance in production quality, logistics, storage and transportation facilities; compliance with food safety and quality assurance standards and access to market information and technology.

5.2.2 Vertical Linkages

Large retailers procure produce through grower's agreements with farmers but provision for the inclusion of small farmers through these contracts has not been made. Van der Heuden argues that it is commonly accepted that small farmer exclusion results purely from the deficiencies in their farming production systems and not from the design and structure of the supply chain [3]. Furthermore, small-farmer inclusion interventions are based predominantly on supply-side improvement and not on end-market restructuring [3]. Reviewing literature has revealed that there are very few cases where small farmers have been able to access these supply chains and it is usually done by supplying directly to franchise-format stores in their local area. The channelling of produce through centralized distribution centers remains the dominant supply chain design. Increased market power allows retailers to dictate their contract terms so that their own transaction costs are reduced [3]. Costs such as packaging and transportation become the responsibility of farmers [28]. This supply chain model therefore increases the risks and transaction costs for farmers. Only those large enough to achieve the volumes and quality requirements become the preferred suppliers. Large farmers are at an advantage because of the large-scale, industrialized mono-cropping methods they use.

5.3 Enabling Environment

5.3.1 Legal and Regulatory Environment

Table 2 shows the enabling environment factors that contribute or hinder market access for small organic farmers. These factors were identified through the secondary research.

Table 2: Legal and regulatory factors

	Factors contributing to the market entry of organic farmers relative to commercial farming	**Factors hindering market entry of organic farmers relative to commercial farming**
Organic policy and regulations	Alignment with government's sustainability strategies could see more investment in the organic industry [29].	Unformalised organic sector- loss of consumer trust, no standardisation of organic labels, unregulated produce marketed as organic [12].
	More control of unsustainable agricultural methods. Organic farming embodies these regulations inherently- the SUPAR Bill (Sustainable Utilisation and Protection of Agricultural Resources Bill)	
Certification	Certification affords access to price premiums and a high-value niche market [13].	Currently no national organic certification standards or legislation [30].
	Protection of market share loss from farmers who falsely claim to be organic [13].	Three year conversion from non-organic to organic methods required before certification is granted. No access to premiums during this period. [15]
	Group and PGS systems reduce certification costs for small farmers. [38]	High certification and annual inspection costs which are often driven by international standards [14].

5.3.2 Infrastructure

The key infrastructure requirements identified from the secondary research are summarised in table 3.

Table 3: Infrastructural factors

Factor contributing or hindering market access	Factors contributing to the market entry of organic farmers relative to commercial farming	Factors hindering market entry of organic farmers relative to commercial farming
Water usage for irrigation	Better water retention and nutrient cycling in organic farming. Improved soil structure resulting in less erosion and higher productivity. [31]	Lack of irrigation is a limiting production factor for small farmers [14]. (Both organic and conventional)
Energy usage		Organic farming is more labor intensive - higher labour costs [32].
Transport, packaging and storage		Extra organic standards and regulations above the general food handling and storage regulations. Therefore training required [32].
Agricultural inputs	Less input expenditure required due to creation of inputs (organic fertilizers) within the organic farming system. [10]	Fertilizer availability in general is constrained by a lack of infrastructure, research, development and extension services [35]. (Both organic and conventional)

5.3.3 Extension Support

Extension support plays an important role in developing small-scale farmers. It facilitates the adoption of new technologies to improve production and it is a channel through which farmers' problems can be identified and policies and strategies consequently adapted [33]. However, the market deregulations and withdrawal of financial support in the 1990's coincided with a decrease in the support for agricultural extension services [34]. DAFF does provide programmes to assist new entrants in their farming operations but many emerging farmers have continued to experience serious difficulties [34]. The organic extension personnel available today do not receive sufficient training and there is a lack of information on production methodologies and market information [29]. Furthermore, in a study on the knowledge of agricultural extension officers' in the North West Province, Oladele & Tekena inferred from results that extension officers had more production knowledge than marketing of organic agriculture [33].

6 CASE STUDY

The secondary research identified both direct and indirect market access factors. These factors were then investigated through a case study. An organic farmers' cooperative that had successfully been integrated into a formal supply chain was chosen. The cooperative consists of eleven small farms located near Tzaneen, Northern Limpopo. The cooperative supplies vegetables to one of the large retailers in South Africa.

A preliminary investigation was undertaken to understand the history and operating characteristics of the cooperative. Ninety-two questions were used to interview two cooperative members, one being the chairman. Two farm visits were conducted to view the organic systems. Subsequently, another seven cooperative members were interviewed telephonically using a shorter questionnaire pertaining to the most important factors identified through the secondary research.

7 RESULTS AND DISCUSSION

7.1 Market-oriented Factors

The current market opportunities for organic farmers include all of the conventional markets as well as organic farmers' markets and contracts with retailers. Thus it may appear that organic farmers have more market opportunities. However, seven of the nine farmers in the case study complained that they do not receive price premiums when selling at National Fresh Produce markets. They do however receive better prices through their retailer contract. These price premiums are especially needed to cover the annual organic certification costs. Contrary to expectations, market-oriented motivations for converting to organic farming, such as price premiums, were cited by only two out of the nine farmers in the case study. The most common motivations were organic health benefits and concern for the environment. The environmental motivations correlate to the study conducted by Niemeyer & Lombard where it was found to be a major motivator [15]. However, the health benefits did not appear in their study. The partiality of the case study farmers towards the health benefits of organically grown vegetables may be because they were all exposed to the same organic workshop presented by a South African university who may have focused on this factor.

In the context of the case study, there are potentially two major factors that have contributed towards the market access of these farmers. These are the decision to operate as a cooperative and the decision to convert to organic farming. Many of the farmers do attribute their market access to organic farming. All nine farmers believed that they were able to sell their produce at better prices because it was organic and four farmers explicitly attributed their better market access to organic farming. However it is unlikely that the farmers would have been awarded the retailer contract if they were operating individually. All 9 farmers cited that working through a cooperative had increased their bargaining power and market access. The secondary cooperative functions such as assistance in production quality, logistics and transportation facilities had contributed to this market access.

7.2 Enabling Environment

The case study highlighted that production support is poor. Although five out of nine farmers mentioned that more agricultural inputs, such as fertilizers, were produced within an organic farming system, the unavailability of external inputs was still a constraining factor. When organic fertilizers or sprays did need to be sourced externally, they were not easily available. An even greater problem was sourcing organic seeds as cited by seven farmers. The lack of production inputs seen in the case study correlates to the literature [35]. Of the infrastructural support factors, the lack of a pack house was highlighted. The cooperative carries higher transaction costs because it has a contract with a pack house in Johannesburg. The cooperative is hoping that such costs will be reduced through the establishment of a pack house in Tzaneen. However, markets will still remain distant as the retailer requires that all produce is directed to the DC before entering stores. The cooperative is responsible for these weekly transportation costs.

The unavailability of inputs, a pack house and local markets correlate to the results of the 1996 Agricultural Census. The census found that packaging services were the least available service, followed by trading centres and input dealers. The results of this census are applicable to the case study farmers as they are situated near to the former homelands, which is from where the data was gathered. However, the infrastructural deficiencies are also a result of their decision to farm organically. Organic pack house facilities need to adhere to stricter organic regulations and be certified. Such facilities specializing in organic vegetable packaging are not available in Tzaneen. There are also no organic trading centers in Tzaneen. Therefore the cooperative does not receive price premiums when selling locally. However, even before converting to organic methods, farmers had a limited choice of markets and consequently sent produce to the Johannesburg FPM. Lack of inputs, particularly seeds, is a problem for organic farmers in South Africa. The farmers had found only one organic seed supplier in the country. The unavailability of input suppliers may be a result of the organic sector's current small size and underdevelopment.

Based on the literature, it was expected that the farmers would lack sufficient water due to the scarcity of the resource. However, none of the farmers cited this as a problem as they were situated near to large bodies of water. What they did lack was the financial resources to fund the irrigation equipment. The DTI had to assist them with this. In terms of extension services, organic farmers face two disadvantages. Firstly, six out of seven of the case study farmers believed that such services were insufficient. The literature supports this result [34]. Secondly, in light of this deficiency, all farmers believed that organic farming was more knowledge intensive (supported by Giovannucci [36]). Farmers therefore require more skills and knowledge to farm organically but the current enabling environment lacks the support functions to provide this training.

In conclusion, the organic supply chain exists within a less established, enabling environment. It lacks support functions such as extension services, agricultural inputs and infrastructural facilities. The case study results support the arguments in the literature. There are currently insufficient production support functions because the South African organic industry is underdeveloped.

7.3 Financial Constraints

The farmers in the case study have successfully entered formal markets through the retailer contract but they have received substantial support, most of it being provided by government. Equipment, fertilizers, seeds, certification costs, trucks and production expertise were funded jointly by dti stakeholders and the farmers themselves. Manure is produced in the compost manufacturing plant which was built with a grant provided by LIBSA and it is expected that the dti will assist with a pack house.

This type of direct financial support targets individuals or in this case, groups of farmers but not the entire population. Such interventions are not leveraged enough because they are target specific. The general production environment needs to be developed so that inputs, infrastructure, and technical and market information are more widely available. Based on the interviews, farmers did and still do rely heavily on government for further support. They struggle financially even with the support they have received. This was attributed to the general risks associated with farming and the fact that it is an expensive business. Research into the financial health of the farmers could not progress beyond a qualitative investigation because formal financial records are not kept. Although the farmers managed to obtain loans to purchase land, they have struggled to obtain production loans due to their inconsistent income and high-risk profile.

In conclusion, the lack of financial services, particularly production loans, is a major constraining factor. However, there is no comparative advantage as this factor is common to both organic and conventional farmers. The increased risks involved in organic farming are a disadvantage as they result in a higher risk profile. However, the case study farmers did not see such risks as a major problem as they could be mitigated through increased monitoring and control.

7.4 Production advantages and disadvantages

The views of the farmers in the case study supported the organic production advantage of reduced use of external inputs and subsequent savings (supported by Hewlett [7]). No conclusion could be drawn about yields. Three out of six farmers claimed that their yields had increased while two were unsure. Only one farmer thought that his yields had not increased. The range in responses can most likely be attributed to the variety of factors that affect yields. These included increased pests and weeds, access to farm management principles through increased extension support, use of improved production inputs and better access to water for irrigation. Furthermore the sample size of farmers is too small to draw conclusions and no records of yields exist from before and during the organic conversion period.

The case study revealed that there was an increase in risks in organic farming. Five out of seven farmers in the case study believed that there were more risks in organic farming. Figure 2 shows the risks identified by the farmers.

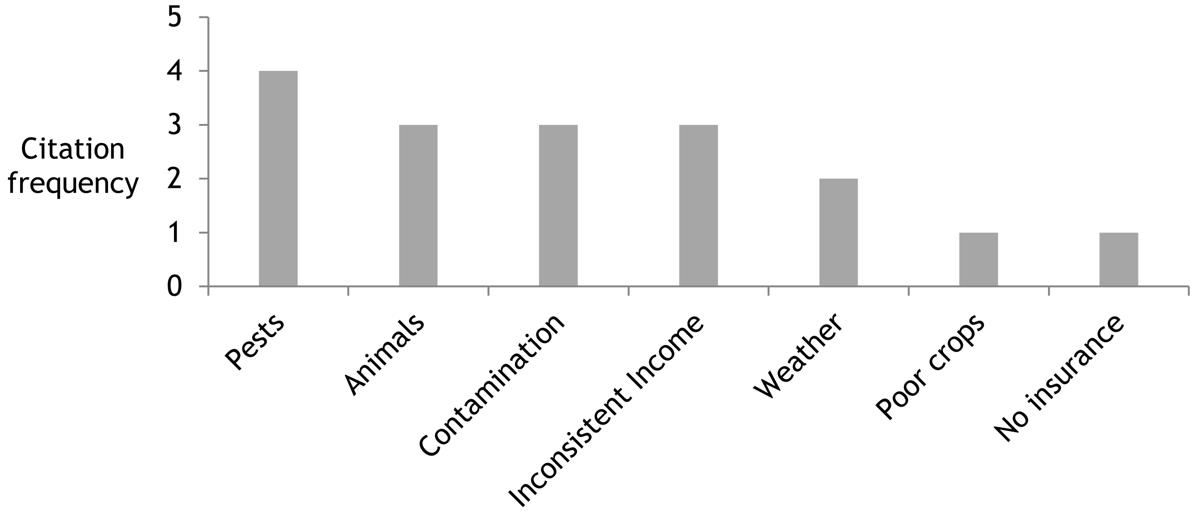

Figure 2: Frequency of risks identified by the 9 farmers

Although pests were the most commonly identified risk, three of the farmers explained that they could be sufficiently controlled by using organic methods. Therefore no conclusion can be drawn as to whether pests are an increased risk. The case study confirmed that contamination from adjacent farms was a risk (supported by Watson [37]). It was also confirmed that labour expenses increased with organic farming (supported by Twarog [32]). Half of the farmers believed that organic farming was less expensive than conventional farming. These inconclusive results are similar to the results from the study be Svotwa *et al* where only 57 percent of the 246 Zimbabwean small farmers found that organic farming was a less costly strategy [9]. The problems faced by the Zimbabwean farmers were inadequate inputs and a lack of production expertise. This environment is similar to that seen in the case study.

The three year conversion from conventional to certified organic farming was identified as a major barrier by the farmers in the case study. The reasons for this were the expensive certification costs, the three years of no access to price premiums, the increase in pests due to the adjustment to organic control methods, the initial increase in inputs to improve the soil (not identified in the literature) and the initial decrease in yields. For certified organic farming, the initial investment and transition to the knowledge intensive production methods is a barrier to entry for resource poor farmers, especially since the financial support functions and extension services are inadequate in supporting farmers through the conversion period.

7.5 Market Access

The price premiums in organic farming are a major benefit if the farmers can access them. The end market opportunities for organic farmers are therefore better than those available to conventional farmers. In terms of horizontal coordination, neither organic nor conventional farmers are afforded a market advantage over the other. Both industries benefit from farmer collaboration through cooperatives. The success of the case study farmers is largely a result of their combining volumes through a cooperative.

Organic agriculture is seen as an opportunity for small farmers to use traditional farming methods to access high value, niche markets [1]. On a very small-scale, these traditional methods are suitable in supplying local, informal markets. This is due to the production benefits such as the reduced reliance on costly external inputs and the increase in soil health and moisture retention. However, in expanding a production system to meet retailer requirements and certification, the reliance on control systems, complex organic methods and agricultural skills is greater. Traditional, rural farmers will not have the skills and financial resources to achieve this. As unanimously expressed by the case study farmers, organic extension services in South Africa are not easily available to develop these skills. Furthermore, certification is costly. Unless retailers accept alternative, economical certification systems such as PGS (Participatory Group System), resource poor farmers will have little chance in meeting retailer requirements. The type of small farmers who stand a better chance of accessing organic, niche markets are those who are already commercially oriented (i.e. they farm purely for an income and already sell to more formal markets such as FPMs). These farmers have a better financial resource base and if already operating through a cooperative, the step from selling to FPMs to retailer markets is smaller.

The maturity of the food retail sector matches that of developed countries yet the South African agricultural sector operates within a developing country environment. This means that small farmers do not have sufficient, accessible resources to improve their production systems to meet the first-world expectations of retailers. The development of the sector is hindered by the delay in finalization of an organic policy, standards and regulations. Without national standards and regulations, the organic sector operates in an uncertain environment where there are non-uniform certification standards. This results in:

- Low consumer trust and consequent stifling of market growth
- Government extension services that cannot cater to all of the various standards and farmers' needs.
- Substitute regulations from the EU that are not based on South African conditions
- Certification being provided predominantly by expensive, private, international certifying bodies
- Higher transaction costs for farmers due to scarce and remote input suppliers

For the sustainable involvement of small farmers in retailer value chains, their contribution cannot be at the expense of retailers' corporate social responsibility initiatives. Their contribution needs to involve adding actual value to the efficient movement of produce in these chains. This needs to be done either through changes in the structure and design of retailer supply chains or through production improvements on the supply side. However it is unlikely that retailers will alter their current, vertically integrated chains to support the inclusion of small farmers. The changes will therefore need to emerge from the supply-side. This case study has highlighted that collaboration through cooperatives is an effective strategy in meeting retailer requirements and reducing transaction costs for both parties. This collaboration strategy, coupled with organic production advantages and organic market growth, could result in a system where small farmers are in demand and viewed as an essential player in the supply chain. However, at this point in time, in relation to conventional farming, organic farming is not a better market entry enabler for small farmers. This is because the enabling environment in which organic farmers operate is poorly resourced. The lack of dissemination of market and technical information through extension and advisory services and the unavailability of reasonably priced organic production inputs are the major constraining factors. Until national regulations and standards are finalized, such factors will remain a barrier to market entry for small farmers.

8 CONCLUSION

The organic sector is a better market opportunity for small farmers due to the price premiums, market growth and the market gap due to the small number of large farmers operating in the domestic market. The case study highlighted the organic production advantage of the reduced use of expensive, external inputs. However the current organic enabling environment is not conducive to supporting small farmers during the organic conversion period in which there is a high capital investment, a steep learning curve and an initial increase in production inputs. The main enabling environment problems identified through the case study were the poor extension and advisory services, the lack of reasonably priced and easily available production inputs and the scarcity of secondary production facilities and markets. Based on this current poor enabling environment, organic farming is not a market entry enabler for small farmers.

Using the market access factors identified through the case studies, further research should involve surveying a larger sample of farmers to identify larger-scale patterns. Furthermore, this research was limited to a qualitative investigation due to the lack of financial and production records as well as limited time to monitor extended production periods for expenditure and sales figures. It is recommended that further case study investigation involve a quantitative analysis of input and output volumes and production expenses for similar organic and conventional small farms. Adding this to the case study will triangulate the research instruments and therefore increase validity.

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AN INVESTIGATION OF THE EXTENT TO WHICH THE SEVEN BASIC QUALITY TOOLS ARE USED TO EFFECT IMPROVEMENTS IN QUALITY AND PRODUCTION PROCESSES AT A BATTERY MANUFACTURING COMPANY IN SOUTHERN AFRICA

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ABSTRACT

This is a case study that investigates the extent to which the seven basic quality tools are used to effect improvements in quality and production processes at a battery manufacturing company in Southern Africa, hereafter referred to as Company B. The company manufactures lead acid batteries for the manufacturing, mining and automotive sector. The study is a case study conducted at one of the branches of the company and it analyses departments and processes where these tools find application. It also looks at the scope of application and the logical approach followed in identifying the causes of quality problems. Quality and process improvements derived from the use of the tools were discussed. The study revealed that the tools are applied throughout the company from sourcing of raw materials to the delivery of finished products. Benefits enjoyed by Company B include low rejects and reworks, better customer/supplier relationships and teamwork within the company workers. Although Company B enjoys these benefits, it experiences challenges in applying the tools in a structured manner.

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1 INTRODUCTION

Company B was established more than 80 years ago and is the leading battery manufacturer in Southern Africa. It manufactures a large range of automotive and non-automotive batteries. In the non-automotive category it makes miner lamp, marine, mining, leisure, standby and solar batteries. The batteries are manufactured for the Original Equipment Manufacturers (OEM) and the aftermarket. On the local market the batteries are distributed through franchise centres. Company B exports its products to more than 30 countries worldwide. The company is strongly integrated and moulds plastic components and recovers lead from spent batteries in compliance with the environmental controls dictated by ISO14001:2004. These components are then used in subsequent manufacturing processes. The company has adequate technical capability to design and build batteries that meet OEMs' quality and performance standards. Mercedes Benz, Toyota, Nissan, BMW, Volkswagen, Renault, Nissan Diesel and MAN are some of the beneficiaries. Mines, power generation and telecommunication companies rely on Company B standby batteries.

All batteries are manufactured in accordance with ISO9001:2008, VDA6.3 and ISO/TS 16949:2009 quality systems. These quality systems are sustained through investment and application of modern manufacturing equipment, product testing equipment, quality standards and environmentally friendly practices and programmes. The Chief Executive Officer of Company B has shown commitment through the pronouncement of a company vision, quality and environmental policies. In addition Company B has recorded a number of quality listings and awards. This study investigates the extent to which the basic quality tools are used to effect improvements in quality and production processes at the battery formation plant of Company B.

Bamford and Greatbanks [1], define a process as an activity that takes in an input and transforms it into an output. On the other hand McQuarter et al [2] define quality tools as practical methods, skills, means or mechanisms that can be applied to a particular task. There are seven practical methods or tools used in statistical process control, sometimes referred to as the 'maginificent seven'[3]: (1) control charts, (2) histograms, (3) Pareto charts, (4) check sheets, (5) process flow diagrams, (6) scatter diagrams, and (7) cause-and-effect diagrams. They were first emphasized by Ishikawa (in the 1960s), who is one of the quality management gurus [4]. Most of these tools are statistical and/or technical in nature [3]. They are used to facilitate positive change and improvements. They can be used in all phases of production process, from the beginning of product development up to product marketing and customer support [5]. The application of each of these basic quality tools is given in Table 1.

Bunney and Dale [7] suggest that the use and selection of quality management tools and techniques are vital to support and develop quality improvement processes. According to McQuarter et al [2], quality management tools play a key role in a company-wide approach to continuous improvement, and allow:

- process to be monitored and evaluated;
- people to solve their own problems;
- a mindset of continuous improvement to be developed;
- a transfer of experience from quality improvement activities to everyday business operations;
- reinforcement of teamwork through problem-solving.

Table 1: The Seven Basic Quality Tools [4]

Tool	Definition	Application
Check sheet	A form used to collect, organise, and categorize data so that it can be easily used for further analysis.	Data acquisition
Histogram	A graphic display of the number of times a value occurs.	Data acquisition
Control chart	A graph of time-ordered data that predicts how a process should behave.	Data acquisition
Process flow diagram	A graphical illustration of the actual process.	Data analysis
Pareto diagram	A bar chart that organises the data from largest to smallest to direct attention on the important items (usually the biggest contributors).	Data analysis
Scatter diagram	A graphical tool that plots one characteristic against another to understand the relationship between the two.	Data analysis
Cause and effect diagram	A schematic tool that resembles a fishbone that lists causes and sub-causes as they relate to a concern, also known as Fishbone diagram or Ishikawa diagram.	Data analysis

McQuarter et al [2] further argue that before the above benefits are derived from quality tools there are also nontechnical aspects that should be in place. These include:

- a full management support commitment;
- an effective, timely and planned training;
- a genuine need to use the tool;
- clear aims and objective for use;
- a co-operative environment; and
- support from improvement facilitators.

Sousa et al [8] state that there is a great variety of quality tools since there are many quality improvement paradigms to help organisations improve their products or services. Even similar organisations have different needs and consequently use different quality tools. These tools generate important information that could help eradicate the relevant problems and improve not only the product quality, but also the quality of management practices, Ahmed and Hassan [9]. Firms with clear implementation plans of quality tools can secure better performance than those without. According to Paliska et al [5], a continuous quality improvement process assumes, and even demands that a team of experts in the field as well as company leadership should actively use quality tools in their improvement activities and decision making process. Paliska et al [5] moreover argue that quality tools are required in any firm irrespective of its size. However, the choice of any tool or method is not just automatic, but instead it is situation specific [9]. Many companies have used tools without giving sufficient thought to their selection and have then experienced barriers to progress [4]. Another challenge is that the tools are not there to solve the existing or would be problems, but are used as means of identifying the problems or strengths in specific terms through systematic manners. Therefore, the users must understand the applicability of the tools before using them.

2 METHODOLOGY

Information was collected by a University of Johannesburg Industrial Engineering Student from Company B. She had interviews with the production manager, quality manager and internal quality auditors. The student was attending her final year of undergraduate studies and had completed at least two courses in the field of quality. To gain access to the information required in the study, the student undertook the following:

- she arranged appointments with the production manager, quality manager, internal quality auditors and full-time machine operators in charge of production line;
- she had one-on-one interviews with the above personnel; and
- verified the answers given by the interviewees by taking informative tours of the production floor and managerial offices of the plant.

Company B operates from four sites that are involved in manufacturing of automotive batteries, industrial batteries, moulding of plastic components and recycling of used and scrapped batteries. Lack of adequate financial resources and limited time allocated for the study restricted the project team to do their research at the battery formation plant. The scope of the study encompassed the transportation of dry batteries from the plastic plant to the battery formation plant, dry battery warehouse, formation line and the distribution of formed batteries to customers and distribution centres.

3 FINDINGS

According to Ilkay and Aslan [10] motivations for quality system implementation can be grouped as internal or external. Internally motivated companies are interested in the continuous improvement of quality and their perceived benefits are increased productivity, improved efficiency, reduction in cost and waste, better management control and increased employee motivation. External benefits manifest in the form of increased; sales and market share, opportunity for new markets, new customers, customer satisfaction, and company's reliability and image. Company B's motivations to improve quality and production systems are driven by both internal and external factors. To realise these benefits, Company B to some extent exploited the basic quality tools. Section 3.1 to 3.7 explain how Company B benefited from the use of these quality tools.

3.1 Check Sheets

Company B used check sheets throughout the battery formation line and the checks were done daily on:

- non-conforming parts;
- production machinery;
- calibration equipment;
- machine parameter;
- tool change;
- personal protective equipment;
- training; and
- housekeeping (5s).

Table 2 shows data captured in the production control section of the battery formation. Additional data captured on the check sheet is on; non-conforming parts, error proofing, training and lean management tools. The check sheet also has provision to take corrective action on non-conforming products and activities.

Table 2: Daily Layered Check Sheet - Battery Formation

			Mon		....		Sun		Summary
Responsible	**B. Production Control**	**Shift**	**Y/N**	**N/A**	**Y/N**	**N/A**	**Y/N**	**N/A**	**Total nonconforming/week**
	First Offs	A							
Operator	Was a first-off completed?	B							
	Are there evidence that it passed?	C							
	Daily set up sheets	A							
Operator	Was the daily set up sheet completed?	B							
		C							
	Calibration	A							
Operator	Are all measuring equipment used on	B							
	production line calibrated?	C							
	Poke Yoke	A							
Operator	Are all poke yoke processes been	B							
	documented?	C							
	Machine Parameters	A							
Operator	Are all machine parameters	B							
	running within parameters?	C							
	Tool Change	A							
Operator	has any tool change been	B							
	documented?	C							
	Personal protective equipment (PPE)	A							
Operator	Are the operators wearing PPE?	B							
		C							

3.2 Histograms

Company B developed histograms from the data in the check sheets. They were presented to show frequency, cumulative frequency, relative frequency, or relative cumulative frequency of:

- rejects; and
- reworks.

The total rejects were recorded on monthly basis and Figure 1 shows departments where histograms were useful.

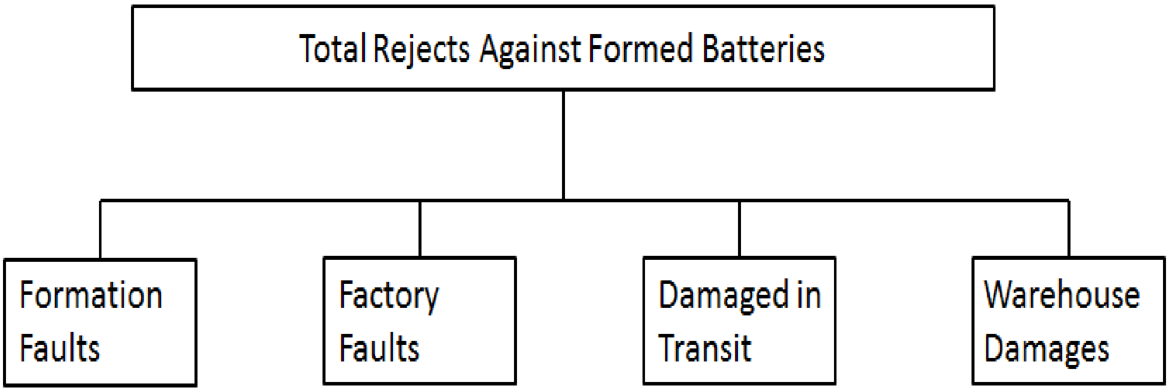


Figure 1: Departments in Company B where histograms were used

The monthly distribution was an input into the yearly graphs. The specific faults recorded in different departments are given in Table 3.

Table 3: Battery faults recorded on histograms on monthly basis

Factory Faults - recorded as a proportion of the total formed batteries		
Broken plates	Weld- partial	Cracked bridge
Incorrectly assembled battery	Loose plate	Over brushing
Poor post burn	Reverse assembly	Top short
Broken welds	COS lead run	Cracked frame/Lug
Leaking lid	Separators	Poor Neg Lug Bonding
Post lead run	Ring welds	Bent feet/plate
Formation faults-recorded as a proportion of the total formed batteries		
operational	Material handling	
Damages in transit-recorded as a proportion of the total formed batteries		
No corner pieces	Damage caused by strapping	
Scratches-factory fault	Post pushed in	
Warehouse damages -recorded as a proportion of the total formed batteries		
Stress marks	Handling	
Battery fell from forklift	Broken handles	
Battery fell from rack	Battery bumped by forklift	
bulging	Battery fell from conveyor	

Figures 2 and 3 are a representation of the relative frequency histograms on total rejected units and total batteries damaged in transit respectively. The graphs gave management an opportunity to deduce the amount of money lost in rejects.

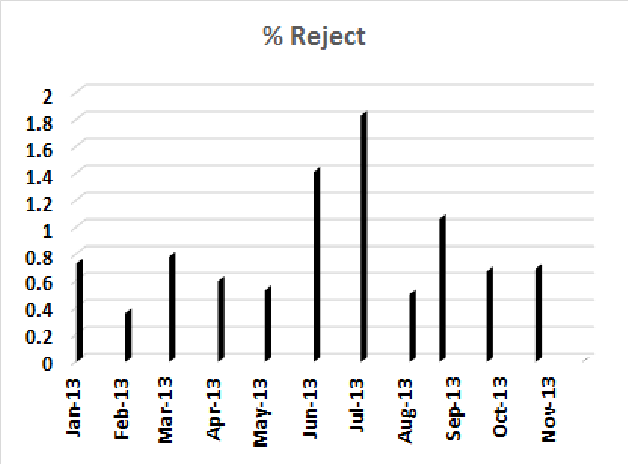


Figure 2: Percent Total Rejected Units Against Formed Batteries

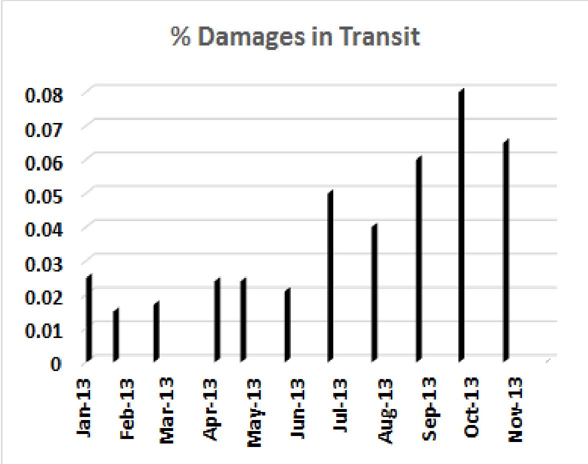


Figure 3: Percent Damages in Transit against Total Formed

3.3 Pareto Diagrams

According to Besterfield [11], Pareto diagrams have a wide application. They could be used to analyse production problems, causes, types of nonconformities, customer accounts, products giving the majority of profit, items accounting for the bulk of the inventory cost, problems accounting for the bulk of the process downtime, vendors accounting for the majority of rejected parts, customers accounting for the majority of sales, quality characteristics accounting for the bulk of scrap or rework cost, to name just but a few.

In Company B, Pareto diagrams were fairly popular. This tool was popular in capturing information associated with:

- warranty claims;
- speed shift line processes quality reports (weekly and year to date records);
- machine failures;
- reworks; and
- rejects.

This powerful tool was limited to the identification of problems in two departments. There was need to expand the scope of application.

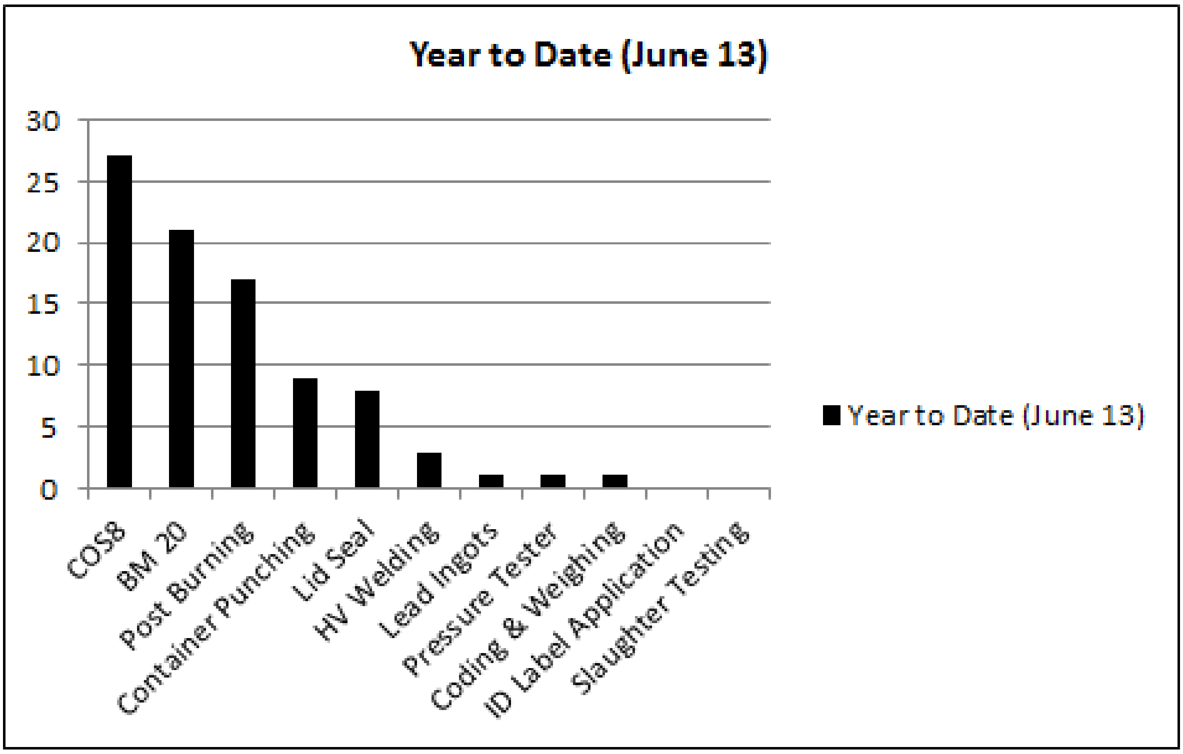


Figure 4: Pareto Analysis Based on Weekly Findings - Formation Line

3.4 Cause and Effect Diagrams

In general, the cause-and-effect diagram is a quality tool known to show the relationship between an effect and its causes. It is used to investigate either a 'bad' effect and to make action to correct the causes or a 'good' effect and to learn those causes responsible [11]. Determining all the major causes requires brainstorming by a cross-functional project team. This tool has an unlimited application in research, manufacturing, marketing, office operations and so forth [11].

Company B used the cause-and-effect diagram in conjunction with the 5 whys or on its own to identify the root causes of problems in management, quality, technical, warranty claims, battery formation line, warehouse and maintenance. Members of a cross functional team performed the root cause analysis. The process did not end with the identification of the cause, but proceeded to the problem solving stage. Figure 5 shows the stages that Company B went through in identifying and solving quality and manufacturing problems in the company.

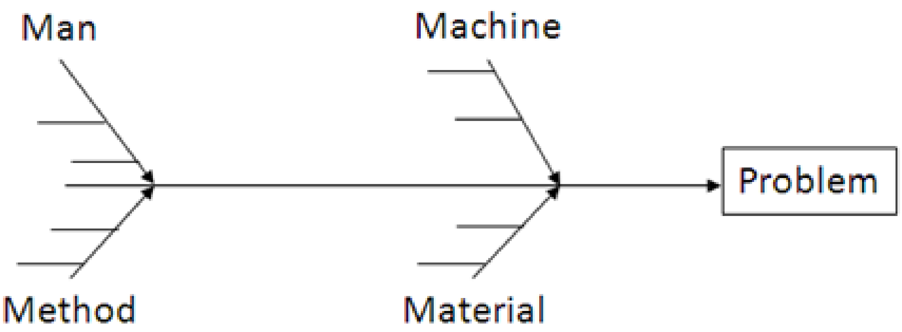
The tool was restricted to the 'bad' effects only. It would be handy if its use had been broadened to include 'good' effects as well.

Problem Solving Process	
1. Source: i.e. Management, Quality, Techical, Customer, Operator, Warehouse, Supervisor,and maintenance.	
2. Problem Title: ______	
3. Description/ Sketch/ Photo of the Problem: ______	
4. Short term counter measures (proposed by the source): ______	
5. Root Cause Analysis:	

	5 WHYs
Problem	
1. WHY	
2.WHY	
3.WHY	
4. WHY	
5. WHY	

and/or

Cause and Effect Approach



6. Root Cause Analysis:

7. Preventive Action:

Figure 5: Cause-and-effect problem solving approach at Company B

3.5 Scatter Diagrams

According to Besterfield [11], the simplest way to determine if a cause-and-effect relationship exists between two variables is to plot a scatter diagram. At Company B, this tool was not used. Ironically Company B used the cause-and-effect diagram widely. A scatter diagram would have been useful in establishing the extent of the relationship between variables, i.e. causes and effects.

3.6 Control Charts

Control charts are an outstanding tool showing the presence or absence of assignable causes. The out of control condition indicates the need to take action to remove the cause and once the cause is removed, quality improvement or process improvement is realised. It is unfortunate that Company B did not use control charts. It is very useful when used in conjunction with other tools such as the cause-and-effect, brainstorming and Pareto diagrams.

3.7 Process Flow Diagram

The diagram shows the flow of the product or service as it moves through the various processing stations or operations. It makes it easy to visualise the entire system, identify potential trouble spots, and locate control activities. The diagram shows who is the next customer in the process, and this increases the understanding of the process. It is best constructed by a team, because it is rare for one individual to understand the entire process [11]. The diagram is enhanced by adding time to complete an operation and the number of people performing an operation.

At Company B this tool is widely used. A comprehensive process diagram for the battery formation line is given in Figure 6. Besides showing the sequence in which tasks are executed, Company B process diagrams indicate inputs and outputs and people responsible at each stage.

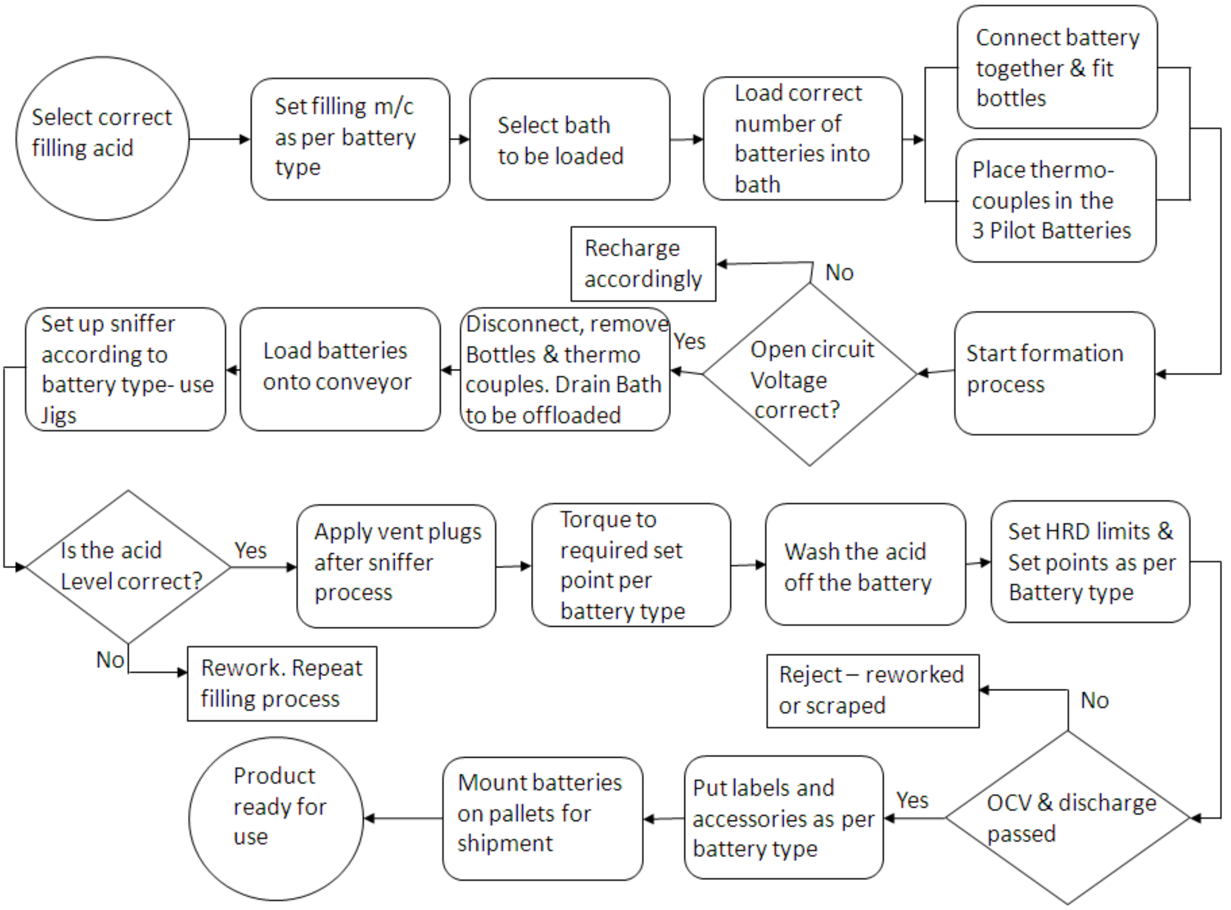


Figure 6: Flow Process Chart - Battery Formation

4 CONCLUSION

The check sheet, flow process chart, and cause-and-effect diagram were popular at Company B, and were exploited throughout the production stages at the battery formation plant. These tools were largely used in collecting data, analysing and identifying the causes of the problem. The performance perspectives for which these tools were used to investigate are many and include quality management, inventory management, plant maintenance, warranty and production management.

Histograms and Pareto charts were moderately utilised. The quality program at Company B did not exploit scatter charts and control charts.

In addition to the above tools Company B also used other tools such as 5whys and pie charts. The 5whys were used to determine relationships between causes in a hierarchical way. They were used in place of or in conjunction with the cause-and-effect diagrams and the pie charts were used together with Pareto charts and histograms.

Although Company B had a number of quality tools at hand, its problem-solving program lacked a structured methodology for the selection of the appropriate tools. Moreover there was no consistency in both approach and deployment.

Company B could take a leaf from Bamford and Greatbanks [1] who proposed the framework in Figure 6. This framework provides a structured approach to the application of the basic tools of quality management.

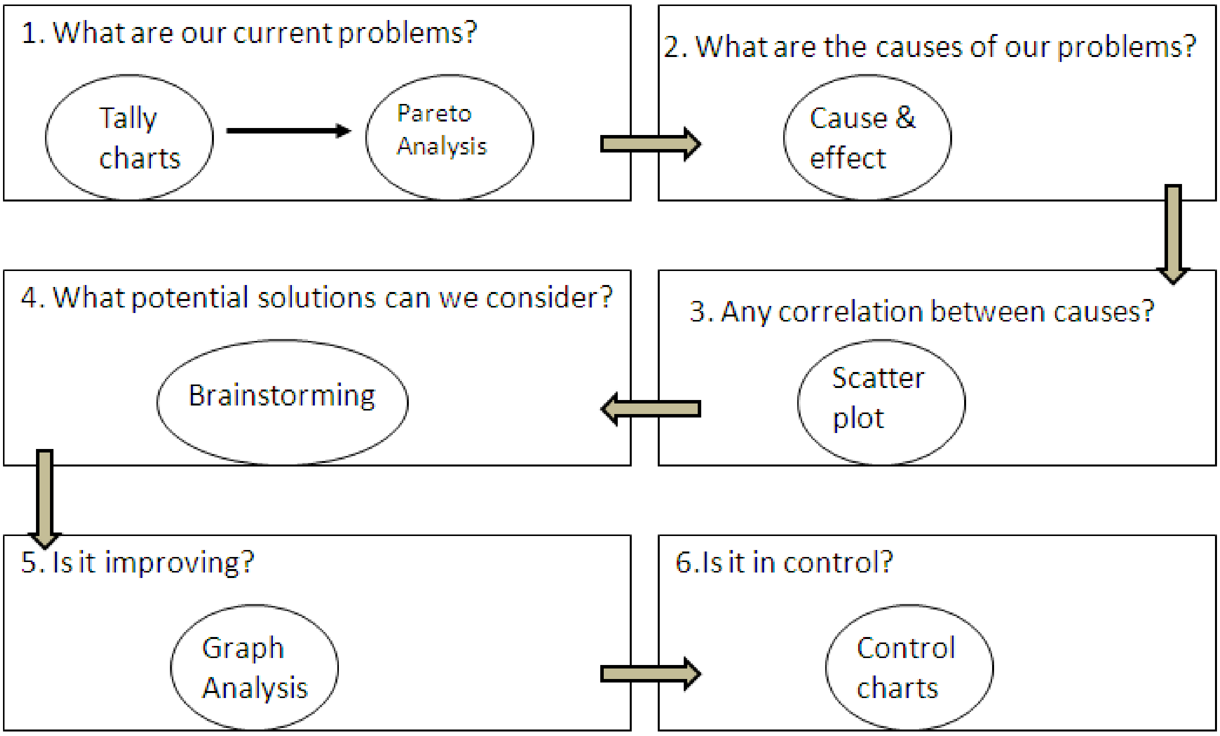


Figure 6: Structured application of quality tools [1]

The order in which the tools are applied differs depending on the process, Bamford and Greatbanks [1]. What is important is to have one tool's output being and input into the next tool.

Part of the problem was due to insufficient training in the use and application of these tools. There is need to train the users on how to link up the tools, construct the charts and interpret the results. The users also need to know the areas of business (or process) to apply the tools.

Another hindrance to the application of the tools, was the mind-set of the operators, and supervisors when introduced to quality control tools. They seemed not to appreciate the benefits derived and regarded the application of the tools as an additional workload over and above their current responsibilities.

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AN INVESTIGATION OF FACTORS AFFECTING THE AVERAGE CREDIT COLLECTION PERIOD FOR SMEs SUPPLYING TO A MAJOR MUNICIPALITY IN SOUTH AFRICA – IMPLICATIONS FOR POLICY

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ABSTRACT

It is widely agreed that SMEs, unlike big firms, are sensitive to specifically, among other things, changes in their cash flow position. Negative cash flows threaten the survival of SMEs and situations that create these conditions making them vulnerable are to be avoided. An example of such a situation is when there is delay in paying SMEs for goods and services rendered. While it is recognised that Government through its structures such as Local Government and Municipalities is a key customer for SMEs pre-qualified as suppliers, there are complaints that Government delays in paying its suppliers. This would seem to contradict Government policy as Government also tries through various initiatives to develop and promote SMEs. This study undertakes a survey of SMEs that supply one of the major municipalities in South Africa and investigates factors affecting the average credit collection period. A similar study in South Africa is not known. Findings from the study are expected to highlight weaknesses in the current procurement practices of South African Government structures that disadvantage SMEs, hence contradicting Government's policy of promoting SMEs in business, which are flags for policy makers to pay attention to.

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1 INTRODUCTION

1.1 Background and relevance

Small to medium scale enterprises (SMEs) is a name given to a wide range of firms classified into 4 categories, namely micro (survivalist), very small, small and medium. The classification of these groups is in line with the National Small Business Act of South Africa 1996 and its amendment of 2003 (NSBA) [1]. The survivalist operates less formally, operating more within the poor population; it has less than 5 permanent employees. Small to medium enterprises operate formally within established markets, with permanent employees of up to 50 and 200 respectively depending on the industry sector.

SMEs play a key role in the development of the country's economy, with a significant contribution towards job creation and employment. According to Dalberg and Morgan's [2] SME survey report, SMEs contributed six million jobs in 2011 excluding owners. Abor and Quartey in their report [3] indicate that SMEs contribute between 52% to 57% to GDP and about 61% of employment.

South Africa is currently facing an unemployment crisis, with the unemployment rate at 25% and up to 40% including the 'discouraged' or people that have given up on getting employment [16]. South Africa currently has a low entrepreneurial activity, falling behind countries such as Ghana, Zambia, Brazil and Chile in its ability to foster successful new businesses [2]. SMEs have become an integral focus for the government due to their remarkable capacity to absorb labour, display sensitivity towards poverty mitigation, provide a nursery or proving ground for entrepreneurship and innovation [4]. However the estimated failure rate of SMEs in South Africa of 40% in the first year, 60% of the remaining in the second year and 90% within the first ten years of existence [5] raises concern.

The ability of SMEs to survive in an increasingly competitive environment is largely dependent among other things upon their capability to manage their cash flow. A positive cash flow allows the SME to meet its operating costs, grow its business and acquire the ability to borrow funds for investments needed to compete in its industry [24].

1.2 Aim of research

This paper aims to establish if the average collection period of credit in particular for products and services rendered to a selected major municipality in South Africa is contributing towards sustainable business relationships between the Municipality and the SME service providers. The paper will investigate if the average collection periods tend to be related to certain SME characteristics specifically size, socio-demographics or the industry sector which the SME is operating in. These characteristics follow Zanudin [11] who uses similar characteristics. Nevertheless, instead of socio-demographics, Zainudin uses financial performance as an independent characteristic and notes that data for financial performance of SMEs is difficult to get if it is not in the public domain [11]. It is worth noting that the three characteristics may be easily used to categorise SMEs and are easy to measure facilitating an investigation of a possible relationship with average collection period.

