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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 the Industrial Engineering and related disciplines. The first conference was held in 1986 at the Burgerspark Hotel in Pretoria, organised by Proff Paul Kruger and Kris Adendorff. As a post graduate student, I had the privilege to be part of the very first conference. It is therefore an honour to be the editor of the 25th Annual SAIIE conference proceedings – an important milestone in the history of SAIIE!

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 150 submissions were received of which 62 peer-reviewed papers made it through the review process, with another approximately 25 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 the University of Stellenbosch, to ensure that it remains accessible and indexed by scholarly search engines.

We trust that you will enjoy the 25th Annual SAIIE Conference, and that this publication will serve as an ideal first step for exposing the work of the authors to the world!

Prof Corné Schutte
Editor
July 2013

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Table of Contents

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HOSPITAL SUPPLY CHAIN MANAGEMENT AND OPTIMISATION

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ABSTRACT

This project was directed at seeking solutions to the constraints imposed on the pharmaceutical supply chain of one of the largest and busiest state-owned hospitals in Africa. We attempted to identify the major sources of waste and inefficiency in the pharmaceutical supply chains and to quantify these wastes where possible.

The inventory management processes currently in operation at the hospital are fairly ineffective and inefficient. Stock outs are regular, annual inventory procurement costs average R 12 million, average monthly trade deficits accumulate to R 3 million of unaccounted stock, and almost R 700 000 of expired medication is disposed of annually.

This points towards inadequate management and supply chain nous. Comparison with best practices showed significant failings and highlights opportunities for improvement.

1 INTRODUCTION

Supply chain management and optimisation are major research themes in process operations and management for all sectors within the service, retail and manufacture environments [1]. Research is conducted and improved continuously in the areas of capacity and production planning, facility location and design, logistics networks, inventory and warehouse management, and all other areas aiming to pursue strategic supply chain management.

For a government pharmaceutical supply chain, only a handful of these areas can be addressed, since resource allocation and funding are fixed, and in most cases, insufficient to address all supply chain issues. Various interventions by the national Department of Health and external entities play a role in the increasing complexity of the pharmaceutical supply chain.

Numerous intensifying issues regarding the late payment of suppliers, late renewal of tenders, and hence the withdrawal of medication supply by manufacturers has arisen in recent years. Above this, the lack of efficiency and effectiveness of daily pharmaceutical operations encourage lengthy queues, high shrinkage rates, employee absenteeism, and regular inventory stock-outs at many of the nation's public hospitals' pharmacies. With the high volumes of consumers served on the daily basis and the aforementioned issues taken into consideration, it was necessary to gain a more profound understanding into the complexities surrounding the pharmaceutical supply chain through a local hospital. Acquiring this understanding would enable one to increase the knowledge of pharmaceutical management and operations, and the opportunities for much needed streamlining and optimisation.

1.1. The state of pharmaceuticals in South Africa

In May 2012, the Sowetan newspaper reported that there had been a shortage of anti-retrovirals (ARVs – used to treat HIV and AIDS) in six of the nation's nine provinces. Approximately 1.7 million people had been placed at risk due to the shortage of the life sustaining drug [2].

In June 2012, Gauteng's centralised procurement department for pharmaceuticals, the Medical Supplies Depot (MSD) in Auckland Park, was short of the HIV drugs Abacavir and Efavirenz and the diabetes medication Metformin. MSD spokesman Simon Zwane stated that in an attempt to prevent future shortages, the MSD would increase its stockpiles of essential and fast-moving medicine from six weeks to three months [3].

In July 2012, the Western Capes' Groote Schuur Hospital and Tygerberg experienced major drug shortages for essential medication such as insulin for the treatment of diabetes, steroids to treat inflammatory conditions and certain chemotherapy drugs. Helene Rossouw, spokeswoman for Health MEC Theuns Botha, said the shortages had originated at the national level as a result of tenders not being awarded and suppliers not being able to source drug stocks for South Africa [4].

The Department of Health reported that its hospitals were owed over R1.5 billion by consumers [5], hence the backlogs in payments to suppliers. This becomes an issue since a report published in 2011 [6] indicated that South Africa's pharmaceutical industry would grow by 22% (the value of sales) by the year 2013, this provides the opportunity to drug importers to set up manufacturing bases in South Africa.