The average collection period is the approximate amount of time that it takes for a business to receive payments owed, in terms of receivables, from its customers and clients [6].

1.3 Central Research Question

What are the determinants affecting the average credit collection period for SMEs from the selected major municipality?

1.4 Hypotheses

a) H_0: There is no difference in the average collection period between the industry sub-sectors in which SMEs operate within the selected municipality.

H_1: There is a difference in the average collection period between the industry sub-sectors in which SMEs operate within the selected municipality.

b) H_0: There is no difference in the average collection period between the differently-sized SMEs rendering goods and services to the selected municipality.

H_1: There is a difference in the average collection period between the differently-sized SMEs rendering goods and services to the selected municipality.

c) H_o: The average collection period is not influenced by the SME owner's level of education or training.

H_1: The average collection period is influenced by the SME owner's level of education or training.

1.5 Assumptions

- Average collection periods are stipulated in the service contract between Client and SME Owner.
- In this study, other factors that may influence average collection period, including but not limited to SME collection efficiency, access to finance, SME profitability, technology, crime and corruption, are assumed constant. These are difficult to find information from SMEs and, even if obtained, are difficult to quantify and measure. The approach taken would require subjective interpretations and qualitative research design not necessary for the purposes of this study as explained in the aims section.

2 LITERATURE REVIEW

SMEs are viewed as important contributors to national economies, widely regarded as engines of economic growth and substantial generators of local and broad based employment [7]. World-wide governments have developed strategies to expand and integrate the SME sector into the mainstream economy [8]. However the failure rate of SMEs in South Africa is very high and was between 70% and 80% in 2003 [9]. According to Olawale and Garwe [8] SMEs have achieved limited growth despite assistance from South African government; the authors consider the failure rate of newly created SMEs in South Africa to be among the highest in the world, and argue that it is about 75%. It can be seen that although authors differ on failure rate figures of newly created SMEs in South Africa, they all agree that the failure rates are high.

The major factors that contribute to the failure of SMEs are classified as either internal or external environments [10]. The internal environment consists of factors that are within the firm's control such as management skills, cash-flow management, location, and others, whereas external factors are not within the firm's control e.g. access to finance, economic variables such as inflation, crime & corruption, government policies & regulations, among others [8].

Previous research has been done on the factors that contribute to the failure or success, the obstacles and challenges facing SMEs in South Africa. Olawale and Garwe [8] cited the business environment to have a significant impact on the growth or failure of SMEs especially the new SMEs. Luiz [4] classified the business environment issues into 7 categories namely finance, labour, trade, tax, infrastructure, demand and procurement. All these issues need to be understood in order to minimise the failures of SMEs. Significant research has been done on these issues e.g. [18,19, 20, 21, 22], however one of the most important elements is cash flow management for SMEs in particular credit collection [13].

No research studies were found conducted in South Africa to determine the effect of collection period on the survival of SMEs, however extensive work has been done on the topic in Malaysia. Zainudin [11] cited collection period as an important factor that influences a company's performance, and related the average collection period to SME financial performance as measured by operating profit on total assets.

According to Zainudin and Regupathi [12], SMEs sell their goods and services on credit in order to generate more volumes of business by allowing the customer to delay payment for goods and services already rendered. However this creates a risk of late or non-payment, which in turn causes a strain on the SME resources negatively impacting business operations and survival. Late payments or a longer collection period delay the reinvestment of funds by the SME, creating a lost opportunity.

Although studies by Richards and Laughlin [13] employed the cash conversion cycle on SMEs instead of collection period data directly, there was an implied relationship between average collection period and financial performance. According to Correia [6] and Richards and Laughlin [13] cash conversion cycle (CCC) is "net time interval between actual cash expenditures on a firm's purchase of productive resources and ultimate recovery of cash receipts from product sales". Because of capital constraints it is critical for SMEs to manage cash effectively through efficient handling of working capital, defined as current assets less current liabilities.

SMEs face significant constraints in raising external finance or equity capital [14]. Lenders and investors are reluctant to provide financing due to high risk and costs involved, on the other hand SME owners are also reluctant to obtain external funding with reasons relating to control, debt aversion, among others [24]. According to Ebben and Johnson [14] and Richards and Laughlin [13] a more efficient cash conversion cycle increases SME performance and liquidity while reducing external capital requirement, by financing a greater portion of their operations via payables (debtors).

Banos-Caballero et al [15] suggested that although a long cash conversion cycle may increase sales because it allows customers to assess the quality of the product/ service before paying, it meant that the SME had to maintain high levels on investment in working capital, which meant higher direct costs in keeping larger inventory and had an opportunity cost if the firm had to forgo other lucrative investments. Banos-Caballero et al [15] concluded that long cash conversion cycles might be a primary reason why SMEs went bankrupt.

Regupathi and Zainudin [12] indicated that collection periods for SMEs in Malaysia were affected by liquidity, efficiency, SME size, industry sub-sector and profitability. They noted that manufacturing SMEs in Malaysia that had more liquid assets, and those that were more efficient in managing their assets collected their trade credit faster. Zainudin and Regupathi [12] also noted that the effect of the industry sub-sector on credit collection period was "sometimes" present in some sub-sectors but not in others, positive in some sub-sectors but negative in others, or higher in magnitude in some sub-sector compared to others. From their study, it is apparent that several factors can affect the collection period of SMEs. However, Zainudin [11] reduces the factors studied to three.

This research adopts Zainudin's [11] study into Malaysian SMEs, taking South African SMEs dealing with a selected major municipality in South Africa as the subject, and investigates how the municipality's response to the stipulated collection period affects SMEs in South Africa.

3 METHODOLOGY

Data used for the study was obtained from the bidder's list of SMEs registered as approved vendors to provide products and services to the selected municipality, the list being obtained from the Supply Chain Management Unit of the municipality. To qualify for the approved vendor list applicants must meet requirements specified by the municipality including VAT & PAYE registration, unemployment insurance fund registration, workman's compensation fund registration, income tax & tax clearance, registration to a statutory body regulating the SME industry and BBBEE or EME certification. The survey was conducted on SMEs across all industrial sectors on the bidders list. The bidders' list had 166 SMEs but only 147 SMEs participated in the study. Of the 147 SMEs, 113 had actually done work for the Municipality to date, the remainder were yet to bid for any tender or job. Table 1 shows the breakdown of the 147 SMEs and how they were grouped in this study. The SMEs were grouped by industry sub-sector, e.g. gardening services and horticulture became landscaping, electrical components and electrical switchgear supplies became part of construction, and so forth.

Table 1: SME distribution by industry sub-sector

	Based on overall SME Participation		**Based on active SMEs**	
Industry Sub- sector	Frequency	Share %	Frequency	Share %
Landscaping (garden maintenance, horticulture etc.)	37	25.2	34	30.1
Construction (buildings, paving, precast concrete, electrical components etc.)	29	19.7	23	20.4
Cleaning Services	21	14.3	18	15.9
Waste management (disposal, sewer etc)	3	2.0	2	1.8
Security Services	23	15.6	12	10.6
Catering (Nutritional care, functions, Groceries etc.)	8	5.4	6	5.3
Training & Development	8	5.4	5	4.4
Stationary Supplies	11	7.5	8	7.1
Medical Supplies	7	4.8	5	4.4
Total	147	100	113	100

A structured questionnaire was used and data captured telephonically. This approach ensured instant response from the participants (i.e. the responses are obtained in real time irrespective of location) and was preferred because it is quicker compared to the alternative of arranging face to face interviews (which requires travelling to the agreed location at the agreed time) or use of emails (which risks not receiving feedback or delaying the process). The questionnaire captured socio-demographic which was indicated by ticking the correct box from options provided and sought information including the owners' highest qualification, no of employees, turnover and years in existence; a second set of questions were related to the collection period and related problems which were captured on a likert-style five point scale with 1 being strongly disagree and 5 being strongly agree; the third category was an open-ended question on collection period to products and services rendered to government departments.

The validity of the questionnaire was checked during the pre-testing phase whereby the proposed questionnaire was submitted to and completed by at least five SMEs that were on the bidders' list in the selected municipality. Their responses, concerns or difficulty in understanding the questionnaire were used to improve the questionnaire hence improving its validity.

3.1 Data Analysis

This study considers the dependent variable as the average collection period and defines average collection period as the actual time taken by the SME to recover its payment from the municipality starting from when the service is rendered. The study considers three independent variables namely SME industry-sector, SME size and the highest training or qualification of the majority shareholder who is expected to exert significant influence in the day-to-day running of the SME. The SME industry-sector is obtained from table 1. SME size is defined primarily by the number of employees and characterises SME size as less than 5 employees, between 5 and 50 employees, between 50 and 100 employees, and between 100 and 200 employees. Highest level of training or education is specified in the questionnaire which gives three qualification levels namely tertiary (any education after matriculation), matric and other which could be any level before matric.

The data obtained from the questionnaire is mostly ordinal categorical data, with variables having two or more categories which can be ordered or ranked. Non-parametric testing is used for analysis which does not require any specific distribution of the sample or population as normal distribution cannot be assumed. Friedman's test is used with the assumption that the independent variables for the study are mutually independent. From common experience with SME BBBEE-highly-compliant companies in South Africa, it may be assumed that the three variables meet this assumption by indicating insignificant and if any, inconsistent correlation with each other. For example, the researchers' experience is that the larger SMEs do not necessary have better educated majority shareholders that run the day-to-day affairs of the business and even if some have there is no consistent pattern observed. For Friedman' test the data is set out in tabular form comprising of n rows by k columns. The data is ranked across each row and the mean and sum ranks for each column are compared [17]. Taking the statistical 95% confidence level, Friedman's test applies the decision rule that the null hypothesis is rejected if:

Fr ≥ critical value at α = 5%

Whereby the test statistics for Friedman test (Fr) is calculated from the formula:

$$\left[\frac{}{nk(k \quad 1)}\right]\sum \qquad n(k \quad 1) \qquad \textbf{(1)}$$

Where;

K = number of columns

n = number of rows and,

Rj = sum of ranks in column j.

2 RESULTS

The following results were obtained.

4.1 Average collection period profile

The table below represents the frequency of the average collection period of the 113 active SME that participated in the study.

Table 2: Average collection period

Ave. collection period	Frequency	Share %
1 -30 days	46	40.7
31- 60 days	33	29.2
61 -90 days	16	14.2
91 – 120 days	12	10.6
More than 120 per	6	5.3
Total	113	100%

4.2 Average collection period by industry sub-sector

The table below represents the frequency of the average collection period of the 113 active SMEs categorised by respective industry sub-sectors.

Table 3a: Average collection period by industry sub-sector

	Landscaping		Construction		Cleaning		Waste management		Security services		Catering services		Training and development		Stationary and printing services		Medical supplies	
Average collection period	Frequency	share %	Frequency	share %	Frequency	share %	Frequency	share %	Frequency	share %	Frequency	share %	Frequency	share %	Frequency	share %	Frequency	share %
1-30 days	15	44.1	7	30.4	9	50	1	50	2	16.7	2	33.3	4	80	3	37.5	3	60
31-60 days	5	14.7	8	34.8	4	22.2	0	0	7	58.3	3	50	1	20	3	37.5	2	40
61-90 days	6	17.6	5	21.7	2	11.1	0	0	1	8.3	1	16.7		0	1	12.5		0
91-120 days	4	11.8	3	13	2	11.1	1	50	1	8.3	0	0		0	1	12.5		0
More than 120 days	4	11.8	0	0	1	5.6	0	0	1	8.3	0	0		0		0		0
	34	100	23	100	18	100	2	100	12	100	6	100	5	100	8	100	5	100

The table below represents the ranked data for the average collection period of the 113 active SMEs for the different industry sub-sectors as specified by Friedman's test.

Table 3b: Calculations for Friedman's test (average collection period by SME industry sector)

	Landscaping		Construction		Cleaning		Waste management		Security services		Catering services		Training and development		Stationary and printing services		Medical supplies	
Average collection period	Frequenc	Rank	Frequenc	Rank	Frequenc	Rank	Frequenc	Rank	Frequenc	Rank	Frequenc	Rank	Frequenc	Rank	Frequenc	Rank	Frequenc	Rank
1-30 days	15	9	7	7	9	8	1	1	2	2.5	2	2.5	4	6	3	4.5	3	4.5
31-60 days	5	7	8	9	4	6	0	1	7	8	3	4.5	1	2	3	4.5	2	3
61-90 days	6	9	5	8	2	7	0	1	1	5	1	5	0	1	1	5	0	1
91-120 days	4	9	3	8	2	7	1	5	1	5	0	2	0	2	1	5	0	2
More than 120 days	4	9	0	3.5	1	7.5	0	3.5	1	7.5	0	3.5	0	3.5	0	3.5	0	3.5
	34		23		18		2		12		6		5		8		5	
Sum of Ranks, R		43		35.5		35.5		11.5		28		17.5		14.5		22.5		14
Mean of ranks		8.6		7.1		7.1		2.3		5.6		3.5		2.9		4.5		2.8
R-squared		1849		1260.25		1260.25		132.25		784		306.25		210.25		506.25		196
No. of columns, k	9																	
No. of rows, n	5																	
Sum of R squared	6504.5																	
12/nk(k+1)	0.026667																	
3n(k+1)	150																	
Test Statistic Fr	23.45333																	

Since k is greater than 6 the chi-squared table is used to obtain values of F_r. From the chi-squared table the critical value at 5% significance level and *k-1* degrees of freedom is given as F_r = 2.73. This is less than the test statistic obtained. Hence **F_r > critical value**

4.3 Average collection period by SME size

The table below represents the frequency of the average collection period of the 113 active SMEs in the selected municipality categorised by respective sizes based on the number of permanent employees.

Table 4a: Average collection period by SME size

	less than 5 employees		between 5 and 50		between 50 and 100		between 100 and 200	
Average Collection Period	Frequency	Share %	Frequency	Share %	Frequency	Share %	Frequency	Share %
1 -30 days	3	16.7	29	47.5	12	44.4	2	28.6
31 - 60 days	11	61.1	13	21.3	7	25.9	2	28.6
61 - 90 days	3	16.7	11	18.0	2	7.4	0	0.0
91 - 120 days	1	5.6	6	9.8	4	14.8	1	14.3
More than 120 days		0.0	2	3.3	2	7.4	2	28.6
	18	100.0	61	100	27	100	7	100

The table below represents the ranked data for the average collection period for the different SME sizes as specified by Friedman's test.

Table 4b: Calculations for Friedman's test (average collection period by SME size)

	Less than 5 employees		between 5 and 50		between 50 and 100		between 100 and 200	
Average c	Frequency	Rank	Frequency	Rank	Frequency	Rank	Frequency	Rank
1-30 days	3	2	29	4	12	3	2	1
31-60 days	11	3	13	4	7	2	2	1
61-90 days	3	3	11	4	2	2	0	1
91-120 day	1	1.5	6	4	4	3	1	1.5
More than	0	1	2	3	2	3	2	3
	18		61		27		7	
Sum of Ranks, R		10.5		19		13		7.5
Mean of ranks		2.1		3.8		2.6		1.5
R-squared		110.25		361		169		56.25
No. of columns, k		4						
No. of rows, n		5						
Sum of R squared		696.5						
12/nk(k+1)		0.12						
3n(k+1)		75						
Test Statistic Fr		8.58						

From Friedman's test table the critical value at 5% significance level for n= 5 and k =4 is given as F_r = 7.8. This is less than the test statistic. Hence **F_r > critical value**

4.4 Average collection period by SME owner's training

The table below represents the frequency of the average collection period of the 113 active SMEs categorised by the SME owner's level of training.

Table 5a: Average collection period by SME owner's level of training

	Tertiary		Matric		Other (less than Matric)	
Average Collection Period	Frequency	Share %	Frequency	Share %	Frequency	Share %
1 -30 days	27	51.9	12	33.3	7	28.0
31 - 60 days	12	23.1	17	47.2	4	16.0
61 - 90 days	9	17.3	3	8.3	4	16.0
91 - 120 days	3	5.8	2	5.6	7	28.0
More than 120 days	1	1.9	2	5.6	3	12.0
	52	100.0	36	100	25	100

The table below represents the ranked data for the average collection period for different categories of SME owner's level of education or training as specified by Friedman's test.

Table 5b: Calculations for Friedman's test (average collection period and SME size)

	Tertiary education or training		Matric		Other (less than matric)	
Average c	Frequency	Rank	Frequency	Rank	Frequency	Rank
1-30 days	27	3	12	2	7	1
31-60 days	12	2	17	3	4	1
61-90 days	9	3	3	1	4	2
91-120 day	3	2	2	1	7	3
More than	1	1	2	2	3	3
	52		36		25	
Sum of Ranks, R		11		9		10
Mean of ranks		2.2		1.8		2
R-squared		121		81		100
No. of columns, k		3				
No. of rows, n		5				
Sum of R squared		302				
12/nk(k+1)		0.2				
3n(k+1)		60				
Test Statistic Fr		0.4				

From Friedman's test table the critical value at 5% significance level for n= 5 and k =3 is given as F_r = 6.4. This is greater than the test statistic. Hence **F_r < critical value**

5 DISCUSSION

Table 2 representing the general profile of the average collection period of the 113 active SMEs that participated in the study showed that about 40% of the SMEs that rendered goods and services to the municipality actually collected their credit within the first 30 days period which leaves the majority not serviced within the earliest period. At least 30% are serviced after 60days of which close to 10% are serviced after 90 days. This indicates that the payment period for services rendered to the municipality is less than satisfactory and must be negatively impacting the SMEs concerned as discussed in the literature.

Based on Friedman's test (table 3b), F_r (23.45) is greater than the critical value (2.73) hence the first null hypothesis (H_o) that there is no difference in average collection period between the industry sub-sectors in which SMEs operate within the selected municipality is rejected. This means that the average collection period is not consistent among the different industry sub-sectors involved. From table 3a some of these discrepancies can be noted. The average collection periods (ACP) for medical supplies, training and development, and catering (except for one supplier) do not go beyond 60 days. These seem to be related to essential services or have closer contact with internal personnel compared to the rest. Within waste management services which has only two suppliers, one supplier is paid within 30 days and the other consistently over 90 days, which suggests unequal treatment and requires further investigation to establish the facts of the situation. ACP of more than 120 days is suffered most by landscape service providers (4 out of 6) and slightly by the cleaning and security services. In comparison to the other industry sub-sectors listed in table 3b, these seem to be services that are either outdoor or less in contact with internal personnel.

Based on Friedman's test (table 4b), F_r (8.58) is greater than the critical value (7.8) hence the second null hypothesis (H_o) that there is no difference in average collection period between the differently-sized SMEs rendering goods and services to the selected municipality is rejected. This means that the average collection period is not consistent among the differently sized SMEs involved. From table 4a some of these discrepancies can be noted. Companies employing less than 5 people do not suffer from ACPs of greater than 120 days but all the others do. The larger percentage of companies with more than 5 employees are able to get most of their ACP within the first 30 days compared with companies of less than 5 people most of which get their ACP in the second month of 30 days to 60 days. The two categories between 5 – 100 employees are the ones most able (about 45% of them) to get paid within 30 days. The most inconsistent pattern is that involving the largest employers of 100-200 employees who are equally likely to be paid within 30 days, 60 days or more than 120 days. By selecting an arbitrary cut off point of ACC 90 days (the median ACC category in our table) we may compare the total percentage of companies paid by 90 days' time across all the SME sizes to obtain an indication whether some SME sizes are paid earlier than others. This comparison shows that by 90days, 95.1% of SMEs with less than 5 employees are paid, 86.8% of SMEs with employees between 5 and 50 are paid, 77.7% of SMEs with employees between 50 and 100 are paid, and 57.2% of SMEs with employees between 100 and 200 are paid. The comparison suggests that in the selected municipality, the bigger the SME size the more it suffers with ACP.

Based on Friedman's test (table 5b), F_r (0.40) is less than the critical value (6.4) hence the third null hypothesis (Ho) that the average collection period is not influenced by the SME owner's level of education or training is accepted. As this indicates no significant difference, it means that not much meaning should be read into the minor differences observed in table 5a.

It is worth noting that in this municipality the number of SMEs participating in providing goods and services differ markedly according to size (table 4a), which indicates the impact their fortunes may have on employment. The greatest number of SMEs involved with the municipality (over 50%) employ 5-50 people. Taking the average value for each category we can estimate the total number of employees in the participating firms by category. The category with less than five employees per firm (the average is 2.5 employees and there are

18 firms) boasts a total of about 45 people employed in this category. Likewise the category with 5-50 employees is estimated to employ about 1,678 people, the category with between 50-100 employees about 2,025 employees, and the category of between 100-200 employees to employ about 1,050 people. It is apparent that in this municipality firms employing over 5 people per firm represent the overwhelming majority of SME employees. It follows that if there is any undue stress to SME suppliers in the municipality e.g. undue delays in payment, the SMEs employing over 5 employees per firm have more employees exposed to risk. This seems to be the case in the municipality studied as these are the only categories experiencing payments more than 120 days old.

The findings of this study are similar to that done by Zainudin [11] using three independent variables implicitly assumed to be mutually exclusive and findings confirmed by Zainudin and Regupathi [12] using more variables who found that SME size and industry sub-sector influence the average collection period. The study by Zainudin and Regupathi [12], however, differs from this one as theirs did not assume the independent variables to be mutually exclusive and also investigated how the independent variables were affecting each other.

6 CONCLUSION

The results obtained in this study point to inconsistencies in average credit collection period for SMEs supplying goods and services to a major municipality in South Africa. The findings indicate that the SMEs experience varying levels of delays in payment for goods and services rendered to the municipality. According to the literature reviewed earlier, delays such as this when unexpected and not part of the company's deliberate plan (e.g. planned cash conversion cycle) affects the liquidity status of SMEs and risks pushing them out of business. In a wider sense this has implications for policy. A question of interest for policy is which areas need attention so that municipalities can ensure that service delivery is achieved through effective participation of SMEs sustained through a reliable and consistent credit collection policy. This would support well-publicised government policies advocating for SMS development and growth, such as the National Development Plan [23]) which identifies SMEs as key players in Government's strategy to reduce unemployment rates in the country.

The bigger sized SMEs appear to be suffering the most inconsistencies and late payments, and even if some may be able to get early payment others seem to be unable to do so. Given their potential to employ more people (absorb more labour), jeopardising their source of income can threaten their existence and hence reduce employment or cause withdrawal from participating in municipal activities. This would means that employment is not being optimised and therefore ways of encouraging more participation by bigger sized SMEs should be investigated as they have higher labour absorbing capacity.

SMEs whose goods and services appear to be 'essential' in nature seem to be enjoying timely payments compared to the rest. Likewise SMEs whose activities require close interaction with the internal personnel in the municipality appear to be receiving timely payments. On the other hand, SMEs providing services which may be perceived as not 'life-threatening' or that may require out-door activities, appear to be receiving delayed payments more than others. The observation made suggests that there is non-uniform treatment of SME suppliers to the municipality regarding the timing of payments for goods and services rendered. The effect of this is that the payment system and administrators responsible can lose credibility with the SME suppliers who may lose interest and reduce their commitment to the municipality. To avoid this, the oversight body responsible should ensure that there are no privileges, in line with Government's non-discriminatory and transparency policy, to ensure a consistent and fair implementation of the relevant procurement policy.

The ACP policy needs to be reviewed to ensure that it guarantees consistency of treatment across and within SME sizes and industry sectors, and to ensure that credibility of the system is preserved. Regular monitoring and evaluation mechanisms will then need to be put in place to ensure that implementation of the policies are met.

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THE TRANSNET MARKET DEMAND STRATEGY (MDS) AND CONTRADICTIONS ARISING FROM ITS IMPLEMENTATION - IMPLICATIONS FOR GOVERNMENT POLICY

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ABSTRACT

The MDS to which Government has committed an unprecedented 300billion Rands is central to the South African government's New Growth Path and Industrial Policy Action Plan with expected outputs being, among others, job creation, increased national capacity to manufacture, creation and development of indigenous supply chains. Kingsburgh conducted a survey of component suppliers to one of Transnet's divisions and investigated among other things how the MDS was perceived among suppliers. The findings revealed unexpected results. A key finding and concern is that while Transnet is building its capacity to become a manufacturer of choice for the future, it appears not to be developing its supply chain accordingly. This raises the question whether the current approach to implementing the MDS even if successful in terms of meeting quantities targeted is aligned to the spirit and intentions of Government expressed policies indicated earlier. This paper argues that that there is deviation in purpose pointing to vagueness and inadequacy in Government policy that allows possible conflicting interests. This has important implications for Government policy regarding how conflicting interests can arise from implementation of policy and how the unintended consequences need to be managed.

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1 INTRODUCTION

The Market Demand Strategy is a massive and unprecedented expenditure program of R300 billion allocated to Transnet by Government as part of its National Development Plan. The aim is to spend on major national infrastructure that will create an impetus to drive economic development, while addressing unemployment, poverty and inequity.

The MDS is located within Government policy documents which include the National development plan, the new growth path, the Industrial policy framework, and the Industrial policy action plan. These policies reinforce each other, providing a set of integrated frameworks for guiding decision making from the overall vision stage to implementation stage. There is much anticipation within Government, Transnet and the public at large that much progress in the economy will be achieved through the MDS, including the much needed reduction of unemployment.

1.1 The problem

The volumes, frequencies and variety of transactions involved in implementing the MDS are significantly higher than any handled before by Transnet due to the massive resources injected by Government. Transnet is expected to grow rapidly to absorb new labour into its internal infrastructure while at the same time facilitating the creation of employment within its external infrastructure involving suppliers.

A key component of the job creation strategy with regard to suppliers is the development of local suppliers. However a recent survey by Kingsburgh [1] found that a significant number of component suppliers that were surveyed felt neglected or 'shut out' by Transnet with regard to the MDS. This suggests that there is a conflict between Government policy and the implementation of the MDS even though the documentation on both sides is clearly defined and harmonised, with keen oversight by Government, there is a possible grey area that needs to be investigated. This has implications for Government policy regarding areas that should inform its implementation particularly if it is a massively funded project such as the MDS.

2 LITERATURE REVIEW

2.1 The economy and employment imperative

The South African (SA) economy is the largest in Africa with a GDP of around $384.3 billion in 2012 [2] and a total estimated population of about 53 million people in 2013 [3]. However, its estimated GDP growth in 2013 was low at 1.9%, having declined from 3.5% in 2011 and 2.5% in 2012 [2]. This was sluggish growth compared to an average GDP growth of 5% in the period 2003 to 2008 [4]. During this period the population growth averaged about 1.2% in the ten years from 2002 to 2012 [2]. Meanwhile, unemployment increased from 23.5% in 2008 to 25.2% in 2009 and remained largely at that level for the subsequent four years to 2013 [5]. Unemployment has been relatively high for several years, in spite of Government interventions to bring it down and this is of great concern to Government [4]. An unemployment rate of 25% is high compared with data of other upper middle- income countries in which South Africa is categorized [2].

Referring to the status of the economy in his budget speech, the Finance Minister reported that the World financial crisis of 2009 affected the economy of SA from which it is still recovering. It led to a collapse in commodity prices, sharp declines in international trade and a crisis in financial markets, during which the SA economy contracted by 1.5 per cent in 2009 and nearly a million jobs were lost [4]. Against this background SA needs to grow at a rate between 4% and 7% per annum so as to employ an additional 5,000,000 people by 2020 [6] or 11,000,000 people by 2030 in order to lower the unemployment figures to 14% by 2020 and to 6% by 2030 [7].

According to the Minister of Finance great effort has already been made by Government through its budget expenditure to create jobs, "Government has spent more than R100 billion on employment programs over the past five years, including municipal and provincial spending. More than 4 million job opportunities were funded over this time. Allocations will continue to grow strongly and 6 million job opportunities will be created over the next five years" [4]. Among the projects mentioned by the minister include public works programs in which Government has invested billions of Rands in order to provide employment to more South Africans.

The drive to economic growth and job creation was given impetus by research done by Government and provided in a guideline document [8]. The recommendation given was that the growth rate needed to achieve the country's social objectives was around 5% on average between 2004 and 2014. A realistic assessment of the capabilities of the economy and the international environment, two-target phases were set. In the first phase, between 2005 and 2009, an annual average growth rate of 4,5% or higher was sought. In the second phase, between 2010 and 2014, an average growth rate of at least 6% of gross domestic product (GDP) was sought. In addition to these growth rates was the need to meet social objectives. All these required new businesses to proliferate and expand and improving opportunities for creating more labour absorbing activities [8].

2.2 Relevant Government Policy

The SA Government has enacted policies to deal with the challenges of unemployment through industrialization, which is a vehicle used by nations to achieve economic development while at the same time resolving the challenges of unemployment [9, 10]. Unemployment is a key consideration for Governments and a major challenge to both developed and developing nations [11]. Generally an economy should be able to absorb labour. In South Africa, the 'New Growth Path' framework and the 'Industrial Policy Action Plan' framework have been instituted to tackle the challenges of unemployment and industrialization respectively. Both being part of an integrated set of frameworks that derive from a broader, more encompassing national plan document called the 'National Development Plan'.

2.2.1 *The National Development Plan (NDP*

In November 2011 the SA Government proposed a vision for the country, and its long-term plan for the next twenty years is declared in 'the National Development Plan (NDP)' document , stipulating the nature of the ideal state to be achieved by 2030 [12]. The overriding theme is the elimination of poverty and inequality. It states that "poverty is still pervasive … millions of people remain unemployed … many of these are young people … it is important to understand why these problems persist-and to fix them … we require urgent measures to address our most pressing needs, particularly high levels of unemployment, especially among the youth" [12]. The creation of employment is therefore given a very high priority in the Government's list of priorities. The document further says with regard to poverty and inequality that the elimination of these two aspects should be "the guiding objectives of the national plan over the next 20 years. All elements of the plan must demonstrate their effect on these two goals" [12], and the national plan makes reference to the growth and development plan of Government. While launching the NDP implementation, Minister Trevor Manuel said "The main change we seek is an economy that is more labour absorbing. We need to create more jobs, and make progress in broadening ownership of the economy" [13]. The report of the National Planning commission states that one of the key challenges to eliminating poverty and reduction of inequality is that "too few South Africans work" [14]. President Zuma in handing over the NDP to parliament says of unemployment "Given our struggle against unemployment, a scourge that renders many families restless and in distress, we are encouraged by the long-term employment creation proposals, which are in line with our New Growth Path framework … we believe that it is an achievable goal if we … enable (the economy) … perform in a manner that will enable growth and job creation" [15]. From the NDP document and comments made by the President and Minister responsible, it is clear that employment is a key issue for Government policy. It can be ascertained therefore that the 'spirit' of Government as discerned from speeches of top Government officials and the primary national plan document, is to effectively create employment, in the short term, medium term and long term.

2.2.2 *The New Growth Path (NGP)*

Government adopted the NGP as the framework for economic policy and the driver of the country's jobs strategy [16] and in his address at an anniversary of the governing political party President Zuma reiterated the commitment of Government to "identify areas where employment creation is possible on a large scale …"[17]. The president also promised the youth that Government would work to create opportunities for jobs in general that includes them [18]. The policy framework dealing directly with creating employment is the NGP.

The NGP [19] identifies the key drivers in Government policy to be the creating of jobs, the reduction of inequality and the alleviation of poverty. It can be assumed that the creation of jobs helps address the problem of poverty and to some extent inequality. In this paper, creation of jobs is therefore the main component discussed.

The NGP proposes strategies to strengthen the domestic and international market segment by growing employment, increasing incomes and undertaking other measures to improve equity and income distribution. It says, "if we can grow employment by five million jobs by 2020 (around three million more than the anticipated growth if we extrapolated from 2002 to 2009), over half of all working-age South Africans would have paid employment and narrow unemployment would drop by 10 percentage points from 25% currently to around 15%" [19].

According to the NGP document, two key variables that affect the target of five million new jobs are the rate of economic growth and the employment intensity of that growth (or rate of growth in employment relative to the rate of growth in GDP). It urges for maximising growth and ensuring that it generates more employment, mostly in the private sector in order to reach the national employment target. The NGP framework recommends targets for the employment intensity of growth and for the rate of growth in GDP [19].

The NGP document identifies two key job drivers as (i) substantial public investment in infrastructure to create employment (including manufacturing the required inputs) and (ii) targeting more labour-absorbing activities across the main economic sectors (including manufacturing and services). The document also identifies priority areas it will promote such as enterprise development through promoting small business and entrepreneurship.

The NGP document assures that Government's medium term expenditure framework (MTEF) and annual budget are to be guided by the need to support the NGP through appropriate spending on infrastructure, skills, rural development and economic programs. Local and provincial governments are to undertake similar work, all which involve considerable resources [19].

In the NGP document, a targeted number of jobs per year is indicated for various sectors including places of potential employment. Some of these are 250,000 jobs a year in infrastructure and housing through 2015 (including manufacturing of inputs for the anticipated infrastructural and housing projects), and anticipated interventions include "stronger local procurement to maximise the economic multiplier" [19]; 350,000 manufacturing jobs projected in IPAP2. The main drivers are given as the need to "focus on sectors that can generate employment on a large scale and meet basic needs at lower cost in short to medium term, while sustaining development of more knowledge intensive industries for long-run growth" [19].

The NGP therefore provides a broad guideline on strategies to adopt, identifies priority areas to focus Government programs and recommends broad actions required to create employment through Government intervention at a national level. The NGP also indicates the active role that IPAP provides as a driver in creating jobs in the manufacturing sector.

2.2.3 *Industrial Policy Action plan (IPAP)*

The Industrial Policy Action Plan gives detailed key actions and time frames for implementation of the Industrial Policy. The National industrial policy framework (NIPF) gives a vision for South Africa's industrialization route, which include facilitating diversification beyond the current reliance on traditional commodities, long-term intensification of South Africa's industrial processes towards a knowledge economy and promotion of a more labour-absorbing industrialization path with a particular emphasis on tradable labour-absorbing goods and services. Tradable goods and services refer to exportable and import competing goods and services. Other goals of the NIPF include, promotion of a broader-based industrial path involving people from previously disadvantaged groups and contributing to industrial development on the African continent. [20].

The IPAP has three main components, namely: range of Sectoral actions, cross cutting actions of importance to industrial policy and measures to improve Government organization and Industrial policy. All the three components aim to give effect for implementation of the Industrial Policy. Hence IPAP aims to promote long term industrialization and diversification beyond the traditional commodities, expanding production in value-added sectors with high employment and growth opportunities [21]. This paper considers the possibility that the high employment drive through expanding production in value-added activities might contradict with the growth drive of organizations.

2.3 What is the procurement policy of Transnet?

Transnet is a fully owned Government parastatal and therefore its procurement policy is fully guided by that of the Government policy. The Department of Public Enterprises (DPE) has the responsibility to oversee all state owned enterprises or corporations (SOC), including Transnet, therefore Government policies originating from NDP and translated in the NGP and the IPAP are applicable to Transnet. To implement the policies of Government, the Department of Public Enterprises instituted the Competiveness Supplier Development Programme (CSDP) as a guideline to be followed by all State owned enterprises with regard to developing their internal procurement policies. The CSDP requires that preference is given to local suppliers during procurement of goods or services provided they are adequately competent. This is aimed at increasing economic growth through improving national supplier industry competitiveness. According to DPE, this concept was supported by research which indicated that "a modest increase in the contribution of national industry (read: local suppliers) to the capex program will result in a large increase in the contribution of the capex programme to economic growth" [22]. It is therefore a guideline that state-owned enterprises are required to translate into their own procurement policies.

Transnet developed its internal procurement policy, the 'Transnet Supply chain policy' approved September 2013, that is aligned to the CSDP. Under this policy section 14 defines and addresses "Supplier Development (SD)" saying: "SD is an initiative of the Department of public enterprises supported by Transnet. The aim of the SD is to increase the competitiveness, capability and capacity of the SA supply base where there are comparative advantages and potential for local or regional supply. This can be achieved through skills transfer, as well as building new capability and capacity in the South African supply base. In addition, the SD has its roots grounded firmly around the transformation of South Africa and the empowerment of previously disadvantaged individuals and enterprises" [23].

In a review of the overall implementation of local procurement via the IPAP, it is reported that significant progress has been registered with respect to localization and supplier development programs of some SOCs; most notably, Transnet, Eskom and PRASA. However, a significant proportion of Government procurement is still conducted on an ad hoc rather than a strategic basis and does not deliver adequately on either value for money, economies of scale or key industrial policy objectives. The report concludes that there is thus a need to develop a framework for a purchasing strategy that will directly address these policy issues [21].

This paper argues that in an important respect, aspects of the implementation of the Transnet procurement practice with regard to the MDS is not properly supporting the intended Government spirit with regard to supplier development and therefore not maximizing employment as intended.

2.4 The Transnet Marketing Demand Strategy (MDS)

The Transnet MDS was launched in April 2012, to spend R300 billion on capital projects for the next seven year period. This is in line with Government strategy to spend on infrastructural projects that increase economic growth and increase employment as stipulated in the New Growth Path. Up to 588,000 new jobs created in the South African economy are envisaged in the next seven years of which an additional 15,000 are direct jobs into Transnet including contractors [24].

3 DISCUSSION

Given the various policy documents by Government, how does Transnet envisage achieving the objectives of NGP and CSDP through the MDS? This is clearly laid out in the documents available in the public domain on the MDS e.g. [24]. However it is instructive that a different perspective emerges when some suppliers to Transnet were surveyed and information regarding their experience with the MDS was obtained as indicated below.

An independent survey conducted by Kingsburgh [1] on the manufacturing strategy of component suppliers to Transnet, covering 30 suppliers, reported that 43% of the firms were not aware of the MDS and only 27% had communicated formally with Transnet regarding the MDS. Many felt alienated or 'shut out' by Transnet. This is a significantly high percentage, from the sample taken, that are not in touch with Transnet's plans for inclusion in its supplier development program. Given the lack of contact and involvement, this paper assumes that the suppliers not formally communicated to by Transnet have been excluded from Transnet's SD program. This apparent action by Transnet seems to contradict the spirit and intent of Government that desires to develop local supplier capacity. On the other hand, it is known that Transnet is developing its own internal capacity and capabilities [25] however it is possible that in its effort to grow internal capability Transnet may have developed an internally motivated agenda such as supplying the same components that it has been sourcing from local suppliers. This then fits with the observation indicated in Kingsburgh's survey that Transnet appears to be relaxing on its supplier development [1] while it appears to be deepening its own manufacturing capability. Meanwhile, there are reports that component suppliers to Transnet are investing more in capacity in order to meet anticipated increased demand but nevertheless remain uncertain whether they will win contracts with Transnet [26]. The survey by Kingsburgh [1] corroborates the view that local component suppliers are fairly uncertain of doing future business with Transnet and are unclear of what is going on regarding the MDS.

A question then arises, whether the MDS in particular and Government projects of this magnitude in general provide leeway for the SOC involved at this level of investment to take advantage of the situation and promote its company-specific interests.

The paper postulates that this is the case, particularly when the drive to develop internal capability is at variance with that of developing capability through suppliers (external capability), that the company will choose a path promoting its best interests. This can happen when the SOC realises that developing its internal capabilities reduces its transactional costs [27] compared to buying the same services in the market (suppliers). The economic considerations for the organization then become more important than other considerations, and decisions are made 'in the best interest of the firm'.

The paper argues that due to mega-investments (R300 billion) into the SOC and a broad mandate given to management, the possibility of building its own internal capabilities (through training, research, resources acquisition and others) has been discerned or reached and having the mandate to do so yet also developing suppliers, the SOC has reached a point where it has to make the most suitable economic decisions for the organization. This paper proposes that based on Economic theory [27], faced with this option the company will make decisions based on 'its best interests' such as taking preference for ownership and control of skills, reducing costs of production, and reducing related transactional costs.

4 CONCLUSION

A key issue for Government is to create maximum possible employment in order to fulfil its promise made to the nation that it will reduce unemployment. In order to do this Government has committed large funds to be expended on infrastructural development both in the public domain and its SOCs such as Transnet, expecting that there will be spin-offs through permanent employment, skills development and supplier development, among several others. Transnet was allocated R300 billion with this plan to create jobs in mind, among other considerations. Through specific policies and guidelines, an important vehicle to fulfilling this mandate is the development of local suppliers through preferential procurement of goods and services. Through suppliers, additional people are employed directly or indirectly, leading to an even wider network of activities that also create jobs, and hence a multiplier effect of employment is achieved.

Nevertheless there appears to be a contradiction in implementation of the MDS as some suppliers have indicated signs of alienation by Transnet. One possible explanation is that Transnet is developing parallel capabilities that local suppliers could offer, and in the process is crowding out some suppliers. Since the mandate to build its capabilities is also given to Transnet this paper believes that the management of Transnet is encountering decision concerning the transactional costs due to growth of the company and associated increase in transactions in the market place. Williamson [27] predicted that increased transactions lead to decisions by management to control them, such as by favouring the development of internal capabilities compared to transacting in the market place such as through suppliers.

This paper argues that during implementation of the MDS aspects of it are deviating from the original spirit and intention of Government in the way it was envisaged to be the vehicle for creating a maximum number of jobs. Through the massive allocation of public funds towards capital expenditure, Transnet has grown rapidly while retaining its autonomy in making operational and tactical decisions, and has grown to the point where its increased transactions require management to make decisions that make economic- sense in the best interest of the organization. Such decisions may act against the interests of Government which desires to fulfil its promises.

The implication for Government policy is that massive injection of funds into SOCs can lead to contradicting interests between Government (the provider) and the semi-autonomous corporation (the implementer). Grey areas can arise that provide management of the SOC with flexibility to make decisions which may in the long run give strategic impact. Government needs to recognize these grey areas, study them carefully and provide guidance with appropriate monitoring and evaluation instruments.

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A CONTROL ALGORITHM APPROACH FOR OPTIMIZING ENERGY RESOURCES THROUGH POWER GENERATION FOR A SOUTH AFRICAN STEEL WORKS PLANT

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ABSTRACT

Numerous engineering plants have varieties of processes, where individual process flows are dependent on previous processes and operated by default or manual settings. Initial raw material feeds may fluctuate over time, possibly resulting in inefficient use of energy resources. This paper describes a study on power generation capabilities of such a plant.

Off-gasses from various steel production processes are utilized in boilers; producing steam for the Works. Excess steam is used for power generation. The Works experienced unstable power generation, due to fluctuations in available steam. This resulted in regular turbine trips, causing power generation losses, additional gas flaring and reducing machine life expectancy.

To address this problem; off-gas and steam production data were analyzed over three months. A control approach was set up, where the algorithm's objective was optimum power generation, for a 5MW and 30 MW turbine. Results showed potential power generation increase over 26% was possible, still not eliminating trips. The algorithm incorporated the possibility of burning natural gas in a boiler, when needed. This scenario could have led to no trips and an increased generation capacity of over 48%. Additional power generation's financial impact overcame the high cost of utilizing natural gas for power generation purposes.

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1 INTRODUCTION

Numerous engineering plants consist of a variety of processes, where individual process flow rates are mainly dependent on previous processes and are mainly operated by default or manual operating settings. The initial raw material feed or flow input values are not necessarily constant and may fluctuate over any time interval, which may result in an inefficient use of energy sources over the whole spectrum of an industrial engineering plant. One such engineering sector is the steel production industry.

For the current works under investigation, Natural Gas and coal are burned as external energy sources, in various combinations with production off-gasses that form, i.e. Coke Oven Gas (COG), Blast Furnace Gas (BFG) and Basic Oxygen Furnace Gas (BOFG). These energy sources are used for production processes all over the Works, including steam generation. Steam is used throughout the Works for multiple process applications and excess steam is finally utilized for power generation. Continuous fluctuating process mass flows directly lead to fluctuating off-gas production, which results in inconsistent steam and ultimately volatile power generation. This fluctuating off-gas production and in a lesser sense, plant processes that have a changing demand for off-gas and steam use, set the scene for an unstable power generation and inefficient utilization of energy resources. Off-gas that is not utilized at the present moment is burned off into atmosphere through flares or bleeders. Even though power generation is not part of the core business, it has a direct financial impact on the work's net cost.

Inefficient use of energy sources, brought forth the quest to conduct a research study on how these sources could be optimized, setting up a universal control algorithm. One such control philosophy is by means of setting up a neural network (NN) for process control and optimization.

1.1 Neural Networks

Artificial Neural Networks (NN's) are problem solving techniques that learn from data and solve nonlinear models. For system modeling and identification, time series forecasting and control, the multilayer perceptrons (MLP's) and radial base function networks (RBFN's) are the most utilized NN's [1].

Bloch and Denoeux [1] presented two studies where NN's were used to control process optimization. The first study was to determine the inductive temperature at an induction furnace for a steel plant's hot dip galvanizing line. The second study was the control of a clotting process in water treatment plant, where raw water was purified to produce drinking water.

Castellano and Fanelli [2] used a NN model to determine what input variables were needed to create a model and what inputs may be rejected. Their network commenced by using all available inputs, creating a model and then worked backwards, removing the unnecessary nodes. Weights were assigned to each input node, which might vary as input nodes were removed, in order for the simulation results to stay virtually the same.

The quality of a NN optimization model depends not only on the model validation, but also legitimacy of the data used to set up the model. Ensuring correctness of data plays a vital part in NN design and the need may arise to generate additional and complementary experimental data [3].

According to Simutis *et al*. [4] the grounds on which a process optimization model must be investigated, is the ratio of benefit over cost that the model brings. Hybrid modeling seemed to be most fitting for production processes.

2 OPTIMIZATION STUDY ON POWER GENERATION POTENTIAL FOR A STEEL WORKS

A study was conducted on the power generation capabilities of a steel works. The sole purpose of the study was to investigate the additional potential power generating capabilities from off-gases.

The study focusses on how available off-gasses could have been utilized for steam and therefore extra power generation. Measured data is used to develop a control algorithm on what could have been done to improve power generation. This study form the basis of a follow up study, where a NN will be set up to statistically predict what the following flow values might be, within a confidence interval. Accurate prediction will lead to accurate control.

Off-gases are production by-products that possess a significant formation enthalpy, i.e. the ability to be utilized as fuel. These gasses are burned in a boiler houses to generate steam. Steam is mainly used in various plants processes and excess steam may be used for power generation.

The works find power generation to be unstable, due to fluctuations in available steam. This instability causes turbines to trip regularly, not only ensuing power generation loss to unused steam or additional flaring, but also decreasing the life expectancy of these rotating machines. A turbine is designed to be kept in continuous operation and only be stopped and taken off-line for general overhauls and inspections, once every three to five years. For this works shortage has made it a common occurrence to have a turbine tripped once every three to seven days.

At the time of the study, the works had three power generation turbines, i.e. a 5MW, 30MW and a 40MW Turbine-Generator (TG) set. Both the 5MW and 30MW TG operate on 30bar steam and the 40MW uses 66bar steam with an additional steam injection at 16bar. 66bar steam is generated by two Kilns, the High Pressure Boiler House (HPBH) produces 30bar steam and 16bar steam emanates from four low pressure Kilns and also 30bar steam that gets de-superheated.

Initially the works consisted of only two different steam productions, namely 16bar low pressure (LP) steam and 30 bar high pressure (HP) steam. Power was generated with a 5MW and 30MW TG set. Years later an additional 40MW TG set, utilizing 66bar steam, was installed.

The 5MW and 30MW TG sets both operate at an efficiency of 5tons/MW. For the 5MW to stay operational a minimum flow of 10tons/h is necessary and the 30MW will trip for flow below 30tons/h. The 40MW operates at an efficiency of 3.9tons/MW for the 66bar steam, with the capacity to generate 30MW, where the additional 10MW is generated from 16bar injection steam at an efficiency of 7tons/MW.

The perception from management was that off-gas and not steam production capabilities were the limiting factor and therefore not much could be done about the situation at hand.

2.1 Off-gas and Steam production

Hourly COG, BFG and steam production data were analyzed for a three-month period, ranging from 1st of March 2011 till June 6th 2011 (from here on referred to as 'the period'). The logged readings represent the average readings over the hour and not an instantaneous flow rate value. The authors acknowledge that finer time interval measurements will be crucial for a real time control algorithm, since hourly averages might smooth out outlier data points, leading to a misrepresentation of the data.

In Figure 1, the total HP steam production during this period is depicted over time. Fluctuations in steam production are evident from the figure and it can be observed that these fluctuations do not necessarily follow a clear pattern.

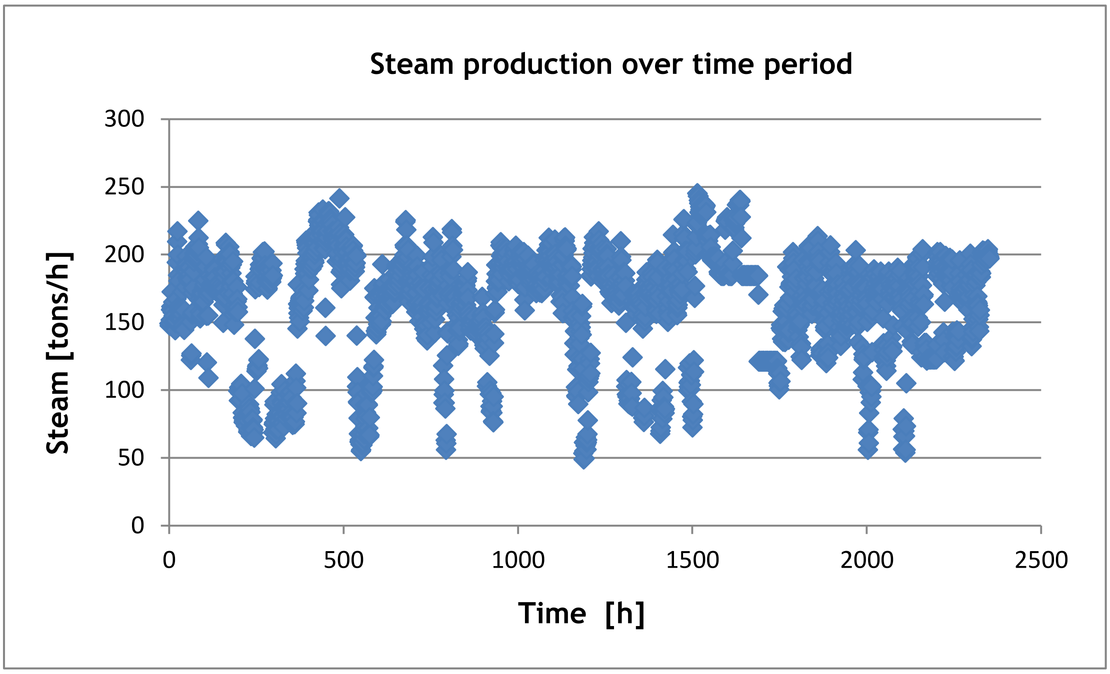

Figure 1: Actual average steam production flow rates [tons/h] plotted over time [h] for the period

Unlike for a power station, the main reason for steam production at a steel plant is not power generation, but for various process necessities and uses all over the works. As mentioned, only excess steam, after plant demand, may be consumed for power generation. Figure 2 depicts the available steam for power generation during the period.

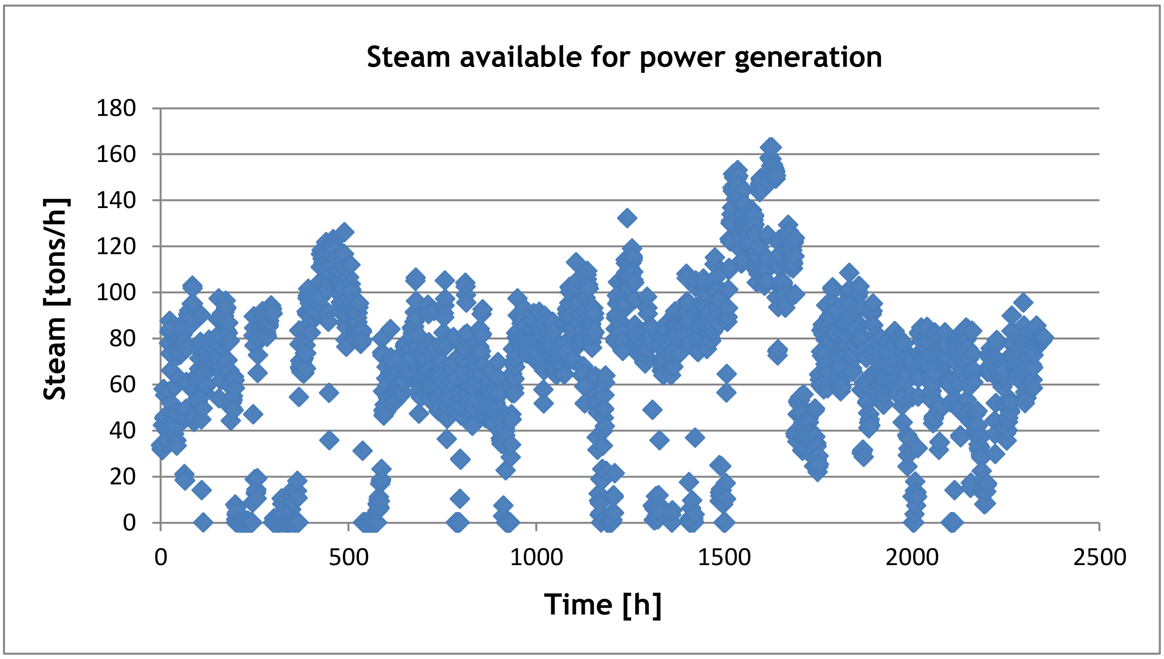

Figure 2: Steam [tons/h] over time [h], available for power generation

As in Figure 1, the fluctuations depicted in Figure 2 are unmistakable, but a pattern similarity to Figure 1 is observed. The related patterns may be contributed to a plant steam demand that does not vary drastically over short time intervals.

2.2 Power generation and the control algorithm

Common operating practice is to set the 5MW TG set at a set point of 20tons/h, irrespective of what the flow might be. This creates the scenario where the turbine cannot receive more steam, even if sufficient off-gas is available to produce the steam. This operating procedure also results in more 30MW trips, from low steam availability conditions. A tripped turbine will only be put back into operation, once a continuous period of not shorter than 15 hours of sufficient steam is evident. The 15 hours depend on operator observation and may stretch far longer, especially for night and weekend shifts. A schematic layout of the operation procedure is given in Figure 3.

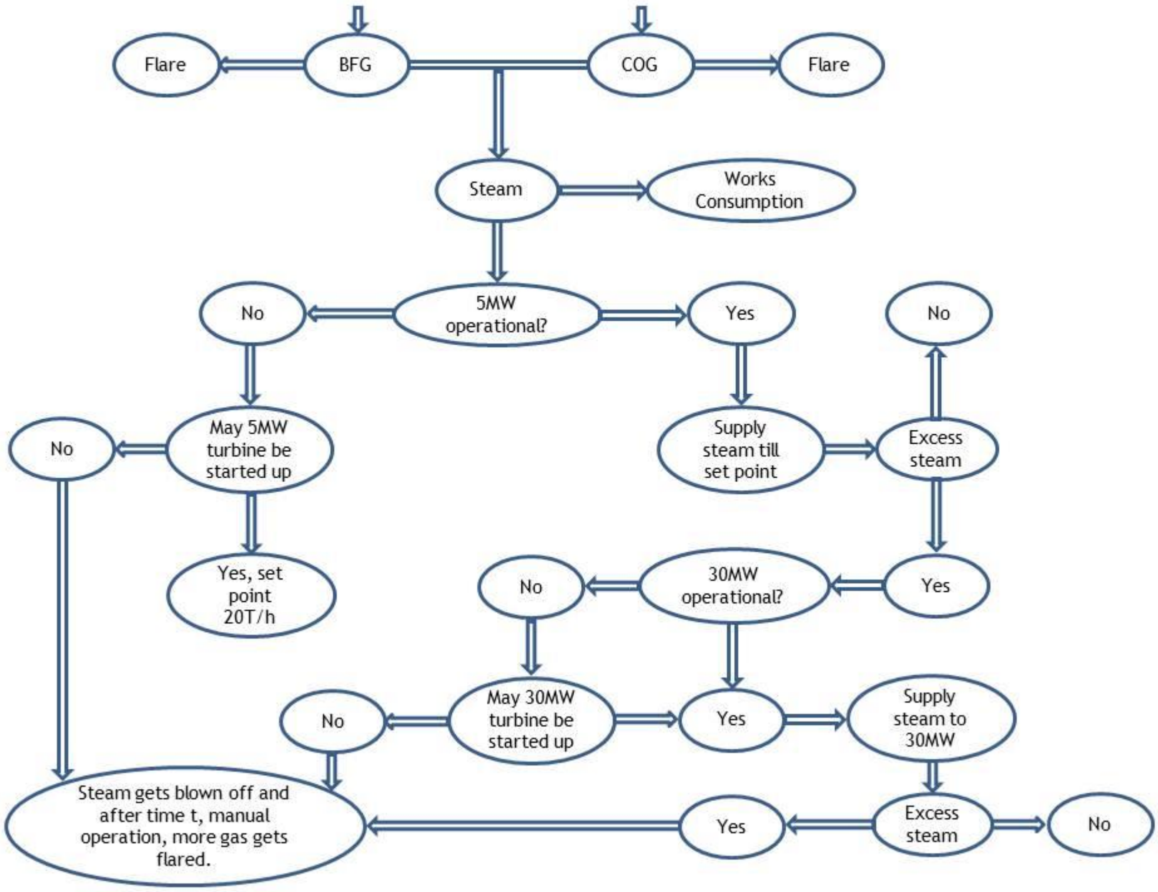

Figure 3: Schematic layout of power generation setup

Figure 4 represents the combined power generation, for the 5MW and 30MW TG sets, over the period for the above mentioned operating philosophy.

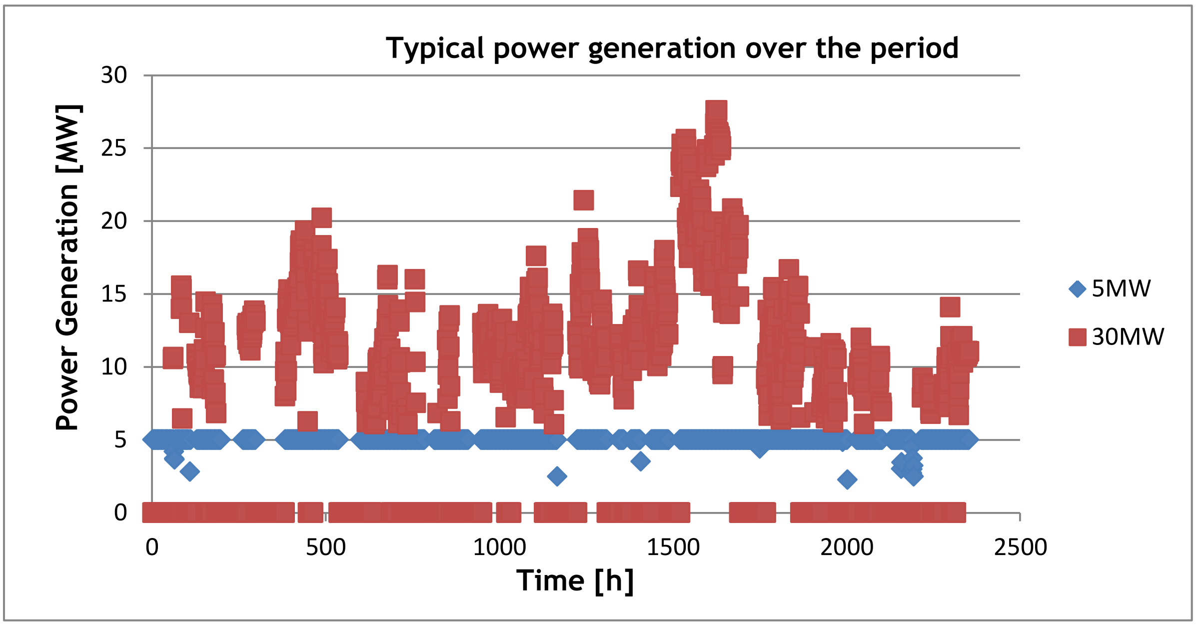

Figure 4: Typical power generation for the 5MW and 30MW over the period, plotted against time [h]

For this time period, under the plant operating procedure, the proposed power generation from the 5MW TG set was on average 3.88MW and the 30MW would have been able to master an average of 5.89MW. The combined power generation would yield 9.77MW out of a possible 35MW. The 5MW machine would have tripped 14 times over the three months and the 30MW would have experienced 32 stop and start conditions.

A control philosophy was set up, where the algorithm's main objective was to ensure optimum power generation with the available steam at hand. The algorithm will use the potential steam data and decide how to divide the steam between the TG sets and also which turbine to trip, when there is not sufficient steam to keep both machines at the minimum functioning point. Decisions are made based on the analysis of data prior to the current situation. Included in the algorithm optimization, are the turbine efficiencies. Figure 5 depicts a broad representation of the control philosophy's structure.

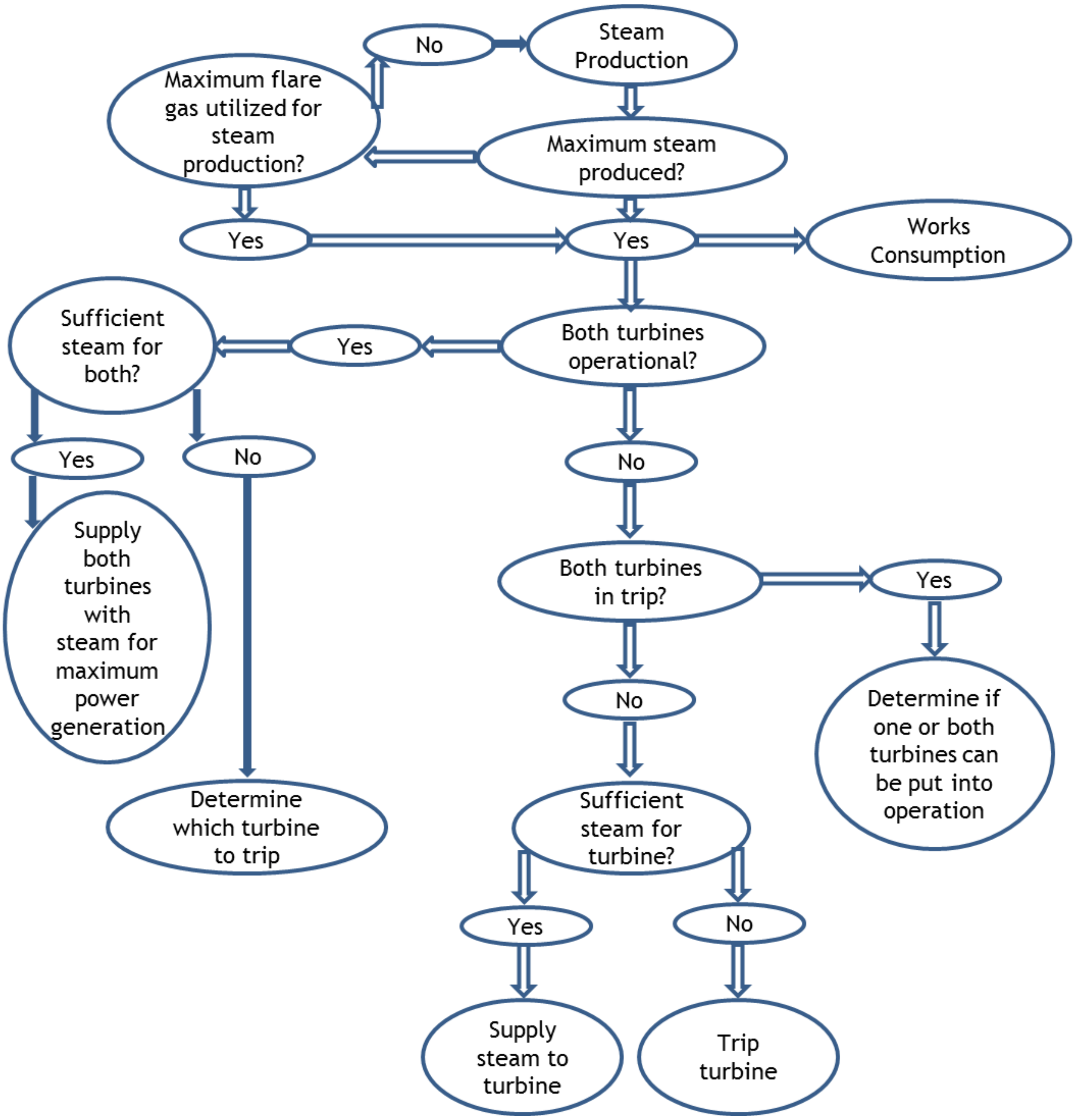

Figure 5: Broad layout of control algorithm

Figure 6 illustrates how power generation would have turned out under controlled conditions. On average, the ability to generate electricity would have decreased for the 5MW from 3.88MW to 3.54MW, while the 30MW would have seen an increase from 5.89MW to 8.85MW. The overall result would have been a total generation 12.39MW, 2.62MW above the plant expectation. This increased power generation, with optimized control philosophy, would have seen the 5MW being tripped 33 times (compared to 14), over the three month time period, whereas the 30MW would have experienced steam shortages on 21 occasions, compared to the previous 32.

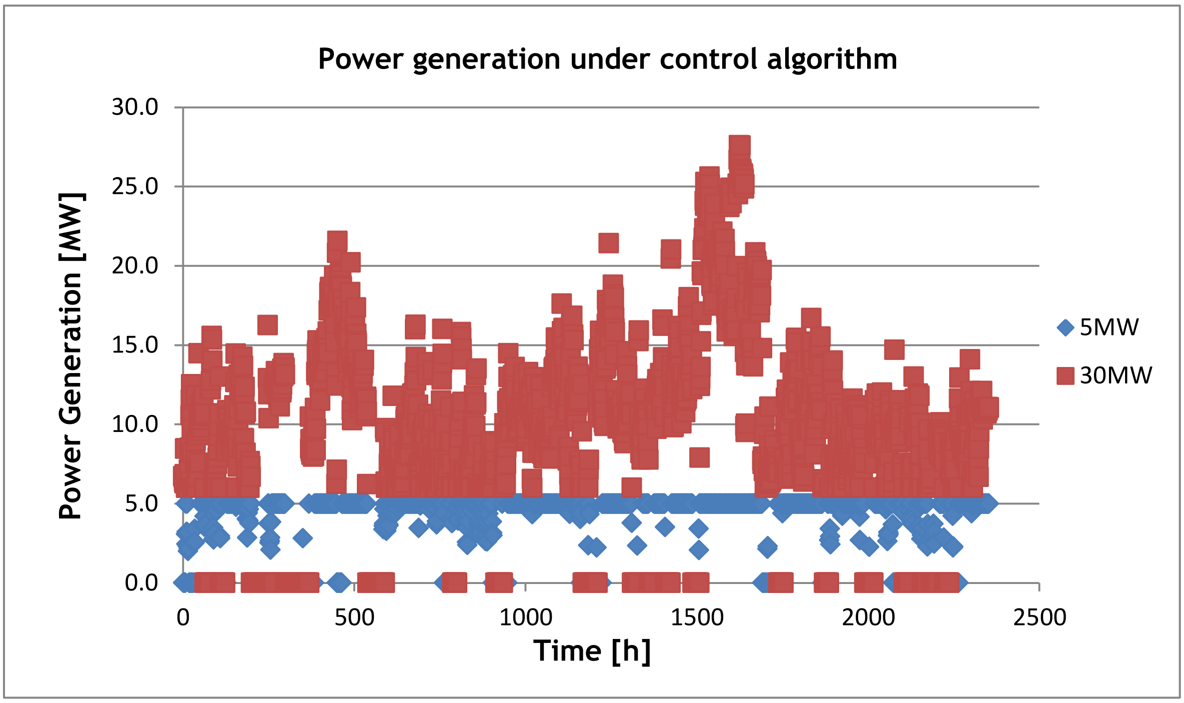

Figure 6: Power generation over time for optimization control philosophy for the 5MW and 30MW

From the data and everyday practical experience it is evident that there are occurrences where steam shortages will result in a machine trip for one or both turbines. The available steam, even if it is inefficient to produce power, is wasted. Taking into account that sufficient steam is necessary for a minimum of 15 hours to restart a TG set, rather large potential power generation losses may be incurred. It must be noted that if only one TG set is operational, the steam will only go to waste, once full power generation capacity is obtained for this operational TG set.

2.3 Incorporation of Natural Gas in the control algorithm

In an attempt to investigate and address the potential impending losses, the simulation conveyed the possibility of installing Natural Gas (NG) burners at the HPBH. NG will be used to ensure that both turbines will receive the minimum quantity of steam to prevent all steam shortage trips. It must further be noted that the control algorithm will always seek to optimize the system; therefore the fixed amount of steam per 5MW practice does not hold.

In Figure 7, the proposed power generation is plotted over time, where NG is burned as an additional energy source. As expected, the simulated results for Figure 7 are similar to the obtained results for Figure 6, with one large difference; no turbine experiences a trip condition. The question may arise as to why NG is not being used to simply ensure that both TG sets operate at full designed capacity? Power generation by means of NG is far more expensive than to just buy electricity from Eskom and therefore, the additional generation gain must outweigh the heavy input cost from an economical point of view.

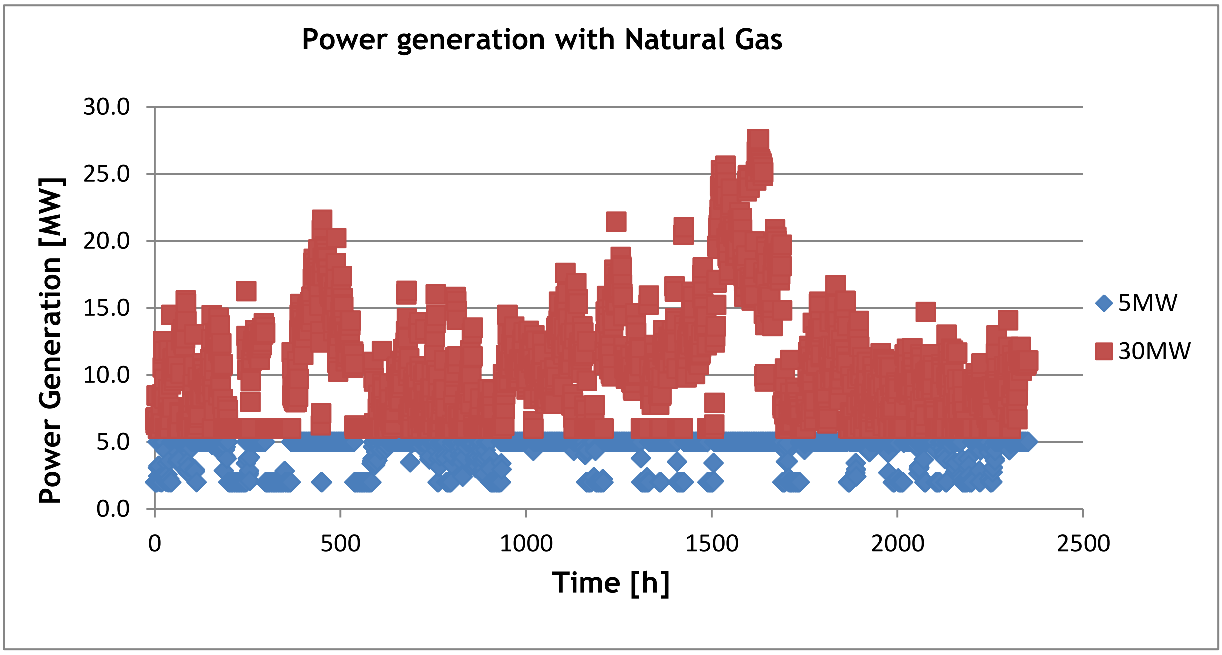

Figure 7: Power generation while using NG as additional energy source, plotted over time

The anticipated power generation, with NG present, yields a simulated result of 4.32MW compared to 3.54MW for the 5MW TG set. The 30MW will see a proposed increase from 8.85MW to 10.21MW. A rise of 2.15MW is proposed for the use of NG, where NG contributes 1.20MW and previous lost steam 0.95MW of the further generation. During the study period, the works paid approximately R360/MW-h to Eskom and using NG for power generation would have yielded a cost in the region of R800/MW-h, taking into account the HPBH and HP TG efficiencies. Plant costing data available showed that the maintenance cost per trip for the 5MW was over R8000, whereas the 30MW could be placed at about R12100 per trip. With these costs taken into consideration, the use of NG would have led to an annual gain of more than R450000, with respect to the control algorithm without NG.

2.4 Investigation of flared gasses

Figure 8 shows the amount of steam that could have been generated from the flared Coke Oven Gas (COG) and Blast Furnace Gas (BFG). The assumption is made that all of the COG may be utilized for steam production and 95% of the BFG. The remaining BFG will be flared for line pressure control purposes. More BFG than COG are produced over the works and the rate of flow in m^3/h for BFG over COG for the period was a factor of 15.35:1.

The potential in HPBH steam generation, for flared gas only, amounts to 25.27MW. Apart from ill control, boiler house capacity is a limiting factor and an additional 25.27MW were not entirely possible. The Works started off with 6 HP boilers, all with the potential to generate 65tons/h. At the time of the study, four boilers were operational, amounting to a steam generation capacity of 260tons/h.

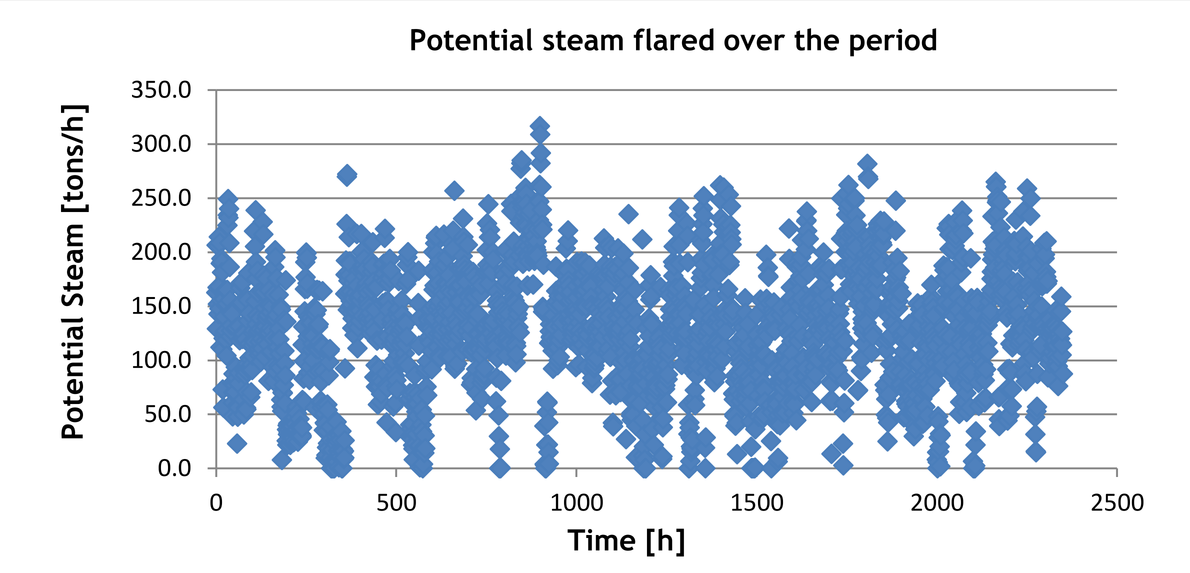

Figure 8: The potential steam capacity that was flared during the period

If the HPBH capacity is taken into consideration and the 5% restriction on BFG for pressure control, Figure 9 displays the potential steam for power production that could have been available. Using this steam production for power generation, in combination with the control algorithm, the 5MW would have been able to generate 4.60MW, trip 12 times and the 30MW power generation would have had a steep increase to 24.29MW.

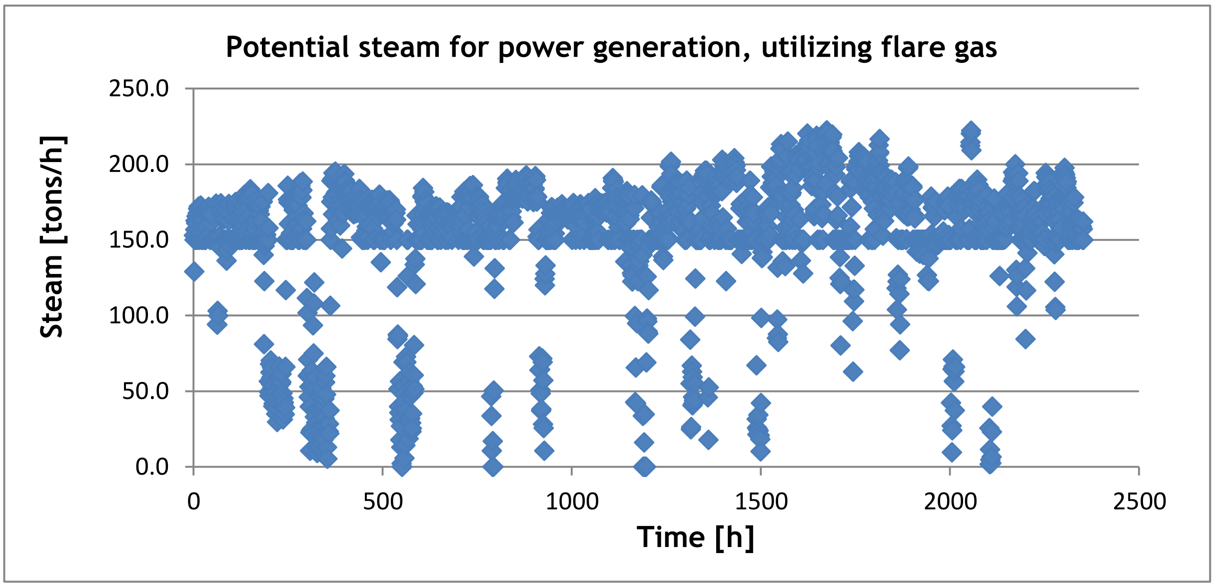

Figure 9: Potential steam for power generation if flared gas was used to HPBH capacity

Figure 10 represents the power generation that would have been possible if the HPBH was used to full capacity with the accessible BF- and COG and also the utilization of NG.

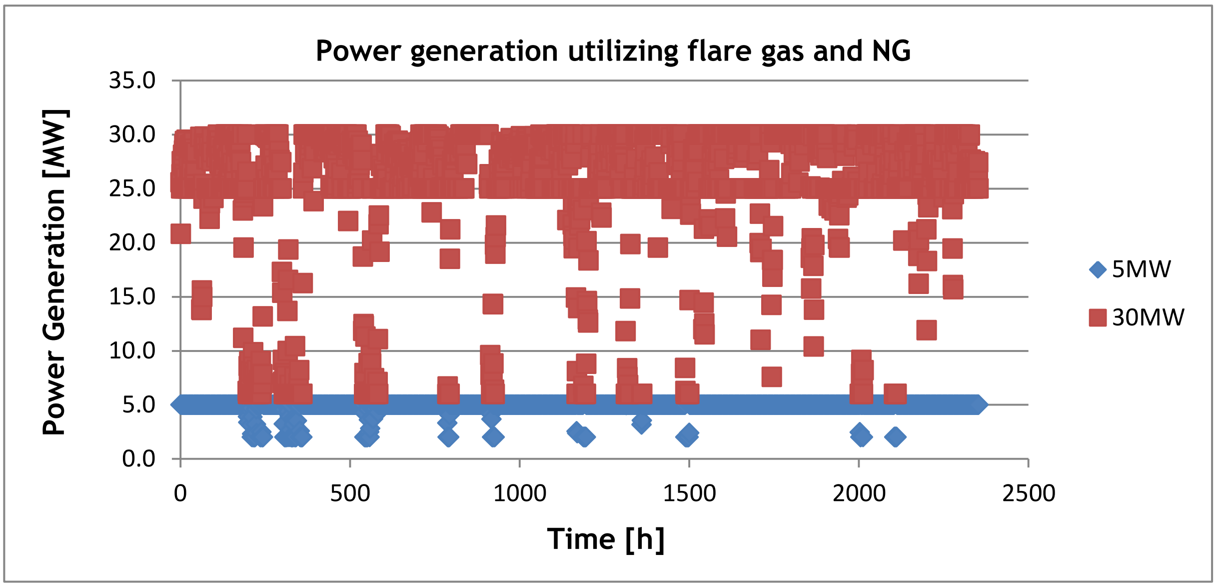

Figure 10: Potential power generation over time, utilizing flare gas and NG to prevent steam shortages

The energy producing capability of the 5MW TG set could have reached a value of 4.85MW over the period, while the 30MW machine could have seen an average of 25.31MW during this time interval. Due to NG a total of 1.27MW would have been generated additionally, where only 0.23MW would come from NG and the remaining 1.04MW from steam losses.

2.5 Comparison of results

The isolated situations of the HPBH and flared BF- and COG have been discussed. A simulation program was set up to determine what the typical power generation capabilities were over the time period. The program perceived what would realistically have happened and could have happened in a controlled environment, where off-gas steam production and steam flows to the turbines are managed. It must also be mentioned that the actual generation would probably have been even lower than the simulated values. A 15-hour interval will be far exceeded on some night and weekend shifts. Furthermore, operating staff have no indication on whether sufficient steam was present for 15 hours, resulting in biased decision making.

Table 1: Comparison of different power generation combinations

Situation	5MW [MW]	5MW trips	30MW [MW]	30MW trips	Total [MW]	NG financial impact [mR]	Financial impact to initial situation [mR]
Initial	3.88	14	5.89	32	9.77	-	-
Control Algorithm	3.54	33	8.85	21	12.39	-	8.262
Control Algorithm with NG	4.32	0	10.21	0	14.53	0.460	8.722
Flared Gas with Control Algorithm	4.60	12	24.29	13	28.89	-	60.297
Flared Gas with Control Algorithm and NG	4.85	0	25.31	0	30.16	3.424	63.720

A further step was taken and the hypothetical question was asked what the impact of additional NG burners could have been, in times of steam shortages. After the possibility of NG for the setup has been investigated, the attention shifted to BF- and COG that were flared into the atmosphere and yet again the influence of NG for this particular situation. Table 1 portrays all the simulated values that were obtained by way of the control algorithm. For every occurrence the proposed power generation and number of trips were tabulated, together with the financial impact from the simulated situation in comparison to the plant's status quo.

From Table 1 it is apparent that the introduction of a control algorithm, could have contributed to a positive financial impact in the order of R8.3 million per annum. As mentioned, these values were obtained on 2011 costs and the current real values will be larger, due to electrical tariff increases. The larger financial gain would have had an offset of more turbine trips. Even though a common occurrence, a turbine trip should not be taken lightly. It was mentioned earlier that the power generation turbine is not developed to have stop-starts in operation and each trip has a negative influence on the rotating machine's life span. The use of NG might have an initial cost and would only contribute an additional income of less than R500000, but it would serve a higher purpose, insurance against trip conditions and therefore protection of the TG sets.

What is more apparent from the simulated results, is the potential positive financial impact, if not only the steam flow to the turbines could be managed, but also the vast amounts of energy being flared to no avail. If the BF- and COG flows were better controlled and optimized for maximum steam generation, power generation might have experienced an additional financial gain of just over R60 million per annum and a gain slightly less than R64 million per annum, if NG was used to utilize all the potential energy and protect the turbines from steam shortage trips.

The representation of data thus far was only what happed at the HPBH, and the amount of flared gas. The simulation program also included all possible flows to the 66bar TG set, and the ability to introduce new TG sets into the program, to find the hypothetical optimum power generation scenario for the works. The incorporation of these scenarios and effects thereof was not discussed in this paper.

2.6 Actual power generation

It should be noted that the actual power generation was never compared throughout the paper. Due to the start-stop operation of the turbines and time in operation, both turbines' condensers had leaks to atmosphere. The 30MW was limited to a maximum, inefficient, power generation capacity of not more than 6MW and the 5MW turbine experienced a catastrophic failure in May of 2011, destroying the machine and emphasizing even more the importance of the exploiting NG for protection purposes.

During a trip phase, after the steam supply was cut off, an electrical fault led to the turbine being driven by Eskom power. Since the condenser was filled with incondensable air and not only condensable steam, unable to create a low pressure after condensation, rotating energy was transferred to the surrounding air. The heated air melted away four of the fifteen blade rows, three stator rows, damaging not only blades, but also the rotor.

The 5MW was due for a general overhaul in September of 2011, for an amount of R25 million. The damage was estimated at R40 million for a machine worth R50 million and it ended up being scrapped. Plant operation directly led to this damage.

3 CONCLUSION

The proposed study for the works was a control philosophy than does not only monitor and optimize the power generation, but energy resource management over the whole works. There are important factors to take into consideration when the control algorithm is examined, i.e.

- The data that was used was averages over an hourly interval. One second intervals may fluctuate even more than what was observed over an hour.
- The model works backwards and realizes what could have been done. A real life model will have to predict what is about to come, within a certain confidence interval and then arrange the flow over the works through control valves to the desired flow quantities. A further study is underway to set up such a prediction model, to be incorporated for the works.

The next phase will attempt a real life control algorithm. The algorithm must have accessible data to simulate statistical flow distributions and predict how to direct all available energy sources for the next time step. Necessary corrections will have to be made in the time step for adjustments and the newly received data will be worked into the statistical prediction model or Neural Network for future predictions. The model will also have to be flexible for future, external events, i.e. the knowledge for instance of when a blast furnace will receive a new slab.

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FACILITY DESIGN OF FRUIT AND VEGETABLE STORAGE AT RETAIL OUTLETS: A GENERIC DESIGN APPROACH

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ABSTRACT

Fast moving consumer goods retail outlets are constructed on high value properties. Occupation of floor space needs to be limited to the essential minimum, especially for non customer interaction spaces. Retail outlets are generally not built to standard designs, but customised to suit their locality and customer potential. The result was the requirement of a supermarket chain for a design tool for fruit and vegetable receiving facilities. The space requirements of storage areas as a function of operational parameters such as store sales volumes are the model outputs. Apart from using the tool for new store designs, it is required to serve as a measurement tool for existing stores.

The study describes the development of the design tool using Pareto principles, regression and finally facility design practices. The tool defines the floor space required relating to the confidence level required for the storage area to be large enough for variations in receipt volumes through the course of a year.

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1 BACKGROUND

Fast moving consumer goods, notably fresh fruit and vegetables, are increasingly becoming within reach of consumer groups with increased disposable income, causing growth in the sector. A major supermarket chain envisaged opening more than 170 new supermarkets in 2013. Fruit and vegetables are delicate merchandise due to the short life cycle, the specific requirement of each product with regards to temperature and humidity as well as the response to ripening hormones such as ethylene and also bruising. From a facility design perspective, the fruit and vegetable receiving, storage and preparations area of a fast moving consumer goods retail outlet needs to be specifically designed. Other factors that influence the design of this functional area are the volumes received at the specific supermarket as well as the space available.

This paper reports an investigation into a fruit and vegetable receiving, storage and preparations area requirements model, that provides space requirements for this functional space of any envisaged or newly established supermarket. For each new store that is in the process of being planned and designed, the goal is to be able to determine the space requirements with inputs such as the store brand, geographical location and the expected annual sales for the store. Pareto principles and regression analysis are used to categorise stores according to fruit and vegetable sales revenue. The distributions of these flow volumes are examined to predict the safety margins of the design guidelines. In the design of fruit storage and handling spaces both production of and sensitivity for ripening hormones, such as ethylene, needs to be key guiding principles. Both the design approach for ripening hormonal considerations as well as the facilities solution is specifically excluded from this paper for focus and length of document reasons.

2 INTRODUCTION

In supermarket supply chains, fruit and vegetables are transported and stored in deep trays of dimensions 600 x 400 x 225 mm at 8°C [1]. In this work, supermarket receipt data for a range of stores are investigated. This information represents relatively large amounts of data that are examined for the presence of statistical distributions, for example the distribution of the number of cases of produce that enters the storage area per day. As fruit and vegetable demand is independent and store orders aim to accurately match sales, variability is considerable. In order to predict volumes, it is therefore necessary to be able to calculate the amount of variation separate from the mean and characterise the data as a distribution. This enables the calculation of confidence intervals to assess both the risk of under design and wastage due to overdesign.

2.1 Normal distribution

A normal probability distribution function can be used to describe the quantity of crates of fruit and vegetable received at a retail store, daily. It describes the probability that a certain variable will have a value that falls in a specific interval of values. Two parameters are considered when dealing with a normal distribution, namely the mean, μ and the standard deviation, σ [2]. The mean is the expected value for a distribution and is the value that is most likely to be observed if an event is repeated [3]. The mean and standard deviation for a sample of n number of observations are calculated as follows:

$$\mu = \frac{\sum_{i=1}^{n} X_i}{n} \quad (1)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \mu)^2}{n-1}} \quad (2)$$

$\mu = mean \quad \sigma = standard\ deviation \quad X_i = observation\ i \quad n = number\ of\ observations$

The standard deviation is used to calculate how much the fruit and vegetable quantities received vary per day. Considering that the normal distribution depicts certain probabilities that values will fall into certain intervals with a level of confidence, it is necessary for this project to be able to calculate these intervals as the receiving space is designed accordingly. For example, 95% confidence defines an interval beyond the mean of Z= +- 1.96 standard deviations of the sample [2].

These Z-values are standard for normal distributions and for a certain confidence level, a Z-value exists. When this Z-value, mean and standard deviation are known, it is possible to calculate the upper and lower interval limits for the specific distribution using the following formula:

$$\boldsymbol{Z} = \frac{\boldsymbol{X} - \mu}{\boldsymbol{\sigma}} \quad (3)$$

$\mu = mean$

$\sigma = standard\ deviation$

$X = upper\ interval\ limit$

$Z = number\ of\ standard\ deveations\ from\ X\ to\ \mu$

2.2 Regression analysis

Regression analysis determines the relationship between variables. It is also necessary to investigate the statistical significance of the calculated relationships in order to determine the degree of confidence with which the relationship is accurately determined and with which it can be used for the required objective [4]. For this project it is necessary to find the relationship between certain variables such as size, brand, location, etc. of a retailer and the volume of F&V received during a specific time [5].

The first step in regression analysis is to form a hypothesis that some or other relationship exists between certain variables. As an example, the hypothesis may be formed that the size of a store has an effect on the volume of fruit received per day. Then the volume of fruit becomes the dependent y variable and the size of the store becomes the independent x variable. It is necessary for regression analysis to assign the correct quantitative values to variables [5].

The following definitions and assumptions are made with regards to simple linear regression:

Definition: $x_i = Independent\ Variable$

$y_i = Dependent\ Variable$

$i = Number\ of\ Observations$

$u_i = Error$

Assumption: $E(u_i) = 0$ — $u\ has\ a\ mean\ of\ zero\ for\ all\ i$

$E(u_i^2) = \sigma_u^2$ — $u\ has\ thesame\ variance\ for\ all\ i$

$E(u_i u_j) = 0, i \neq j$ — $no\ correlation\ accross\ observations$

The hypothesized relationship between the dependent and independent variable is formulated as follows [4]:

$$\boldsymbol{y_i = \beta_0 + \beta_1 x_i + u_i} \quad (4)$$

Where: $\beta_0 = constant\ for\ x_i = 0$

$\beta_1 = coefficient\ for\ x_i$

$u_i = Error \quad (5)$

Regression analysis is based upon the principle that a certain line $y_i = \beta_0 + \beta_1 x_i$ is fit to the scatter of observed data. β_0 is the intercept of the line on the vertical axis and β_1 is the slope of the line [5]. In order to decide where to fit this line and determine the coefficients the error term u_i is added to the equation. The error term portrays the estimate error for each observation as the vertical distance between the data point and the estimated line. Regression analysis then chooses among all possible solutions, the line that results in the minimum sum of the squared errors (min SSE) [4].

There is no certainty in only performing a regression analysis that the best fit line is even close to an accurate estimate. Further evaluation is therefore required. By calculating the difference between the actual observed value and the fitted value as per the estimated equation for each observation in the data, and determining the sum of the square of each of these values a conclusion can be made. This value is known as the SSR (sum of squared residuals) [4]. In order to determine the 'wellness of the fit', the coefficient of determination is calculated using the values of SSR [5]. This coefficient is also known as R^2. The closer R^2 is to 1 the closer the fit is and the closer it comes to zero the less accurate the estimation is.

2.3 Multiple linear regression

It is seldom the case in reality that only one variable has an effect on another variable. For multiple regression, the theory changes as follows [4], [6]:

$$y_i = \alpha + \beta x_i + \gamma e_i + u_i \quad \textbf{(6)}$$

Where:

$$\alpha = constant\ for\ x_i = 0$$

$$\beta = coefficient\ for\ x_i$$

$$\gamma = coefficient\ for\ e_i$$

$$u_i = Error$$

Previously a two dimensional problem, has now become a three dimensional problem and graphical presentation is not so obvious. The concept of fitting a line to the data is not possible anymore and the idea has changed to manipulate the coefficients of the new equations in order to find a plane within the data that will fit best and still result in minimising the SSR [5], [6].

Multiple regression analysis can deal with a large number of variables. Even though people lack the ability to see in multiple dimensions, computers and mathematics can define such a condition. With n variables a 'hyper plane' will be sought in the n-dimensional space to fit the data in such a way that will minimise the SSR. The intercept is the constant term α, where the other coefficients β and γ, etc. form the slope in each dimension [5].

2.4 Storage considerations

In the supermarket storage area, unit loads are defined as deep trays measuring 600 x 400 x 225 mm. These unit loads are received and assigned to a certain storage location. In fixed storage location allocation, each individual Stock Keeping Unit (SKU) is assigned to a specific location. This method holds the advantage of making items easy and quick to find, at the cost of space utilisation, especially where item volumes are seasonally fluctuating such as with fruit and vegetables. In the case of random location storage, a unit load may be assigned to any available storage location. Although this method requires other methods of locating the items once they have been placed, it usually requires less space than fixed storage location as there are no open spaces waiting on specific items [7], [8].

Popularity based storage is linked to Pareto's law. Typically, 85% of the volume will be occupied by 15% of the materials stored. In order to store such products in an efficient manner, the 15% of products with the highest volume need to be stored together and in close proximity to the entrance/exit so that the travel distance is minimised [7]. A combination of fixed and random location storage is practical. A SKU is assigned to a certain zone in which it will be stored according to its volume. This zone is fixed, however where each item is placed in the zone is random and assigned according to the quantities received on the day. An ABC analysis can be done in order to identify these zones. Zone A is located closest to the receiving and shipping areas and zone C is located furthest away from these areas. It is clear from data analysis that Pareto's law is applicable as items such as apples and bananas, etc. are more popular and consume more volume in the storage area. They are therefore located close to receiving and shipping entrances.

Material accessibility is the degree of effort it takes to reach a certain item in a storage facility [7]. The storage area needs to work according to First-In-First-Out principles and the naturally occurring Last-in-First-Out practice is to be avoided deliberately. Honeycombing is also to be constantly considered and avoided. This is wasted space when a row or stack cannot be utilised, because adding other materials would result in blocked storage [7].

2.5 Data analysis

For primary handling of data, a database program such as Microsoft Access is more suitable for larger datasets than spreadsheet types of software, such as MS Excel. Investigating Statistical Analysis Software, there are different levels of programs categorised by cost and the amount of experience necessary to use the program, starting with the most basic programs such as Microsoft Excel and R. Both these programs require only basic programming skills and are easy to use, however are not suitable for this project as they cannot process the amount of data required [9].

For more advanced needs, programs such as STATA, Statistica 11.0 and SPSS statistics exist. STATA can handle moderately sized data sets and is affordable. It lacks some features as it is only able to open one data source per operation. It is however easy to use and easily programmable. SPSS Statistics is also an easy to use program with the necessary features to handle the data of this project. It lacks some control in statistical output, however for this project this might not be a concern [9]. Statistica 11.0 is easy to use and can handle vast amounts of data. It can do various types of regression analysis necessary for this project as well as execute the desired statistical analysis functions on the data. The highest level of statistical analysis tools includes SAS Analytics Pro. This is an efficient statistical tool with many features and allows comprehensive data manipulation. Relatively comprehensive and advanced programming is required for the use of SAS [9]. For the regression analysis Statistica 11.0 is used.

3 METHODOLOGY

The bulk of the design project included the analysis of store receipt data and facilities design. It is performed as follows: (1) Data is transformed into MS-Access format and appropriate queries are coded. (2) Statistica 11.0 is used to analyse the data statistically and the desired distributions of fruit and vegetable crates received per day are determined. (3) A Pareto analysis is done and the stores are divided in eight categories. (4) Storage space layout design is performed employing storage appropriate locality practices, such as popularity based, random and fixed as well as combinations of these methods. (5) Layout design receives particular attention to implement FIFO storage. (6) The user tool is developed in Microsoft Excel using Visual Basic for Applications coding.

4 ANALYSIS RESULTS

Branch data was categorised according to Fruit and Vegetable annual sales revenue. This resulted in eight store categories that have a certain range of fruit and vegetable volume delivered daily. A distinction was made between produce stored at 5 and 15 degrees C. Figures 4 and 5 show the relationship between the number of cases received and the category of annual sales revenue. The large difference between average and maximum volumes emphasise the need for a statistical approach, considering the variance as well.

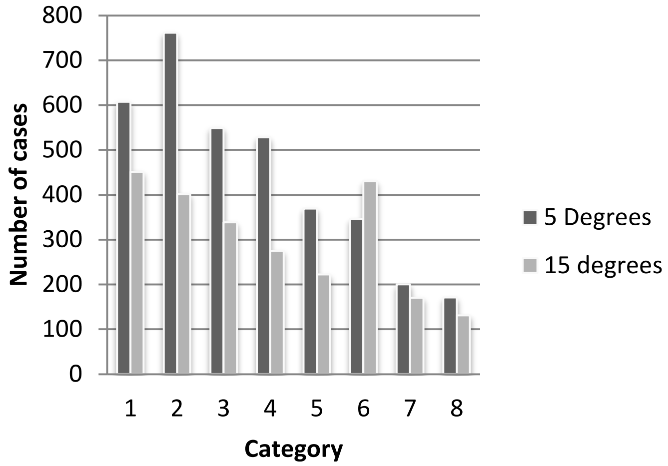

Figure 1: Average number of cases fruit and vegetables delivered per day per category for both temperature compartments

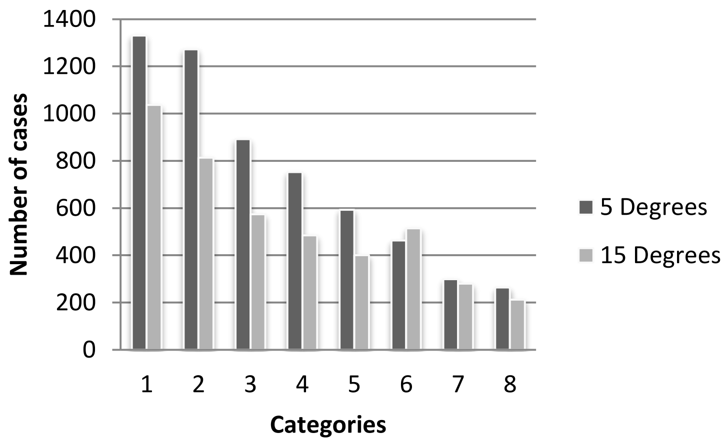

Figure 2: Maximum number of cases of fruit and vegetables delivered per day per category for both temperature compartments

Other information shows the number of crates received per year for each fruit and vegetable item. This is used to compile the ABC analysis determining which items use the most space during the year. This data differs for each category. Therefore a design for each category is done using basic design principles in order to acquire the volume for each new store.