1.2. Background to the hospital

The research site is one of the largest and busiest state-owned hospitals in Africa with over 1100 beds. The pharmacy provides medication to all areas of the hospital, including theatres and clinics.

The main out-patient dispensary (OPD) distributes the highest volume of medication from all pharmacies located in the hospital, and is located above the pharmaceutical store room, hence it is responsible for the distribution of medication to all the hospitals' wards, theatres, clinics and satellite pharmacies (oncology, adult, paediatric and anti-retroviral). The hospitals' pharmacies dispense more than 1400 pharmaceutical items to out-patients, and approximately 1100 pharmaceutical items to in-patients in wards and theatres daily, whilst processing approximately 1200 medication scripts with a limited resource base, of staff and equipment.

1.3. Literature review

Previous research by tertiary education students in Gauteng [7, 8, 9] into operations at hospitals and medical supply depots concluded that the lack of resources (people, equipment, systems and finances), inefficient store layouts and absence of process quality control were some of the contributing factors which lead towards discrepancies into pharmaceutical operations. From previous studies one can also note that in-house pharmacy processes were fairly inefficient since no proper data trails existed, a lack of collaboration between the relevant entities in the supply chain existed, and certainly a lack of 'best practice' philosophies were present.

The following background material is required to understand the context of the research conducted.

1.3.1. Supply chain management

The supply chain is divided into core and extended functions. The core functions of the supply chain (SC) are related to activities which are restricted to the four walls of the organisation, these activities form part of the supply chain management (SCM) space [10]. The extended functions of the SC are those activities or functions which are extended vertically at either end (suppliers or customers) of the organisations' SC, therefore creating an extended SC and the enablement of collaboration where applicable [10].

Figure 1 - The supply chain landscape [10]

1.3.2. Supply chain maturity model

The supply chain maturity model is a model used to assess the level of capability for each of the processes defined in the Supply Chain Operations Reference (SCOR) model – plan, source, make and deliver - and also the SC management practices which govern the strategies and links all functions together [11]. The model is also used to evaluate the extent to which Information Technology (IT) enablement enhances the practices and collaboration between entities of the SC [11].

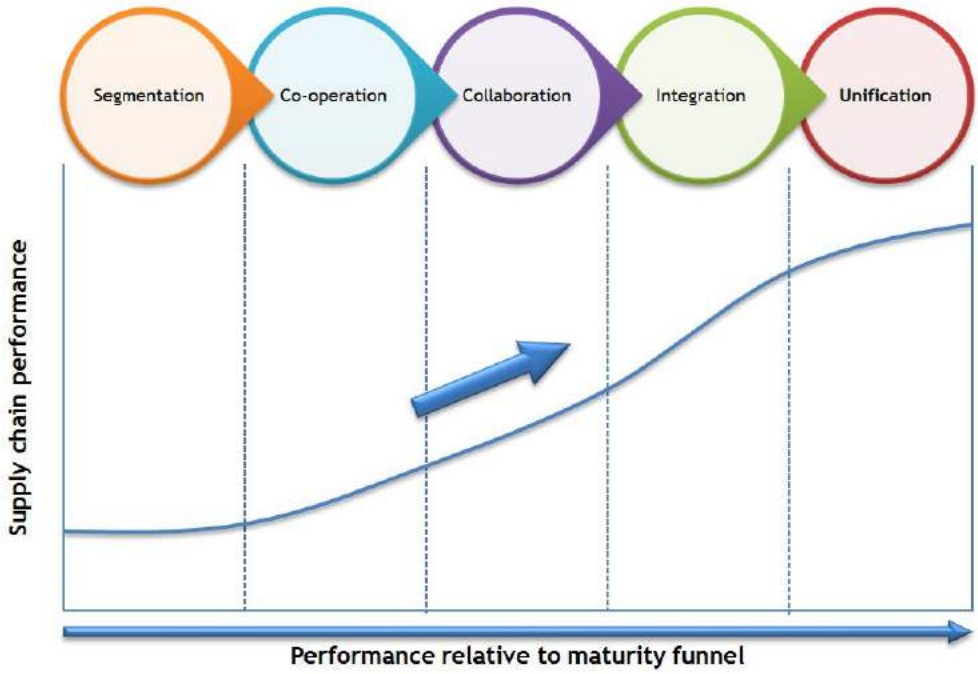

Figure 2 - Supply chain maturity funnel [12]

1.3.3. Supply chain optimisation

Best practices can be classified as processes which have been 'tried and tested' in industry which have proven to be effective and efficient in multiple aspects. Issues' arising from determining which best practices is the most optimal includes defining a level of practice which is suitable to a specific SC: what resources are available for the processes to be implemented, what level of commitment from the organisation can be expected and what unintended consequences need to be assessed prior to implementation. All the above aspects need to be scrutinised and assessed according to the milieu of the operation.