4.1 Regression analysis on store data

A regression analysis is done in order to find a relationship between the various parameters of a store and the annual fruit and vegetable revenue. This was done in case of the situation where the company does not have the annual fruit and vegetable revenue estimates to enter into the tool, and then it can be calculated using a formula.

The result of this regression was that annual sales, brand and division are strongly correlated with the annual fruit and vegetable sales of a store. A R squared of 0.599 was obtained. Therefore this regression results can be used in order to obtain the estimated annual fruit and vegetable sales for new stores using the available variables and a store can then be categorised accordingly in order to find the appropriate design for the storage area.

4.2 Statistical analysis of quantity crates received per day

By running queries in MS Access and obtaining records for each temperature compartment per category store, the quantity of crates received per day for a year, it was possible to run this data with Statistica 11.0 for each category and for both temperature compartments.

Histograms are drawn up to portray the frequencies of the different quantities of crates received at stores per day and the results tended towards normal distributions. Normal distributions were fit to the data and by using Statistica 11.0 it was possible to calculate the mean and standard deviation for data from each temperature compartment for all categories. The results of all categories were plotted and the histograms for both temperature compartments of category 1 is shown in Figures 3 and 4.

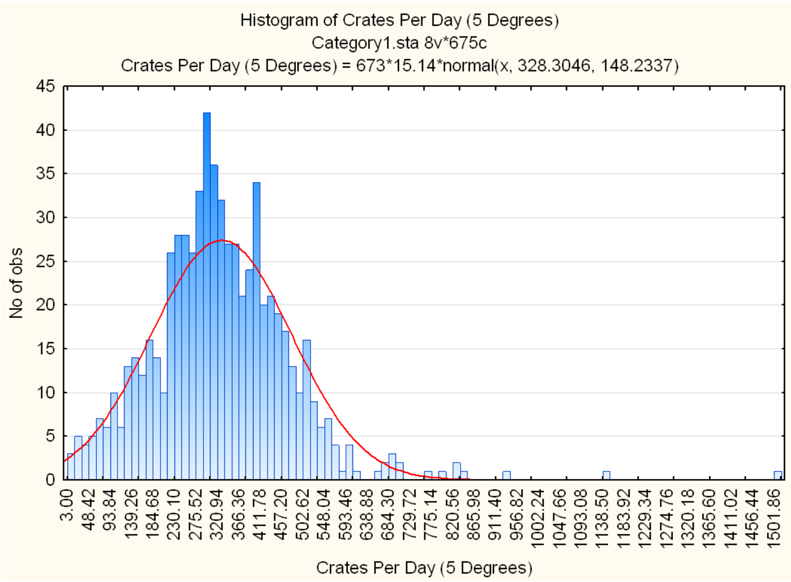

Figure 3: Frequency of quantity crates received per day for a category 1 store (5˚C area)

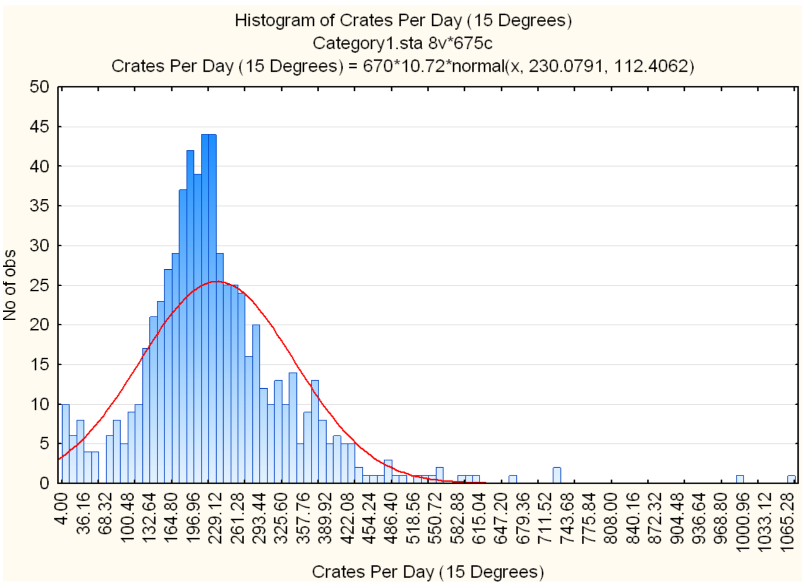

Figure 4: Frequency of quantity crates received per day for a category 1 Store (15˚C area)

The calculated means and standard deviations are shown in *Table 1* below. These values were used to calculate confidence intervals for two different confidence levels, namely 70% and 90% confidence. These values are also depicted in the table below.

Table 1: Category means, standard deviations and confidence limits

Category	Mean	Minimum	Maximum	Standard Deviation	70% LL	70% UL	90% LL	90% UL
Category 1 (5 Degrees)	328.3046	3.000000	1517.000	148.2337	251	406	139	519
Category 1 (15 Degrees)	230.0791	4.000000	1076.000	112.4062	172	289	86	375
Category 2 (5 Degrees)	370.3022	1.000000	1412.000	182.3206	275	466	137	605
Category 2 (15 Degrees)	185.8348	1.000000	958.0000	106.0386	131	242	50	322
Category 3 (5 Degrees)	260.2631	1.000000	1566.000	133.8748	191	331	89	432
Category 3 (15 Degrees)	142.7319	1.000000	940.0000	85.30550	99	188	34	253
Category 4 (5 Degrees)	260.2631	1.000000	1566.000	133.8748	191	331	89	432
Category 4 (15 Degrees)	142.7319	1.000000	940.0000	85.30550	99	188	34	253
Category 5 (5 Degrees)	165.4381	1.000000	1682.000	89.42009	119	213	51	281
Category 5 (15 Degrees)	93.34987	1.000000	880.0000	58.79087	63	125	18	169
Category 6 (5 Degrees)	126.5316	1.000000	1210.000	70.82611	90	164	36	218
Category 6 (15 Degrees)	136.9428	1.000000	2012.000	84.65687	93	182	29	246
Category 7 (5 Degrees)	84.80151	1.000000	1449.000	54.63793	57	114	15	155
Category 7 (15 Degrees)	52.78603	1.000000	960.0000	39.86671	32	74	2	104
Category 8 (5 Degrees)	65.27929	1.000000	857.0000	46.94592	41	90	6	126
Category 8 (15 Degrees)	41.78666	1.000000	806.0000	32.30156	25	59	1	84

5 DESIGN RESULTS

5.1 ABC analysis on item volumes

For this project the ABC analysis items were categorised as follows: A-items are the few items that make for 70% of the volume received, B-items are the items that take up the next 20% of the volume and C-items are the smaller items that account for the final 10% of the volume. According to Pareto's principle there are only a few items that make up the A group, where the C group will consist of most of the items. It was possible to obtain the amount of cases received per year for each item type. This information was necessary to do an ABC analysis. By using this information, it was possible to calculate the average percentage of volume that each item takes up per year for each category. These calculated percentages for the 5 degree area for category 1 is shown in *Table 2*.

Using the percentage of the received volume per item type it is possible to convert this information into quantity of crates received per item type with regards to both 70% and 90% confidence levels. The quantity of crates received is also shown in *Table 2*. The ABC analysis for both temperature compartments for the remaining categories are part of the study but not shown in the paper.

Table 2: ABC classification of item types throughout the year as well as the quantity of crates received per item according to the fraction of volume.

5 Degrees Area			**Confidence:**	**0.7**	**Confidence:**	**0.9**		
Sub Category Description	Crates per year	Percentage	Cumulative %	Max	Min	Max	Min	Zone
GREENS	35004	0.158	0.158	65	40	96	22	A
LETTUCE	22359	0.101	0.260	42	26	62	14	A
MUSHROOMS WHITE	16419	0.074	0.334	31	19	45	11	A
VEG FRESH CUT	12218	0.055	0.389	23	14	34	8	A

CARROTS	10716	0.048	0.438	20	13	30	7	A
HERBS	10132	0.046	0.484	19	12	28	7	A
CABBAGE	9156	0.041	0.525	17	11	26	6	A
RED APPLES	8937	0.040	0.565	17	11	25	6	A
CAULIFLOWER	8696	0.039	0.605	16	10	24	6	A
SPINACH	6546	0.030	0.634	13	8	18	5	A
GOLDEN APPLES	6063	0.027	0.662	12	7	17	4	A
PLUMS	5870	0.027	0.688	11	7	17	4	A
BI-COLOUR APPLES	5458	0.025	0.713	11	7	15	4	B
BEANS & PEAS	5457	0.025	0.738	11	7	15	4	B
POT PLANTS ASSTD	4395	0.020	0.758	9	5	13	3	B
GRAPE SEEDLESS	4231	0.019	0.777	8	5	12	3	B
PADKOS PREPACKS	4126	0.019	0.796	8	5	12	3	B
GREEN APPLES	3966	0.018	0.814	8	5	11	3	B
CLING PEACHES	3673	0.017	0.830	7	5	11	3	B
SWEET CORN	3609	0.016	0.846	7	5	10	3	B
STRAWBERRIES	3501	0.016	0.862	7	4	10	3	B
PEARS BAG PREPACK	3455	0.016	0.878	7	4	10	3	B
GRAPE SEEDED	3115	0.014	0.892	6	4	9	2	B
NECTARINES	2945	0.013	0.905	6	4	9	2	B
PEACHES	2892	0.013	0.918	6	4	8	2	C
BEETROOT	2758	0.012	0.931	6	4	8	2	C
SALAD PRE-PREPARED	1959	0.0089	0.940	4	3	6	2	C
PEARS LOOSE SELL	1663	0.0075	0.947	4	2	5	2	C
COCONUT	1603	0.0073	0.955	3	2	5	1	C
LITCHI	1183	0.0054	0.960	3	2	4	1	C
KIWIFRUIT	1106	0.0050	0.965	3	2	4	1	C
SOFT FRUIT MIX PACKS	1058	0.0048	0.970	2	2	3	1	C
SPRING ONION	1028	0.0047	0.974	2	2	3	1	C
BROCCOLI	1004	0.0045	0.979	2	2	3	1	C
CELERY	911	0.0041	0.983	2	2	3	1	C
PERSIMMON	703	0.00318	0.986	2	1	2	1	C
RADISH	649	0.00294	0.989	2	1	2	1	C
MUSHROOMS BROWN	630	0.00285	0.992	2	1	2	1	C
PRUNES	559	0.00253	0.995	2	1	2	1	C
FOREST BERRIES	233	0.00105	0.996	1	1	1	1	C
SPROUTS	166	0.00075	0.996	1	1	1	1	C
CHERRIES	164	0.00074	0.997	1	1	1	1	C
FRUIT CUPS	134	0.00061	0.998	1	1	1	1	C
CHICORY	133	0.00060	0.998	1	1	1	1	C
F&V GENERIC ITEMS	123	0.00056	0.999	1	1	1	1	C
RHUBARB	62	0.00028	0.999	1	1	1	1	C
FIGS	42	0.00019	0.999	1	1	1	1	C
VEGETABLE MIXED PREPACKS	42	0.00019	1.000	1	1	1	1	C
ASPARAGUS	40	0.00018	1.000	1	1	1	1	C
LEEKS	25	0.00011	1.000	1	1	1	1	C
PARSNIPS	15	0.000068	1.000	1	1	1	1	C
QUINCE	12	0.000054	1.000	1	1	1	1	C
TURNIPS	3	0.000014	1.000	1	1	1	1	C
APRICOTS	1	0.0000045	1.000	1	1	1	1	C
HORSERADISH	1	0.0000045	1.000	1	1	1	1	C

5.2 Structured layout design per category store

When designing the layout for each category, the following factors are taken into account, namely the storage location allocation method, material accessibility and travel distances. For the fruit and vegetable receiving, storage and preparations area a hybrid of popularity based, fixed and random location allocation is used, where fixed zones are allocated to A-, B-and C-items, but in the zones random allocation occurs between items. It is also necessary to design using the FIFO principle and minimise travel to the most popular items.

ABC analysis data (percentage of received volume per item) and 70% and 90% interval data is used to determine the average number of crates of a specific item received per day. From this the total average number of crates received at the RSPA for A-items, as well as B-items and C-items, are determined. This data determines the size of zones A, B and C.

Four methods for stacking deep trays in the RSPA were chosen as set methods for this design. These methods and the dimensions for each are detailed in the project report. The stacking options have set base dimensions and can hold a certain number of cases, making the design process determined and adjustable. The quantity of cases calculated was converted into floor space through using these set options.

Taking company preferences as well as the set options described in the previous paragraph and basic design principles, such as aisle space, into consideration, it was possible to design layouts for all 8 categories. Only the layout design at 90% confidence level for category 1 can be seen in Figure 9 below.

Figure 5: Layout design at 90% confidence level for category 1

The set stacking options are shown in the image. For this category it is observed that option 1, is used for all the A-items (depicted in red). This option holds 36 cases and has dimensions 1.2m x 1.2m. This layout also uses option 2 stacking for B-items shown in blue which holds 24 cases and option 5 racking that holds 30 C-items. An aisle width of 0.7 m is used throughout designs and aisle direction is longitudinal and parallel to the direction of product flow through the storage space. A-items are located closest to doorways with good accessibility in order to keep travel distances to a minimum for these popular items. All designs follow the same basic principles. Results regarding the sizes calculated for the various sections can be seen in the following table, Table 3.

Table 3: Layout dimensions and calculated area

	Confidence (%)			²)		Total (m2)
		5 Degree Area	15 Degree area	5 Degree Area	15 Degree area	
1	90	5.4m x 6.7m	5.4 x 5.2	36.18	28.08	64.26
	70	5.4m x 5.5m	5.4m x 4.3m	29.7	23.22	52.92
2	90	5.6m x 6.7m	5.6m x 4.3m	37.52	24.08	61.6
	70	5.0m x 6.1m	5.0m x 4.3m	30.5	21.5	52
3	90	5.2m x 5.5m	5.2m x 3.6m	28.6	18.72	47.32
	70	5.2m x 4.3m	5.2m x 3.1m	22.36	16.12	38.48
4	90	5.6m x 4.8m	5.6m x 4.8m	26.88	26.88	53.76
	70	5m x 3.7m	5m x 2.5m	18.5	12.5	31
5	90	5m x 4.3m	5m x 3.6m	21.5	18	39.5
	70	4.4m x 3.7m	4.4m x 3.0m	16.28	13.2	29.48
6	90	5.2m x 3.0m	5.2m x 3.0m	15.6	15.6	31.2
	70	4.0m x 3.7m	4.0m x 3.6m	14.8	14.4	29.2
7	90	3.6m x 3.6m	3.6m x 3.7m	12.96	13.32	26.28
	70	2.7m x 3.0m	2.7m x 3.7m	8.1	9.99	18.09
8	90	3.6m x 3.2m	3.6m x 3.5m	11.52	12.6	24.12
	70	2.1m x 3.6m	2.1m x 3.2m	7.56	6.72	14.28

From this table it is evident that the 5 degree area usually stores larger quantities and larger space should be assigned to this compartment. A trend can be observed in the sizes and lower categories have significantly smaller floor areas, as was expected.

6 CONCLUSIONS

The main objective for this project was to develop a generic facility design tool, namely a fruit and vegetable receiving, storage and preparations area requirements model that largely automates and structures the fundamentals of the facility design for any newly planned store with a fruit and vegetable division. The task consisted of the following elements: (1) a background study of the theory and literature, (2) analysis of data to identify distributions and relationships, (3) categorisation of stores based on fruit and vegetable sales, (4) application of relevant facility design principles for operational efficiency and (5) implementation of the results in a MS Excel tool for the user.

The end product of this project is a user friendly management tool that takes certain inputs from the company and provides all the desired outputs of a new store, such as expected fruit and vegetable daily receipt distribution, and a detailed layout suggestion for the store. Practical company preferences were implemented in the design phase and the end product is in accordance with the requirements of the customer.

As the customer is a major supermarket chain in Africa, South of the Sahara, the implementation scope of the tool may be significant.

7 ACKNOWLEDGEMENT

The support of the Shoprite-Checkers Group and access to data is gratefully acknowledged.

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AN INVESTIGATION OF CELLULAR FACILITY CONFIGURATION FOR TABLE GRAPE PACKING

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ABSTRACT

Although labour unrest in export fruit industries was limited to the Western Cape, the 50% increase in the minimum wage became applicable to the industry countrywide. Table grape packhouses in particular, are finding it difficult to increase productivity as the quality of the grapes has a major influence on operational parameters. Rapid changes of grape quality upset line balancing and increases unproductiveness. Contract workers, especially in the Northern Cape, do not have a broad educational background which adds to the challenge of increasing productivity. The labour cost increase has caused several producers to move away from traditional production line Taylorism, to experiment with cellular layouts in their packhouses.

The introduction of cellular manufacturing has been successful in some industries but less so in others. Implementation and whether cellular designs are actually more productive is not clear. Cellular facilities therefore do not appear to be a guaranteed solution to recover the minimum wage increase.

The merit and the most suitable configuration of grape packaging cells are investigated. The design places an emphasis on reduced double handling for both productivity and grape quality purposes. An analysis of cellular principles and facilities in manufacturing is presented as the foundation of the work. The work is concluded with throughput measurements of different cellular configurations in the 2013/2014 packing season.

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1 BACKGROUND

The violent labour protests at the end of 2012 in the Western Cape initiated the implementation of a new minimum wage law. The sustainability and profitability of the farming industry is threatened by the 50% wage increase and table grape farmers specifically, are required to find alternative solutions for their labour intensive production processes [1].

In the Northern Cape, seasonal workers have had limited access to education and experience in a working environment where workers are integrated into business goal achievement. The result is that workers tend to be uncommitted to business goals against a background of limited skill with technological equipment. Supervisors are appointed to help manage the workforce and workload but struggle to promote identification with enterprise goals and worker engagement. This alongside the wage increase, the competitive international market, weather unpredictability and the constant burden of being more productive are some of the major industry challenges [2].

These factors place pressure on farmers to create and design work environments that by default promote productivity and drive. Management structures and human resource management should align in strategy to achieve the organization's objectives [3]. Trends are moving towards changing the layout design of a packing facility from the conventional production line Taylorism to that of cellular configuration alongside a system of incentives. Production Line Taylorism is the sequential processing of grapes in production line fashion. It is a labour intensive process and causes unsatisfactory productivity levels, the underutilization of resources and large amounts of WIP throughout the production line. The wage increase has been the proverbial "last straw that broke the camel's back" to precipitate a major shift towards an urgency in the table grape industry to reduce cost and increase productivity.

A sample production line that incorporates this cellular configuration approach is setup within a packing facility of an industry partner. This paper covers an investigation to determine the output capabilities of the system before implementation. Experiments are done to test the system and to determine possible loopholes, wastes, problems and risks.

2 INTRODUCTION

According to Wemmerlöv & Hyer [4], competition in the manufacturing industry has led companies to implement ideas that assure competitive advantage. The table grape industry in South Africa has a competitive local and international market and continuous improvement is required to maintain market share [2]. Table grape farmers wish to do this by increasing productivity and using input resources at maximum capacity.

Productivity can be defined as a measurement that indicates how well a company is utilizing its resources [5]. In quantitative terms it is achieved by dividing the outputs by the inputs and this can be done per week, per day or per hour depending on what is valuable to the user. In order to increase productivity, research has been focused on reconsidering the current processes and new alternative processing methods. Cellular facility configuration is of particular interest.

Cellular manufacturing ensures many advantages if implemented successfully. Amongst these advantages are the improvement of quality control and throughput time, the reduction of setup times, work-in-progress, finished goods inventories, material handling time and costs, space requirements and tool requirements [4, 6]. In 1989 Volvo Kalmarverken's automobile assembly plant incorporated cellular manufacturing and it achieved efficiency alongside the successful implementation of the team concept at the time [7].

The physical configuration of the facility is not the only aspect that influences productivity and [3] emphasizes the impact and advantages that cellular manufacturing has on the team of workers. Workers become more flexible, less frustrated and experience a sense of recognition and increased security when group technology is implemented [8].

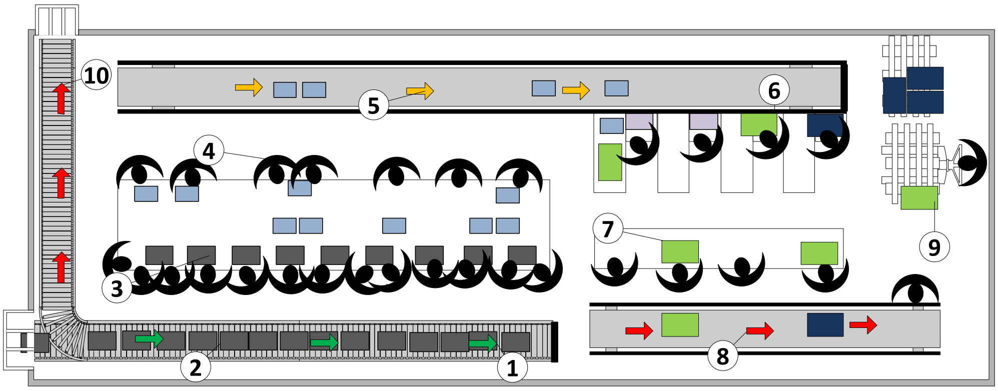
The success of cellular manufacturing and group technology is to a large degree dependent upon the relationship between the workforce and the company [3]. This relationship should be treasured for Juran states that the workforce should be involved in forming a quality culture within the company [9]. A culture of 'doing it right the first time' is non-negotiable because the productivity in the table grape industry is predominantly determined by the quality of the grapes.

Amongst other influences are the packaging program followed for the day, the bonus or rewards system and what day of the week it is. Companies need to adjust and ensure the best combination of factors discussed previously, in order to deliver maximum productivity whilst maintaining excellence in product quality.

3 OVERVIEW OF OPERATIONS

3.1 Conventional production line Taylorism

The conventional method of grape packaging is a division of the work into small tasks that are organized into separate functional areas. From the vineyards grapes are transported in polymer crates, known as lugs, to the packing facility. The grapes enter the pre cooler where it gets cooled to ensure grape quality and to extend shelf life. The pre cooler also functions as a packhouse buffer. Grapes are transported from the pre cooler; using a three level conveyor belt. The middle conveyor belt transports the lugs inwards and the top level is an output conveyor belt for empty lugs. The first part of the production line is the cutting area. Berries that do not conform to specifications are cut out and the remaining good bunches are placed into smaller crates. Inspection is done on the clean cut bunches and thereafter the smaller crates are transported via a conveyor belt to the weighing area. Grapes are weighed and then placed in the appropriate packaging. Workers close the packaging and place the boxes on a different conveyor belt that leads to the palletizing area. For the purpose of this report the scope of the system ends at the palletizing area. This production line requires that workers be allocated to one of the five functional areas; cutting, inspection, weighing, packaging and palletizing. In each area, workers practice a different skill and this makes changing between areas problematic. In Figure 1 the facility layout of the conventional production can be seen.



Number Description

1. Input Conveyor:3 level conveyor belt structure.
2. Full lugs arrive from the pre cooler on the middle conveyor
3. Cutting Area
4. Inspection Area
5. Grapes in transit
6. Weighing Area
7. Packing Area
8. Output Conveyor: Packaged grapes leave the system
9. Palletizing Area
10. Empty lugs move to crate washer on the top conveyor

Note* Green and blue boxes refer to different packing combinations

Figure 1: Facility Layout of conventional production line

3.2 Cellular facility configuration

The sample production line receives the grapes in the same way as the conventional system; from the vineyards to the pre cooler and eventually being fed to the palletizing area. Unlike cellular manufacturing that is based on grouping part families together [10]. The cellular configuration approach in the table grape industry aims to simplify the process by integrating all three required process functions (cutting, weighing and packaging) around one table. Workers are expected to do self-inspection of their work and supervisors are appointed to help in this regard. Therefore the focus is placed on the team concept that is identical to the approach in cellular manufacturing [3].

Figure 2 shows the facility layout of the production line using cell configuration. The layout shows 3 workers per work station. For the sample production line tables are placed perpendicular to the conveyor belt that feeds the lugs from the pre cooler. There is a small aisle between the table and the conveyor belt. Flush to the opposite end of the table there is a long conveyor belt that links all the tables. This conveyor belt sends the finished products to the palletizing area. Each table operates as a separate work cell and cutting, weighing and packaging are the tasks that are performed. The emphasis is placed on facilitating team work with this layout. Workers are required to share the workload and apply common sense and judgment to determine when a task on the work table needs to be treated with additional urgency or relaxed.

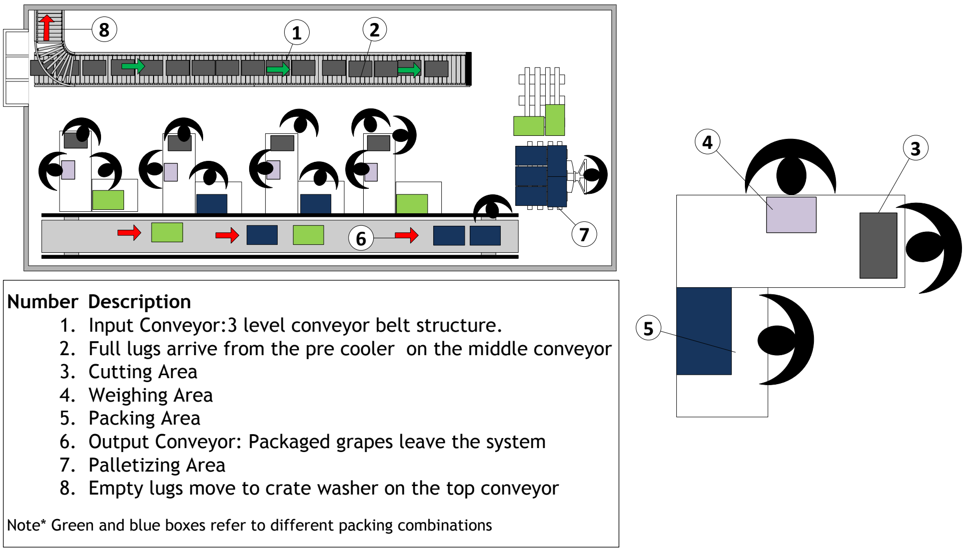


Figure 2: Facility Layout of sample production line

3.3 Packaging compositions

The composition of production outputs are mainly determined by the weekly packing schedule. A packing schedule is set up after considering market demands (local and international) and grape availability. There are four general packaging compositions namely; loose, loose and punnets, just punnets and stem-up's.

For the "loose" packaging composition, grapes are placed into plastic sachets and then in 4.5kg or 9kg boxes. Punnets are small, transparent plastic containers with an ideal packed weight of 500g that are placed in 5kg boxes for transport. Stem-up's are grapes, loosely placed in protected packaging in 7.5kg boxes.

4 METHODOLOGY

A sample production line is setup in a packing facility of an industry partner and each general packaging composition is seen as a test to be performed. Four different tests were done for 3 different cases as seen in Table 1. Time and grape availability limited the investigation of case c (4 workers per cell) to test 1. For the remainder of the document the different cases are referred to as case a, b and c.

Table 1: Summary of the experiments performed

Tests Performed	Case a) Two workers per cell	Case b) Three workers per cell	Case c) Four workers per cell
Test 1 : Packing Loose	X	X	X
Test 2 : Packing Loose and Punnets	X	X	
Test 3 : Packing Punnets	X	X	
Test 4 : Packing Stem-up's	X	X	

The amount of workers per cell refers to the number of workers that are occupying each work table. These workers are responsible for cutting, weighing and packaging. The weighing station at a work table has a capacity of one worker whereas the packaging and cutting station respectively can accommodate up to 3 workers simultaneously. Workers decide amongst themselves who does which task and once a station is starved the worker moves to another station to help relieve the workload

For the sample production line team a number of workers are randomly assigned and they operated independently from the other teams within the packing facility. Workers that form part of the sample production line team always operate at the same work table. Therefore the sub teams per work table generally remain the same and only vary slightly when the different cases are observed. As most of the workforce are contract workers and many of them are working in the packing facility for the first time, the training happens as the day proceeds. Not too much emphasis is placed on a formal training week before the packing season as this is costly and does not necessarily deliver results. Supervisors are appointed as permanent staff and training are focused on them during harvest season preparations. It is expected of the supervisors to pick up on quality problems and to train the workforce on the floor.

As previously stated the packing combinations followed for the day varies according to the packing schedule and grape availability. Therefore the different cases experimented with for each test (see Table 1) did not necessarily occur consecutively and were not observed for the same duration of time. We will call a production period within which a certain case is observed a sample period. These sample periods are measured and documented. When considering test 1: packing loose, for example, there were a total of 8 sample periods recorded. Of the 8 sample periods taken, 1 sample period is for case a, 4 for case b and 3 for case c. The duration of each sample period differs, being dependent on the test performed (packaging composition), the speed at which the grapes are processed as well as the quantity of grapes that need processing. All sample periods irrespective of their duration are taken into account.

Productivity measurements are calculated as a value of cartons per man per hour. The output in cartons per day is derived back to an industry standard of 4.5kg cartons per day. All workers actively involved with the production line are brought into consideration for calculations. This includes the worker that feeds the lugs from the pre-cooler, the workers in each cell (2, 3 or 4), 2 supervisors, 2 workers palletizing the outputs and a worker folding the cartons. There are 18, 24 and 30 workers active on the production line for cases a, b and c respectively.

Therefore the number of workers on the line, the number of cartons produced and the duration of a sample period is used to perform productivity measurements. Measurements are taken for each case and compared to each other to determine the relationship between the variation in workers per cell and the productivity of the production line.

5 RESULTS AND DISCUSSION

For the first three tests, Prime Seedless grapes were processed. It is a green grape with relatively large berry sizes that makes it easier to handle and process. Test 4 was done with Flame Seedless grapes. Flame has small, dark, red berries that are more fragile and this makes cutting difficult.

Test 1: Packing loose

Eight sample periods were considered. One sample period, observed for case a, was done after a pay weekend which influenced the productivity of the workforce. The productivity measurement is expected to rise if a second sample period is observed; unfortunately grape unavailability prevented this.

Four sample periods were observed for case b and 3 sample periods for case c. The grape quality was good and no external factors influenced the productivity of the workforce during these sample periods. **Figure 3** below compares the overall productivity of cases a, b and c.

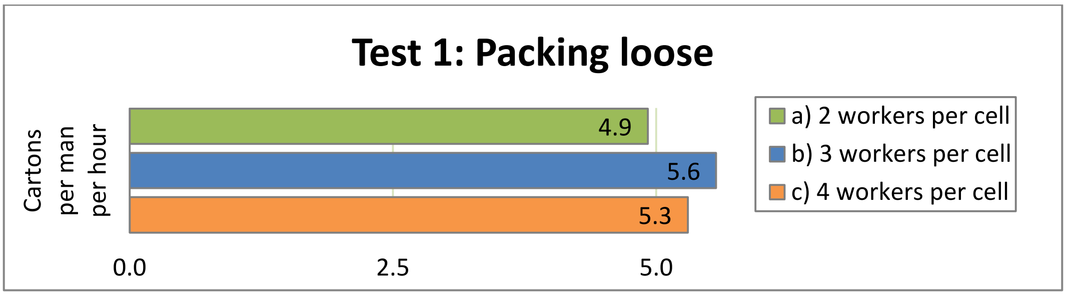


Figure 3: Summary productivity measurements of Test 1

Test 2: Packing loose and punnets

Three sample periods were considered for test 2; 1 was for case a and 2 for case b. For both cases an average grape quality was applicable and a variety of large and small berries were present. No other external factors influenced the productivity measurements. In Figure 4 a visual comparison of the results are shown.

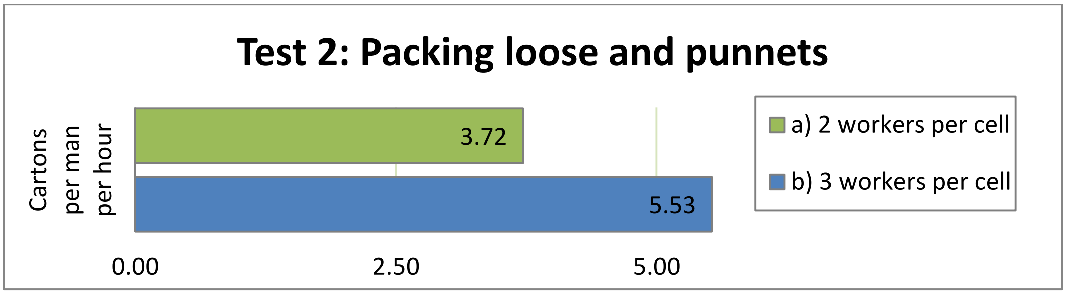


Figure 4: Summary productivity measurements of Test 2

Test 3: Packing punnets

Two sample periods were considered for both cases a and b during test 3. A substantial amount of cutting was required for case a's sample periods. The grape quality for case b was good and little cutting was required. In Figure 5 it is interesting to note that the productivity measurement for case a or two workers per cell, where more cutting was required, exceeds that of case b, or three workers per cell. This places emphasis on the necessity of cooperation and team work when considering high productivity levels. The incoming grape quality is the primary influence on productivity levels; however team work has a contributing hand in the success of the day.

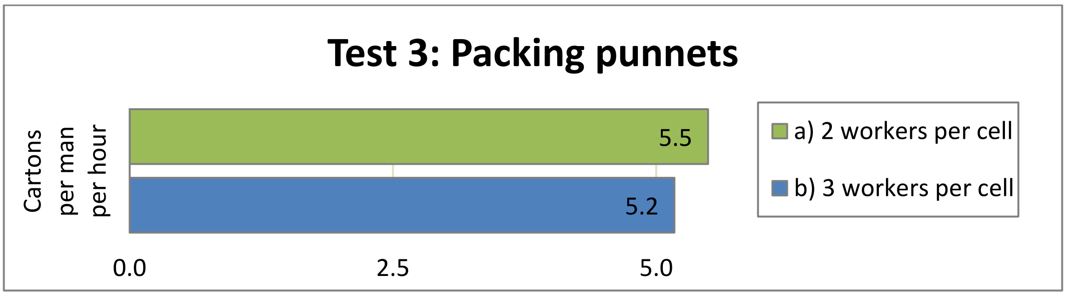


Figure 5: Summary productivity measurements of Test 3

Test 4: Packing stem-up's

Two sample periods were considered for case a. The grape quality ranged from good to poor (a large amount of cutting required). Rework also had to be done which suppressed the morale and therefore efficiency of the workforce. Two sample periods were considered for case b. For one of the case b sample periods the grape quality was excellent, in the other sample period average quality grapes were processed. Additionally the overall morale in the packing facility was low after disagreements between supervisors and the workforce. The productivity measurements taken for Test 4 can be seen in Figure 7

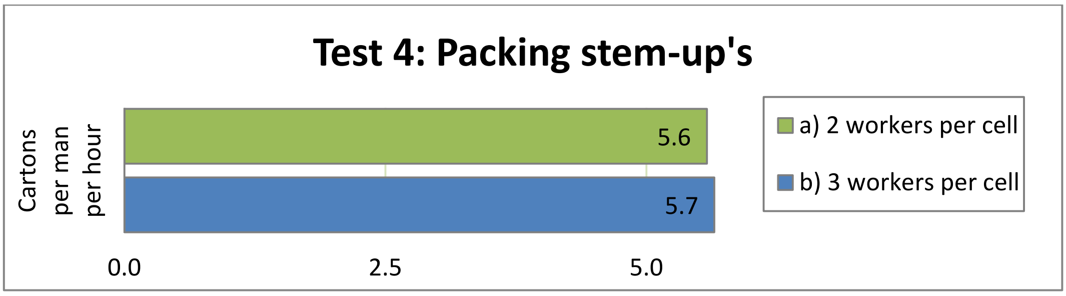


Figure 6: Summary productivity measurements of Test 4

6 CONCLUSION

An overview of the productivity measurements for case a, 2 workers per cell and b, 3 workers per cell for each test is shown in Figure 7. For comparative reasons the data for test 1 c is eliminated from the overview.

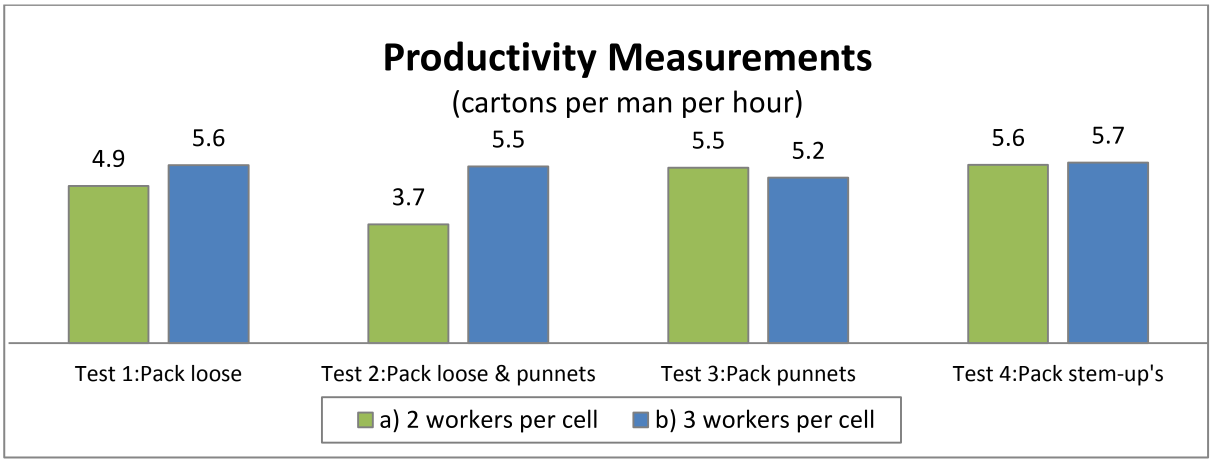


Figure 7: Productivity measurement overview

The difference in productivity measurements between case a and b, for test 4, is so small that it is disregarded in the comparison. Given the summary above it is evident that 2 workers per cell achieve a lower productivity than 3 workers per cell for test 1,2 and 4. Test 2 in particular, shows that 3 workers have a large advantage over 2 workers. However for test 3, 2 workers per cell perform better. The increase in productivity emphasizes that when packing punnets, 2 workers are able to handle the workload and that with 3 workers social loafing is present. Observations suggested that two workers make an effort to correctly size berry bunches before placing them into the punnet. This eliminates double handling and increases throughput rate. After evaluating all the information, the recommended configuration is 3 workers per cell. When packing punnets only (test 3), however, it is advised to limit the cell to 2 workers and use the remaining workers in the vineyards. Efficiency and productivity is dependent on the grape quality but also on the ability and the morale of the workforce. Ongoing disagreements can lead to long term negative influences on productivity and worker engagement.

No comparative analysis is done on the advantages of cellular configuration as opposed to the conventional production line. However through visual inspection it is possible to conclude that the WIP and material handling time for the cellular configuration line is less than for the conventional line. The long lead times for the workers working in the weighing and packaging areas in the conventional line are eliminated with the cellular approach.

It is of the utmost importance to promote team work among the workforce and the approach of cellular configuration within the packing facility is designed to specifically do this.
Further research can be focused on experimenting with different layout designs.

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ANALYSIS OF SUPPLY CHAIN AS AN EFFECTIVE MANUFACTURING STRATEGY TOOL FOR A TEXTILE MANUFACTURING FIRM

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ABSTRACT

Supply chain issues have become critical for an operation's ability to manage raw material supply, processing of these raw materials into products and their delivery to customers in an efficient manner. As a matter of fact, supply chain management is a key attribute in a globally competitive environment because it dictates the firm's delivery performance through the control of products or services from suppliers to processing stages up to the end customer. So it is critical for a firm to ensure that each member of the supply chain contributes to the desired mix of competitive priorities, that is, quality, speed, dependability, flexibility and cost required by the end customer. This paper sought to establish the supply chain issues pertaining to KM Textiles as well as determining any improvements which could be done to improve the system. It concludes by analysing the current suppliers, and customers; among other collaborators, and suggesting areas for improvement to reduce manufacturing costs for the Zimbabwean textile manufacturing company.

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1 INTRODUCTION

According to Kurien et al. [1], organizations need to capitalize on Supply Chain (SC) capabilities and resources to bring products and services with the appropriate features to the market faster, at the lowest possible cost, and the best overall value. As a result, companies can no longer focus on optimizing their own operations to the exclusion of their suppliers' and customers' operations [2]. Hence, supply chain management is central to a firm's ultimate performance on the market. Flynn et al. [3] suggested that in order to be successful in today's competitive manufacturing environment, companies must be more responsive to the constantly changing needs of their customers and concentrate resources on their core competencies. Gunasekaran et al. [4] points out that it is pivotal for a firm to properly manage its inbound logistics (raw material supply), the processing of the raw materials at a low cost whilst meeting the quality requirements, and its outbound logistics (delivery to customers). Suwanruji et al. [5] outlines the fact that advances in manufacturing strategies like the Just-In-Time (JIT) principle have put pressure on supply chain dynamics whereby managers have to reduce raw material inventories as well as work in progress in the plant thereby placing further dependence on suppliers to meet raw material supply on time to reduce manufacturing costs. Nair et al. [6] highlighted the fact that the pace of change and the uncertainty about how markets will evolve has made it increasingly important for companies to be aware of the supply chains they participate in and to understand the roles that they play to gain competitive advantage. Rudberg et al. [7] presented that the purchasing function in a firm was traditionally viewed as a transaction oriented function but the evolution of supply chain issues in raw material supply made it to play a more strategic role in determining the overall success of the firm. A study by Ribas et al. [8] found out that Nestlé India's supplier development department managed to cut costs by overcoming quality and food safety issues, and creating a wider, more flexible supply base through provision of technical assistance, and support to suppliers' management systems and products. The research findings estimated that the company has saved over US$5 million in 5 years by developing over 70 new Indian suppliers who meet standards, and the initiative has been so successful such that the company replicated it in Bangladesh, Brazil, Indonesia, Iran, Malaysia, Russia and South Africa. This study sought to understand the supply chain strategy applied by KM Textiles, and how it has contributed to the success of the firm in reducing manufacturing costs, skill improvement, increase in throughput, and gain of market share in a dynamic global market. The case study textile manufacturing firm is a member of ZSW Limited a group of companies which include its spinning division. In addition, the firm produces a wide range of cotton based fabrics for industrial use, for both the local and global market.

2 LITERATURE REVIEW

2.1 Linking corporate strategy and competitive strategy to supply chain strategy

Rudberg et al. [7] points out that fierce competition in today's global markets, the introduction of products with shorter life cycles, and the heightened expectations of customers have forced business enterprises to invest in, and focus attention on, their supply chains. In today's competitive market, manufacturing industries have to satisfy more diverse queries from the market, such as widening the product ranges, increasing quality and precise delivery time [6]. Datta et al. [9] suggests that manufacturing companies need to be knowledge-intensive and highly creative to develop new products. Kurien et al. [1] defines Supply Chain Integration (SCI) as the degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra- and inter-organization processes. The authors highlights that the ultimate goal of SCI is to achieve effective and efficient flows of products and services, information, money and decisions, to provide maximum value to the customer at a low cost and high speed (using advances in communications and transportation technologies). Datta et al. [9] presented the fact that in a typical supply chain, raw materials are procured and items are produced at one or more factories, shipped to warehouses for intermediate storage, and then shipped to retailers or customers. Consequently, to reduce cost and improve service levels, effective supply chain strategies must take into account the interactions at the various levels in the supply chain [10]. Peidro et al. [11] points out that the Supply Chain (SC) planning problem can be decomposed according to the time horizons considered, which results in strategic, tactical and operational decision models that can be applied to SC planning. Rudberg et al. [7] outlines the fact that strategic planning models affect SC design and configuration over a relatively long time (5 to 10 years) whereas tactical planning models attempt to adopt the most optimum use of the various resources, including manufacturing plants, warehouses, suppliers, distribution centres, and transport; among others, with planning times lasting 1 or 2 years. According to Ribas et al. [8], operational planning models are related to the detailed scheduling definition, sequencing, lot size, assigning loads and vehicle routes; among others. Wilding [12] gives an overview of the corporate strategy formulation to gain competitive advantage and how it is linked to supply chain strategy as shown on Figure 1.

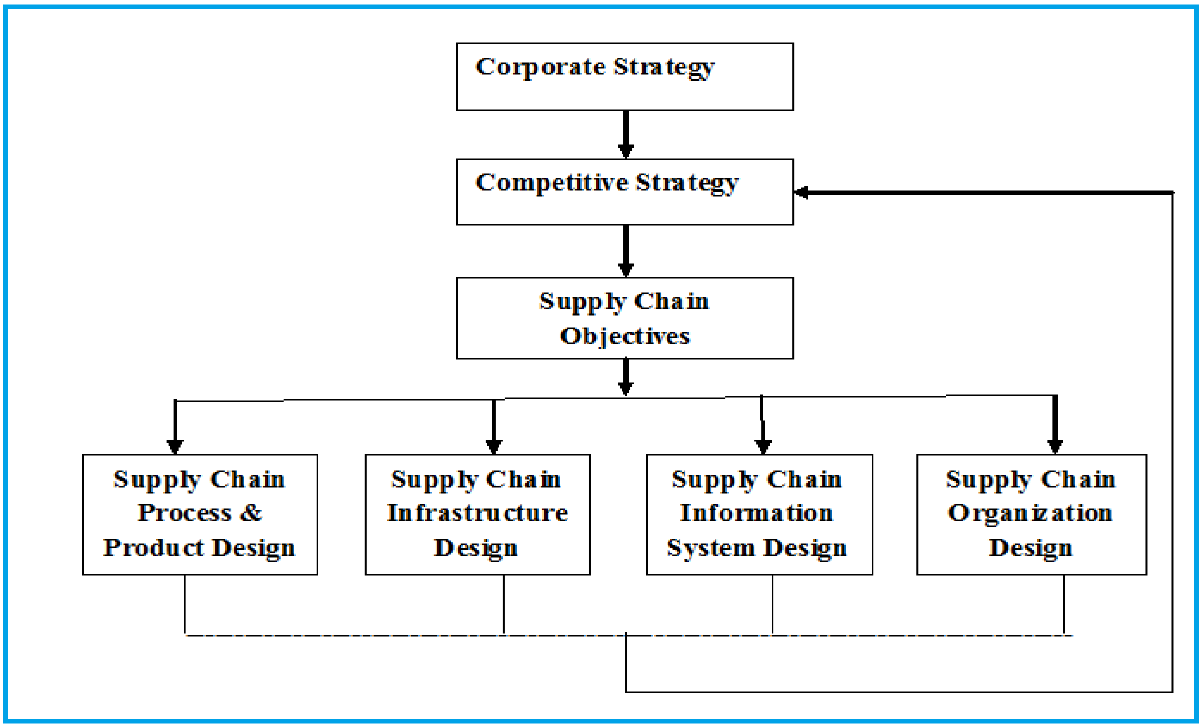

Figure 1: Supply Chain Innovation, Linking Corporate Strategy and Competitive Strategy with Supply Chain Strategy - Adapted from Wilding [12]

2.2 Supply Chain Performance

Cagnazzo et al. [13] proposed that a supply chain measurement system must place emphasis on three separate types of performance measures, namely: resource measures (generally costs), output measures (generally customer responsiveness), and flexibility measures (ability to respond to a changing environment). Morgan [10] addressed that these three types of performance measures have different goals and purpose. Kurien et al. [1] suggested that some of the resource measures include: inventory levels, personnel requirements, equipment utilization, energy usage, and cost; whereas output measures include: customer responsiveness, quality, and the quantity of final product produced. Rudberg et al. [7] outlines that flexibility measure a system's ability to accommodate volume and schedule fluctuations from suppliers, manufacturers, and customers. Figure 2 shows performance measures and metrics in a supply chain.

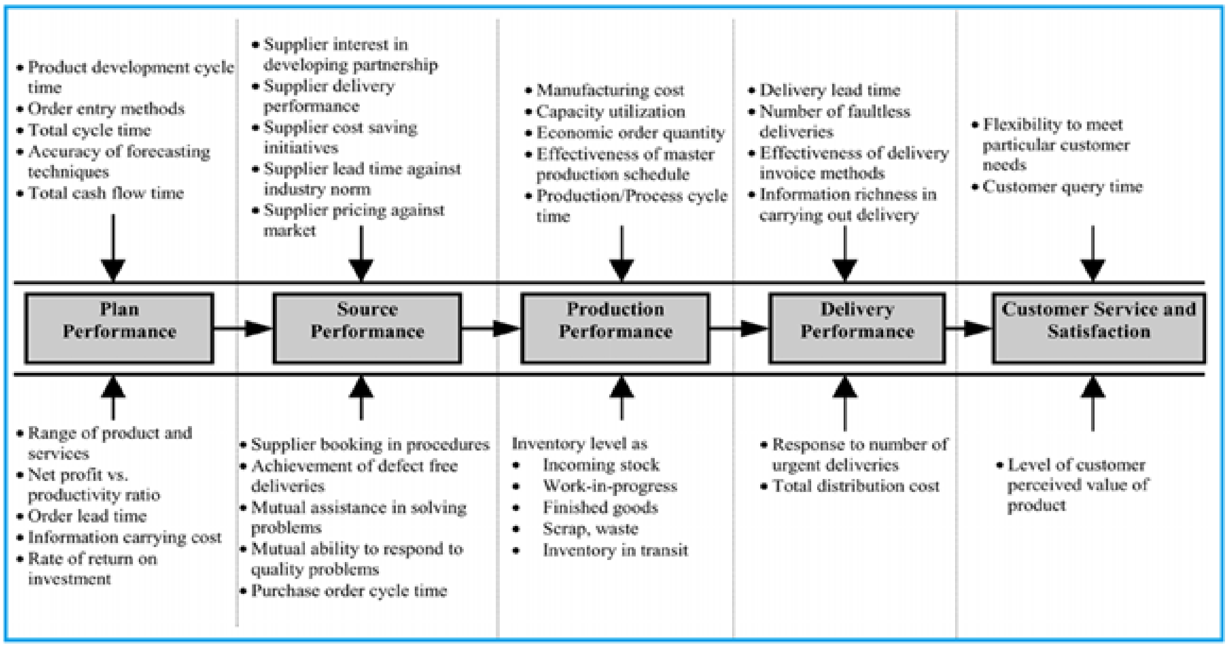

Figure 2: Measures and metrics at five basic links in a Supply Chain – Adapted from Kurien et al. [1]

2.3 The Value chain analysis as a source of competitive advantage

Chiang et al. [2] highlighted that the supply chain, also known as the logistics network, consists of suppliers, manufacturing centres, warehouses, distribution centres, and retail outlets, as well as raw materials, work-in-process inventory, and finished products that flow between the facilities. According to Porter et al. [14], competitive advantage grows fundamentally out of the value a firm is able to create for its end customers. The authors use the concept of a value chain to disaggregate buyers, suppliers and a firm into discrete but interrelated activities from which value stems as depicted on Figure 3. Suwanruji et al. [5] points out that value chain analysis is critical to supply chain in terms of recognizing and creating actions that support the selected generic strategy. That is, a firm applying a cost leadership strategy (pricing) or differentiation strategy (product characteristics) would initiate suitable activities throughout its value chain. The discrete value activities (primary and support activities) are the building blocks of the value chain and provide linkages crucial for competitive advantage through co-ordination with business partners [14]. Flynn et al. [3] suggested that linkages not only exist within a firm's value chain, but between a firm's chain, and the value chain of suppliers and channels (vertical linkages) thereby providing potential benefits of integration for competitive advantage.

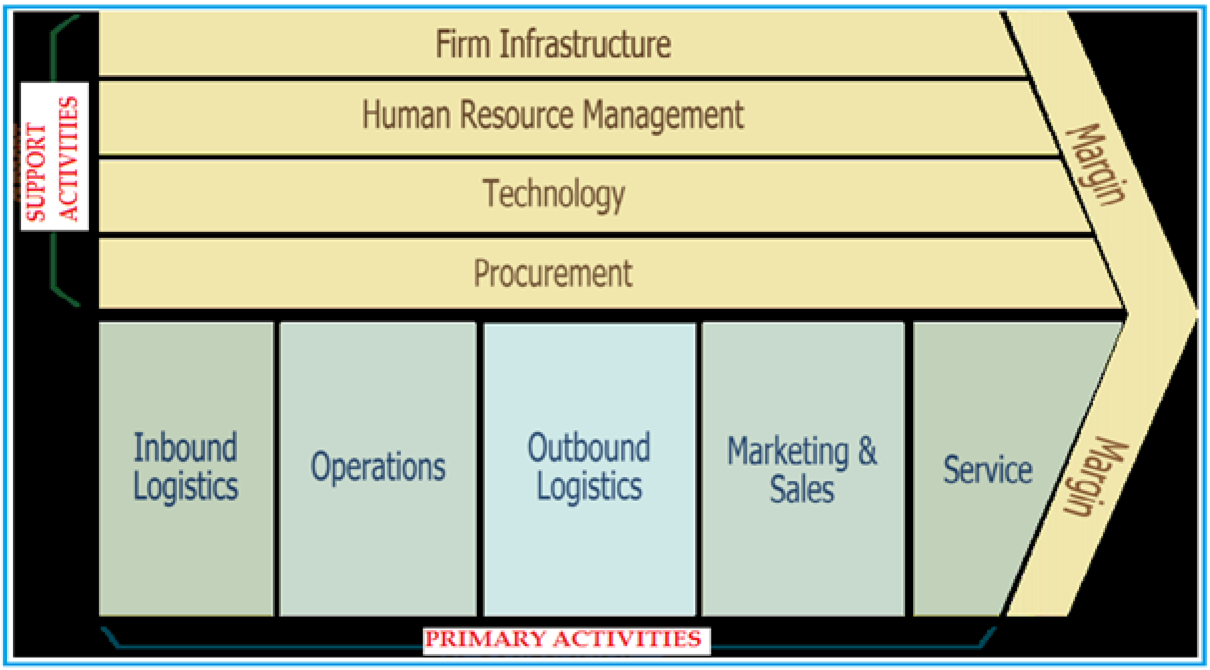

Figure 3: Value chain as a source of competitive advantage in supply chain - Adapted from Porter et al. [14]

2.4 Factors Impacting the Supply Chain

Nair et al. [6] and Rudberg et al. [7] summarize the factors impacting on supply chain strategy formulation as follows:

- Reduced number of suppliers – the concept of supply chain has forced firms to reduce the number of vendors they deal with in order to reduce costs and establish long term relationships with a few highly reliable suppliers.
- Increased competition – the increase in the number of competitors that offer similar products in the market put pressure on firms to clearly focus and develop robust supply chains which reduce cost and offer the best value to the end customer.
- Shorter product life cycles – as competition introduces new products, firms are forced to shorten product life cycles and this call for flexible processes that can be converted easily to new product requirements.
- Increase in supplier managed inventories – most firms empower their suppliers to replenish low cost components whenever they are needed in the production system. Hence, suppliers have direct access to the manufacturing plant and usually restock items at the workstations where they will be used.
- Advances in technology – the advent of technology have a significant impact on supply chains where Electronic Data Interchange (EDI) is used to link the firm's database to supplier and customer databases. Quick response strategies are supported by technology advancement.
- Shared or reduced risk – the rise of shorter product life cycles expose firms to risk associated with new product developments. Hence, firms share this risk with their suppliers and customers whenever a new product is introduced on the market.

3 RESEARCH METHODOLOGY

3.1 Research design

In this study a case study research design was used to tap data on the supply chain strategies applied by the textile manufacturing firm. The unit of analysis in this study is KM Textiles. Furthermore, this study applied both quantitative and qualitative data collection methods. Interviews were used as the main research instrument complimented by observations and archival records to extract key data for the research. Stratified random sampling was used in selecting research participants in order to ensure representation.

3.2 Data collection

The research interviews were carried out on 10 head of departments and 20 supervisors (2 employees from each department) selected on the basis of work experience, covering a range of 5 to 10 years. Furthermore, the General Manager (GM) of the organization was also interviewed on key issues affecting the supply chain and the future plans to develop the value chain. During these interviews the researcher wanted to extract data on the different types of raw materials used by the firm in its processes and the suppliers of these raw materials. The interviews were also focusing on the processing stages that the raw materials pass through until delivery to the end customer, and the various customers directly linked to the firm. In this study the researcher wanted to understand the level of integration between the firm and its suppliers as well as customers. The interview response was encouraging and provided key data required for the study. It was found that 8 out of 10 (80 percent) interviewed head of departments were at least 5 years old at the company whilst 17 out of 20 (85 percent) interviewed supervisors were at least 8 years old at the company. This provided the researchers with the necessary data about the supply chain issues related to the firm and the various collaborations involved. Observations and archival records were used to show production sequence, and to provide data on various production stages that the different products manufactured by the company go through.

3.3 Data analysis and presentation procedures

In analysing the research data, both qualitative and quantitative methods were used. A qualitative approach was applied on explanation of the supply chain issues applied by the firm and the quantitative approach was used through statistical and graphical illustrations of the data collected to provide key information for the study. The study results explains the current supply chain strategy applied by the firm and the improvements which can done in order to come up with an optimum result to help reduce production costs, improve production flow and ultimately reduce cost for the end customer.

4 DATA PRESENTATION AND DISCUSSION OF RESULTS

This section outlines the research findings on supply chain strategies applied by the textile manufacturing firm in its quest to gain competitive advantage in a volatile global market. More so, the discussion of the results was done to bring about key information about the company's key suppliers, production processes and customers; among others. The study results further outlines the strength and weaknesses of the firm's supply chain system and how it can use other strategies to improve its supply chain to gain competitive advantage over its rivals.

4.1 The major inputs, processes and outputs for the firm

The research interviews, observations and archival records provided key information on the major inputs, processes, and outputs of the textile manufacturing firm in order to highlight issues of supply chain management. The information depicted on Table 1 shows how the organization sources its major inputs. That is, the firm acquires most of these inputs from local retailers (39 percent) and South African suppliers (43 percent), with only a few from global suppliers (18 percent) as shown on Figure 4. It is vital to note that local retailers and South African retailers are middlemen accordingly, and it is expensive to buy from middlemen.

Table 1: Results on inputs, processes and outputs of the firm

Inputs		
Major Inputs	**Primary Source**	**How the company acquire the resources**
Sizing agents	Asia	Imports from South Africa
Dyes	Asia and Europe	Local retailers, South Africa and Global sources
Sodium Hydroxide	Asia	Local retailers
Hydrogen Peroxide	Asia	Asia
Other chemicals	Asia	Local retailers and Asia
Auxilliaries	Asia and Europe	Local retailers
Finishing chemicals	Asia and Europe	Local retailers and also from South Africa

Processes	
Major Processes	**Resource Requirements**
Spinning	Cotton lint, Lubrication and gearbox oils, and imported machine spares
Sizing and Weaving	Sizes, oils, yarn, and imported machine spares
Pre-treatment	Chemicals, greige fabric, oils, and imported machine spares
Dyeing	Bleached fabric, dyes and auxiliaries, oils and imported machine spares
Finishing	Bleached or Dyed fabric, finishing chemicals, oils and imported machine spares
All Wet processes need coal for boilers to generate steam for production machines	

Outputs	
Major Outputs	**Target Market**
Industrial Fabrics (Greige, bleached, white or dyed)	Local, Export and Global
Medical Textiles (Theatre gauzes, bandages, swabs)	Local, Export and Global
Napkins	Local
Sheets	Local, Export and Global
Other Products	Local

It was highlighted during interviews that although South African suppliers manufacture some chemicals like sizing agents and reducing agents, the raw materials used are sourced from Asia. Therefore, it could be better if the firm considers bulk purchasing of major raw materials (inputs) directly from source. The firm's major processes use dyes and chemicals, gearbox oils, and machine spares; among other key components which are imported which need cash flow to acquire. It is critical to note that the rise of global manufacturing champions call for the firm to consider long term synergies with reliable global suppliers of key dyes and chemicals used in the textile manufacturing process. This will provide an impetus against world leaders in textile manufacturing like China, India and other Asian countries. Although these raw materials come from China and Asia in general; the creation of long term strategic alliances with these global suppliers will mean reduced prices of raw materials through bulky purchases or purchasing as a consortium.

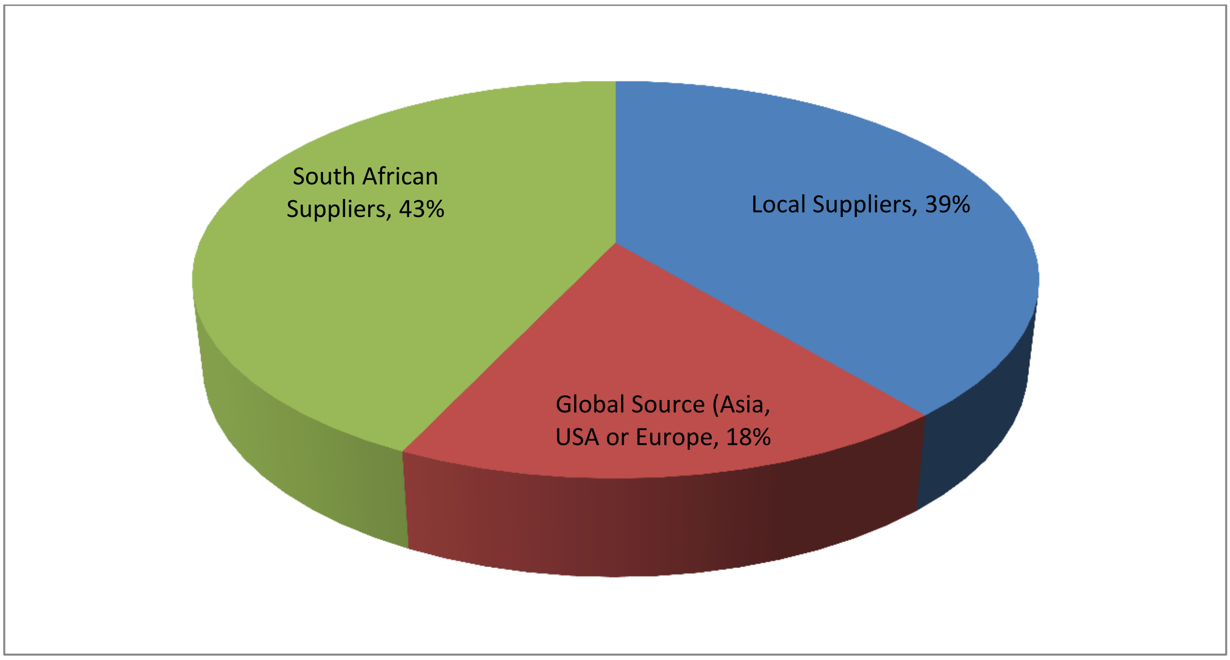

Figure 4: Sources of raw materials for the textile manufacturing firm

The collected data for the research provided key information on contribution of raw materials to manufacturing costs. It was highlighted that dyes and chemicals (used in pre-treatment and dyeing processes) as depicted on Figure 5 are the major contributors to cost with 47 percent, followed by machine spares with 17 percent, auxiliaries with 9 percent, finishing chemicals with 8 percent and hydrogen peroxide with 7 percent; among others.

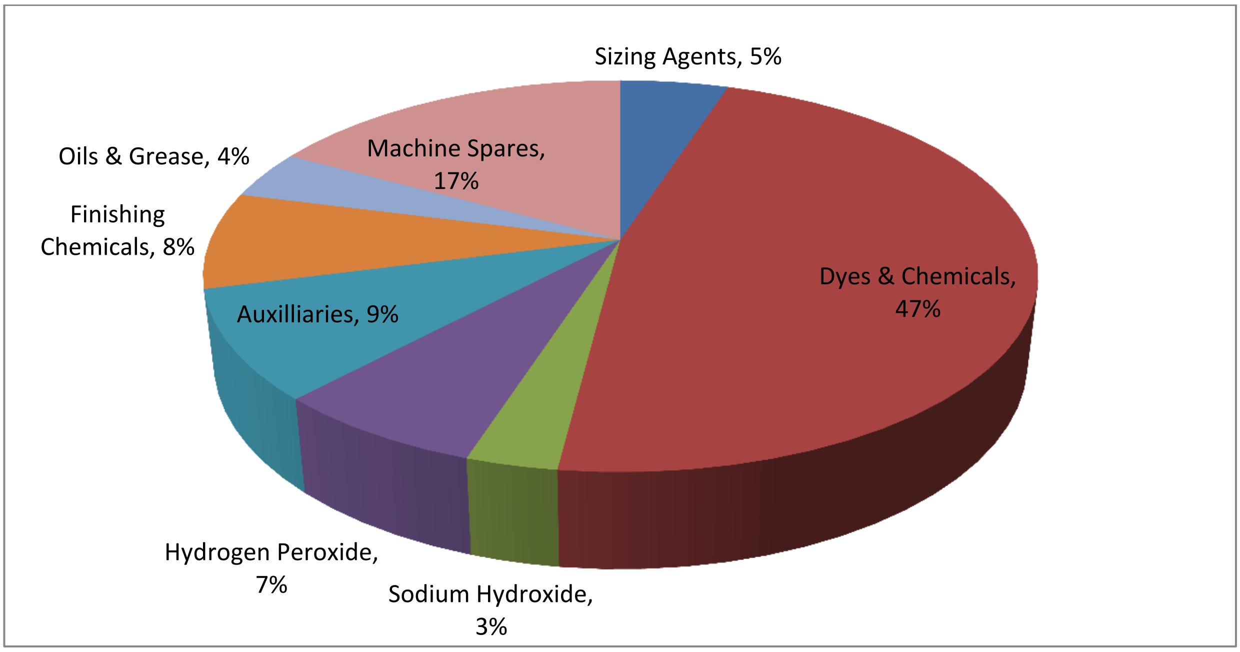

Figure 5: Contribution of various raw materials to manufacturing costs

4.2 Market for the firm's products

It is pivotal to note that firms initially desire to saturate the Zimbabwean market and as it learns the manufacturing system it goes into the regional export market and lastly global market as economies of scale are realised. That is, the goal is to increase shareholder value as the firm matures in the industry. Generally, most of the products from the firm are sold locally (48 percent) with 37 percent going into the SADC region, and the remaining 15 percent into the global market as depicted on Figure 6. The African Growth and Opportunity Act (AGOA) eliminated tariff and quota restrictions to the United States market for sub-Saharan Africa countries that managed to get their visa systems approved. However, the Zimbabwean textile manufacturing sector failed to access the American markets due to failure by the government to meet AGOA standards on corporate governance. This revealed the requirement for the firm to come up with marketing strategies to manage their supply chains effectively to provide a viable market for the firm's products globally.

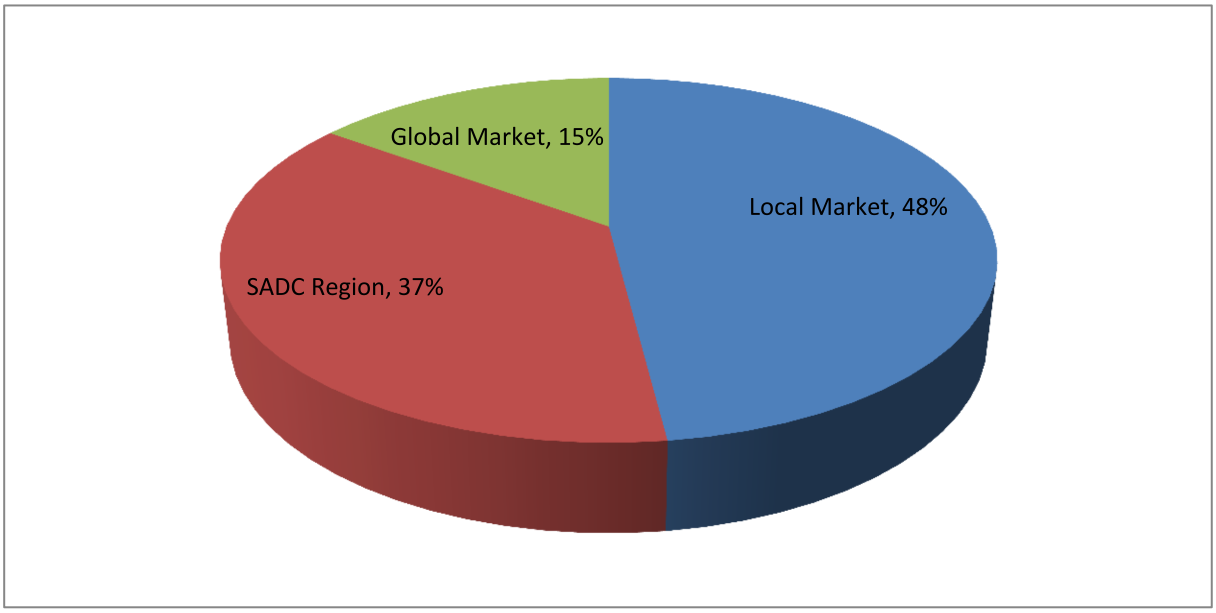

Figure 6: Distribution of customers for the textile manufacturing firm's products

4.3 Use of information technology (IT) by the firm to provide quick response

Global competition forces companies to opt for an extended enterprise within the framework of supply chain to provide a link within the firm's value chain as well as linking with suppliers and buyers of the firm's products. The study found out that the organization has only departmental systems which do not integrate the whole company, that is, it has Manufacturing Information Systems (MIS) as standalone systems. For example, most of the firm's manufacturing systems have SCADA systems, accounting department uses ACCPAC package which is also linked to the purchasing department and human resources department uses e-business Skillset Enhancement Tool (ESET) for employee database and payroll management. The interview results on 10 managers and 20 supervisors depicted on Figure 7, pertaining to their opinion on the current Information Technology (IT) used by the firm revealed that 53 percent advocates for staying with the current system, 27 percent wants a system upgrade and the remaining 20 percent wants the firm to purchase a new IT system. Generally, the results show a reluctant desire by the firm's management to acquire a new Enterprise Resource Planning (ERP) system, to aid its supply chain.

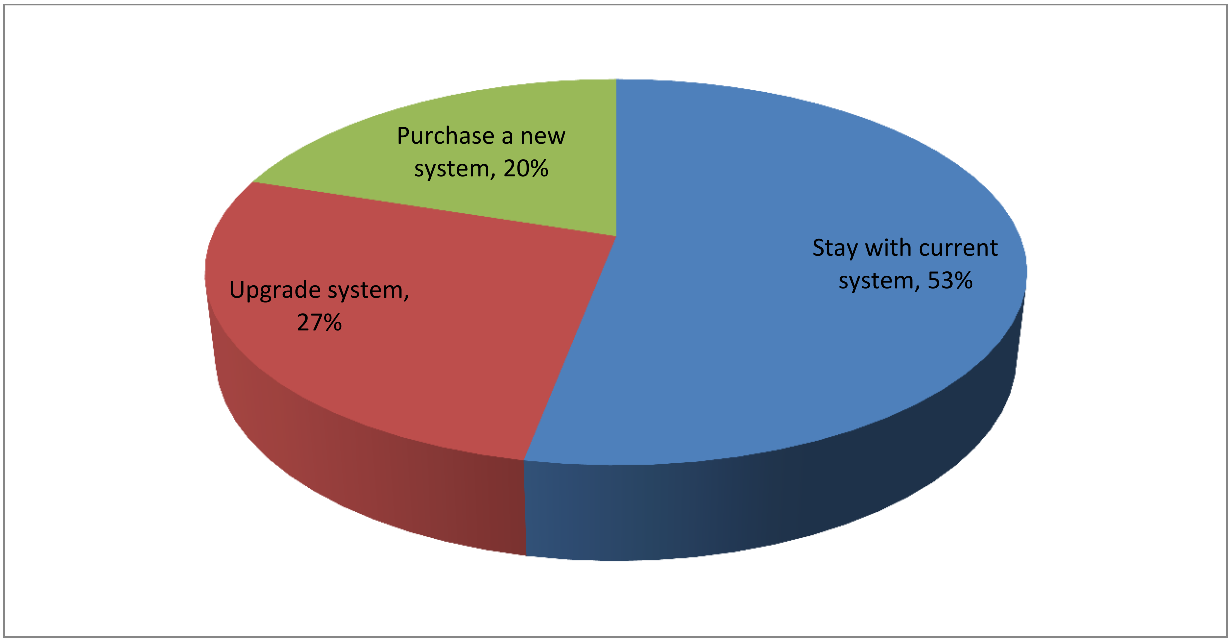

Figure 7: Plans for future IT systems improvement by the firm

It was found out that the organization is using Outlook Express for Intranet (departmental links) communications and Internet to link with business partners. However, there are no database linkages with suppliers for stock replenishments and customers for checking finished product availability; among other issues. As a matter of fact, these systems need to be fully integrated with suppliers and customers through the use of Enterprise Resource Planning (ERP) systems such as SAP, Oracle, People-Soft, BAAN, and SAGE; among other packages. The extended enterprise demands commercially available tools for the integration of applications in a supply chain. This poses a challenge to the firm to adopt modern IT system in order to achieve responsiveness in the supply chain.

4.4 Value chain analysis (future plans)

In this study it was found out that value chain analysis is pivotal to supply chain strategy implementation and provides the basis for carrying out a resource audit. During interview with the company's General Manager it was highlighted that the firm has future plans to effectively use the value chain to support its linkages with suppliers and customers as shown Figure 8.

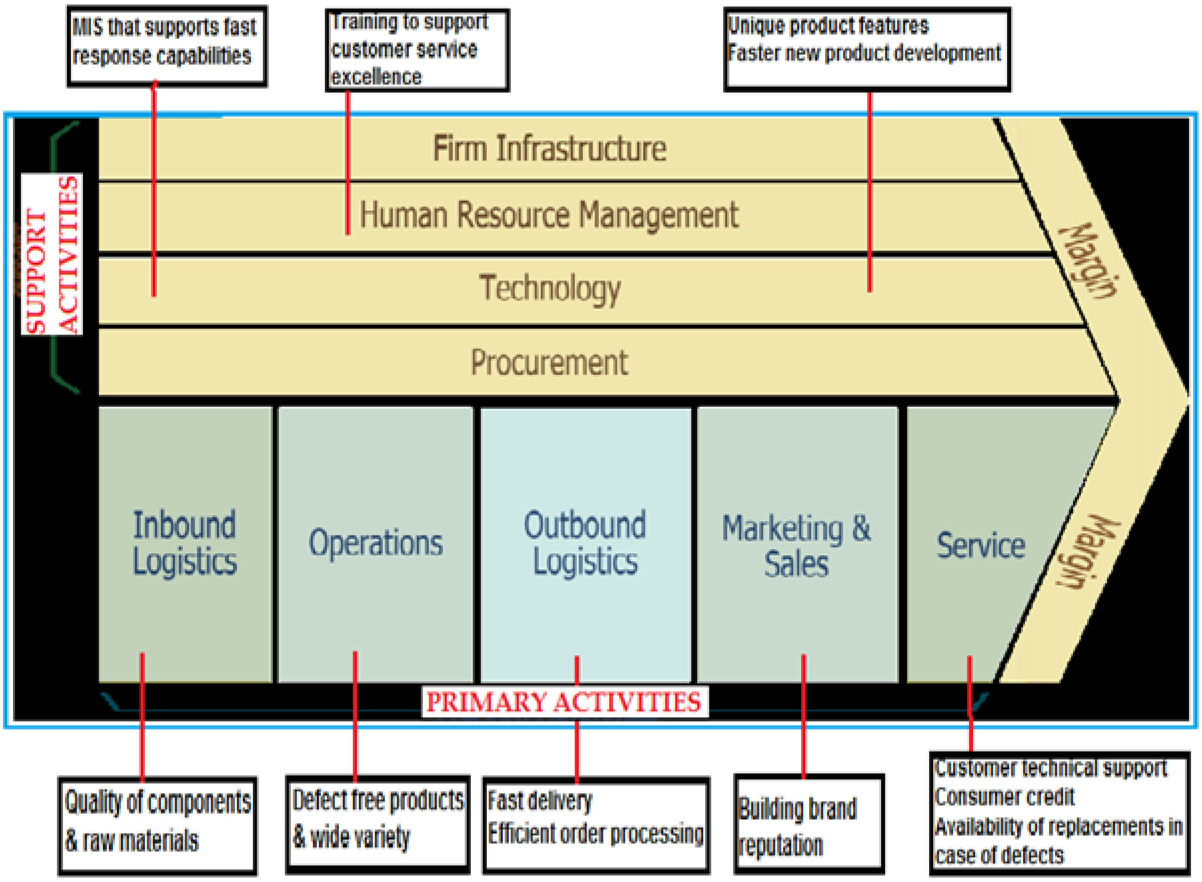

Figure 8: Ideal value chain analysis for the firm depicting areas that need attention

5 Recommendations

In order to keep pace with global manufacturing standards, supply chain management must be the top priority for KM Textiles, and the following need to be done by the firm to improve its supply chain:

- To create synergies or long term relationships with global suppliers of key raw materials like dyes and chemicals, machine spares and auxiliaries; among others so as to reduce manufacturing costs related to raw material sourcing.
- To partner companies in the global textile industry in order share data on sales trends, forecasting data, and production schedules, promotional plans, engineering changes, new product development plans and global product enhancements. Data sharing benefits a company's operations and helps it better understand the needs of its customers.
- To purchase new Information Technology (IT) systems such as acquiring ERP systems which provide a link to all departments as well as linking with business partner databases. This provides a basis for rapid response and real time information provision for quick decision making.
- To carry out benchmarking (internal, external, competitive and performance) in order to determine the gap between the current and the required performance.
- To train employees in order to develop skills so that the workers become the drivers of supply chain strategy. Training is critical to support customer service excellence.

- To carry out a marketing drive to increase global market share for the firm's products by focusing on developing robust delivery and communication systems with customers.

6 CONCLUSIONS

The study found out that the challenge in today's global business is to identify the appropriate supply chain solutions to meet the different needs of the different product or market characteristics. Value chain analysis was found to be critical to a manufacturing firm because it provides a basis for a resource audit to determine the gap that need to be filled-in to create a competitive supply chain system. The study found out that well managed supply chains reduce manufacturing costs through synergies thereby creating value for the end customer. It was observed that in order to achieve a robust supply chain, a suitable information system integrating Enterprise Resource Planning (ERP), Electronic Data Interchange (EDI), and the Internet is important for improving communication and ensuring a smooth flow of materials along the value chain. The effective implementation of Information Technology (IT) by manufacturing firms is highly desirable if a supply chain is to be responsive and flexible. In addition, it is also appropriate to carry out benchmarking, to determine performance measures, and metrics to build a competitive supply chain. With the dynamism in the world market today, it is clear there is still room for improvement in managing raw material supply and delivery of products to end customers by KM Textiles that will keep it with a competitive edge over its rivals.

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A REVIEW OF THE PROCEDURES AND PROCESSES TO START-UP A NON-PROFIT ORGANISATION (NPO) UNDER SOUTH AFRICAN LAW WITH SPECIAL REFERENCE TO THE NPO ACT 71 OF 1997 (THE NPO ACT)

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ABSTRACT

Most research on non-profit organisations (NPOs) concentrate on operational issues such as organisational sustainability, governance, business plans, marketing and funding. Little research has been done on the experience of NPOs during the registration process. This study investigates the familiarity of NPOs of the rules and procedures involved in the registration process and the influence of the Department of Social Development (DSD) in executing the requirements of the NPO Act. The paper considers background information on NPOs, their role in society and the governance procedures instigated as per the NPO Act. The results of the research are expected to assist to prepare start-up NPOs, before the registration process, such that registration can run smoothly and that the organisation can effectively execute their objectives. Documents archived in the DSD online database [27] and email communications with a Director of the NPOs, was used to analyse the influence the NPO Directorate has on the NPO Act and registration. Multiple case studies of a number of registered NPOs, through an online survey, found out that many NPOs that are registered are ignorant of the rules and regulations and unable to perform efficiently. In addition, most organisations are unaware of the government grants that are accessible to registered NPOs. Therefore, significant prior knowledge before registration can supplement NPOs to prepare for the registration process as well as establishing their organisations with great success. The checklist created shall also provide a guideline for NPOs to establish their organizations efficiently. Organisations should thus take an effort to increase their understanding through networking with other NPOs and DSD.

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1 INTRODUCTION

Non-profit organisations (NPOs) exist to provide funding and services to the community and/or the environment, fulfilling a particular cause and purpose of the organisation. A NPO is an establishment that does not run with the intentions to make any financial or equivalent gain for itself. This does not mean that the normal drivers of efficiency and effectiveness are absent; in fact they are more likely enhanced. For this reason an industrial engineering intervention in this sector was desirable.

A NPO can base their objectives on "*social welfare and development, religion, charity, education and research*" [1]. Other aspects can include environmental and animal rights activism, sports development, arts and other facets that are of interest to the community [2]. The John Hopkins study's defines NPOs as organisations that are structured, separate from the government, independent, not for profit and have voluntary support [3].

NPOs have a large impact on the economy, having a greater workforce than sectors like mining and transport, containing human capital worth around R 13 billion rand [1]. The civil society sector employs about a million people [4]. This sector significantly relieves governments from the responsibility in community upliftment.

The Non-Profit Organisations Act No. 71 of 1997 (NPO Act) has a primary objective in creating a framework of governing NPOs in South Africa, for the execution of an NPO's objectives. The framework involves the registration process for NPOs, dispute resolution processes, cancellations, financial year-end reporting requirements and consequences for any offences committed. The Minister of the Department of Social Development (DSD) has the responsibility to ensure execution of the requirements of the NPO Act. [5]

Previous studies conducted in some aspects of the non-profit sector consist of:

1. Size and scope of NPOs in South Africa [1];
2. Expertise of employees within NPOs [1];
3. Business models of NPOs in relation to the NPO Act [6];
4. The funding process of civil society organisations (CSOs) [4];
5. Control of non-government organisations on local governance [7]; and
6. A brief explanation of the impact of regulations on NPOs [2].

NPOs' knowledge of the regulatory system at start-up have however not been discussed in-depth. Ignorance of the system can result in delayed execution of the objectives of an NPO from point of registration. The investigation would unravel the hypothesis that organisations are not aware of some aspects of the procedures involved before registration.

1.1 Objectives

1. To review existing procedures and policies on the start-up of an NPO;
2. To investigate the perceived user friendliness of existing rules and regulations;
3. To track an NPO through start-up and document it;
4. To create a start-up checklist based on current procedures and policies for potential NPOs.

1.2 Assumptions

The investigation made use of the following assumptions:

1. Proper start-up of an NPO is one of the tools that would lead to sustainability of the organisation;

2. An NPO with a good start-up has a better buy in from the public;
3. Registered NPOs have better donor support; and
4. NPOs have a positive impact on the economy [4].

2 NON-PROFIT ORGANISATIONS ACT NO. 71 OF 1997 (NPO ACT)

Registration within the NPO Act is not mandatory for organisations; yet it carries associated benefits. Registered NPOs are eligible to fundraise, apply for tax exemption and legally source financial assistance [2]. Thus NPOs can continue to exist when members, executives and directors change.

The NPO Act enables NPOs to contribute to the various needs of the South African population. Thus, the NPO Act intends to meet the following objectives [5]:

1. To create a surrounding where NPOs are empowered to succeed;
2. To instigate basic requirements in the manner in which NPOs are governed;
3. To replace particular sections of the Fundraising Act of 1978;
4. To offer governance on other concerns related to NPOs;
5. To create an environment where registered NPOs information is easily accessible to the general public; and
6. For government, donors, individuals and companies engaging with NPOs to collaborate and have mutual accountability.

An NPO is any *"trust, company or other association of persons"[5]* created for the benefit of the public and where any income and property generated or acquired cannot be allocated to its members, director, trustee nor executive unless it is related to a salary or wage payment for a service provided to an NPO [5]. All income and property under an NPO are for the sole purpose for which that NPO was established.

2.1 Non-Profit Sector Analysis

Over a period of five years, between April 2007 and March 2012, there has been a 14 % average annual growth rate of voluntarily registered NPOs (Figure 1) [8]. In the five year period, 10 274 registered NPOs deregistered, 99 % were due to non-compliance to the NPO Act while the 1 % was due to voluntary deregistration and termination of the organisation. The percentage of deregistered NPOs is in proportion to the percentage of registered NPOs across provinces [8].

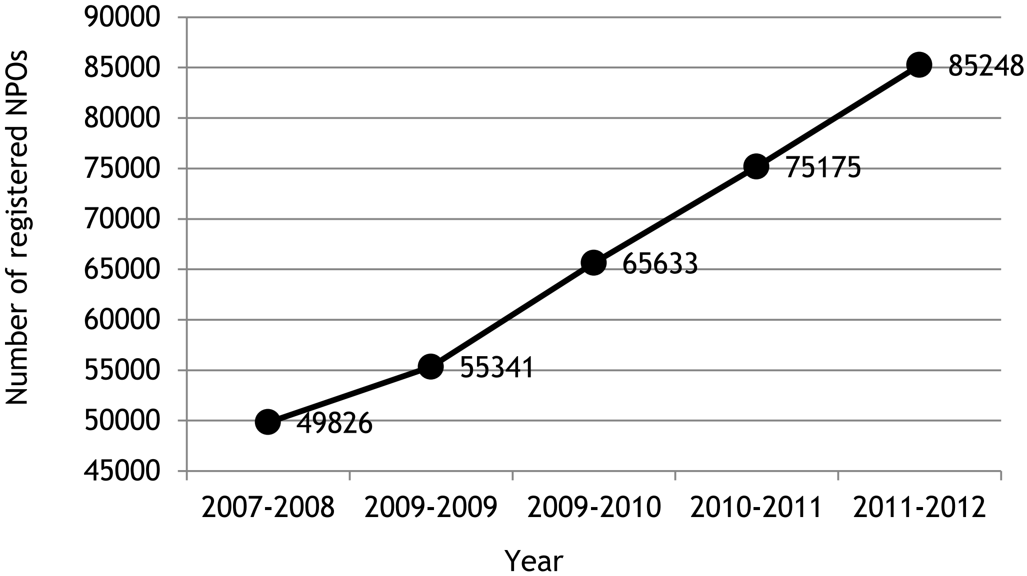

Figure 1: Growth of NPOs registration over a 5 year period [8]

Figure 2 shows the number of registered NPOs per province.

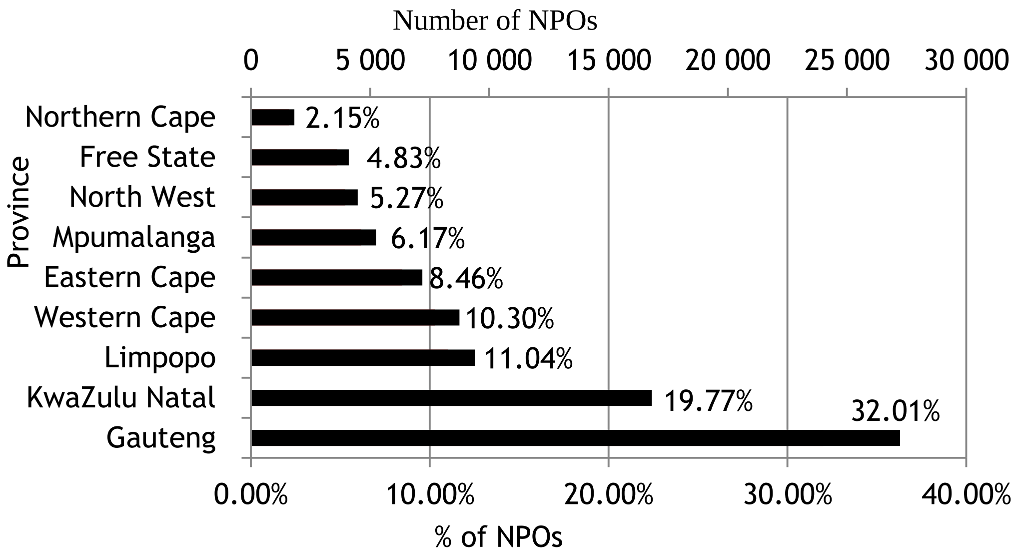

Figure 2: Registered NPOs per province [8]

The Department of Social Development (DSD) assist in enabling the non-profit sector. Conferences and discussions amongst the government, donors and NPOs link relationships, aids in coordination and build the sector. DSD has taken measures to implement the NPO Act, which actions are ongoing. The main concern is a high non – compliance rate.

3 RESOURCES AVAILABLE TO NPOS

"The major source of income and support for Civil Society Organisations is direct foreign government funders, private foreign funders, the South African government and corporate social investment" [4]. Like any organisation, NPOs require resources to exist, the difference however is that NPOs provide a service to the community, rely heavily on voluntary services to enable functions, obtain a large contribution of finances from external donors and utilise generated incomes to execute the NPO objectives.

Registered NPOs have the potential to access financial benefits of the Lotteries Act 1997, National Development Agency Act (NDA) of 1998 and Taxations Laws [1, 3, 4, 9]. Though different boards are responsible for these grants, the DSD contributes in the decision-making. Success in grant making is dependent on a number of requirements met by an NPO. NPOs must complete the required funding forms and have sound record keeping for eligibility for tax exemption. [1]

NPOs' objectives must be in line with the DSD to be eligible for funds. The NPO must present a funding proposal. NPOs must have a financial system managed by qualified persons. Most NPOs lack this skill and the process is cumbersome and confusing for first time participants. Competition for funding amongst NPOs further reduces grant – success [10].

3.1 Taxation Laws/Income Tax Act (ITA) No. 58 of 1962

The South African Revenue Service (SARS) governs tax related issues with individuals and organisations. Registered NPOs are not automatically exempt from Income Tax. NPOs must meet the requirements of the Income Tax Act (ITA) and be approved to obtain tax exemption which are granted to public benefit organisations (PBOs) [11]. Violation of the act may lead to fines or the revocation of PBO status [12].

3.1.1 Public benefit organisation (PBO)

Registered South African organisations may apply for PBO status. Because NPO registration is a voluntary system, it is not a requirement to be a registered NPO to apply as a PBO provided the organisation is tax compliant [12].

The main objective of the PBO must be to conduct one or more public benefit activities (PBAs) as stipulated in the ITA. At least 85 % of PBAs, in terms of time or cost, should be within RSA for the benefit of those residing within the country [12].

3.1.2 Donation tax benefit (Section 18 A of the ITA)

The Tax Exemption Unit with SARS is responsible for handling PBO status and section 18A status. Section 18A of the ITA refers to the relief of the donations tax for monies that were issued for PBAs. PBOs would be able to issue a section 18A certificate to donors. [12]

A donation tax of 20 % is liable on a donor. A maximum value of R 100 000 made by an individual is relieved from donations tax in a given tax year, while donors that are not individuals only have the benefit until R 10 000. A joint tax liability will suffice for both the donor and recipient if the donor does not pay the donations tax within three months from the donation. PBOs are exempt from donations tax. [13]

Section 18A status is not applicable to overseas NPOs or their RSA branch. [12]

3.1.3 Requirements of a documented constitution

Even though, an NPO registration is not required, there is still a requirement in terms of section 30 of the ITA that is quite similar to registered NPOs. A PBO requires a documented constitution [12].

3.1.4 Reporting requirements

PBOs must submit income tax returns at the end of their financial year, so that SARS can ensure that the PBO is exercising within its exempted limits. Submission of financial statements (income statement, balance sheet and other supporting accounts) is not required with the return, but is required to be stored for five years. PBOs shall retain financial records, documents and receipts for 4 years. SARS may request financial statements if need be. A person with fiduciary responsibility as well as the person who has arranged the statements on behalf of the PBO should sign accounts. Only non-profit companies are required to have audited financial statements. It is expected that firm and economically viable PBOs, to submit statements organised by a certified accountant. A PBO should issue an audit certificate to SARS, verifying that the use of donations received for section 18A was exclusively for the eligible PBAs. [12]

3.2 Lotteries Act No.57 of 1997 (Lotteries Act)

The Lotteries Act allows for allocation of funds to NPOs [14] that make applications for consideration for the following year.

Figure 3 illustrations allocation of funding across NPO categories in 2011.

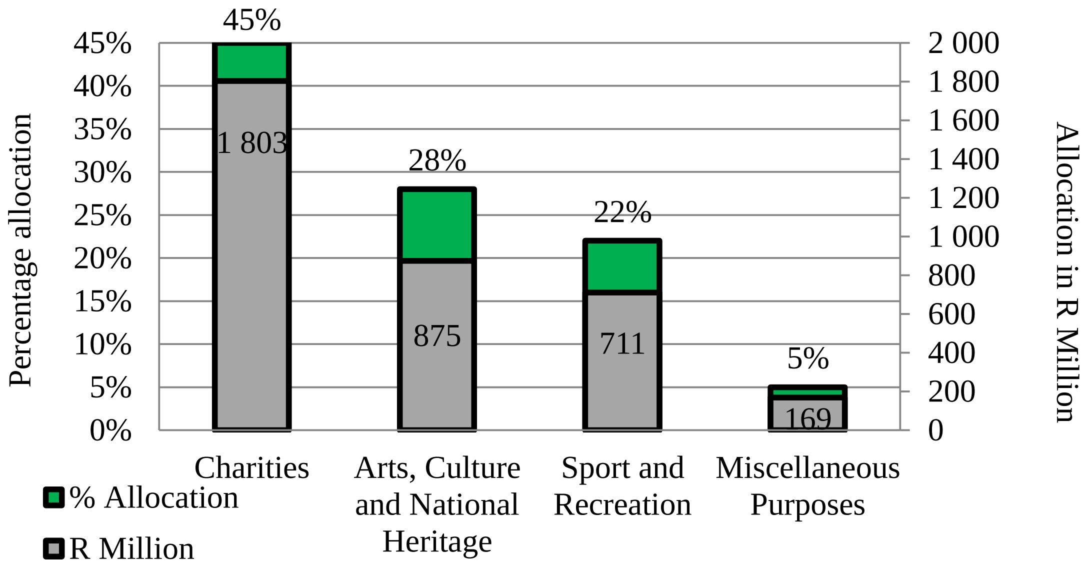

Figure 3: Allocation of Lottery funding across NP sectors in 2011 [15]

NPOs should show evidence of use of the grants provided as stipulated in the application. The National Lottery Distribution Trust Fund (NLDTF) provides a list of organisations and the associated grant provided to date, which is accessible to the public [16].

3.3 National Development Agency Act No. 108 of 1998 (NDA Act)

The NDA Act governs the relationship between government and Civil Society Organisations (CSOs) to alleviate poverty; to define the role of the Agency and; to standardise financial and employee issues.

The National Development Agency (NDA) provides grants to Civil Society Organisations that eradicate poverty and focus on *"early childhood development"*, *"food security"*, *"income generation"*, *"capacity building"* and *"support of vulnerable groups"* [4, 17 &20].

The NDA has funded at least 839 Civil Society Organisations, since 2007 and has supported the following type of organisations: community based organisations, cooperatives, faith based organisations, non-government organisations, non-profit companies and trusts. [19]

Grants provided to any Civil Society Organisation must not be used for gain for its members, unless it is purely for payment for services made. An organisation, who has received a grant, must provide audited financial statements to the NDA. The grant includes the expenses that the organisation may incur in providing the NDA with such records. [17&18]

Application to the NDA requires [21]:

1. Proof of registration as a non-profit organisation;
2. The organisation's constitution or founding documents;
3. The two most recent annual audited financial statements;
4. A motivation for project, which explains it significance;

5. A project implementation plan and
6. A detailed and realistic budget for the project.

An organisation should also be a registered PBO and NPO†. [21]

4 NPO QUESTIONNAIRE DESIGN PROCEDURE/RESEARCH METHODS

This study used a qualitative approach that involved information gathering, questionnaires, surveys and interviews.

4.1 Case study method

A multiple case study is when more than a single unit of analysis is considered [22]. The investigation observed several NPOs for context. Multiple case studies involve the replication of cases that may yield literal (similar) or theoretical (contrasting) results. Sampling logic does not form a basis within the multiple-case study [22].

Holistic case studies observe a single unit and the global nature of an institution [22]. The research tended towards a holistic multiple case design as the same information filtering occurred across various non-profit sectors. An individual was a single data source but the organisation itself served as the unit of analysis for the research.

4.2 Questionnaire design

Questionnaires are a method of addressing research questions in conjunction with other methods to improve the quality of research [23] whilst result-convergence gives credibility to findings.

An invitation letter called for NPO participation in the study. It explained the importance of the investigation and assured confidentiality. Some questions were collated from previous studies [3, 4, 24] while others were created around the project's objectives and the NPO Act. The questionnaire was semi-structured with both closed and open-ended questions [22].

The questionnaire draft was piloted on a number of persons (academics, psychologists, dentist and students), specialised and not specialised within the non-profit sector [22, 23, 25]. This assisted to improve format, structure, wording, interpretation and flow of questions. It took approximately 23 minutes to complete the survey.

The use of a free online survey website, (eSurv [26]), provided ease and professionalism to the questionnaire. eSurv is a "*tool designed for students, educators and small to large organizations*" that allows for unlimited questions to be created and for unlimited number of responses. The design of the survey included a heading to provide context to the survey, an introductory note on the purpose of the survey, a 'University of Witwatersrand' logo for credibility, numbered questions, a status bar on the progress of the survey and a thank you note at the end of the survey. There were 40 questions spread across eight pages, with a

† SARS does not require NPO registration but an organisation should be a public benefit organisation (PBO) that conducts public benefit activities (PBAs) as in terms of the Income Tax Act (ITA) and relates to all the types and sectors of NPOs. The National Lottery Distribution Trust Fund requires NPO registration but the benefits are across type and sector of NPOs with set budget portioned for each sector. The National Development Agency requires both NPO and PBO registration with benefits limited to NPOs that handle alleviation of poverty and welfare related issues.

maximum of six questions per page. The survey mainly consisted of closed questions with possible answers and an option for the participant to add their own response under 'other'.

4.3 Invitation to Participate

NPOs received invitations by telephone, email and in person to participate.