Lean is a systematic approach to improving value to the customer by detecting and eliminating waste (time, effort and materials) through kaizen (continuous improvement), by flowing the product at the pull of the customer, in pursuit of perfection [13].

The implementation of lean philosophies in various industries has enabled organisations to become more customer-focused, flexible and profitable. The reduction of various forms of waste in a SC allows for the building of adaptive, collaborative SC's [13]. One has to ensure that for lean to be effective, it should not only be applied to a certain aspect or entity of the SC, but rather to the entire SC. Some of the many benefits of using lean tools include reducing cycle times, the ability to prominently deliver, improved throughput and turnover times, faster lead times and improved working capital through the reduction of holding inventory.

2 OBJECTIVES

The following objectives had been formulated for the research investigation:

I. To investigate and understand the management of the pharmaceutical supply chain at the hospital, and its respective complexities.
II. To investigate the hospitals' pharmaceutical inventory management system.
III. To compare the current pharmaceutical supply chain against industry best practices.
IV. Quantifying waste due to poor inventory management.

3 METHODOLOGY

A rich case study [14] was undertaken which investigated the supply chain and inventory situation at a large public hospital. This required the acquisition of qualitative data to highlight operational issues which would act as the constraints for models built from quantitative data.

The data would be acquired through the following avenues:

1) Interviews with the:
    i. Customers and pharmacists of the pharmacy
    ii. General members of dispensary staff (assistants, trainees)
    iii. Ward stock staff
    iv. Doctors and nurses
    v. Procurement manager (including staff of the procurement department)
    vi. Storeroom manager (including staff working in the storeroom)
    vii. The chief pharmacist or pharmacy manager
2) Visual observation of pharmaceutical operations, i.e. the flow of information, finances, services, products and the use of resources throughout all entities of the pharmacy.
3) The mapping and modelling of pharmaceutical inventory processes to compare them to industry best practices.
4) Data collection for pharmaceutical inventory:
    i. Amount of product dispensed
    ii. Amount of product procured
    iii. Amount of product in holding
    iv. Amount of product returned
    v. Amount of product disposed

This would be adequate for the scope of this phase of the project, and will allow for conclusive data to be acquired from which logical and meaningful recommendations and evaluations can be proposed.

4 OBSERVATIONS & RESULTS

To begin with, the pharmaceutical SC consists of the following entities, where the primary role of each entity is briefly described:

i. National Health – responsible for the offering of tenders
ii. Provincial Health – responsible for the tender selection process
iii. Suppliers – the supply of original pharmaceutical medication (OPM) and generic pharmaceutical medication (GPM) to the Medical Supply Depot
iv. Medical Supply Depot (MSD) – based in Auckland Park, the MSD is Gautengs' centralised procurement department responsible for ensuring the management of supplier contracts, and the distribution of pharmaceuticals to the provinces' hospitals
v. The hospitals – responsible for the dispensing of medication to consumers

The following figure describes the end-to-end supply chain of pharmaceuticals in South Africa:

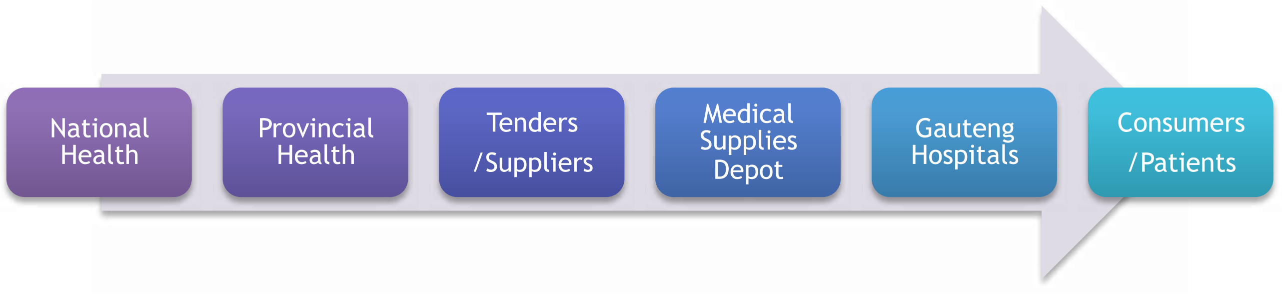

Figure 3 - The pharmaceutical supply chain

4.1. Pharmaceutical operations

This section highlights the effects of inventory management, processes and tendering on the overall pharmaceutical SC performance

4.1.1 Inventory management

The storeroom for all medication at the hospital is located directly below the out-patient dispensary (OPD), hence access for staff is gained through the pharmacy into the storeroom. It should be noted at this point that the storeroom has an open-door policy for all pharmacy and store room staff without mandatory security checks. This is due to the absence of safekeeping strategies and resources (personnel and equipment), and non-adherence to established standard operating procedures.

Within the storeroom is a packing department which repacks bulk volumes of medication into smaller quantities for dispensing purposes. An accuracy level of ±75 % existed in this process.

Additionally, inventory received from the MSD is manually relabelled by the store manager with a felt tipped pen since the original label is illegible when placed on higher shelving. A considerable amount of inaccuracy exists due to the vast amount of boxes which require relabelling and the monotony of the process itself. Figure 4 shows human error where a 500 mg dosage medication was relabelled as 1000 mg (1 g shown in the figure); meaning the incorrect product may be dispensed to the consumer.

Figure 4 - Error in relabelling

The storeroom holds approximately R57 million worth of stock at any given time. In the absence of an electronic inventory system, an inaccurate manual inventory logging system is used (see figure 5),

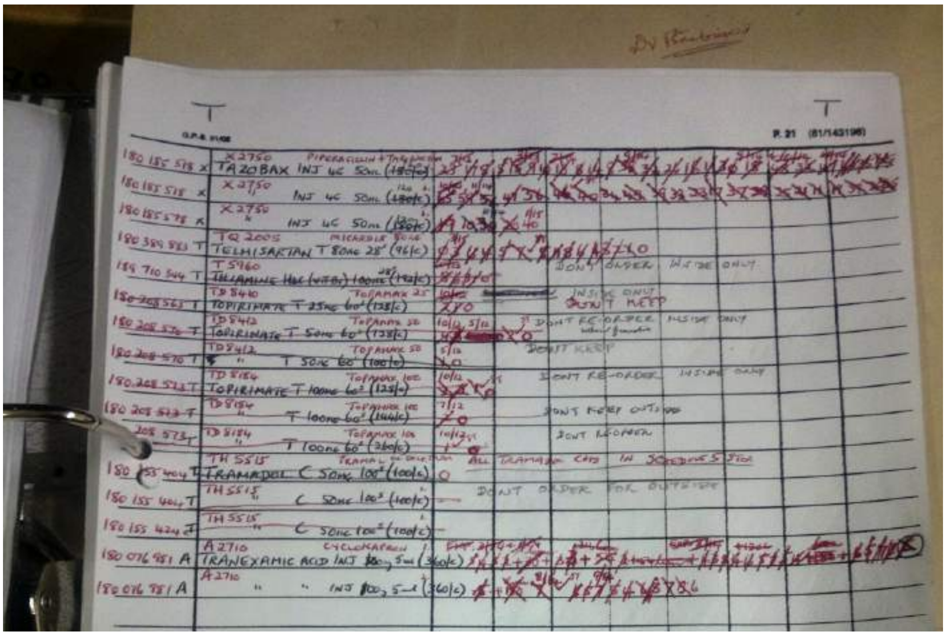

Figure 5 - Manual inventory log book

No proper forecasting techniques are used to determine order quantity levels. Demand data is used to determine order quantities - from order point to order point, the average is taken – which is usually two withdrawals from stock data. This ensures that high levels of inventory are ordered hence increasing inventory drastically.

One of the main issues faced by the hospital is the minimal communication between the hospital and the MSD. Added to poor response times this leads to orders being placed twice and double stocking of inventory.

4.1.2 Dispensing

Products are dispensed to patients with minimal information regarding the patient, i.e. the doctor who issued the medication, the department from which the prescription had been issued, the type of medication dispensed and the respective amount. This is also true for products which are dispensed internally to wards, theatres and clinics within the hospital. This leads to gaps in the information trail required for forecasting and recording purposes for the hospital. Table 1 shows the amount of product purchased for a specific month and the respective inventory dispensed, and consequent deficits. This means that poor record keeping directly leads to as much as R 49 m per year in unaccounted medication, which may be lost, expired or likely stolen.

Table 1 - Unaccounted inventory deficit

	Apr-12	May-12	Jun-12	Jul-12
Number of Items Dispensed	301939	368962	337276	314146
Dispensed Items Value [R]	R 16,742,042	R 14,030,878	R 11,817,401	R 10,969,396
Procurement Cost [R]	R 20,104,974	R 17,297,794	R 15,436,410	R 13,311,046
Deficit [R]	**R 3,362,931**	**R 3,266,915**	**R 3,619,008**	**R 2,341,649**

4.1.3 Tender management

The MSD manages tender contracts. On numerous occasions supplier contracts expire and as required, the tender selection process is initiated. The notification of the expired tender contract is only brought to the attention of the MSD when the hospital requires additional supplies of a certain product, the waiting period for that product may then be extended by up to two months.

Due to the large amounts of stock held at the hospital, many of the items which enter the storeroom go undocumented and hence lack of knowledge of holding stock exists – this includes the amount of product which is present and the products whose expiration dates are approaching the earliest. This leads to large amounts of wasted product which is then regarded as medication waste and disposed. A recent study obtained from the Western Cape News Online [15] indicated that Gauteng disposed of R2.3 million of medication in the period April 2011 to April 2012 (see Figure 6). It should be noted that the waste for this hospital in this period equated to R768 116, which is 33.4% of the provinces' total medication waste.

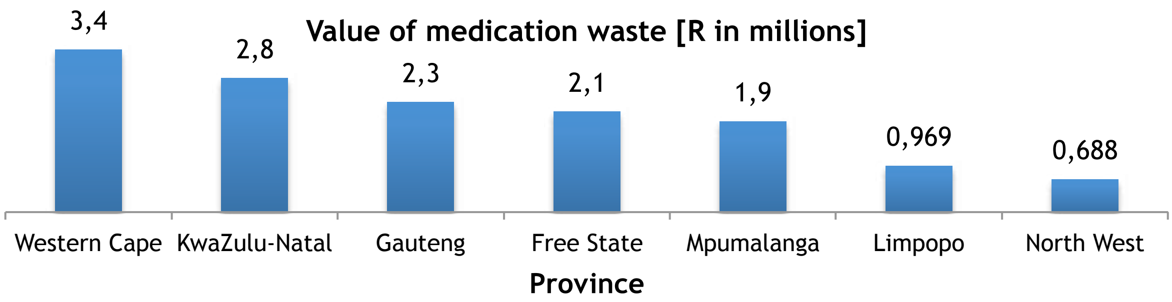

Figure 6 - Provincial medication waste [April 2011 - April 2012] [15]

5 CONCLUSIONS

From the objectives, the following conclusions can be drawn:

The overall effectiveness and efficiency of the pharmaceutical SC is lowered due to operational deficiencies within each of its entities –

- At the hospital:
    - The work ethic of pharmacy and storeroom employees is poor due to the lack of effective performance reviews, poor communication with management, and minimal coordination and realisation of team and individual efforts
    - The inventory management system is coordinated entirely manually through hand-written log books, no form of systematic processes are followed to ensure reliable procedures, accurate records of information, and product flow
    - Due to the nature of the management of inventory at the hospital and communication networks with the MSD, SC instabilities occur such as incorrect demand forecasting and low product visibility
    - With high values of monthly 'unaccounted stock' at the hospital, the storeroom maintains an open-door policy (absence of safekeeping strategies) - documentation of goods received and product dispensed are of an ineffective nature due to the manual logging system (with human error) ; high levels of known shrinkage is present in the storeroom
    - The cost of poor management and inventory control is as high as R 40 m per annum
- The MSD:
    - Low reliability with respect to order placing with suppliers
    - Ineffective supplier management practiced
    - Verification of valid tenders for medication is poor
- National and Provincial Health:
    - Contract and tender management is particularly poor
    - Poor commitment and responsibility of upper management towards the improvement of the industry is propagated downwards to the rest of the pharmaceutical SC and its employees