Possible participants received an Invitation - letter for the survey, which introduced the investigator, the purpose of the survey; mention of confidentiality and a link to the survey. Though sent from *eSurv*, email invitations would appear as sent from the investigator's academic email, with a subject line 'Non-Profit Organisation Survey Invitation'. This assisted that it is not confused as unsolicited mail.

The NPO database [27] was used to randomly select participants for the survey. Most of the information on the NPO database was outdated. The investigator called NPOs personally, to invite them to participate and to gain responses. Calls were made to Non-profits trusts, non-profit companies and voluntary associations. The telephone invitation repeated the disclaimers of the covering letter sent by email.

NPOs that were available telephonically were keen to participate, citing an interest in information on government grants. After each telephone call, an electronic invitation letter with a tracked survey link was sent to the contact people. The NPOs were given a week to respond and were sent a reminder email two days before the response deadline.

5 RESPONSE

The data created from the survey does not represent the entire non-profit sector and is exclusively for the group of respondents that participated in the study. The sample size is insufficient to generalise the non-profit sector. Its purpose rather is to contextualise perceptions around registration as an NPO.

At least seventeen, of the two hundred and fifty one NPOs contacted, completed the survey. This response rate is disappointing, but adequate in terms of Yin, who suggests at least ten responses are required [22].

Table 1 shows the breakdown of all the organisations that were contacted.

Table 1: Numbers of NPOs considered

Total NPOs obtained from NPO Database [27]	251
Attempted calls	38
Attended calls	20
Emails sent	176
Returned emails	34
Incomplete surveys	10
Invalid numbers	18
Active email addresses	142
Successful telephone invitations	7
Successful email invitations	10
Total completed responses	17

Figure 4 shows the response rate of total invitations, telephone invitations and email invitations; percentage of invalid numbers and active email addresses. Successful email and telephone invitations were considered as a percentage of active email addresses and attended calls. The NPO database [27] does not contain updated email addresses and telephone numbers. This raises questions about the validity of other information. For instance, the NPO Directorate may communicate using the incorrect postal address. The response rate of 12 % is quite low when considering Gillham [23] who recommends atleast a 30 % response rate. However, it is not relevant for a case study method as it would be for a survey research method where population behaviour is studied [22].

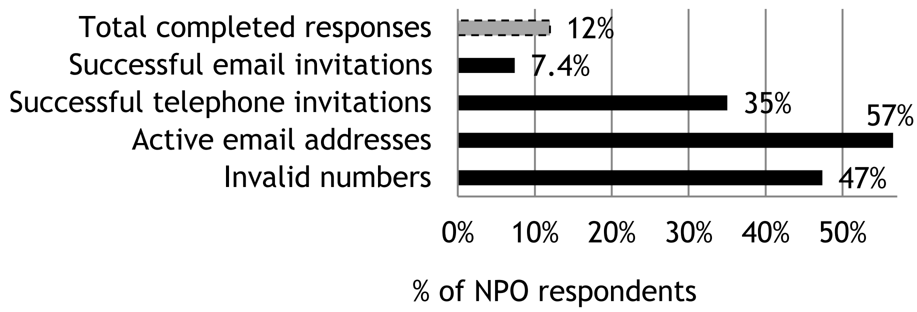

Figure 4: NPO response rate

6 RESULTS AND ANALYSIS

An understanding of NPOs experience during the registration process was required to determine significant aspects that start-up NPOs should consider before registering. The questionnaire provided an aid to achieve this and is discussed below.

One organisation failed to inform the NPO Directorate of their new name as required in terms of the NPO Act to update of changes in constitution and organisational information. Three organisations provided registration dates that differed with the NPO database. The respondents might have provided dates of existence, which does not correspond with date of registration, as some organisations existed for some time before registration within the NPO Act that only came into play in 1997.

All the respondents had accurately selected the founding document type that their organisation has registered, but nine of the respondents selected organisation type that differed with the type registered with the NPO Directorate. This could be due to lack of understanding as to the different structures or inaccurate capture on the NPO database. Each structure has a specific type of associated founding document. A constitution is for a voluntary association, a deed of trust for a trust, and memorandum of incorporation is for a non-profit company.

Ten organisations gained registration information through self-research, three through legal advisors, two by tax advisors and two through DSD office or a DSD campaign. The NPOs that participated in the study were randomly selected from the NPO database [27]. As required by the NPO Act, eight of the organisations that had outstanding documents for registration received a notice within a month of applying; three NPOs appealed within one month of rejection while two received a response from the arbitration tribunal within three months. Insufficient participating NPOs could provide information on the arbitration process as their registration was pending document submission. All the NPOs that received their certificate of registration make use of the NPO number on their official documents.

Twelve NPOs exceeded two months to complete their registration. This could be due to delays caused by outstanding documents or on the DSD's side. The NPO Directorate mentioned that more than 90 % of registrations are processed within a period of two months, a claim that is supported on the NPO website.

Registration delays impeded organisations in achieving their objectives on time. According to the 'NPO impact assessment' [3], NPOs receive an acknowledgment letter upon completion of the application process. This however was not the case for one respondent of the survey. The reasons for this were unclear though it may have been due to inaccurate data on the database.

Annual financial reporting remains an issue for eleven respondents of the survey and is similar to the results from the 'NPO impact assessment' [3]. Capacity and lack of funding resulted in organisations not submitting reports. The case studies, did not gather information on NPOs that provided DSD with an affidavit of financial situation and bank statements due to lack of funds, as opposed to financial statements. Thus, it cannot be concluded that the participants are aware of this provision of the NPO Act. Two organisations had issues in sustainability and keeping all receipts on record. Such NPOs could benefit from the capacity building, funding and organisational strategy workshops offered by DSD.

Seven organisations did not benefit from the Taxation Acts, fourteen did not from the National Development Agency Act and fifteen did not benefit from the Lotteries Act either due to lack of awareness or capacity for eligibility. A number of NPOs are unaware that NPO registration alone does not grant for tax benefits or that they have to register with SARS as a PBO. Some NPOs are struggling to obtain PBO status. This is important in creating an enabling environment for NPOs. There is a lack of integration between the Department of Social Development and SARS, both NPO and PBO statuses should occur concurrently. Though section 11 of the NPO Act does not specify benefits of registration, most NPOs are still to reap benefits. This aspect of the NPO Act has a lot of room for improvement and hinders creation of a user-friendly environment for NPOs.

It is a concern that eight NPOs are unaware, while ten NPOs lack understanding of the NPO Act itself. The registration process should incorporate such information.

Information between the NPO database and the respondents of the survey did not seem to tie up. This raises concern on awareness on NPOs side and accuracy of the database. Documents of all NPOs registered before the creation of the online NPO database should be transferred to the database. Constitutions of NPOs missing from the database should not be a standard. This also negatively affects organisations, as donors are not able to verify the authenticity of an organisation. The NPO database also has out dated contact information. Organisations might not be aware of the online database that can be used to update information. This could affect receiving important notices from NPO Directorate.

In the opinion of the Investigator, the NPO Directorate has done thorough work on executing the objectives of the NPO Act as far as possible. However, as time and environments change, continuous improvement of processes and procedures is significant. Though various benefits lie with registering as an NPO, it is important for an NPO to create strategic plans to succeed as if it were on its own. Grants provided by government organisations are not to be considered as a long-term funding solution.

The case studies consisted of seventeen registered NPOs. The 'NPO impact assessment' [3] conducted by Umhlaba considered a nationwide survey of registered NPOs in 2005. Both investigations yielded similar results despite being conducted eight years apart. Some of the questions asked in the impact assessment were also used in the current study.

The investigation followed the scope of the project as far as possible. Though the NPO Act was the primary area of discussion, other Acts (Taxation Acts, Lotteries Act and NDA Act) that influence NPOs were also considered.

The first three assumptions made are justified in the investigation. 'Start-up can lead to sustainability' is warranted when organisations that have been registered for some time are unaware of the possible benefits and are struggling. This is ideal to know before registration with a mind-set of long term plans. Donor and public interaction improved once organisations registered as NPOs.

7 CHECKLIST FOR A START-UP NPO

Informed by our findings, a checklist was created (Table 2), with which NPOs could be equipped to speed up their registration process, and also to ensure that registration is comprehensive and covers them to the full extent of legislation and structures that are in place.

Table 2: Checklist for a start-up NPO

No.	Tick	Item	Possible sources of information/ guidance
1.		Consult with registered NPOs from the same sector (request for mentorship)	Check within own neighbourhoods, NPO database
2.		Liaise with DSD office with an NPO agent for clarity and follow ups	Call DSD and NPO Directorate and make a physical visit
3.		Understand the NPO Act (know your rights)	The Act (DSD website, DSD Offices, Lawyers)
4.		Understand the difference between NPC, Voluntary Association and Trust	DSD, CIPC, Internet, registered NPOs from NPO database
5.		Develop constitution in terms of NPO Act	NPO Directorate guidelines
6.		Provide NPO Directorate with any change of information	The Act, DSD and NPO Directorate
7.		Ensure to have three unconnected (no family relation) directors	Lawyer, DSD and NPO Directorate
8.		Be aware to keep records of all financial transactions	Registered NPOs from NPO database, Tax advisor
9.		Gain information on how and when to complete narrative reports and audited financial statements	NPO Directorate guidelines registered/experienced NPOs, Tax advisor
10.		If there are no financial transactions, know that an affidavit and bank account statements are required	DSD office and NPO Directorate
11.		Obtain PBO and section 18A of Income Tax Act statuses	SARS, TEU, registered/experienced NPOs, Income Act, Tax advisor
12.		Create a funding plan and options	Guidelines from DSD website, NDA, NLBSA
13.		Show interest to participate in workshops and conferences	DSD, Charity SA, registered/experienced NPOs
14.		Share best practices	DSD, Charity SA, registered/experienced NPOs
15.		Cater for delay in registration	Registered/experienced NPOs
16.		Be self-reliant than dependant on limited government funding	DSD, Charity SA, registered/experienced NPOs
17.		Focus on the organisations objectives	Charity SA, registered/experienced NPOs

8 CONCLUSION

This paper presents a practical framework that was engineered to assist start up charitable organisations to fully benefit from structures and legislation in South Africa, which is often an institutional blind spot.

- The poor response rate of the study might have been due to a problematic national NPO database. Though it does not impact a case study, it does indeed show that inaccurate information on the database does not justify the requirements of the NPO Act.
- NPOs' prior knowledge of registration is important and has an influence on operation of the organisation.
- Efficiently set up NPOs are able to make valuable contributions to the sector.
- Though registration as an NPO is voluntary, there is an increase in the rate of registration of NPOs since conception of the NPO Act.
- Organisations experienced financial losses due to registration delay, mainly from the withdrawal of potential donors, potential contracts, credibility, funding and delayed projects.
- The main benefits of registration, as a public benefit organisation and section 18A statuses, were donation tax exemption. Donors are encouraged to donate to PBOs with section 18A statuses to obtain a tax exemption certificate, which they can use to claim tax, from the South African Revenue Service (SARS). SARS, the National Development Agency and the National Lottery Board do require NPO status for eligibility to benefits.
- The case studies confirmed the hypothesis that some organisations were unaware of the implications of the NPO Act and the registration process.

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EXPLORING THE NEED FOR PLANNED MAINTENANCE IN REPONSE TO LOW PRODUCTIVITY AT A HEAVY STEEL MANUFACTURER

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ABSTRACT

A large steel fabricator observed poor productivity and bottlenecking in their shot-blasting section. This study aimed to identify the causes of low productivity and further identify improvement opportunities. The shot-blasting section was found to add value only 19% of the time. Production records revealed that downtime accounted for 61% of machine non-availability, whilst time study data further revealed that idle time accounted for 11%, rework 9% and yield 21%; all of which contributed to low productivity levels. These factors were further analysed using fish bone diagrams, 5-Why analyses, and interviews to determine root causes of low productivity in shot-blasting. It was concluded that the chief cause of downtime is a lack of planned preventative maintenance (PPM), with downtime, low yield and rework being attributable to a lack of PPM. Implementing PPM would significantly improve throughput at shot-blasting and significantly reduce downtime costs.

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1 INTRODUCTION

The company under investigation specialises in heavy steel fabrication, structural detailing, procurement and heavy machining on very large and time sensitive projects. This means that the company works with large orders and varying demand throughout the year. Reliable lead times are both contractually and organisationally important. Increasing global competition is driving the organisation to streamline fabrication processes to reduce costs, material and time wastage.

A generic steel fabrication process has five stages: 1.Preparation, 2.Assembly, 3.Welding, 4.Fettling and 5.Shot blasting and painting when required. The shot blasting section (5) was identified as the bottleneck to throughput. The shot blasting section comprises three shot blasting machines, hereinafter referred to as Wheelabrators.

Shot blasting is a method used to clean, strengthen (peen) or polish metal. Shot blasting is used in most metal industries, including aerospace, automotive, construction, foundry, shipbuilding, rail, and many others. There are two technologies used: wheel blasting or air blasting.

Wheel blasting uses a rotating turbine wheel to accelerate abrasive particles. The capacity per wheel ranges from 60 kg up to 1200kg per minute. Because wheel blast machines can move such large volumes of grit, they are used for large parts or large areas that require rust-removal, descaling, deburring, or another form of cleaning.

Total productive maintenance (TPM) is the development of a robust, stable value stream by maximising Overall Equipment Effectiveness (OEE). Key elements of TPM includes: preventive maintenance, predictive maintenance, breakdown maintenance, corrective maintenance, and maintenance prevention [1].

This project aimed to understand the flow of material in the Wheel blasting section of the plant by evaluating it as a bottleneck. The study further aimed to evaluate the implications of machine downtime, operational practice and operational efficiencies on the plant as a whole.

Value adding for the Wheelabrator is defined as all time that the machines spend performing shot blasting. A company's main purpose is to make profits [2], and reblasting and idle time, only add to costs. Therefore, failure demand or rework are considered not value adding.

1.1 Objectives

1. Investigate the location and causes for the bottleneck
2. Identify the effects of bottlenecks on the plant
3. Identify opportunities for improvement
4. Recommend plausible solutions for bottlenecks

2 METHOD

This study used both primary and secondary data sources for information. A quantitative approach has been used for the time studies with a qualitative approach used for conducting interviews with informants [3]. Data was collected in the form of a Q&A session. The results were tabulated in an excel spreadsheet and tallied up. All responses were recorded and the most common responses were extracted for the report.

Figure 1: Methodology

Time studies [4] were conducted for 9 days on each of the three Wheelabrators. The studies attempted to identify the utilisation, effectiveness and reliability of the each machine. The time studies provided data on downtime, idle time, yield, rework and non-value adding activities. This data was enriched by looking at historical downtime data from the production monitoring system.

The company implemented a new maintenance logging system in April 2012. Data from this system was used to determine the downtime of each Wheelabrator over 15 month period. The records were first adjusted to account for lunch and tea breaks as downtime giving 7 hour shifts and 14 hour working days[†]. All hours logged as downtime outside normal working hours were rejected.

The convention of idle time has been used, which is any time that the Wheelabrator is available to be used but is not in use for any particular reason. Idle time does not include downtime [5].

To understand why breakdowns and downtime were so high the maintenance procedure was investigated and interviews with various stakeholders were conducted.

3 RESULTS

This section shows the time-study and downtime-history results. It should be noted that Wheelabrator 2 was non-operational for the full duration of the study and was recorded as down time.

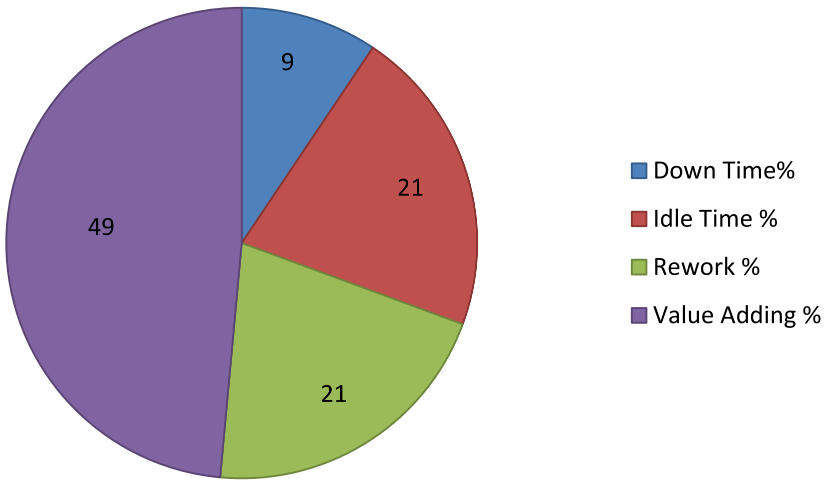

Figure 1: Wheelabrator 1 time study results

[†] Two 8 hour shifts accounting for 30 minute lunch breaks for each shift and 30 minutes for each shift change over. Hence each shift has 7 available working hours and there are two shifts in a day making 14 hours

Figure 2 shows that Wheelabrator 1 displayed 9% downtime, 21% idle time and 21% rework. Value adding time accounts for 49% and the rest, 51 % can be considered waste.

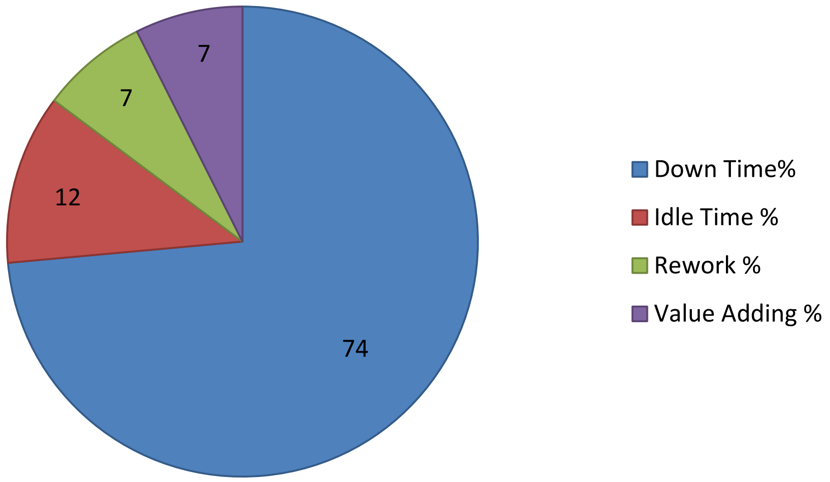

Figure 3: Wheelabrator 3 time study results

Figure 3 shows that Wheelabrator 1, displayed 74% downtime, 12% idle time and 7% rework. Value adding time accounts for only 7% and the rest, 93 % can be considered waste.

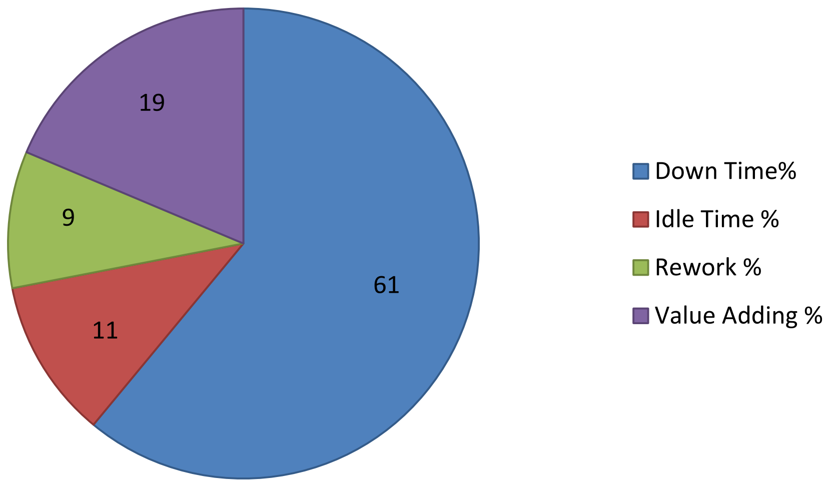

Figure 4: Wheelabrator section averages

Figure 4 shows that the Wheelabrator section displayed 61% downtime, 11% idle time and 9% rework. Value adding time accounts for 19% and the rest, 81 % can be considered waste.

3.1 Downtime

From the data Wheelabrator 1 experienced an average of 8% downtime, Wheelabrator 2 experienced an average of 19% downtime and Wheelabrator 3 experienced an average of 13% downtime. The average downtime from the Wheelabrator section was 14%.

The results led into a root cause analysis (Figure 5) which explored downtime, rework, idle time and general low production at the Wheelabrator section.

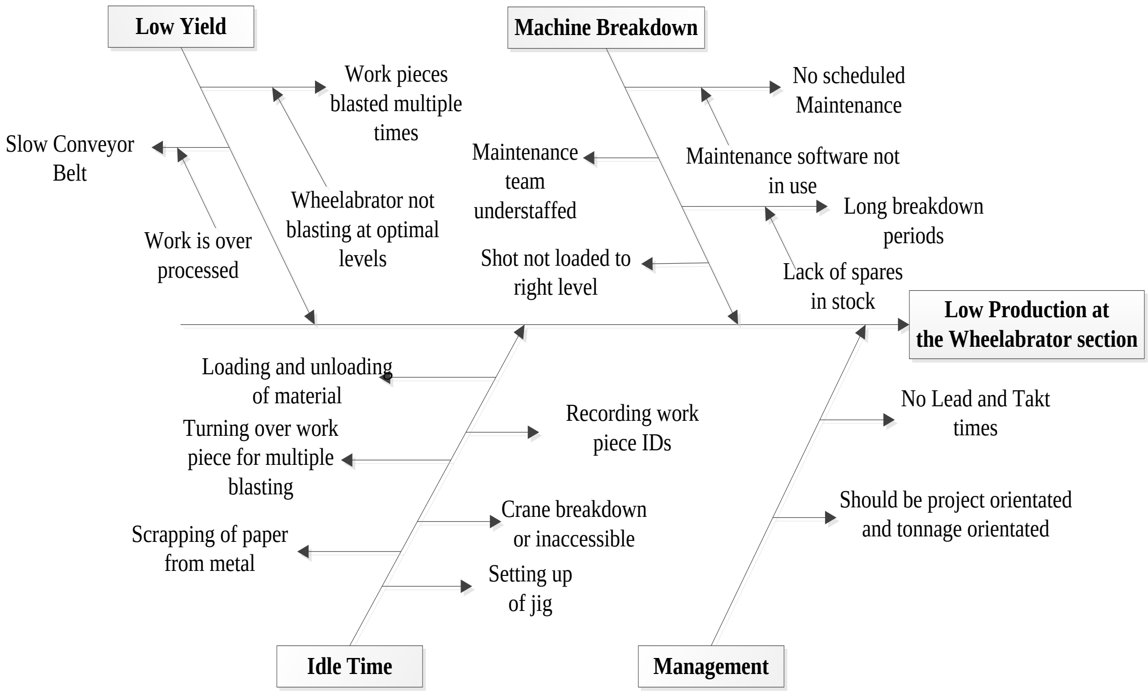

Figure 5: Fishbone diagram for low production at the Wheelabrator section

It is evident that downtime is the most important issue and has the highest impact on production.

3.2 Qualitative analysis of the maintenance department

It was observed that insufficient spare parts are kept in stock and had to be ordered when needed. Interviews in the maintenance department revealed that long lead times occasionally create downtime as long as four weeks. The procurement process requires senior management authorisation, stretching the waiting time even further.

Figure 6, shows the maintenance procedure and identified improvement areas. Key amongst these is the back and forth between the top management that could be eliminated to reduce the time between machine breakdown and spare parts arrivals. Improvement areas are highlighted in yellow.

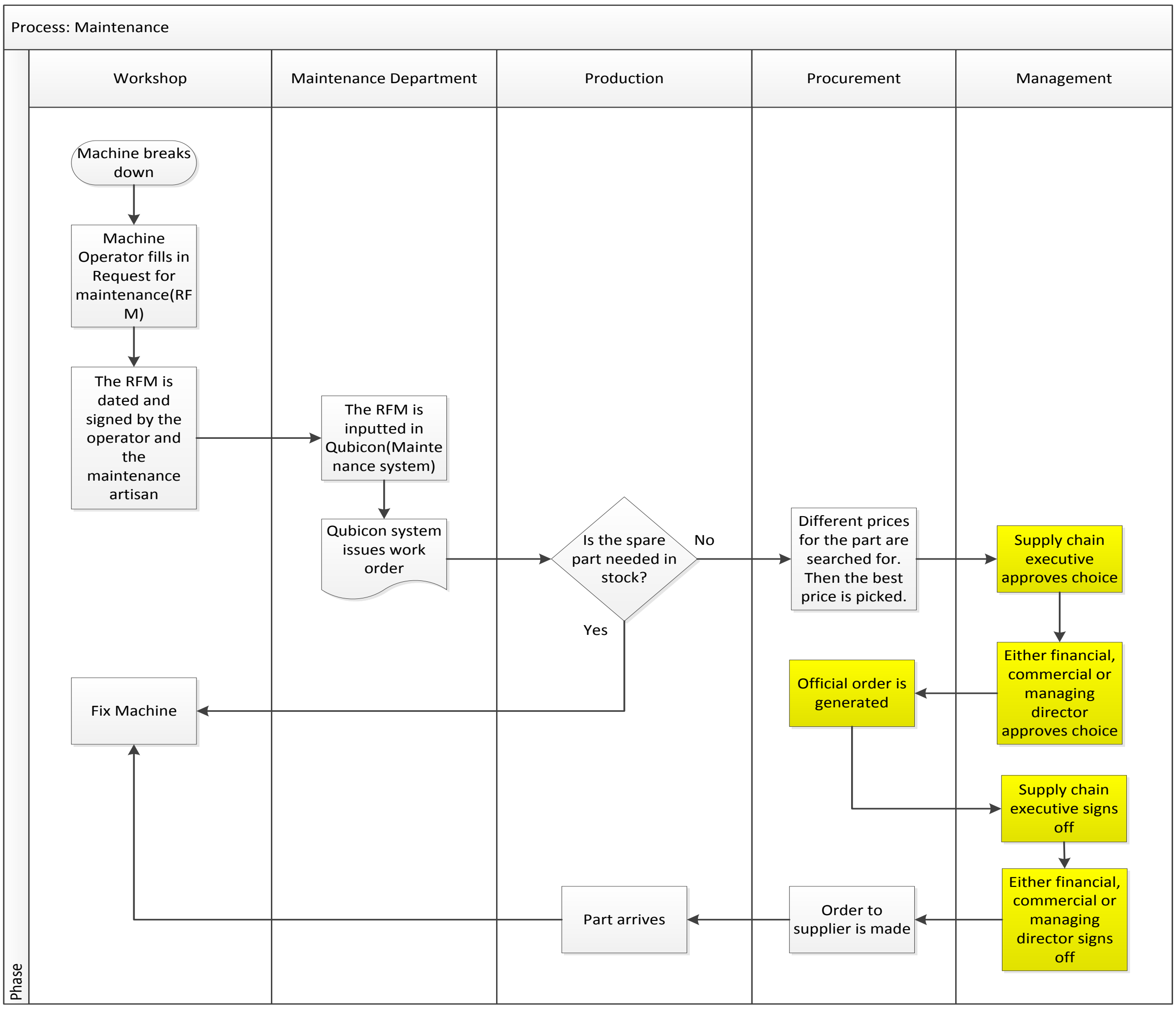

Figure 6: Maintenance procedure

Interviews with the maintenance team revealed a perception of understaffing. There is no scheduled maintenance for the Wheelabrators and the maintenance team is inexperienced in handling the machines.

The reasons given for a lack of scheduled maintenance by the shop floor employees is that the project managers and superiors are not willing to lose the production time to scheduled maintenance. They are concerned with their own production and project deadlines which are approaching soon or are behind schedule and therefore not willing to lose time to scheduled maintenance. This has later been proved as untrue through meetings with the paint department, which contends that there is no planned maintenance system in the organisation.

The interviews also revealed that most employees considered the maintenance team to be inexperienced. This meant most of the issues which occur with the Wheelabrators could be solved in a shorter space of time, if the maintenance team were adequately trained. According to the employees the company previously contracted to repair and service the Wheelabrators was more efficient and competent than in-house artisans. This company manufactured the Wheelabrator, and thus have extensive knowledge of the machines and are able to repair the machines much faster[‡].

Staff also mentioned that the Wheelabrator operators are not adequately trained in the operation of the machines. Thus the machines are run with insufficient shot which strains the machines and may damage them.

3.3 Frequency of breakdowns

Using the historical downtime records an investigation into the frequency of breakdowns was done. The goal was to identify the most common type of breakdowns.

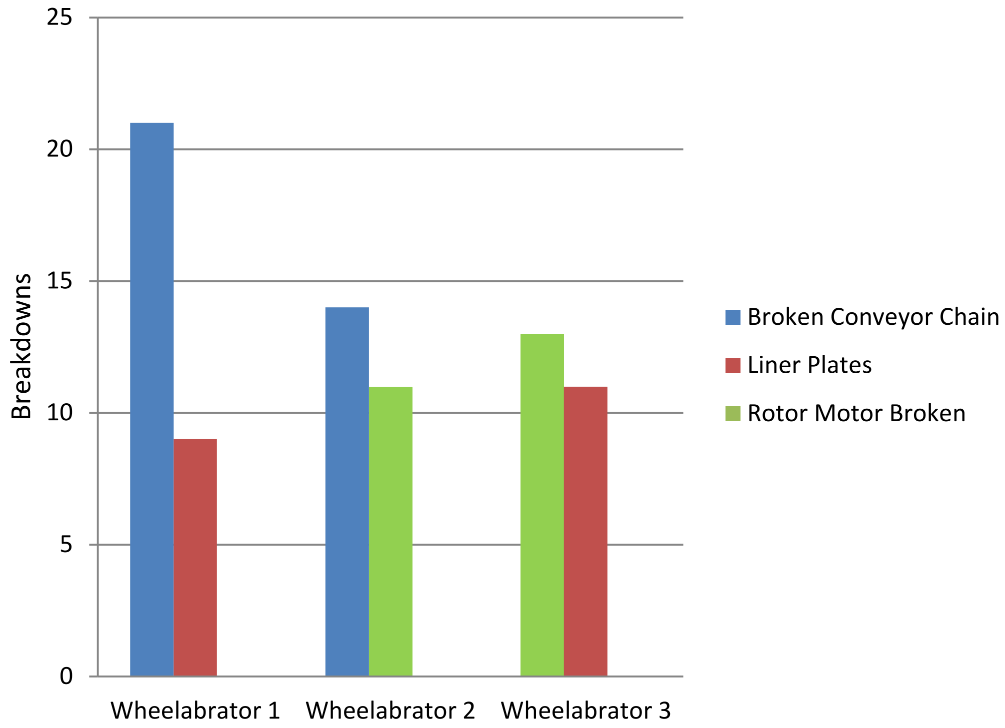

Figure 7: Most Common Breakdowns

From the results shown in Figure 7, the most common types of breakdowns are related to the rotor motors, liner plates and conveyor chain.

The rotor motor is responsible for running the mechanism that physically sprays the shots in the shot blasting process. This was an issue that was addressed through the implementation of IP65 insulation. IP65 is the total protection from dust and external bodies through the use of enclosures.[6]Liner plates are responsible for protecting the interior of the machine from being shot blasted. The liner plates are run to failure. This leads to issues such as holes in the machines that cause shot to leak compounding the pressure on the maintenance team. Most of the issues highlighted in the Historical Downtime Records and Frequency of Breakdowns such as the rotor motors, liner plates and conveyor chain are caused by wear and tear due to a lack of regular maintenance.

Table 1 below shows the number of scheduled maintenance inspections over the past 15 months.

[‡] The outsourcing contract was discontinued for cost reasons.

Table 1: Monthly inspections

Machine	Monthly inspections
Wheelabrator 1	2
Wheelabrator 2	3
Wheelabrator 3	1

3.4 Non value adding activities

From the time studies it is clear that the biggest problem affecting production is downtime. Keeping in mind the theory of constraints which states that the organisation is only as strong as its weakest link[7] and the lean philosophy which states that all wasteful steps must be removed[8], it is important to identify the other issues that are contributing to the bottleneck to remove all waste in the organisation and increase productivity.

3.4.1 Idle time

From the time studies, idle time was caused by:

- Loading and unloading material on the conveyor belts
- Setting up jig for smaller work pieces
- Turning over work piece for multiple blasting
- Cranes for loading and unloading material breaking down
- Recording work piece ID

Work pieces had to be turned over because the machine was not blasting optimally. Depending on the size of the work piece a crane had to be used to help turn it over. Due to every work piece being blasted at least twice they had to be turned over at least once. Wheelabrator 3 blasted up to 40 small items. These 40 small items were individually turned over manually. Wheelabrator 1 blasted large and heavy work pieces that could only be turned over by the use of a crane. Company safety rules stipulate that no employee may lift an object heavier than 25kg. This means that all work pieces blasted in Wheelabrator 1 are turned using cranes and any work pieces blasted in Wheelabrator 3 above that weight are also turned using cranes. From the time studies some work pieces were turned 5 times due to being blasted six times. This results in low yield, high cost of rework and loss of valuable production time.

The crane for offloading and unloading material for Wheelabrator 3 was experiencing downtime for the entire duration of the time studies. This meant that cranes had to be shared and any loading and offloading was done subject to the availability of substitute cranes.

Every blasted work piece has to be recorded which took a considerable amount of time. The manual recording results in time wasted because every item must be recorded before moving to the next production step.

3.4.2 Low Yield and Rework

For this research project a unit was defined as the amount of material that was put through the Wheelabrator once and came out blasted to spec without needing rework or re-blasting. Due to the large variety of parts that are blasted in the Wheelabrator, a unit was considered as any job that was placed on the conveyor belt to be blasted. Hence, a unit that it placed on the conveyor belt and put through the machine for blasting and exits the machine without needing re-blasting would count as 100% yield. If the job had to be blasted twice before being passed as acceptable then the yield would be 50% etc. There is a cost of quality that is incurred due to the low yield and high rework.

Table 2 below shows the yield, as a percentage, for each Wheelabrators and the average determined through time studies.

Table 2: Wheelabrator section yield

Machine	**Yield**
Wheelabrator 1	50%
Wheelabrator 2	0%
Wheelabrator 3	11.9%
Average	**21%**

The time studies showed that yield for the Wheelabrator section is 21%. An attempt should be made to do everything perfectly [9]. There is a high cost associated with poor quality. The lower a company's sigma level is, the higher the chance of cost saving through the increase in sigma levels.[10] The cost savings diminish as the sigma levels increase. A yield of 21% is indicative of a 1 sigma operation. Therefore there is a large opportunity for cost reduction.

The six main causes of low yield were identified as follows: size of shot not appropriate (shot not homogenous), valves not working, filtration system, motors not working, machine setup not correct and blast area not concentrated on workpieces.

3.5 Cost of downtime

From the time study results, down time was considered as the biggest contributor to low productivity in the Wheelabrator section. As a result this section estimates the costs incurred as a result of downtime. It should be noted that this calculation tends be conservative as it ignores[11]:

- cost of repair, such as cost of operator overtime or bringing in consultants
- daily, seasonal variations in revenue
- indirect costs of outages can be as important as these are more immediate costs
- opportunity costs

Importantly, this calculation also ignores that this section is the bottleneck in the plant, and therefore should be costed at the hourly income of the plant [7].

The cost of downtime is calculated using the following equation [11]:

$$Estimated\ Average\ Cost\ of\ downtime\ per\ hour =$$
$$Employee\ Costs\ per\ Hour\ *\ Fraction\ Employees\ Affected\ by\ Outage\ + \quad (1)$$
$$Average\ Revenue\ per\ Hour\ *\ Fraction\ Revenue\ Affected\ by\ Outage$$

Where "Employee Costs per Hour": total salaries and benefits of employees per week divided by the average number of working hours; "Average Revenue per Hour": total revenue per week divided by average number of open hours; "Fraction Employees Affected by Outage" and "Fraction Revenue Affected by Outage" are estimates.

The cost of downtime was calculated as ~R1200 per hour. With downtime in the Wheelabrator section averaging 61% or 4 of the available 7 working hours in a shift, the cost of downtime per day is: ~R5000 per shift. There are two shifts per day therefore the cost is ~ R10000 per day.

4 DISCUSSION

The frequency of breakdowns was investigated to identify a trend in the type of breakdowns. Historical records were analysed and the results displayed in Figure 7 show that the most common type of breakdowns are related to the conveyor chain, rotor motor and liner plates. These are all breakdowns that can be prevented by having planned maintenance.

It can be seen from Table 1 that there is a lack of planned maintenance in the Wheelabrator section. Since the records were over a period of 15 months and the conveyor chain for instance has a life span of 6 to 8 weeks there should have been more planned maintenance occurring. The conveyor chain is responsible for transporting the metal through the Wheelabrator. This is a cause of breakdowns because there is no maintenance and insufficient periodic replacement. Thus the chains exceed their recommended life span leading to damage and eventual failure. The reason for a lack of planned maintenance can be considered contentious. Interviews with shop floor members put the blame on the project managers for not allowing planned downtime as this would impede the chances of them meeting their own personal deadlines. This was dismissed as untrue through meetings with the maintenance department. The actual reason is that there is not a procedure for planned maintenance in the organization and the maintenance team is understaffed.

From the time studies, yield for the Wheelabrator section was identified to be 21%. From the 5-Whys analysis, six main issues that lead to low yield were identified: size of shot not appropriate, valves not working, filtration system, motors not working, machine setup, blast area not concentrated. All these issues are due to a lack of periodic maintenance and can be traced back the maintenance department.

A low yield leads to failure demand. From the theory of failure demand there is an increase in the use of the machines because work is not being done correctly the first time. This means there is more wear and tear which leads to more breakdowns and the feeling that there are not enough workforces in the maintenance department. Essentially if the yield could be increased it would reduce the number of downtime or maintenance related issues and reduce failure demand, thus relieving pressure on the maintenance department. This is an example of the far reaching consequences of a lack of planned maintenance. A lack of planned preventive maintenance, combined with an ineffective spare parts ordering procedure results in added downtime.

Rework is a result of the low yield. Rework accounts for 22% of the shift time, when the machines are online. This is not acceptable as this is considered a waste, hence an opportunity for improvement. There is also a cost attributed to rework. This cost adds to the overall costs of the company and affects profits.

The reason for using the machine online data is to get a clear picture of the other issues that affect productivity in the Wheelabrator section and to see how much each affects productivity when downtime is not an issue. Hence this can be used to see what the next problem areas to cover when downtime has been addressed will be. From the theory of constraints an organisation is only as strong as its weakest link and once downtime is addressed another weak link will appear.

Idle time is another issue that was identified. Idle time accounts for 28% of the shift time when the machines are online. This should be addressed as idle time is a waste and does not add value to the business. Although some of the steps such as loading and unloading are necessary, idle time should be investigated in order to reduce the amount of idle time as it is production time that is lost.

Some of the problems identified in the Wheelabrator section in this research project such as; low yield, filtration system, maintenance and shot starvation are consistent with those found in previous studies[12]. This shows that the results are reliable.

Calculations were done in order to estimate the cost of Wheelabrator downtime on the machine. The cost was approximately R10000 per day. Although this is an estimate it is conservative and the costs are likely higher due to cost of repair, such as cost of operator overtime or bringing in a consultant, seasonal variations in revenue and indirect costs of outages can be as important as these are more immediate costs. This cost also does not include the cost of quality which will add to the above cost and further reduce profits.

5 CONCLUSION

The main objective of this study was to investigate the causes of the bottleneck at the Wheelabrator section and to identify the effects of the bottleneck on the plant. Based on the research findings;

- The Wheelabrator section is a bottleneck as its performance is limiting the capacity of the entire production system.
- The biggest contributor to the bottleneck is downtime as 61% of the shift is down time.
- The other contributors to low production at the bottleneck are: rework 9%, idle time 11% and yield 21%
- The cost of downtime is ~R10000 per day.
- Maintenance plays a significant role in low productivity as downtime, rework and yield are linked to maintenance.

6 RECOMMENDATION

The plant should implement a structured planned preventative maintenance programme to reduce the Wheelabrator downtime and increase throughput. The ordering process for spare parts needs to be streamlined. There is a lot of opportunity to improving downtime if the order process is streamlined. Maintain stock for parts causing the most frequent breakdowns to reduce amount of downtime.

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WASTE MANAGEMENT IN SOUTH AFRICAN POST OFFICE USING LEAN PRINCIPLES AND ENVIRONMENTAL LAWS

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ABSTRACT

Conservation and prudent use of resources plays an important role in sustainable development. Waste management is one of the scopes that forms part of the Sustainability strategy that is adopted by the South African Post Office. The paper aims to highlight different process that mail goes through in mail operations, and the waste generated during operations. It will further highlight how the use of Lean Process and the implementation of various environmental laws such as National Environmental Management Act (NEMA) Act no 107 of 2008 can offer a better waste management strategies and tools in the inventory centre.

Mail operation is the major service provided by the South African Post Office and its core function is mail sorting and delivery. Currently waste is measured and managed only at administrative level, and these possess a challenge as most waste is generated through the process rather than at administrative level. This disables the organisation to measure and categorize the existing waste and to place corrects and effective strategies that will enable them to manage waste.

Lean principles will be used to address the aspects of defects and rework which is one of the major losses contributing to productivity and profitability. A site visit was conducted, and it gave insights to the challenges outlined above. It is evident from the information collected that there is a need for waste to be managed at process level and the implementation of effective strategies.

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1 INTRODUCTION

1.1 General introduction

Inventory control plays a vital role in most industrial process to manage production. Companies depend on inventories to operate and plan production schedules however; Inventory inaccuracy can also have a negative impact on financial strength, customer satisfaction and competitive advantage. With growing pressure on best practice globally, lean principles among other techniques offers a better approach for inventory control strategy and operational dimension.

Various case studies on inventory waste control were conducted, and the focused was more on total quality management system, whilst others used lean principles to manage supply chain management systems and industrial processes. Generally, Total quality management systems focus on the social ethics, such as human resource management.

South African Post Office will benchmark the approach used to control inventory waste from the study that was conducted by Coca Cola in Nigeria [9]. This study will be focused on the inventory centre for mail operations known as the Return Letter Office (RLO) which is in the Western Cape. The aim is to improve the inventory centre using lean principles and Environmental laws. The objective will be to establish the current procedures in use and evaluate if these process adheres to lean principles. The study will also be conducted to establish how complaint the process is to legislative procedures and obtain an optimal inventory system that will used to effectively improve efficiency. Hypothetically, if inventory is controlled using lean principles will result in waste reduction; however with the combination of environmental laws will result in a desirable waste management system.

1.2 Process background

The National Environmental Management: Waste management Act no 59 of 2008, defines waste as any substance which is not used, whether or not that substance can be reduced, re used, recycled or recovered. Waste can further be defined as any material that no longer has any economic, social and environmental benefits. The management of waste is the process of collection, transporting and the disposal of waste. The National Environmental Waste Management Act, Emphasis every organisation to develop a sustainable waste management strategy, where if waste cannot altogether be avoided, minimised, reused or recycled therefore be disposed in an environmental friendly manner

Lean defines waste (Muda) as activities that do not contribute to value, whether it is a total waste or temporarily necessary value adding [1]. Value is measured by the total revenue generated as a reflection of what the customer is prepared to pay for. It is also determined by time delivery, place of convenience for the customer and form (design and utility). Waste is classified into two which is value adding and non-value adding activities [1]. Lean is the system which is envisaged at creating more value with fewer resources. It is classified into five principles that specify the value from the point of view of the customer, identifying the value stream, making the value flow, setting up work for flow (pull system) and perfection [1].

Waste in the South Africa Post office ranges from general waste to hazardous waste, which is mainly generated in the mail operations. Mail operation is the major service provided by the organization. It is classified into seven processes which consist of acceptance of mail, two sorting processes, three processes of transportation and distribution to the designated areas as shown in figure 1.

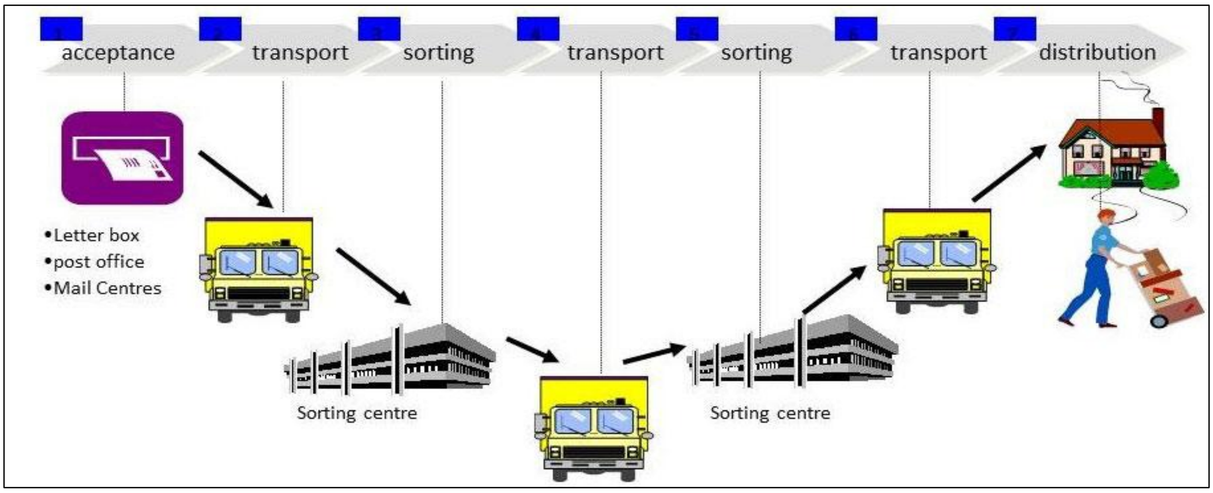

Figure 1: Seven processes of mail operations (*South African Post Office intranet for mail operations*)

Mail operations consist of an inventory centre known as the Return letter office which is widely used internationally in the postal operations. It is used to recover mail through return addresses known as the "return to sender". Which is the address that is used return the mail if the designated address cannot be found, or it contains insufficient data. In a case where the address is not attached or the data is also incorrect, it will be repossessed. The process is regulated by the Postal Service Act No 124 of 1998 which is integrated from Independent communication Authority of South Africa (ICASA) Act No13 of 2000. The inventory centre has been regulated to keep the contents for a year before they are repossessed. The repossession differs with the content and with respect to waste disposal; hazardous waste is also kept for a year before it can be disposed [4].

1.3 Problem statement

Currently there is no formal address structure, other than the bulk mail guideline. Name and address data capture is a highly error-prone action, usually with no verification or correction function. If not corrected at source, it is at times difficult and costly to correct further downstream. There is a very poor data quality checking and correction which result in high rejected rate from defects.In postal operations, defects results from letters and parcels. A defect is referred as the imperfections that exceed certain limits or standards ranging from those that can be traceable to hidden defects [2]. Defects results from raw material, in the process or in the end of the process.

Defects are then identified at the later stage of the sorting process and mostly, prohibited goods (parcels) are processed in the operations and only are identified at the Return letter office. There is no record of what is in the contents due restrictions to confidentiality and protection to the goods. Traces of these items were established to be hazardous, pharmaceutical, chemical, and radioactive contents.

2 METHODOLOGY

2.1 Area of study

The study is conducted at the Return Letter Office (RLO) also known as the Inventory centre for the mail operations. It is geographically located corner showground and mail street, Western Cape. It is estimated to covers $200m^{2}$, with an average capacity to store 10 000 letters and parcels on a monthly basis.

2.2 Measurements

Qualitative and quantitative methods were used in the research [2]. The quantitative study was focused on high rejection rates of product volumes and root causes of defect work. The measured parameter was the process efficiency and the effectiveness of the inventory centre. The quantitative study was used to determine if the inventory system currently in place is effective and to also establish the major contributors to high rejection rate.

[Efficiency] = [——] x 100%

(1)

The output refers to letters which were recovered in the Return letter office, whereas the input refers to the rejected mail that was handed to the Return Letter Office.

The qualitative evaluation was based on the potential risks resulting from the waste generated, the procedures of handling the material, capacity utilization, skills and training offered to the employees and safety precautions. The quantitative study was used to establish how effective the lean principles were applied and the how compliant the process is to the environmental laws.

2.3 Data collection

The data collected for this study includes observation and documentation analysis, for the Return letter office (RLO) and mail operations. The data encompass of a five year data analysis (2009-2013) for input product volumes, processed volumes, rejected volumes and disposed volumes.

2.4 Data analysis

Lean principles will be used to assess the standard procedures used, defect analysis and opportunities that will be used to improve the current operation. Qualitative analysis will be conducted using the environmental laws. Environmental legislative framework will be used to question the hierarchy sequence used to manage waste, and legislative procedures followed to conduct the service.

3 RESULTS

Table 1: Total product volumes vs. rejection rate in percentage in the mail operation

Product	Received	Processed	Inventory	Rejection rate
Registered letters	104,887,550.00	103,402,856.00	1,484,694.00	1.416%
Standard letters	6,157,340,515.00	6,151,352,888.00	5,987,627.00	0.097%
Parcels	25,812,971.00	25,672,725.00	140,246.00	0.543%
Nonstandard Letters	1,578,739,884.00	1,578,667,877.00	72,007.00	0.005%

Table 1 present the actual volumes of products received over a period of five years. The data shows how many letters or parcels were processed and how many were send to inventory which is also represented as rejected rate in percentage. Standard letters is the major product, whilst registered letters are the most rejected product.