In general –

- Overstocking in the storeroom should not be confused with good product availability to patients, wards, theatres and clinics

- The lack of collaboration and communication between pharmaceutical SC entities leads to a segregated SC, with fragmented operations which results in debasing management practices

6 RECOMMENDATIONS

Having conducted the investigation and analysed the pharmaceutical SC, the following recommendations are made to the hospital:

- Develop and implement an electronic inventory management system
- Improve safekeeping strategies immediately
- Conduct employee meetings on a more regular basis to ensure information is communicated to all the pharmacy and storeroom's workforce
- Group or individual efforts should be realised and the awardees should be incentivised accordingly in an effort to minimise pilferage
- Greater expertise should be acquired for the management of inventory and its respective replenishment cycles – to allow for improved order scheduling, demand management, holding inventory reduction and product visibility
- More accurate data should be obtained from the dispensing and procurement departments during pharmaceutical statistics acquisition
- Improve the communication network between the hospital and the MSD

The following recommendations are made if forthcoming studies are to be conducted in this area:

- Arrangements should be made to conduct studies at Auckland Parks' MSD. This shall enable greater understanding into the logistics network and supplier relationship management practices. Further arrangements should be made to possibly conduct studies at both Provincial and National Health – this would aid in the contextualisation of tender selection processes and resource allocation
- In-depth studies should be conducted into performance management and education and training – to understand the employee review system and employee empowerment strategies
- A risk analysis should be conducted to identify the more evocative consequences of ineptness to standard operating procedures and supply chain complexities
- In-depth investigations into the use of technology at the hospital should be conducted, to develop an understanding for further information technology integration into the current supply chain

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ENERGY SUPPLY CHAIN RISK MANAGEMENT USING ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

Energy supply is the backbone of almost all economic activities powering critical systems and infrastructures required for the functioning of our modern economies and societies. Regardless of where and how they are produced, energy must be delivered to the points of consumption and any disruptions in the chain can rapidly degenerate into a national crisis. However, sustaining an undisrupted production and supply of this vital resource has been identified as a major challenge globally with issues like terrorism, spiralling and unstable energy prices, technology uncertainties and natural disasters posing serious threats to the supply chain. This study develops a risk management framework for the energy supply chain using artificial neural networks as the transformation and simulation engine. To get a reliable estimate of the health of the critical path in the supply chain, a few genetic algorithms were tested and the one with best performance chosen for this framework after a comparative analysis.

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1 INTRODUCTION

Practically speaking, there's no escape from the presence of risk but explicit knowledge of this phenomenon can lead to informed decisions about its source, drivers and associated events. On the other hand, given the global relevance of energy (electricity, hydrocarbons), its supply and demand dynamics, environmental and safety requirement, complex production systems, processes and infrastructure, huge capital outlay, the energy supply chain appears to be a significant risk, high impact industry with huge opportunity for risk optimisation. The acknowledged global challenge of making this resource available to end users on a consistent, uninterrupted basis is the motivation for this study. Suggesting a web platform for data services and artificial neural networks for simulation, this paper presents a simple, easy to adopt framework for players in the energy supply chain to identify, quantify and mitigate risks in a systematic, structured and sustainable manner. Section two of this paper describes the energy supply chain in general while section three is a brief literature review of the concepts of risk and risk management. Section four deals with the theory and application of neural networks, section five presents the results while sections six discusses the evolved framework.

2 ENERGY SUPPLY CHAIN

Modern life without energy supply is unimaginable, yet uninterrupted supply of this resource is constrained by several bottlenecks along the supply chain. Energy sources can be classified from primary and secondary sources perspective or simply grouped into renewable and non-renewable. The United Nations technical report on concepts and methods in energy statistics [1] defines primary and secondary sources of energy as follows:

"P*rimary energy sources should be used to designate those sources that only involve extraction or capture, with or without separation from contiguous material, cleaning or grading, before the energy embodied in that source can be converted into heat or mechanical work*"

"*Secondary energy should be used to designate all sources of energy that result from transformation of primary sources*".