Table 2: Rejected work per product vs. product recovered in percentages for inventory centre

Product	Received	Processed	Disposed	Process efficiency
Registered letters	1,426,802.00	1,382,480.00	44,322.00	97%
Standard letters	4,979,917.00	4,167,053.00	812,864.00	84%
PE Parcels	116,818.00	5,998.00	110,820.00	5%
PA Parcels	12,990.00	822.00	12,168.00	6%
RI Registers	57,892.00	57,892.00	-	100%
Foreign Parcels	10,438.00	2,872.00	7,566.00	28%
Speed service	72,007.00	6,378.00	65,629.00	9%
Foreign ordinary mail	1,007,710.00	1,007,710.00	-	100%

Table 2 present the total number of volumes received by the inventory centre per product. It also shows how much was recovered and how much was repossessed. This table simplifies if the inventory process is effective and efficient. It is observed that parcels are the least recovered.

4 DISCUSSION

The study was about managing waste in the South African Post office, specifically to manage the waste generated in the inventory centre and improve the current procedure used. The study was based on a two evaluations being to assess if the current procedures followed lean principles and adheres to environmental laws. The initial goals for having the inventory was to fulfil the customer's needs with the objective of recovering 100% letters that are sent to the inventory centre.

The data collected at table 1 shows how much in percentage of production was rejected, however at the same time in table 2, it illustrate how much of it was recovered. The process can be referred as efficient; however it does not adhere to lean principles completely. The inventory centre in itself generates waste as table 2 shows that Parcels are the most rejected products. Lean stipulate that less resources should be utilized to produce more, however it is observed that more resources are utilised and in excess, waste is generated.

The procedure of handling and storing these items is not regulated; some of them possess a safety and environmental risk that infringes with Section 24 of the Constitution. As it stipulates that "everybody has the right to an environment that is not harmful to their well-being and to have the environment protected [5], for the benefit of present and future generation". South Africa has extensive legislative and regulatory framework governing various aspects of the generation, handling, storage, transportation and disposal of waste that might have a potential to harm or degrade the environment as shown in table 3

Chapter 8 of the National Traffic Act no 93 of 1996 regulates responsibilities of all people involved in handling and transportation of Hazardous goods by road, of which most of the defect items are transported to RLO from various mail centres by road, it further prescribes operational norms and standards on how hazardous goods should be marked, packaged, secured and transported. The implementation of these standards (SANS 10228, SANS10229, and SANS 10231) will enable us to know the content of the parcel from packaging, as it would have been marked per regulated standards, and we will not have to wait for the allocated timeframe to know the content. Specialized vehicles would be designated to transport only such parcels as to compile with the said standards.

RLO is a storage facility for all the defects waste. It is termed a temporary storage facility for the work still in process. The National Environmental Management Waste Act no 59 of 2008 stipulate that a temporary waste storage facility should store waste for a period of 90 days before disposal and therefore RLO facility shouldn't be regarded as a temporary storage as it exceeds the allocated timeframe. Any waste storage facility should be free from nuisances such as odour, visual impact and ensures that breeding of vectors don't arise and ensure that pollution of the environment and harm to health are prevented. Most of the defect waste kept in the RLO has the potential to cause nuisance odour from meat products that are found there.

According to the Western Cape Health Care Waste Management Act no 7 of 2007 [7], all pharmaceutical waste must be stored separately in a secure waste container, it further stipulate that the storage facility should have adequate ventilation and lighting and must comply with Specialized vehicles would be designated to transport only such parcels as to compile with the said standards. The vehicle will be registered, and fitted with appropriate placards which include, an orange diamond in front of the vehicle, as well as placards on the sides and rear of the vehicle as outlined in the National Road Traffic Regulation published in the GNR 225 on the 17 March 2000.

All waste defects are kept at RLO for a period of a year before being disposed or actioned. Disposal should be seen as the last option in waste management hierarchy, as other option of avoid, reduce, recover, recycle should be explored before resorting to disposal. Waste is mainly disposed to the landfill site. Waste assessed in terms of the Norms and Standards for assessment of waste landfill disposal set in terms of Section 7 of the National Environmental Waste Management Act no 59 of 2008 must be disposed at a licensed landfill site.

Business waste not containing hazardous waste should be disposed only at a Class B landfill, which is designed in accordance with Section 3(1) and (2) of the standard and norms as specified in the minimum requirements for waste disposal by landfill (2nd Ed, Department of Water Affairs and Forestry).

Hazardous waste defects should be disposed only at Class A licensed landfill site in accordance with the requirement of Hh landfill as specified in the minimum requirement for waste disposal by landfill (2nd Ed, Department of Water Affairs and Forestry).

5 CONCLUSION AND RECOMMENDATIONS

The study was conducted to evaluate if the current procedures used in the inventory centre adheres to lean thinking and environment laws. It was observed that the procedures favours the lean thinking however it does not adhere to the principle completely. Various section of the process could be improved using 5s. This inventory centre varies to other inventory centres globally which makes it even difficult to adopt other approaches developed by other industrial companies. The procedures where reviewed and it was found that the cause of inventory waste is defects such untraceable address or incorrect address input for letters and parcels. The received letters are kept for a year which opposes the legislative procedures.

This concludes that the process has more environmental risks, due to long retention period of letters and parcels. The current process flow does not satisfy and comply with the environmental laws. Keeping the parcels for a longer period possesses a high risk to health and the environment. The employees within the working environment get exposed to the hazardous waste and they are not trained to handle these items. It is therefore proposed that all the employees be trained and be offered personal protective equipment. The public should also be offered training and awareness on how to write the addresses on the letter and the type of parcels that are acceptable.

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7 APPENDIX

Table 3: Operational procedure for Return letter office

Aspect	Letters	Parcels
Procedure	The procedure is to open the letter and to check the return to sender address, if it attached the employee will re-write the address and sort it per postal area or region. If the letter doesn't have sufficient data it will be shredded and be recycled.	If a customer did not claim the parcel within a period of a year, the South African Post Offices serves the right to dispose the contents. The method of repossession will be either disposal or auctioning of the products.
Method	All the sorting processes are done manually. The letters are moved by roll-tainer and stored in minitainer	All the sorting processes are done manually. The parcels are moved by roll-tainer and stored in minitainer
Documents	There is a standard procedure for the handling and disposal of mail. The process is regulated by the Postal Service Act of 1998 (Act No. 124 of 1998)	There is no Standard procedure for parcels , however they are regulated by the Postal Service Act of 1998 (Act No. 124 of 1998) No material data sheets are placed in the storage or working centre
Manpower	Only one employee is responsible for collecting, storing, sorting and sorting the parcels. Training has been provided for the standard operating procedures. there is a total number of 14 employees at the RLO	Only one employee is responsible for collecting, storing, sorting and sorting the parcels. No skills or training has been offered to the employees exposed to parcels. There is a total number of 14 employees at the RLO
Environment	The letters are stored in a storage area and they are stored according to the years in which they were received. The storage area is exposed to moisture and there is no ventilation. There is no labelling, demarcations, safety precautions and there is poor 5S utilization	The parcels are stored in a storage room; they are stored according to the years in which they were received. The risk is that the parcels differ and they are mixed and may result in chemical reactions, since they are kept for a longer period. the product are not labelled, poor 5s tool utilization and no ventilation

Table 4: Graphical images of the Return letter office process

<table>
<tr>
<td>
Waste is transported to RLO using the operational vehicles</td>
<td>
The waste is stored inside the mail operations bags and then stored in the mini containers and roll-tainer</td>
<td>
The storage area for received parcels</td>
</tr>
<tr>
<td>
Sorting process, per classified waste</td>
<td>
The labelling method used in the RLO</td>
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Awaiting disposal</td>
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MITIGATING DELAYS IN THE OPERATIONS OF A BUSINESS ENTITY WHEN CONVERTING TO THE ISO 55000 STANDARD

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ABSTRACT

Existing business entities often employ their own operational procedures and guidelines regarding asset management. However, converting to the ISO 5500X standards can adversely affect the operational performance of these business entities. Most of these pre-existing asset management systems possess some degree of operational inertia. This operational inertia can lead to delays when change is introduced. These delays could also discourage further adoption of the ISO 5500X standards. This study sets out to describe a method that identifies sources of substantial delays within an asset management system, specifically those originating from converting to the ISO 5500X standards. The identification of these sources is achieved through the use of mathematical modelling methods. The aforementioned information can lead to appropriate planning prior to the conversion to the ISO 5500X standards. If potential delays are identified, they can be pre-emptively mitigated with said plan, thus ensuring minimal reduction in operational performance.

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1 INTRODUCTION

Modern organisations employ many different tools and methodologies to increase operational performance and ultimately value for the stakeholders. Adopting new or existing standards of operation can be a large contributing factor to achieving and maintaining a competitive advantage. This is especially true for areas of operation where international standards do not yet regulate the manner in which these operations are executed.

The International Organisation for Standardisation [1] states that international standards are tools and guidelines that bring benefits from technological, economic and social sectors. These standards aid organisations in enhancing their operations and accessing new markets. Adhering to international standards help reassure clients in an organisation's capabilities and products. Other benefits include cost savings, enhanced customer satisfaction, increased market share and environmental benefits.

The newly developed ISO 5500X family of standards is the first international standard for Asset Management, published by the International Organisation for Standardisation (ISO). According to ISO 55000 [2], this standard provides an overview of asset management and asset management systems. Through the adoption of this standard, organisations can accomplish its asset management goals through effective and efficient management of its assets.

Organisations possess operational inertia; a trait that describes the inability of an organisational entity to immediately adapt to changes implemented. Due to this operational inertia, complications arise when a new standard is implemented and an organisational structure is changed. Change can be met with resistance from the individuals it affects, as well as the organisational departments undergoing said change. This resistance may result in departments, specifically those in Asset Maintenance Management (AMM), experiencing delays in the adoption of the new standard. These delays negatively affect the performance of the aforementioned departments. Incorporating the ISO 5500X family of standards into an operating AMM structure without proper planning and consideration can lead to significant delays. This does not only occur within the separate AMM departments, but can ultimately delay the operations of an organisation. These delays can prove to be costly and discourage the further adoption of the ISO 5500X standards. It is thus the responsibility of the implementing body to properly plan and assess any possible risks involved when introducing change into an existing system.

A simple methodical approach is needed to assess the response of an AMM structure when the ISO 5500X standards are implemented. The method is required to identify the AMM departments that will possibly experience the most significant delays. Appropriate actions can then be taken to prepare these identified AMM departments for change, and ultimately mitigate their expected delays.

This paper offers a simple method to assess the adaptability of AMM departments when converting to the new ISO 5500X standards. It links a department's possible low adaptability to the increased chance of it experiencing operational delays. The method implements information gathered from the personnel associated with each individual department to construct an accurate "on-the-floor" opinion of each department. Upper-management is consulted to determine the departmental resources and capabilities on a managerial level, such as financial support. Inter-departmental relationships are also incorporated to account for the chain-effects an individual department's delay has on the overall AMM structure.

The aforementioned information is used to calculate a numerical value which represents the adaptability of each department. The data collected, as well as this adaptability numerical representation, can aid in formulating accurate opinions of the assessed AMM departments. Implementing these findings in the pre-implementation process of the ISO 5500X standards can help mitigate possible operational delays in an organisation's AMM structure.

2 PAS 55 AND THE TRANSITION TO THE ISO 55000 SERIES

The Public Available Specification (PAS) 55 is an international standard for the enhanced management of physical assets. It was first published by the British Standards Institution in 2004 due to the industry's request for a standard in asset management. However, it is not a British standard. PAS 55 was revised in 2008 to mirror the increased international consensus for required good practices in physical asset management. (PAS 55-1:2008 Asset Management [3]).

According to van den Honert *et al.* [4], PAS 55 has been a success since its introduction to the industry. It has provided a flexible but robust asset management framework that encourages a continuous improvement. However, PAS 55 lacks details. It provides guidelines on what needs to be done, but does not address how it should be done.

The International Organisation for Standardisation (ISO) recently produced the ISO 55000 series, a family of international standards for physical asset management. The ISO 55000 series bases its content on the primary concepts of PAS 55. It aims to make the standard more applicable and user friendly than PAS 55, attempting to rectify the pitfalls of PAS 55. Another benefit of the ISO 55000 series, stated by van den Honert *et al.* [4], is the alignment it has with other major management specifications. This allows the ISO 55000 series to be easily incorporated by an organisation who employs these other management specifications.

3 RESISTANCE TO CHANGE

Change is a necessity for any organisation who wishes to remain a competitor in its relevant field of operation. Change can present itself in many opportunities, and come in a wide range of magnitudes. Carrillo and Gaimon [5] writes that when change is correctly implemented, it can enhance an organisation's performance to better compete in current and future planned activities. One method where change is implemented to improve performance is the Kaizen method. Singh and Singh [6] states that Kaizen is a methodology using change implementation, whereby very small improvements and changes are made in processes to gain a competitive advantage. Toyota is a well-known user of the Kaizen methodology. According to Singh and Singh [6], Kaizen has contributed greatly to Toyota's and the Japanese's manufacturing success.

Change, however simple an idea, is usually met with some resistance when considering the individuals it affects. Personal preferences and perceptions differ from individual to individual, and it is thus difficult to predict how an organisation's workforce will respond to change. Departmental structures can also offer resistance, much like humans. Departmental structures often lack the ability to adapt effectively and quickly when change is implemented. As a result, an organisational structure can suffer as a whole.

Resistance to change (RtC) is defined by Ansoff [7] as a multifaceted phenomenon, that introduces into the process of strategic change unanticipated delays, costs and instabilities. RtC can thus be perceived as a critically important factor that can negatively impact the success of change implementation, a view shared by Waddell [8]. She continues to state that RtC is far more complex phenomenon than once thought; it is a function of a variety of social factors. Although a complex phenomenon, Bouckenooghe [9] states that it can be followed through a series of stages originating at the precontemplative and contemplative stages. It is thus possible, albeit difficult, to assess how individuals would react to implemented change, and whether they would offer substantial resistance to said change. Although Waddell [8] and Bouckenooghe [9] only address the human components of RtC, it is possible to adjust their assessment measures in order to assess how an organisation's department would respond to change.

4 SOURCES OF RESISTANCE

Pardo del Val and Martinez Fuentes [10] list different sources of resistance, which include leadership inaction, capabilities gap, communication barriers and denial. For the purpose of this paper, these listed sources are characterised into two general resistance groups. RtC can originate, as aforementioned, from the human element, as well as from organisational departments. Therefore the two general groups are Personnel and Departmental factors.

4.1 Personnel factors

Organisations are dependent on human input, and thus are exposed to the influences of human emotions and opinions. The assessment of emotional factors in an organisational change situation can be very complex, and sometimes inaccurate. Waddell [8] confirms the aforementioned in her paper:

> *"The conception of resistance to change benefited greatly from the application of psychological, sociological and anthropological disciplines to study of management. As the understanding of resistance became increasingly sophisticated, it became clear that resistance is a far more complex phenomenon than once thought. Rather than being simply driven by the parochial self-interest of individual employees, this research concluded that resistance was a function of a variety of social factors"*

The aforementioned factors include, but not limited to, rational, non-rational and political factors. These are briefly discussed below.

4.1.1 Rational factors

A constant challenge in an organisation is that of aligning the workforce's opinions to that of the organisation to effectively work as a team. When change is introduced, resistance can be encountered when the change's outcomes are evaluated differently by the workforce to that visualised by the organisation's upper management. Waddell [8] states that these differences in opinion can influence the perceived merit and worth of the introduced changes. The differences in opinion may cause the employees to oppose the change, and even develop conflict between people, as discussed by Van Eemeren and Grootendorst [11].

4.1.2 Irrational factors

The prediction of an employee's reaction to change is difficult at best. It cannot be calculated, nor forecasted accurately. Each individual perceives change differently; some individuals welcome change, whereas others prefer unchanging environments. This individual perception of change also varies with circumstances in both the individual's working environment, and personal life. Human comfort zones, preferences and other irrational factors can therefore be powerful contributors to an employee's opinion and reaction to change.

4.1.3 Political factors

Opposition to change can be encouraged amongst employees when there exists internal conflict between those responsible for introducing the change, and those being affected by the change. Organisational politics can greatly influence the success of implementing and maintaining introduced change. Butcher and Clarke [12] speaks of recent study in which a general manager refused to co-operate with politically motivated managers. They continue to state that power is abused rather than used responsibly. All of these political factors can be seen as possible sources of resistance.

4.2 Departmental factors

An AMM system makes use of different departments to execute different tasks and responsibilities. AMM systems vary in complexity, but in general they all share the same core departments in order to achieve the same goals. For any system to operate efficiently and effectively, all the system components need to work together. This results in an inter-dependent relationship between sub-systems. The same can be said of an AMM system and its departments. *Figure 1* shows some of the core AMM departments, and their inter-dependent relationships.

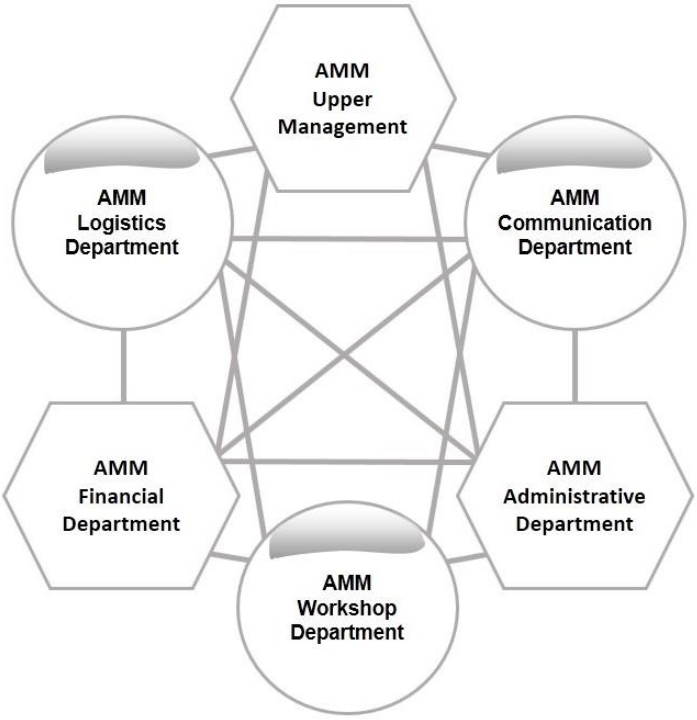

Figure 1: Departmental inter-dependent relationships

Each individual AMM department adapts to change differently due to many department specific characteristics, such as:

- Departmental operational flexibility
- Departmental structure
- Departmental regulations

In general, these factors can be listed under a single element, departmental flexibility. In order to streamline processes, organisations tend to put in place strict regulations and limitations. These regulations and limitations can, however, severely affect the flexibility of a department.

Most of the RtC encountered from a department is caused by its lack of flexibility. A single department that offers RtC can be dealt with individually. Therefore it does not seem to pose a large threat to the overall change implementation success as its problems are contained within the department's boundaries. That is not the case, however. A single department's RtC affects every department within an AMM framework due to the inter-dependence of the departments. One department's fall in performance results in an overall decrease in performance. Therefore, it does indeed pose a large threat to the successful implementation of change.

This paper does not aim to provide a method of identifying the flexibility limiting factors, but stresses the importance of structuring a department in such a way that flexibility is improved rather than limited. Increased flexibility in all AMM departments contributes to the reduction of negative influences each department can have on an AMM structure.

5 ASSESSMENT METHOD

As previously mentioned, a methodical approach is required to assess how an AMM system would respond to the implementation of the new ISO 5500X standards; whether it will offer minute or great RtC. One method of doing so is to assess the ability of an entity to adapt to change. Assessing an entity's adaptability is less complex than directly assessing the entity's RtC; if an entity shows promise of good adaptability, the risk of RtC from that specific entity is reduced [13]. The Departmental Adaptability Assessment (DAA) method accomplishes this through investigating the departments within an AMM system, and the personnel of each. Through means of questionnaires, it collects data from each department being investigated. Unlike most data utilized in AMM frameworks, the data used to identify possible sources of RtC in a department is based on personal opinions. Thus it is very important to query individuals with specific questions, relevant to their roles in the AMM system, to yield data that is accurate and applicable to the investigation.

To gain data on the individual departments, the managerial personnel, as well as the respective departmental personnel, need to be questioned. This is encouraged because information gained by only questioning upper management is usually biased and lacks scope, as well as depth. Investigating relevant documentation is important, but rarely reflects the effects of human involvement and the RtC they can offer.

As the DAA method requires information on each AMM department in the AMM system, it suggests a simple starting point. *Figure 2* depicts a flow chart for the assessing method.

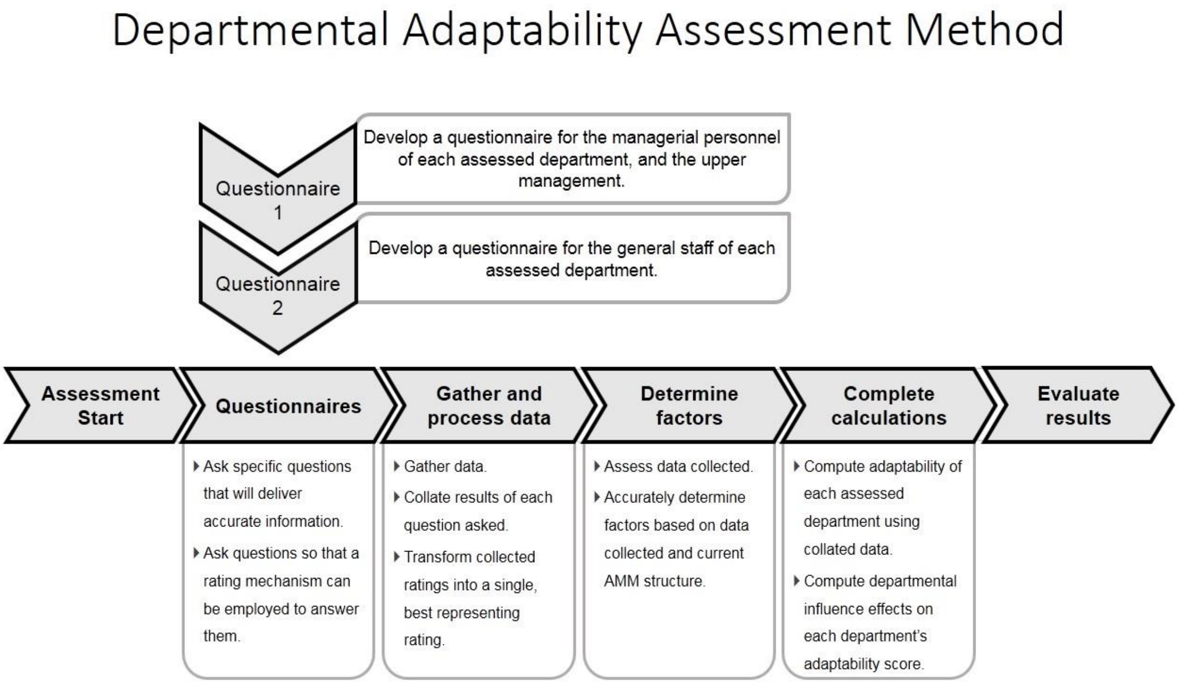

Figure 2: Adaptability Assessment Method

5.1 Evaluating elements

An AMM department's overall adaptability needs to be represented in a numerical manner. An effective way to calculate a numerical representation of adaptability is to rate a department against some evaluating elements. The evaluating elements used in the DAA method are as follows:

- Personnel adaptivity

- Personnel competency
- Departmental flexibility
- Financial resources
- Spare operational capacity
- Inter-departmental communication
- Administrative capability
- Workforce availability

If, however, an organisation wishes to include other evaluating elements they deem necessary, it will not affect the process of the method. For simplicity purposes, it is advised that the number of evaluating elements be kept to a minimum. The above elements will shed light on specific attributes of a department, and are deemed important components of this assessing method and are therefore the key elements to address in the DAA questionnaire.

5.2 Questionnaire development

The personnel working in each department can give valuable insight on the challenges being currently faced; insight that may not clear to the ISO 5500X implementing body. It is important to gather all available insight to create an opinion as accurately as possible. The DAA method requires that a comprehensive, but simple, questioning procedure be implemented to gather information on the aforementioned evaluating elements.

Confidentiality is of critical importance if honest answers are desired from the respondents. It is suggested that the level of confidentiality be communicated to the respondents prior to the distribution of questionnaires. This is to allow the sense of security manifest itself among the personnel being enquired.

The information required from upper management and the departmental workforce is similar. However, the workforce can be asked more specific questions about the department's inner workings which the upper management would be unaware of. The same applies to upper management. Upper management retains more specific information regarding the overall view of a department.

The different sources of information need to be approached effectively to gather accurate and trustworthy information. Thus it is of upmost importance to develop a questionnaire specific to each source of information. A simple, but effective, questionnaire method is one that employs a rating system. It enables the assessed to quickly complete the questionnaire, as well as deliver information in numerical format to the assessor. The main advantage of employing a rating system is that the assessing personnel does not have to transform written answers to the required numerical format. It also yield relatively accurate ratings of departments against the evaluating factors.

5.3 Collecting and processing Information

The information gathered from the different sources needs to be arranged into the relevant information groups. For a large organisation, this can be a large amount of data. Once all the data has been sorted, the assessor can process the information relevant to each question asked easily.

It is desirable that the ratings received on a single evaluating factor, or question, be transformed into a single value representing the overall opinion or result obtained from the personnel queried. This process demands that the assessor give great attention to the motivations behind the ratings to improve the determination of the single representing rating.

If, however, the questionnaires were not designed to incorporate a rating mechanism, then the assessor is required to study the data received thoroughly and determine the most appropriate rating for use in the calculations.

5.4 Determining the employed factors

There are two factors employed in this adaptability assessment method. They are:

- Influence Factor
- Departmental Influence Factor

Both of these factors have to be determined by the assessor. This is to allow as much flexibility in the method, as aforementioned, AMM structures differ in magnitude and complexity. It enables most AMM structures to implement this method effectively. It is important to note that these factors are crucial if accurate results are desired.

5.4.1 Influence Factor

The Influence Factor is intended to reflect the magnitude of the role each Evaluating Element plays in each AMM department. These factors must be determined through a thorough investigation of each departmental structure to see what roles these Evaluating Elements play.

5.4.2 Departmental Influence Factor

The influence each department's delays have on the rest of the AMM system is accounted for through the use of the Departmental Influence Factor. It is a simple attempt to account for the snow-ball effect delays have on an inter-dependent set of subsystems. Each department's influence on the other departments will be assessed, and the most appropriate factor chosen. Great care must be taken when allocating the factors, as mentioned before, to ensure that each organisation's AMM structure is accurately represented and trustworthy results is produced.

5.5 Calculations

The calculations to be carried out are kept simple and straightforward; keeping with the simplicity of employing this method. A detailed description of the mathematical steps taken is given in Step-wise Assessment Procedure below.

5.6 Evaluate results

The results obtained from this method yields information on two characteristics of the assessed AMM structure. The two characteristics are;

- Individual departmental adaptability
- Departmental effect on overall AMM operations

It is possible to identify which departments will have the lowest adaptability potential. This allows the ISO 5500X implementing body to notify these identified departments about their potential delays. These departments are then able to take action to rectify the problems revealed in the questioning process.

The latter characteristic listed above allows the ISO 5500X implementing body to assess the significance of each department's potential delays on a grand scale. A small delay experienced by a department can have a more severe effect on the overall AMM operations than another department's greater delay. The critical departments can thus be identified and steps taken to improve the adaptability of said departments.

6 STEP-WISE ASSESSMENT PROCEDURE

The implementation description of the DAA method can be best followed through the use of an example. The data used in the example was obtained from a confidential source, limited to only a few general departments in their AMM structure. The data collected from the source was simplified and generalized, as per request from the source, but maintained in an applicable format for use in this example. Any number of departments can be assessed in a similar manner, depending on the complexity and grandeur of the AMM under assessment. The general AMM departments assessed in the example are:

- Upper Management
- Workshop Department
- Administration Department
- Communication Department
- Financial Department

The motivation behind the choice of the above departments is merely due to the scope they cover in an AMM structure. These departments are not specific departments found in an AMM structure, but are merely basic representatives of AMM departments found. Large organisations will have specific AMM departments responsible for each facet of AMM, which allows the easy identification of departments. However, the DAA method is also intended to be implemented by small scale organisations, which may not have specific AMM departments. Using basic departments in the example allows small scale organisations to break up their AMM structures in a similar manner.

6.1 Data organisation

The initial stage of the assessment is distributing questionnaires to gather sufficient information to carry out the assessment. The questionnaires, as mentioned previously, are to be developed by each organisation to adhere to their regulations and requirements.

The questions used in this example's questionnaire were focused on obtaining directly applicable information regarding the Evaluating Elements listed in Section 5.1. The questions directed towards the personnel, to evaluate the adaptability of said personnel, were simple, such as:

- "Do you think the current AMM system is effective and efficient enough?"
- "Do you welcome change in your workplace, or do you prefer to continue to operate in your 'practiced' manner?"

These questions are aimed at revealing the adaptability of the workforce, as well as their opinions on the current methods of operation. The implementing organization can incorporate questions to reveal more aspects deemed necessary to accurately construct an opinion of each department and its workforce, but it is suggested that the questions be kept direct and simple.

The information gathered from the questionnaires can be substantial. It is desired that the data be compressed for ease of use in this case. One method for compressing the data is to average the rating scores of each question in the questionnaire. This allows a large number of scores to be transformed into a single value, however, the possible insight gained from assessing each individual rating score can be lost. It is preferable that a thorough study of the information gathered be completed. This allows any potential insight gained to be incorporated, and the most accurate single representing score to be determined.

6.2 Individual assessment

The DAA method individually rates each department against the aforementioned evaluating elements. These ratings are decided upon through the study process of the data collected; thus it is merely an implementation of the compressed data. The mathematical evaluation can be completed using Microsoft Excel©. Table 1 is an extract of the example given, showing the various components.

Table 1: Example of an Individual Department Assessment

AMM Workshop Department	Evaluating Elements	Rating	Assessment Score	Rating: Influence Factor	Influence Factor:	Individual Score
Personnel:	Adaptivity	Poor - Good; [1,5]	2	Low - High; [1,10]	7	14
	Competency / Training	Poor - Good; [1,5]	5	Low - High; [1,10]	6	30
Departmental:	Flexibility	Poor - Good; [1,5]	3	Low - High; [1,10]	10	30
	Financial Resources	Minimum - Excessive; [1,5]	1	Low - High; [1,10]	4	4
	Spare Operational Capacity	Minimum - Large; [1,5]	2	Low - High; [1,10]	9	18
	Inter-departmental Communication	Poor - Good; [1,5]	3	Low - High; [1,10]	3	9
	Administrative Capability	Poor - Good; [1,5]	2	Low - High; [1,10]	4	8
	Workforce Availability	Understaffed - Overstaffed; [1,5]	3	Low - High; [1,10]	10	30
			Total Individual Score			**143**

Table 1 shows the assessment of an AMM workshop department. The evaluating elements are listed, as well as the Rating guide and the Assessment Score. The areas of input are the Assessment Score and Influence Factor columns. The Assessment Score is the final rating a department received when judged against the respective evaluating elements. The individuals responsible for rating a department are preferably representatives from upper management; individuals who have adequate knowledge of the assessed departments. This Assessment Score however does not sufficiently reflect the importance it has in that specific department, thus an Influence Factor is introduced. The Influence Factor scales the Assessment Score to appropriately represent the contribution each evaluating element has to the department's adaptability.

Great care must be exercised when choosing the most suitable Influence Factors for the different departments; the Individual Score contributes heavily to the final position of each department when ranking the department adaptabilities. The evaluating individuals must complete a thorough investigation of the influence each Evaluating Element has on the respective department. A meeting with the managing personnel in the department, in which the influences of each Evaluating Elements are discussed, would provide sufficient information to accurately develop the necessary Influence Factors.

The Assessment Score is multiplied with the Influence Factor to yield an Individual Score for each Evaluating Element. In essence, it represents the positive contribution to the overall adaptability of the assessed department. The Individual Scores are then added together to yield a number representing the overall adaptability score of an individual department, referred to as the Total Individual Score. Table 2 below contains the Total Individual Score of each assessed department in the given example.

Table 2: Summary of Total Individual Scores of the Assessed Departments

Departments	Total Individual Score
Upper Management	164
AMM Workshop	143
AMM Administrative Department	174
AMM Communication Department	177
AMM Financial Department	155

Assessing the departments based on their individual scores will result in an inaccurate conclusion. The larger the individual score does indeed mean that a greater adaptability is possessed by that respective department. However, the inter-departmental relationships has not been taken into account. It is required to incorporate the affects a single department would have on the remaining AMM departments.

6.3 Inter-departmental effects assessment

To account for what affects a department, with a low Total Individual Score, has on the overall AMM structure, a scaling factor is implemented. This scaling factor, named Departmental Influence Factor, represents the influence strength a department has on another. Table 3 below is an extract from the example, in which the Departmental Influence Factor is implemented on each of the respective departments. It shows two inter-departmental assessments on two departments, namely:

- AMM Upper Management
- AMM Workshop Department

Each department is evaluated against the remaining departments. The Departmental Influence Factor represents how much influence the evaluated department has on the other departments' operational capabilities. The evaluated department's individual score is then divided by the determined Departmental Influence Factor to yield the Adjusted Score. The Adjusted Scores are added and the Final Score is determined.

Table 3: Inter-departmental Influence Assessment Example

AMM Upper Management			
AMM Departments	**Departmental Influence Factor: Low - Large [1 - 10]**	**Adjusted Score**	**Final Score**
AMM Workshop	4	41	**139**
AMM Administrative Department	3	55	
AMM Communication Department	6	27	
AMM Financial Department	10	16	

AMM Workshop Department			
AMM Departments	**Departmental Influence Factor: Low - Large [1 - 10]**	**Adjusted Score**	**Final Score**
Upper Management	1	143	**243**
AMM Administrative Department	5	29	
AMM Communication Department	6	24	
AMM Financial Department	3	48	

As aforementioned, the factors employed in the DAA method needs to be determined by each organisation to make it applicable to their AMM structure. The Departmental Influence factor is determined using the information gathered from AMM upper management. Again, great care must be exercised to choose the most realistic factors employed in this method.

6.4 Interpreting results

The summary of the example's results is shown in the Table 4 below. Both the Total Individual Score values from Table 2 and the total Final Score values, a continuation of what is shown in Table 3, of all the departments are tabulated.

Table 4: Departments' Final Scores

Final Scores for all departments		
Departments	**Total Individual Score**	**Final Score**
AMM Upper Management	164	139
AMM Workshop Department	143	243
AMM Administrative Department	174	194
AMM Communication Department	177	125
AMM Financial Department	155	151

Investigating the results of Table 4, conclusions can be drawn up based on the adaptability of each department, as well as the global affects each of department's adaptability possesses. Ranking the Total Individual Score results from highest to lowest, one can determine the most adaptable to least adaptable departments. In other words, the least adaptable department will stand the greatest chance to offer the most RtC. (Piderit, S.K. 2000. [13]).

For this example, the departments are ranked as follows according to their Total Individual Scores:

1. AMM Communication Department
2. AMM Administrative Department
3. AMM Upper Management
4. AMM Financial Department
5. AMM Workshop Department

Thus only consulting the Total Individual Score results one can conclude that the AMM Workshop and Financial departments will offer the most RtC respectively in the AMM structure. However, if the Final Scores are ranked, a different conclusion can be made:

1. AMM Workshop Department
2. AMM Administrative Management
3. AMM Financial Department
4. AMM Upper Management
5. AMM Communication Department

The departments with the lowest Final Scores will stand the greatest chance to cause the largest delays in operations of the organisation. The effects of their RtC are felt most severe by the other AMM departments. The initial conclusion was that the AMM Workshop Department would offer the most RtC. This is correct, however it does not cause the largest delay in the AMM structure. The AMM Communication Department experiences the least RtC, however, the little RtC it experiences will cause the greatest delay in operations.

7 CONCLUSION

This paper aimed to deliver a simple method of assessing an Asset Maintenance Management structure's potential delays, caused by experiencing RtC, when adopting the new ISO 5500X family of standards. Its results can enable an organisation to identify the AMM departments that will potentially offer significant resistance to implemented change, as well as which departments will have the most severe effect on the overall AMM operations.

A rough overview of some sources of RtC was provided to better comprehend the fundamentals on which the Departmental Adaptability Assessment (DAA) method is based. Many different components of an organisational structure can be originating points of resistance. This paper clustered these sources into two general groups, namely Personnel and Departmental Factors. This separation allowed similar sources to be briefly investigated in a similar manner, aiding in some understanding of what causes resistance to change.

The DAA method utilises the information gathered from the personnel involved in all AMM departments. It allows the voice of the workforce to shed light on possibly unknown problematic factors, as well as to gain a better understanding of each departmental structure. The information required is collected through the use of questionnaires, specific to each organisation and its AMM departments. The assessment is completed through the use of Microsoft Excel © whereby numerical representatives of a department's adaptability are computed.

The method offers two stages through the assessment where conclusions can be drawn up. First, each department's adaptability is determined separately. Studying the data of each department allows problematic areas to be spotted as well as further expands the understanding of its inner workings. Secondly, the departmental relationships are investigated, presenting the opportunity to assess the global effects each department has on the AMM system.

The DAA method remains a simple assessment method to understand and implement, however requires large inputs from the implementing organisation. Incorporating large organisational inputs does however have one main benefit. It enables the method to be employed by a wide range of different entities. The intended deliverable from the DAA method was the identification of any department that would possibly critically delay operations when the ISO 5500X standards are implemented. The DAA does present other benefits when employed. It offers a method to better understand the complex mechanisms an AMM system, specific to each organisation. Implementing the knowledge gained through this method can be of great benefit to ultimately mitigate delays in operations when converting to the ISO 55000 standards through identifying the greatest possible sources of RtC.

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CORRELATION AND CAUSATION: A POTENTIAL PITFALL FOR EFFICIENT ASSET MANAGEMENT

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ABSTRACT

The successful coordination of activities and practices within a system rely on the organisation's ability to make informed decisions. Decisions must be made quickly and effectively, while ensuring efficient Physical Asset Management (PAM). Access to processed data, in the form of reliable information, on how sub systems interact greatly simplifies decision-making. Many organisations mistake correlation for causation when analysing this data. Such a mistake carries great consequences for organisations, since important decisions might unknowingly be based on self-invented problems, while the true problem is left unresolved. It is crucial to understand the difference between correlation and causation when practising root cause analysis within a PAM environment. Although root cause analysis is presumed a highly specialised field, organisations can equip themselves to better understand how different events within a PAM system are interconnected. If done correctly this might simplify the process of detecting problems, which might exist within a system. This paper highlights the differences between correlation and causation. Potential pitfalls on how correlation can be mistaken for causation within a PAM environment are identify and explained. Recommendations are made on how to avoid these pitfalls.

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1 INTRODUCTION

Decision-making is a key component within any Physical Asset Management (PAM) environment. Ensuring efficient Asset Management expects organisations to make informed decisions quickly and thoroughly. Redman [1] suggests that this process often happens in the absence of adequate information or knowledge about the system. Understanding the difference between correlation and causation might help organisations to avoid some of these potential pitfalls which might occur during Asset Management decision making.

1.1 Background

Access to the right data can greatly facilitate decision making within a PAM environment. If used in accordance with ISO 55000 [2] and PAS 55 [3] asset data can be transformed into asset information, which might help organisations to make more knowledgeable decisions.

Although data may be of aid in asset management, Quinlan [4] believes it can also have negative consequences if not handled with care. Data used by organisations are often insufficient to substantiate important decisions [1]. When studying data in isolation it is difficult to determine whether all required information is available. Resultantly, organisations might base important decisions on vague interpretations of data, due to a lack of a better understanding of the problem at hand.

1.2 Problem Statement

According to Card [5] distinguishing between correlation and causation is not as intuitive as many might believe. For data to be of aid in decision making within an Asset Management environment, it is essential to ensure correct interpretation of this data. Many organisations mistake correlation for causation when analysing data [6]. Consequently decisions are often unknowingly based on self-invented problems, while the true problem is left unresolved.

Misinterpretations of data during root cause analysis may nullify any effort to develop substantial solutions to a specific problem. On the contrary, this can easily lead to creating an even bigger problem than before. It is therefore important for organisations to understand why it is important to distinguish between correlation and causation, know what this distinction is and ensure that they are capable of applying this knowledge for more efficient Asset Management decision making.

1.3 Objectives

This paper intends to

- Explain the difference between correlation and causation
- Identify and explain potential pitfalls where correlation can be mistaken for causation in accordance to a case study of which data is available
- Make recommendations on how to avoid these pitfalls

This paper is based on the philosophy behind root cause analysis, where the same approach has to be taken as in the legal world where a suspect is *innocent until proven guilty*.

2 CORRELATION VERSUS CAUSATION

In a statistical environment, *Correlation* describes a relation between different and separate events, where these events show a tendency to vary simultaneously. At a quick glance it is easy to assume that these events are linked and that the behaviour of one event has an effect on the behaviour of another. This however is not the case. Although it is important for such a correlation to exist, it is not possible to establish causality from correlation alone [7]. *Causation* on the other hand, describes a cause and effect relationship between events. The behaviour of an event therefore directly affects the behaviour of other. *Root cause analysis* is the process of looking for the root cause which induced a specific effect.

2.1 Requirements for Causation

Many different approaches can be followed to prove causation [8] [9] [10] [11], but not all problems have the same nature. Therefore it is difficult to narrow root cause analysis down to one generic approach which would suite all problems. Card [5] identified three general requirements to facilitate this process.

- Correlation should exist between cause and effect
- Cause should precede effect
- Linking mechanism between cause and effect must be identified

If these requirements are satisfied, a causal relationship between events has been demonstrated.

2.2 Distinguishing between Correlation and Causation

Card [5] further explains the difference between correlation and causation efficiently through an example where people spends time reviewing a document to detect defects such as spelling or language errors. The results for this experiment are shown in Figure 1. It is seen that there exist a definite correlation between the hours spent reviewing and the defects found.

At first it might seem that there exist causality between the two events. Time has to be spent to find defects. The results suggest that if this time is spent then defects will be found. Can this therefore be defined as a cause and effect relationship?

In reality the reviewers will reach a threshold where after they will not likely find more defects, even if they spend infinite time trying. It is also important to note that the action of reviewing and finding defects happens simultaneously. This example fails to adhere to the second requirement and therefore it is evident that there exist no cause and effect relationship between the time spent reviewing the document and the amount of defects found.

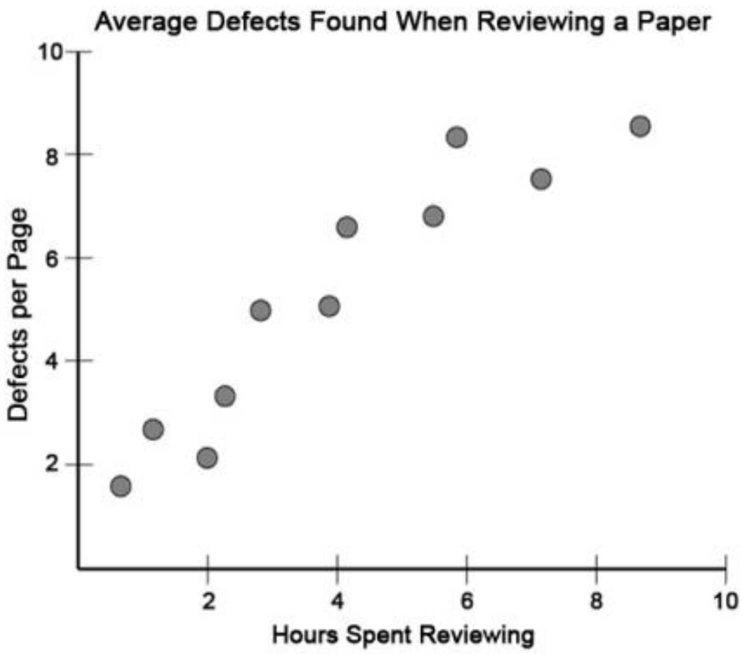

Figure 1: Example of correlation between variables as described by Card [5]

Once explained it is easy to understand that there is no causal relationship between the events described above. Note that this is a very simple example and in reality PAM systems tends to be much more complex. Therefore, root cause analysis requires an in depth understanding of the system to be able to properly define a problem and hopefully help find the root cause for this problem [12]. Only once the root cause has been established can solutions be generated on how to solve these problems.

2.3 Root Cause Analysis within a PAM Environment

All problems are defined by the events which caused the problem. Therefore to be able to solve a problem, the cause which created the problem has to be identified and then strategies can be developed to prevent these causes from reoccurring [12]. Root cause analysis is therefore a very important tool which can be used in a Physical Asset Management environment to find efficient solutions to problems which exist in complex systems.

The following sections will take a systematic approach on how a mining company, practising Asset Management, might go about looking for the root cause for component failure within large mining machinery used on different mines. Pitfalls, where correlation might be mistaken for causation during this process, are identified and explained. Recommendations are made on how to avoid these pitfalls.

3 IDENTIFYING CORRELATION

The first step to prove causality between specific events requires ensuring that a correlation exist between the events which are investigated. Rodgers and Nicewander [13] suggest various methods to establish correlation using the famous Pearson's product-moment correlation coefficient, but regardless of the methods used to establish correlation, this step requires access to relevant data.

3.1 Ensure Data Integrity

Data is an important tool used during decision making within a PAM system [3], but the use of incomplete data for decision making is very dangerous. Crucial information might be missing from the data and therefore basing decisions on this data can lead to inferior solutions to be developed. When this is the case, a problem can become data specific and correlations between events may easily be mistaken for causation. Data integrity must therefore be ensured before data mining can begin.

Organisations should try to ensure, as far as possible, that all needed data is obtained to efficiently help find the root cause for a specific problem [12]. This process might be made easier if sound strategies are followed to record and store data. The use of appropriate unique keys and identification codes can help to better structure data and help facilitate future data analysis. When planning which data will be recorded within a PAM system it might help to implement a virtual root cause analysis on critical components within the system. This should ensure that the organisation have access to all the required data for when a problem do occur.

3.2 Pattern Recognition

Data can be analysed to find reoccurring patterns or specific trends. It might be possible to argue that a repeating pattern within a dataset might also be seen as correlation of some kind. For this to make sense within this context the data will have to be split in two or more parts to be able to compare the repeating data from different time intervals with one another. Note that although this is a very important part of data mining, it is very difficult to prove that the behaviour of data in one interval directly influence a following pattern even if correlation does exist. Usually trends are the results of other external factors and are not specifically dependant of previous behaviour. Therefore it is important to take note of these trends, but they cannot be used to prove causality.

3.3 Matrix Scatterplots

When analysing data with the purpose to find a root cause for a specific PAM problem it is important to start by looking for correlation between events. This will help identifying areas which should to be further investigated for potential causality. Usually this includes filtering through large datasets, which can easily become a tiresome and frustrating process if all variables are investigated separately.

The use of matrix scatterplots is a very effective method to easily filter through large datasets in search of correlation. Figure 2 shows a matrix scatterplot of data which recorded the fitting and defitting information for components during maintenance on large mining machinery. As highlighted, this diagram highlights various locations where potential correlation might occur. These regions show that one set of data change as another varies. Simultaneously it shows which variables can be ignored in the search for correlation.

This is also an effective method to identify whether there are data entries which might be faulty. For instance Var 3, the component code and Var 9, the component description from Figure 2 should show a perfect linear correlation. This is not the case and therefore it is reasonable to assume that there are potentially faulty entries present in the data.

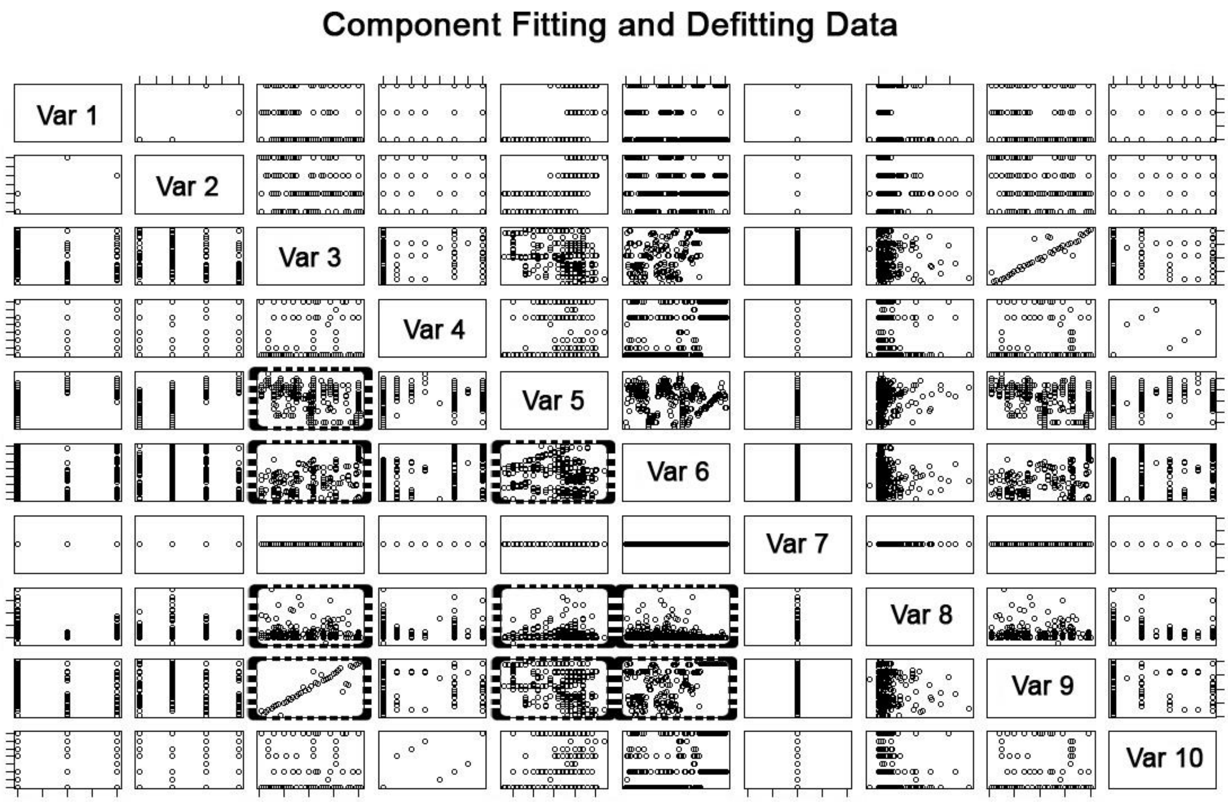

Figure 2: Matrix scatterplot for data from specific machine at specific mine

3.4 Data Comparison

Once events where potential correlations might exist have being identified, these events can be isolated for a further investigation. Figure 3 illustrates the life span of a specific component, from a specific mining machine, on four different mines. If the component fails it is replaced or repaired. Each repair or replacement is represented as a dot on the graph. Wherever a component life of zero is indicated, it is evident that the data is corrupt at this point. It is difficult to pick up any specific pattern in the component lifetime via inspection alone. Nonetheless, it is evident that the components on different mines varied more or less within the same range.

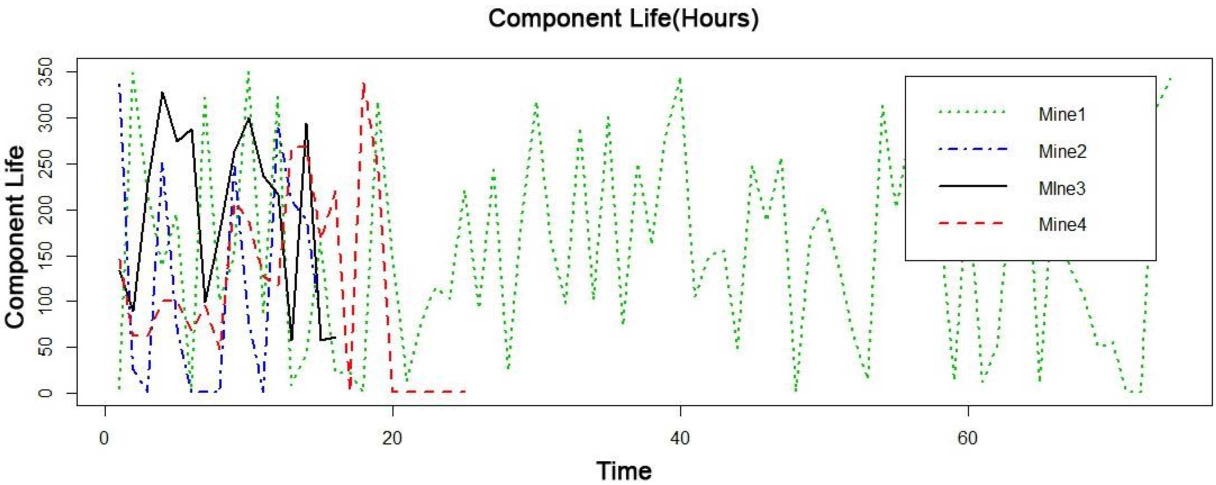

Figure 3: Comparing component life from different mines

This suggests that the component failure is most likely not location specific and is therefore independent of a mine's climate and the product handled by the machines. This might rule out or enforce the possibility that a component failure might be due to material failure such as corrosion. Data does not always provide answers in the format which is expected. It is the responsibility of the organisation to develop sound strategies to help obtain relevant information. To ensure efficient PAM strategies an organisation should be able to think of the right questions to ask and apply the required expertise to answer these questions sufficiently.

4 CAUSE SHOULD PRECEDE EFFECT

Once correlation between events within a PAM environment has been established, the next step to prove causality is to ensure that the cause precedes the effect.

4.1 Causal Tree

An efficient technique to ensure that the cause precedes the effect is by identifying the potential causes which might have caused the problem. A causal tree is an efficient method to visualise this information [14]. Figure 4 shows an initial causal tree showing potential causes which might have caused component failure in a mining machine. Such a tree has to be expanded through an iterative process as far as possible. During root cause analysis new findings should enable an organisation to improve such causal trees. This does not only help during root cause analysis on the current problem which is investigated but also for future problem detection and should also help to improve future designs for future components.

4.2 Cause Before Effect

As seen in Figure 4 the component failure can potentially be caused by six different events defined by Bloch [15].Each of these events are then further expanded into the possible causes which might have induced these six events. All events are repeatedly expanded until all possible causes for the component failure have been identified.

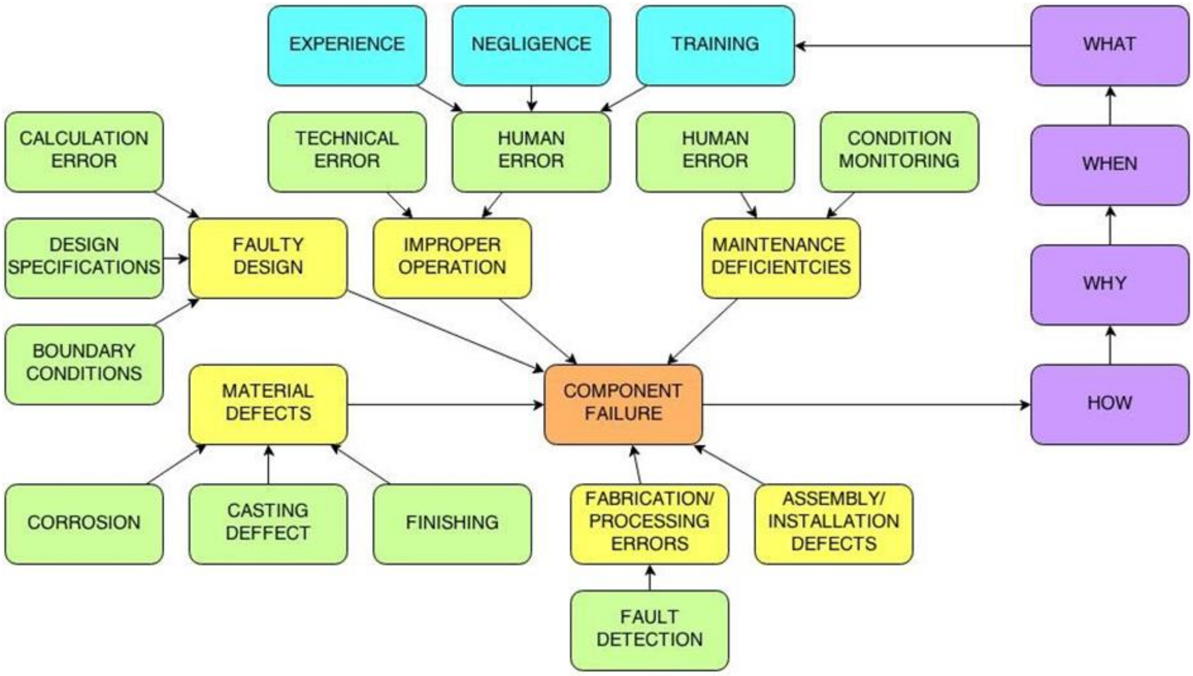

Figure 4: Causal tree for component failure

When two events are investigated to determine the order in which they occur, the causal tree can be used. The higher up the hierarchy an event occurs, the later it happened. For instance, if component failure is compared to the training a driver received before operating a mining machine, it can be seen that component failure may occur due to lack of training, this is a human error resulting in improper operation and therefore component failure occurred. It is not possible to argue that a component failed, which resulted in the driver being inadequately trained for the job, since the driver was trained before the component failed.

5 LINKING MECHANISM BETWEEN CAUSE AND EFFECT

After correlations between events have been established and it can be shown that the effect precedes the potential cause, a linking mechanism has to be identified to prove causality.

In reality identifying the exact root for an event within a complex PAM system is not always an easy task. Initially the only know certainty is that a problem has occurred, but the nature of the problem is not necessarily known. To find the root cause, this problem has to be characterised. Simultaneously potential causes have to be identified and linked to the problem [12]. This involves an iterative process of investigating all potential causes to establish what the problem is, when it happened, why it happened, how it happened and if it contributed to realising the problem. In many aspects this requires completely the opposite approach as was taken in the previous section where the causal tree in Figure 4 was developed.

5.1 Forcing a Cause to fit an Effect

At this stage a common mistake which might be made during root cause analysis involves identifying a potential cause for an effect. This cause is then isolated for further investigation. It is easy to argue that a predefined potential cause is destined to cause a specific effect. Therefore organisations might argue that since the specific effect did happen, it is due to the predefined potential cause. For instance, if you strike a match, there will be fire. Does this mean that if there is fire, it was caused by a match? It might even have been caused by a combination of different events, maybe a match and wind.

A potential cause can easily be forced unintentionally to match an effect. Especially when in a large and complex PAM system where there are little data available to support decision making. It is therefore important to note that root cause analysis tries to mine useful information from complex and interconnected systems, where different events can rarely be completely isolated from one another.

5.2 Understanding the Bigger Picture

Another mistake which might be made when analysing problems in a PAM system, is to isolate subsystems from the goals and philosophies which defines the greater system. Within complex systems there are many different factors at play which indirectly influence a problem and therefore its causes [16].

Consider a component failing on some large mining machinery. This component belongs to a machine, which has a certain purpose on a mine. The mine is part of a specific industry which again is driven by a country's economy. The country's economy forms part of the global economy, which is defined by the global availability of resources and the human need for certain commodities. All of these factors are interrelated and therefore important to consider when making decisions to implement sound PAM.

Although the current position of the global economy do not influence whether or not a gearbox fails within a machine, it might influence the strategies which can be implemented to fix the problem. If the global economy is down and the stock market drops, it is likely that the mine may be financially influenced by the situation.

If a specific mining machine breaks down and the machine is crucial in ensuring the mine's performance, it is important to resolve the problem as quickly as possible. This might involve applying more or less resources to root cause analysis, depending on the criticality of the problem. Root cause analysis strategies might vary and therefore also influences PAM strategies. For efficient Asset Management it is therefore important to know how all events within a PAM system is interconnected and whether there exist a correlating or causing relationship between these events.

It is a good idea to visualise these connections for a better understanding of the relationships between events. Figure 5 visualises the internal and external relations between events and parties involved within a mine. Once the workings of the larger system are known, problems occurring in different locations can be identified, defined and further investigated

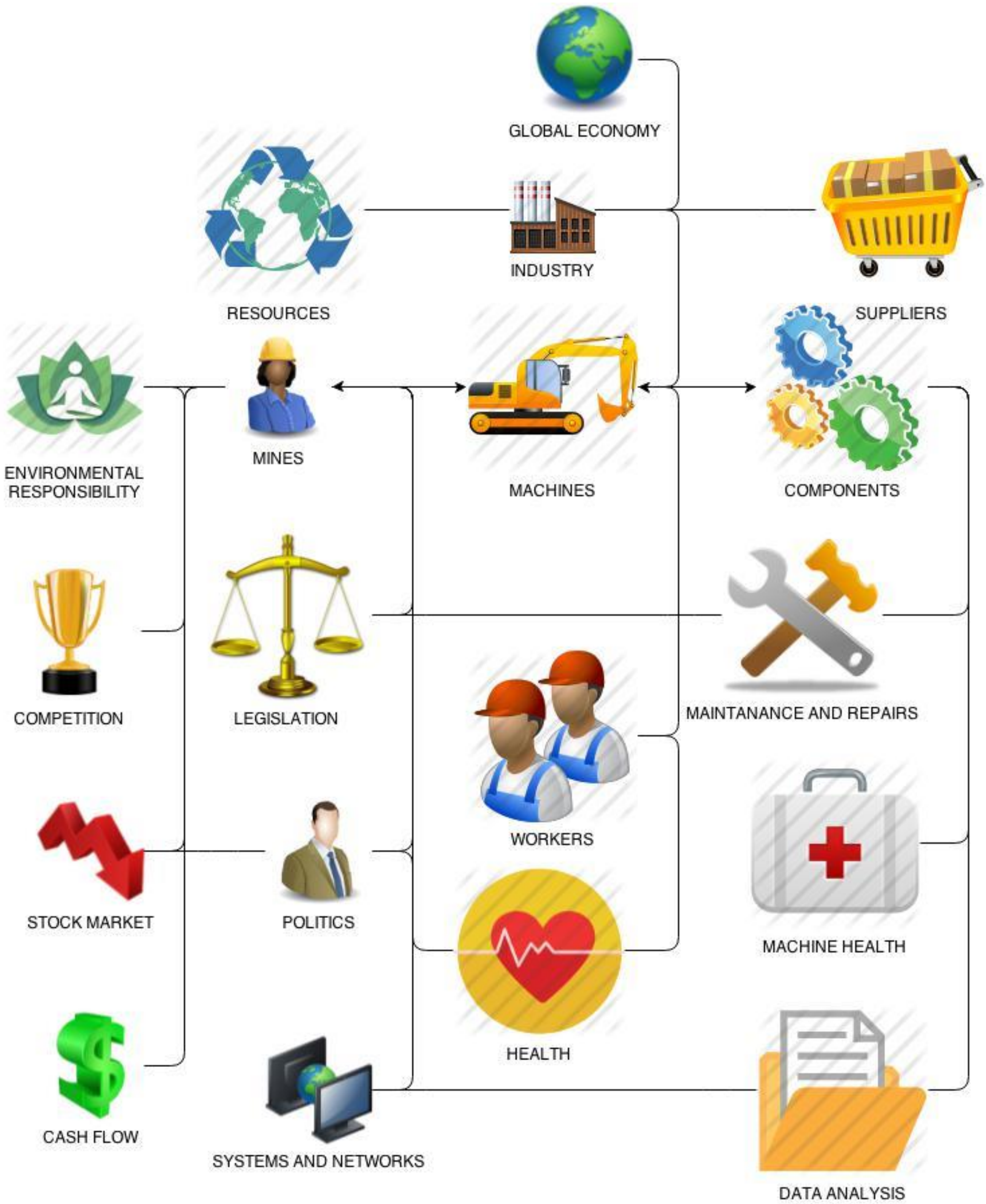

Figure 5: External and internal influences of a mine

5.3 Finding the Root Cause

Only once a problem, which may arise within a PAM environment, is fully characterised and understood, may the search for the root cause begin. As mentioned earlier there are various techniques which can be used to find linking mechanisms to fully prove causation.

Despite the various techniques and tools available it remains important for organisations to truly know the ins and out of a system and simultaneously be able to implement critical thinking, to help find the linking mechanism which will prove causality for a problem within a PAM system.

6 RECOMMENDATIONS

With the complexity of PAM systems ever increasing, it might be important for organisations who take Asset Management seriously, to design their systems for improved root cause analysis. This includes identifying connections between different subsystems and predicting how potentially unwanted behaviour within a system might influence behaviour in other subsystems.

Designing and building a root cause analysis strategy into a PAM system will aid failure detection when problems occur. Root cause analysis is not only meant to be implemented as a maintenance strategy, but can also help preventing potentially unwanted behaviour in the future.

Due to the large infrastructure of interconnected subsystems and events present in a PAM system, it is easy to confuse correlating events for causality. It is therefore recommended to keep the three general requirements as described by Card [5] in mind when trying to demonstrate a causal relationship between events.

Relevant and accurate data is an enormous aid for efficient decision making. Ensure that all data used is correct and factual. Develop sound strategies to ensure that data is properly recorded and user friendly as proposed by Baker [17]. Once the integrity of the data can be proven the search for correlation between events can start.

Use causal trees to break events up into their potential causes as far as possible. This will help determining whether a cause precede an effect and furthermore help to better understand where to investigate when looking for the root cause of an event. Potential weak points within a system can also be identified for later improvement of the system.

When searching for a linking mechanism to prove causality, the goals and philosophies of the larger system should guide the strategies which are developed for root cause analysis. No event which forms part of a complex PAM system, can be viewed in complete isolation.

Root cause analysis requires an organisation to have the same mentality as in law where a suspect is *innocent until proven guilty*. During the process of root cause analysis information is the greatest tool to assist in finding solutions to problems. Use this information wisely, within the systems context, to narrow down problems and find their causes. Be aware of the potential pitfalls when mistaking correlation for causation and ensure PAM strategies which will avoid these pitfalls.

7 CONCLUSION

Due to its wide application, root cause analysis is a topic, which is intensively researched by many. Organisations strive towards improved efficiency, simultaneously systems tend to be more complex than ever before and modern legislation adds to the complications experienced in these systems. Despite trying very hard, no generic tool has been developed to search for and identify causality within a system. For this reason it is important for organisations practising Physical Asset Management to avoid mistaking correlation for causation during root cause analysis.

As shown in this paper the process of finding the root cause to a specific problem is not always easy. Complex systems tend to disguise crucial information which is needed for efficient decision making. The combined knowledge of how events within a PAM system are connected, guidelines for sound PAM such as PAS 55 and ISO 55000, relevant data and knowing how to interpret the data accurately, should help organisations avoid potential pitfalls which might occur from mistaking correlation for causation and to ultimately practise more efficient Physical Asset Management.

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THE ECONOMIC AND STRATEGIC FEASIBILITY OF IMPLEMENTING SUSTAINABLE ENERGY INITIATIVES IN THE SOUTH AFRICAN MANUFACTURING ENVIRONMENT: A CASE STUDY AT ALTECH UEC

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ABSTRACT

Worldwide there is a drive towards energy generation from renewable sources. . This paper will detail the sustainable generation options available and evaluate the feasibility of their implementation in the South African manufacturing environment. This will be done by doing a case study at Altech UEC. In order to determine whether or not sustainable energy solution/s are feasible, the current South African supply situation will be characterized. The South African Government has made a substantial commitment to sustainable energy. As a result there is a beneficial statutory framework within which renewable energy projects operate. The challenge remains to derive the maximum benefit, as many of the structures are mutually exclusive. This paper evaluates the maximum benefit for Altech UEC's context. Solar was found to be the only viable renewable energy source. The preferred technology identified was a grid-tied photovoltaic system. However it was found that this option was too expensive to be economically feasible without an additional revenue stream, which can be tapped by selling carbon credits.

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1 INTRODUCTION

What is sustainable energy and is there room for its application within a South African manufacturing environment? Sustainable energy is a talking point, locally and abroad. Is the South African environment mature enough to enable companies to respond to the need to use alternative sources?

Some background will be provided regarding conventional and sustainable energy and the opportunities that exist to conserve the consumption of coal-generated electricity and the increased efficacy. The current state of electricity in South Africa and efficiency incentives will also be discussed.

This paper aims to provide a realistic picture of the pressures that manufacturing environments face with regards to power consumption. The current setting at Altech UEC, the sustainable energy initiatives that have been implemented and their results will be discussed. Altech UEC's future strategies and opportunities for developing a sustainable energy infrastructure together with its challenges such as the forecasted regulatory demands, electricity cost and the available sustainable energy innovations will be discussed, with the aim to provide some insights into the reality of the financial viability of such initiatives.

1.1 Understanding conventional and sustainable energy

1.1.1 Conventional energy

The basic electricity generation process entails using an energy source to turn a turbine, which in turn rotates the magnet inside the coils, thus generating the electricity. Power stations can be viewed as energy converting stations [2].

Currently, the most conventional source used to generate electricity is coal. According to the World Coal Association [4], coal is responsible for 41 percent of all electricity generation world-wide and 94 percent in South Africa. This coal is burnt to generate steam which rotates a turbine [2].

The use of coal, however poses a few challenges. Firstly for the environment, as it is responsible for the one of the largest sources of carbon dioxide emissions. For every megawatt-hour power generated using coal, approximately 1 015 kilograms of carbon dioxide are emitted [3]. Secondly, the estimated world consumption of coal was approximately 7.25 billion tonnes during 2012 and is projected to increase to 9 billion tonnes by 2030. According to the German Federal Institute for Geosciences and Natural Resources (BGR) there are 1038 billion tonnes of coal reserves left, the equivalent of 132 years of global output. Another organisation, the World Energy Council [4], estimates that there are 861 billion tonnes of reserves left, equivalent to 109 years of output. Irrespective of which estimate is the most accurate, one pivotal fact is that the world's coal reserves are limited and electricity generation cannot depend on this source indefinitely.

1.1.2 Sustainable energy

Sustainable energy can be described as energy which provides for the present without compromising the source's ability to provide for future demand, according to the Energy Futures Lab [1]. It is not limited to only utilizing alternative sources to conventional energy, but also involves optimising the efficiency of the power consumption.

A short description of alternative energy sources as explained by Eskom [2] are itemised below:

- *Hydro power*: There are two types of hydropower; conventional hydropower and pumped storage power. Conventional hydropower plants involve utilising dam water, which is released through opening a dam wall to turn a turbine to generate electricity. Pumped storage hydropower entails using surplus electricity to pump water into a high reservoir. When there is a shortage of electricity, the water is released again and used to drive the generator turbines. This forms the largest source of contingency power in South Africa.

- *Biomass:* This utilises the energy found from the recent carbon fixation from plants, microalgae, municipal solid waste and methane from landfill sites.
- *Geothermal:* Geothermal power utilises the steam generated from certain underground hot springs and the heat retention properties of earth.
- *Solar:* Solar power utilises heat and light from the sun. Concentrated solar power uses heat while photovoltaic cells use light.
- *Wave and Tidal power:* This is where the energy from waves and changing tides of the oceans are utilised for electricity generation.
- *Wind:* Windmills are used to capture the energy from winds and are connected to electricity generators.

Many of the above mentioned renewable energy sources still require technologies to develop further and mature, thus making it expensive to implement at this stage. It is not yet at the point where they can replace fossil fuel energy comfortably.

The other aspect of sustainable energy is optimizing the efficiency of the power consumption. Eskom suggests using power factor correction to maximise useful energy output, investing in high efficiency lighting and ensuring the maintenance of energy intensive devices such as compressors and HVAC equipment are up to date to ensure optimal operation. The uses of electronics should also be investigated to get optimal output from motors.

Detail of these solutions and opportunities that pertain to the environment at Altech UEC, will be discussed in Section 3.

1.2 Altech UEC's current environment, initiatives and achievements

During August 2013, Altech UEC had a significant influx of orders that increased production from 65000 to 125 000 units per week. This posed many challenges, amongst others, installing new lines, ensuring current processes were optimised, accommodating the increased requirement for storage space and an increased demand in electricity.

In an attempt to counter the increased demand in electricity usage, Altech UEC took advantage of the Eskom rebate programme for high efficiency lighting. Eskom gave consent to pay as much as 85 percent of the total cost of replacing conventional lighting with selected high efficiency products. Some of the requirements to qualify for this rebate entailed a real time load drop of 10 kilowatt-hours, a 5 percent of total load lighting component and an annual consumption saving of at least 2 megawatt-hours.

A combination of buying machines that are more power conscious and an increase in utilisation of all machinery meant a lower than expected increase in the demand for power. Power factor correction was also applied which resulted in a 15% increase in electricity efficiency. Figure 1 below indicates the cost savings realised from the implemented initiatives.

Current implemented cost savings		
Item nr.	Details	Percentage savings per month
1	Eskom lighting project	6%
2	Lower power injection moulders	4%
3	Low power SMD ovens	1%
4	Power factor correction	2%
		13%

Figure 1: The current implemented cost savings due to electricity saving initiatives

2 PROBLEM STATEMENT

This section will deal with those factors which need to be considered in order to come to a reasonable conclusion on the feasibility of the implementation of renewable energy solutions.

The first factor is the sustainability of the current power supply, thereafter a general review of the national power supply will be given and site specific issues will be considered. One has to look beyond the physical infrastructure as well and consider the regulatory pressure and relief that would attempt to make the implementation of renewable energy a priority for power consumers. Thereafter the anticipated electricity needs and challenges at Altech UEC are discussed, which brings the focus back as to why there is such a need for a feasible sustainable energy solution.

2.1 State of SA electricity

South Africa has historically been a country with abundant and affordable electricity. However, due to a delay in allocating expansion funding in 2003, demand started to outstrip supply by the end of 2007. The rolling blackouts that have become known as the 'electricity crisis of 2008' were the result [5].

Since 2008, South Africa's electrical supply has been under constant pressure and a number of measures have been taken to protect the supply. Generators are working overtime to supply demand, mothballed power stations have been refurbished, additional capacity is being built and Eskom and the National Energy Regulator [NERSA] have embarked on a programme to increase the cost of electricity. These measures have met with some success, but they have also had additional consequences with regards to the quality of the national power supply.

One of the measures Eskom has adopted to cope with the growing demand is the delay of maintenance on their generation fleet. This has caused unplanned downtime. For the integrated resource plan (IRP) compiled in 2010 by the Department of Energy (DOE) [6], an 86% availability rate was projected. However, an updated analysis done in 2013 found that the real figure was already below 80%. Figure 2, taken from Eskom's interim integrated results presentation, depicts the decrease in energy availability and increased volatility of supply. The constrained Unplanned Capacity Loss Factor refers to those factors within Eskom's control which are affecting their ability to supply power and is primarily related to neglected fleet maintenance. In order to arrest the decay on the fleet, Eskom has proposed a new maintenance strategy which prioritises maintenance irrespective of the current supply-demand situation. This strategy will ensure the long term preservation of the fleet, but from an end user perspective it further destabilises the immediate supply.

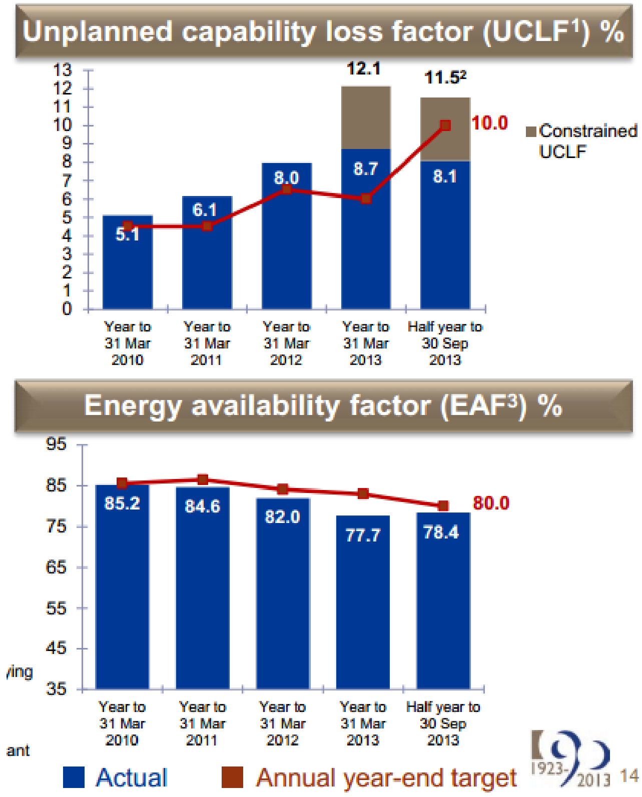

Figure 2: The Energy Supply Volatility and Availability [7]

In Eskom's 2013 mid-year report [7], it is noted that all of the refurbishments have been completed and that the previously mothballed power stations are now supplying power to the national grid. In their update on the IRP the DOE [6] notes that allowance needs to be made for the non-conformance of these stations to existing emission guidelines and the resultant downtime associated with any retrofits. Attention also needs to be paid to these stations' ability to produce power on poor quality coal, as the current coal supply is of a lower quality than initially designed for.

According to the Coal Roadmap for South Africa [8], the increased life and greater demand placed on power stations has impacted Eskom's coal supply. The roadmap warns that a coal shortage can develop as early as 2015. The backbone of South Africa's power supply is dependent on an adequate coal supply.

2.2 Future of electricity in SA and the need for sustainable energy

Eskom is currently undertaking an enormous capital expansion programme aimed at extending the power supply by 17 GW as reported by Botes, A [9]. Figure 3 breaks down the planned projects and their respective forecasted supply capacity. The much publicised Medupi project forms a major part of the programme, absorbing approximately 35 percent of the major projects in the expansion plan. Although originally intended to start generating in 2011, the project has been reported to be delayed until the second half of 2014, according to Eskom's September 2013 interim results. This puts even further pressure on the supply capacity.

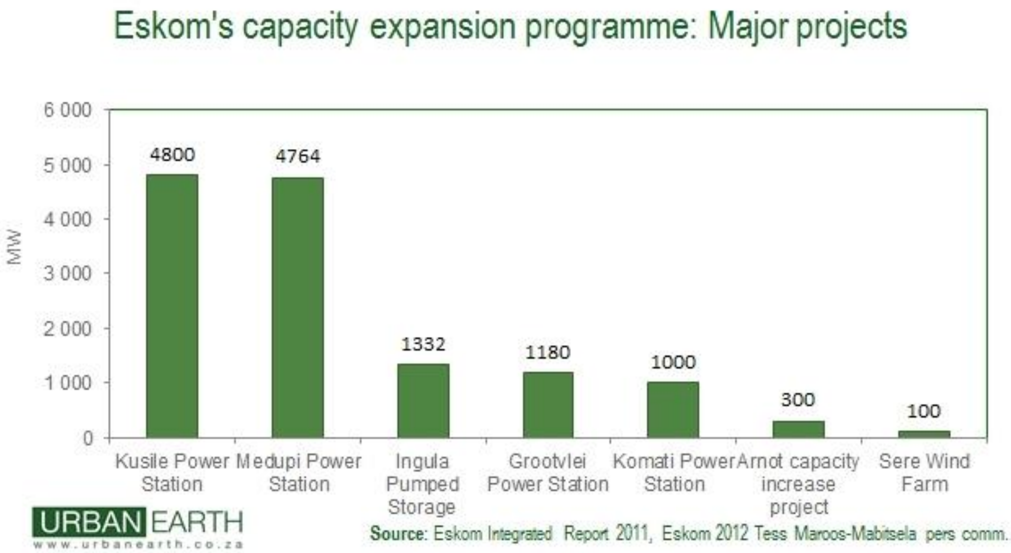

Figure 3: Eskom Capital Expansion Programme [9]

In order to fund the above mentioned capital expansion programme, Eskom has requested price increases to South Africa's electricity rates. NERSA is the regulatory body to which Eskom has to apply for price hikes, and for the final multi-year price determination period (MYPD3) NERSA has granted Eskom year-on-year increases of 8% until 2018. This is half of the original 16% requested. MYPD3 has delayed the increase in cost, but also prolonged the period of increases, according to the updated IRP. The effect of MYPD3 will only work out of the system by 2035. The DOE [6] estimates that electricity costs will continue rising at 12% year on year after MYPD3 until Eskom's debt situation stabilises below an 80:20 debt ratio.

In a critique of Eskom's demand forecasting strategy, Inglesi-Lotz and Pouris [5] argue that the inelasticity of power cost is overestimated. Figure 4 shows the reduction in actual demand compared to the values forecast in the original IRP of 2010. This would seem to support Inglesi-Lotz and Pouris' argument. Allowance has to be made for the fact that Eskom implemented a buy-back scheme, paying large consumers to reduce consumption at critical times.

The lower than forecasted demand curve bodes well for end users, as it would seem that the pressure on the supply is being reduced as consumers implement energy savings.

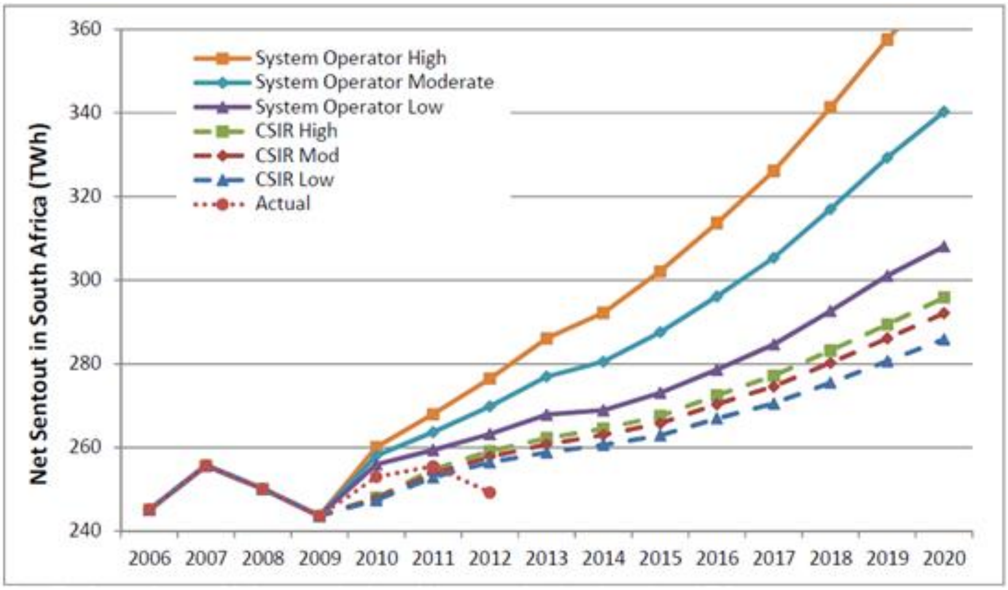

Figure 4: Eskom's Forecasted versus Actual Demand [6]

Taking into account all of the factors discussed above, it would seem that the South African power supply is under severe pressure and has been for some time. The risk of staying dependent on conventional power supplies has to be weighed against the cost of investing in alternatives. The lower than expected demand curve may suggest that many are already implementing energy savings or finding alternatives. This trend supports the argument that the grid will stabilise, however the reduced demand has to be weighed against the impact of the maintenance backlog and particularly the expected coal shortage in order to come to a conclusion as to whether or not the risk of continued dependence on the grid should be accepted.

2.3 South African Regulations and Rebates

The South African government has committed itself to emissions mitigation. In the coal roadmap for South Africa [8], the scenario closest resembling the current legislative mind set is termed

*"**At the Forefront**, where South Africa joins the global leaders in emissions mitigation, while much of the remainder of the world takes limited action;"*

According to the National Climate Change Whitepaper of 2011 [10], the State will deploy a range of economic tools to affect the desired outcome of emissions reduction. The economic tools can be grouped into punitive measures and incentives, which are discussed further below.

2.3.1 Incentives

The current approach is to encourage the voluntary implementation of sustainable or renewable energy solutions, with assistance for new projects and rewards on the savings; penalties will only be implemented later on in the hope that companies have already made the shift. There are a number of incentives and rewards available for increased energy efficiency or a move to renewable energy use.

As a part of their integrated demand management (IDM) strategy Eskom has run a number of comprehensive rebate programmes such as the standard offer programme, where up to 70% of the capital expenditure is paid up front by Eskom in return for a guaranteed reduction in power consumption over a period of three years. Other programmes include the standard product programme and the ESCO model. The rebates for these programmes were so enthusiastically supported that they have been overcommitted and are currently on hold, pending the procurement of funds. Nonetheless, any developments deserve to be monitored, as the possible reinstatement of even a reduced offer would have an enormous impact on the payback associated with a renewable energy alternative.

The only rebate programme still active, Performance Contracting, is aimed at projects which can provide more than 30 GWh savings over three years.

The Department of Trade and Industry provides cash based incentives in the form of a grant. According to Parker and Naidoo [12], their manufacturing competitiveness enhancement programme (MCEP) administers this cost sharing grant for green technology and resource efficiency improvement programmes, the percentage of costs shared is based on the original cost of the participating companies' asset base.

The Department of Treasury incentivises the participation in renewable energy projects and the implementation of efficiency programmes, working with the South African Revenue Service through section 12 of the Income Tax Act no 58 of 1962. Section 12 provides for four possible tax relief mechanisms. An accelerated capital allowance (section 12B), an energy efficiency savings allowance (section 12L), tax exemption for carbon credit transactions (section 12K) and an additional allowance for industrial policy projects (section 12I).

Section 12B provides an accelerated allowance for installations which generate power from renewable sources. The asset is depreciated over three years with a 50% allowance made in the first year, 30% in the second and 20% in the third [13]. This section essentially ensures that any investment into renewable energy generation is only taxed for three years.

While subsection B limits the time assets spend on the books, Gaffney from KPMG [14] explains that subsection K exempts transactions in certified emission reduction credits, commonly known as carbon credits, from taxation. Gwina [15] of Deneys Reitz notes that this provision opens up a tax free financing alternative. Credits can be bought at a discounted rate upfront if production is guaranteed over time, or they can be sold as they are produced as an additional revenue stream. The project needs to be documented appropriately as credits only have value if they meet the criteria specified in the subscribed standard. The Kyoto protocol is used as a reference for the many voluntary emission reduction standards.

Subsections B and K can be implemented concurrently, so it would be possible to finance a project by selling carbon credits and to then depreciate the acquired assets within three years.

An alternative is to claim a tax discount based on the number of kWh saved over the course of a year. This discount is provided for in section 12L. Parker and Naidoo [12] note that the 45 cent deduction applies to any savings which result in reduced greenhouse gas emissions. This includes waste heat utilisation and improved fuel use. The discount is mutually exclusive to any other government assistance, therefore requiring a trade-off between other alternatives.

It should also be noted that all the above incentive schemes involve some measurement and verification criteria which have to be met, at the cost of the applicant.

2.3.2 Punitive Measures

In his budget speech on 26 February 2014, Finance Minister Pravim Gordham announced that the implementation of the proposed carbon tax would be postponed until 2016. Jansen [16] reports that the treasury requires more time to fine-tune the tax structure. Renewable energy projects have long life spans, which justifies the inclusion of a planned carbon tax into this analysis. Global Carbon Exchange SA [17] provides a useful guide to the proposed tax on their website. There are a number of points which need to be considered:

- The tax will only to apply to a specific group of industries, although this list includes an as yet undefined other category. The liable industries can be seen in Figure 5.
- At the outset, 60% of emissions will be tax-free across the board with some sectors qualifying for breaks as high as 100%, a breakdown of thresholds is presented in Figure 5. The intention is to lower the thresholds gradually to encourage companies to continue to reduce their carbon footprint.
- Companies will be taxed on tonnes of CO_2 equivalent at a rate of R120 per tonne, however only Scope 1 emissions or emissions directly produced by sources owned or controlled the company will be included. Clarity is still needed on whether or not scope 1 includes mobile fuel.
- The high threshold means that the effective tax rate will vary between R12 and R48 per tonne.

Sector	Basic tax-free threshold (%)	Maximum additional allowance for trade exposure (%)	Additional allowance for process emissions (%)	Total (%)	Maximum offset (%)
Electricity	60	–	–	60	10
Petroleum (coal to liquid; gas to liquid)	60	10	–	70	10
Petroleum – oil refinery	60	10	–	70	10
Iron and steel	60	10	10	80	5
Cement	60	10	10	80	5
Glass and ceramics	60	10	10	80	5
Chemicals	60	10	10	80	5
Pulp and paper	60	10	–	70	10
Sugar	60	10	–	70	10
Agriculture, forestry and land use	60	–	40	100	0
Waste	60	–	40	100	0
Fugitive emissions from coal mining	60	10	10	80	5
Other	60	10	–	70	10

Figure 5: Tax Thresholds by Sector [National Treasury. 2013. *Carbon Tax Policy Paper*]

The tax policy as it currently stands does not include the use of electricity in its Scope 1 activities, however the current tariff framework allows for the tax to be passed on to end users. As it stands, Altech UEC will not be adversely affected by the tax as they do not operate an emission intensive process, the risk lies in the increased pressure on the cost of electricity.

2.4 Altech UEC's future electricity challenges

Other than the national grid, one has to consider the limitations on electrical supply to the factory site itself. Currently the site receives its power through a 1 500 kVA capacity line. The peak consumption at this stage is around 1000 kVA with a declared maximum of 1 200 kVA. This means that there is capacity for a 50% increase in electricity demand, before changes to infrastructure become necessary. When one takes into account that production has been doubled while demand only increased by 5%, this is more than enough capacity to supply any increase in demand for the foreseeable future.

3 SUSTAINABLE ENERGY OPPORTUNITIES FOR ALTECH UEC

This section will look at sustainable and renewable energy solutions discussed previously in Section 1.1.2 in order to find the possible solutions applicable to the site at Altech UEC. Measures to further the demand side management initiatives discussed in Section 1.2 will also be explored.

3.1 Sustainable energy solutions

The Altech UEC factory is located at 46 Siphosethu Road, Mount Edgecombe in Durban. It is an inland location with no natural water supply, which precludes any investigation into hydro-, wave- or tidal power. The site has already been developed and is currently held under a 5 year lease, complicating the development of any geothermal power.

The processes employed during production do not generate sufficient biomass to warrant an investment in biomass. Wind mills are not recommended due to the scarcity of wind in Durban.

Solar remains the only viable option, there are a number of factors which suggest that it, and in particular photovoltaic cells could be a viable solution. The first among these factors is the available space. There is approximately 13 500 m^2 of roof space with additional space available, should the parking area be developed. Secondly, Durban's average temperature is below 25°C, which is ideal for photovoltaic panels.

In order to minimise maintenance costs it was decided to investigate a grid-tied system. Such a system supplies power directly from the panels, without a storage mechanism. Power consumption peaks during the day at UEC, making this a viable option, however using the grid-tied system would limit capacity to the current peak consumption which is around 1 MW.

Power output has to be adjusted based on the system design and environmental factors. A design guide compiled by the Sustainable Energy Industry Association of the Pacific Islands [19] was used to do the adjustments. RETScreen data from NASA [20] was used to model the solar load while climate data was taken from climatemps.com [21]. Power costs were based on the most recent bills for winter and summer. Table 1 presents the adjustment factors and Table 2 contains data of expected power outputs. The adjustments result in a total correction of around 85% which is why the plant is rated at 1.2 MW. The plant has a footprint of 7 000 m^2.

Table 1: Solar system adjustments

Efficiencies	
PV	16%
Manufacture Tolerance	97%
Dirt	95%
Temperature	100%
DC line	97%
Inverter	96%
AC Line	99%
Final	14%

Table 2: Forecast Power Output of 1.2 MW rated solar plant on site

Month	Days	Air temp	Daily solar radiation - horizontal	Average Sunlight Hours	Power Output		Equivalent Power Cost
Unit		°C	kWh/m2/d	% of 24h	kWh/month	kWh/d	R
January	31	23.4	5.53	0.27	163109.16	5261.59	R 78 585.41
February	28	23.7	5.26	0.28	140131.35	5004.69	R 67 514.78
March	31	23.3	4.8	0.26	141577.57	4567.02	R 68 211.57
April	30	22	4.05	0.28	115602.65	3853.42	R 55 696.95
May	31	20.7	3.39	0.31	99989.16	3225.46	R 48 174.42
June	30	19	2.96	0.29	84489.84	2816.33	R 72 578.58

July	31	18.7	3.17	0.29	93500.19	3016.14	R 80 318.66
August	31	19.6	3.78	0.29	111492.34	3596.53	R 95 774.31
September	30	20.5	4.36	0.24	124451.25	4148.38	R 59 960.17
October	31	20.6	4.56	0.22	134498.69	4338.67	R 64 800.99
November	30	21.6	4.87	0.24	139008.62	4633.62	R 66 973.86
December	31	22.6	5.44	0.25	160454.58	5175.95	R 77 306.44
Annual average	30	21.3	4.35	0.27	125890.34	4138.86	
Annual total	365				1508305.40		R 835 896.14

3.2 Demand management

Altech UEC continues to monitor and manage its power consumption. After the ramp up in production, production lines operate at peak efficiency. The next area of attention is the reduction of demand from peripheral services.

Figure 6, shown on the following page, illustrates the contribution peripheral services make to total demand. On Sunday, the second of March 2014, Altech UEC shut down all the production lines to do server maintenance. The energy consumed during downtime, makes up the peripheral demand. Air conditioning is the most significant contributor to said peripheral demand, given that high efficiency lighting has already been installed.

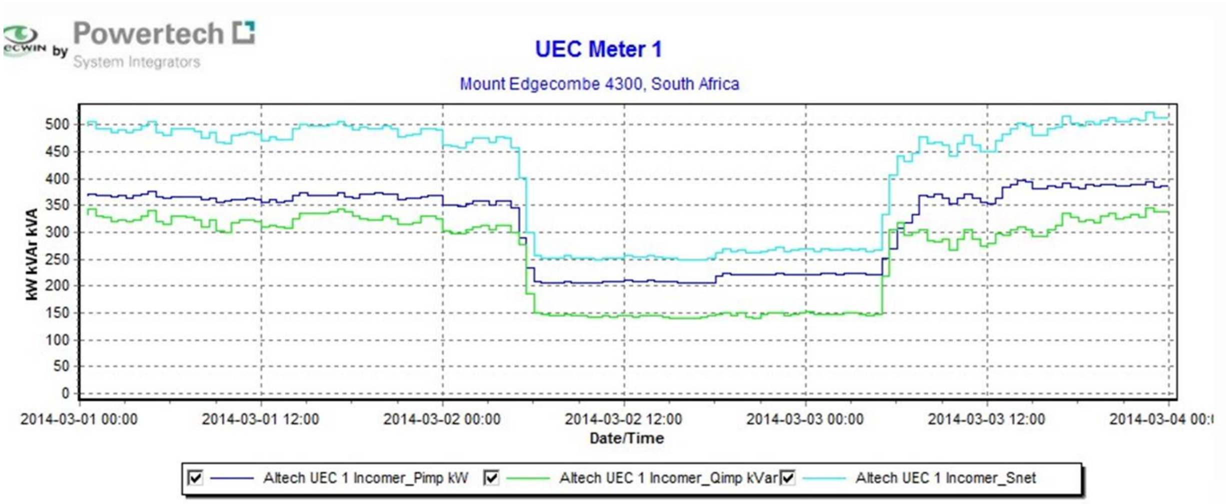

Figure 6: Production Stoppage and peripheral services demand

Future efficiency measures include the installation of timers on office lighting and air conditioning. The possibility of a heat pump to replace the existing kitchen geyser is also being investigated, as well as the use of exhaust air from said pump to cool food stores in the canteen. An awareness programme has recently been implemented and the power consumption is continuously monitored in order to identify areas of concern.

4 EVALUATION

Thus far this paper has described the different aspects of the sustainable energy environment in South Africa and in particular its application to the manufacturer's context. A possible renewable energy solution applicable to the site has been presented and planned initiatives at Altech UEC detailed. This section will evaluate the proposed solution in said context and make some recommendations on the way forward for the company. The feasibility of a sustainable energy project, such as a photovoltaic plant, depends on the economic viability of the solution as well as the strategic benefit to be gained from implementation.

4.1 Economic Viability

As discussed in section 2.3 there are a number of regulatory incentives which impact the achievable savings of an energy project: he only programmes Altech UEC will qualify for are Sections 12B and K, details of which are discussed in Section 2.3.1. Sections 12 B and K need to be compared to Subsection L.

The production of carbon credits provides an additional revenue stream over 25 years which is guaranteed to be tax-free until 2020 by Section 12K, while Section 12B allows for the asset base to be depreciated within three years.

The Section 12L discount does not provide an accelerated allowance on the capital investment, but does guarantee a particular discount rate. The choice between the two approaches hinges on the market for carbon credits.

The photovoltaic system described in section 3.1 will cost an estimated R17.5 million, based on projected electricity cost increase of 8% year on year for the first 4 years and thereafter a 12 % yearly increase until 2035, payback will take around 12 years. This could be reduced to 10 years if Section 12L rebates are applied for. The expected savings generated on investment over the life of the project is 557%. The high return can be attributed to the long project life. Given the rapidly changing nature of the electronics industry in which Altech UEC operates, a 10 year commitment would be unwise. From an economic point of view the project needs to shorten its payback period in order for it to be viable. This could be mitigated by selling carbon credits generated by the plant. Altech UEC is uniquely positioned in this regard as it forms part of the Altron TMT group, with many subsidiaries who can benefit from a centralized emission reduction programme.

This would benefit Altech UEC as well as its holding company's subsidiaries. Another alternative is to wait for the cost of solar technologies to drop or to consider financing models which do not involve total ownership.

4.2 Strategic Implications

From a strategic point of view, investment in renewable energy provides two advantages, market exposure and bargaining power. Marketing Altech UEC as a green manufacturer could be a valuable asset especially when tendering for South African government products. One also has to consider that penalties may occur in the future for not participating in sustainable energy initiatives.

4.3 Recommendation

Irrespective of whether or not a decision is made to invest in a photovoltaic plant, the current demand management programme should be continued. Developments regarding the Eskom rebate programme should also be monitored closely. From a strategic point of view it makes sense to invest in a renewable energy programme, but only if it is financially viable. It is recommended that the funding of the programme through the sale of carbon credits be explored, a client from within the group would be ideal.

Without the revenue stream from carbon credits the payback period for a project such as this is too long, however, given the supply situation and expanding market for photovoltaic panels, the idea should be reviewed regularly.

5 CONCLUSION

At Altech UEC the introduction of a renewable energy plant will be strategically advantageous. The financial viability of such a project cannot be categorically determined as it is dependent on the market for carbon credits.

The manufacturing environment, with its focus on the optimisation of resources is well prepared for the introduction of sustainable energy, however the technology itself is still too expensive to enable implementation. Fortunately the technology forms part of a market which enjoys substantial favourable treatment from policy makers around the world. Within the South African context there are a number of legislative measures which seek to encourage the shift and that do in fact enable the implementation of technologies which would otherwise be unattainable. The promise of future punitive measures adds further pressure along with the expected deterioration in supply.

In essence the feasibility of a renewable energy project in the South African manufacturing environment depends on its ability to generate revenue, not only realise savings and the ability of the driving company to utilise the available benefits.

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