For primary energy, the vital distinguishing factor is the process of extraction, while the transformation process distinguishes secondary energy. Electricity for instance is a secondary source of energy transformed from, for instance, coal, natural gas, uranium and (in its simplest form) the supply chain includes generation, transmission and distribution. Unlike most supply chains, the electricity supply chain is peculiar as there are no commercialized storage technologies that can serve as buffers to generation and transmission disruptions or failures. Renewable energy sources include biomass, geothermal energy, hydropower, solar and wind energy. Non renewable energy sources include coal, natural gas, propane, uranium and petroleum [2]. This study uses the downstream industry of the petroleum supply chain for experimental purposes and as a case study. The petroleum supply chain initiates with the exploration of crude oil and ends with the delivery of separated and converted products to the end users as shown in figure 1. The downstream industry of this chain includes product refining, storage and distribution. In summary, there are three major processes in petroleum refining namely separation, conversion and purification [35].

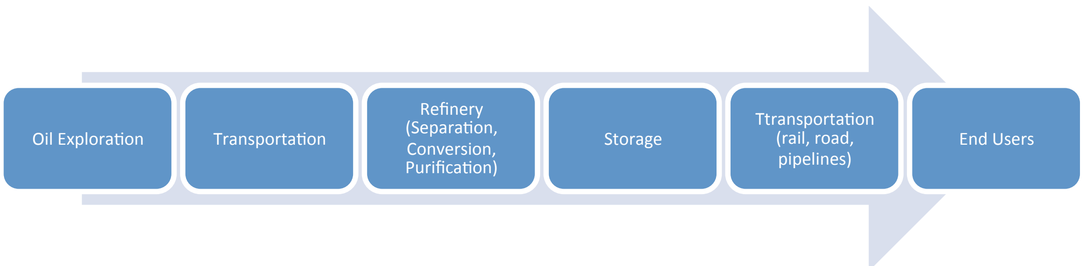

Figure 1: Simplified Petroleum Supply Chain

These processes lead to the production of several products and chemicals for the powering of our modern economies as depicted in figure 2. The necessity for consistent undisrupted supplies of these products to end users is the motivation for this risk mitigation framework. The case study organisation imports crude oil from Africa, Europe and Middle East, stores in a specialised underground storage facility and feeds the refinery through a network of pipelines. Processing 20 000 litres of crude oil per minute, the refinery makes 10 products in 46 different grades. These products are then sent to customers through different transportation modes such as marine, rail, trucks and pipelines depending on the destination.

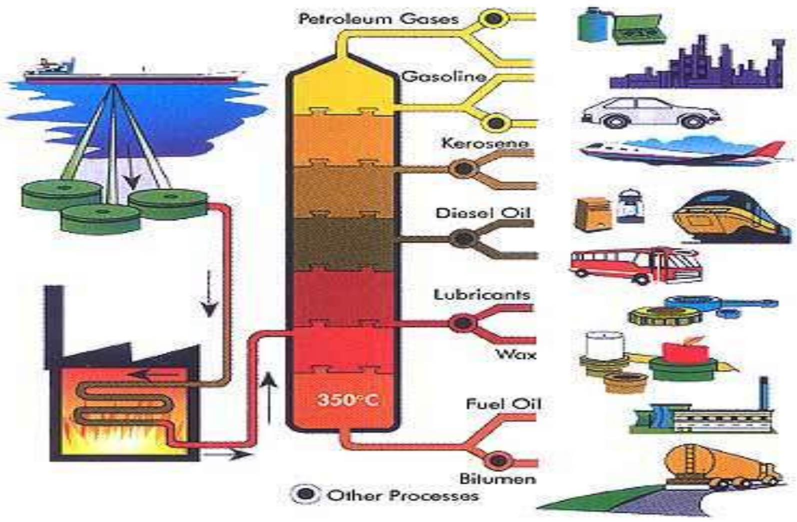

Figure 2: Petroleum Refinery Process Chart

(Source: http://www.sapref.co.za/about/WhatWeDo)

3 RISK AND RISK MANAGEMENT CONCEPTS

3.1 RISK

The word 'risk' is ambiguous and the meaning really depends on context, user [3], and also on the field of application [4, 5]. It can be viewed as a multi-dimensional construct for which no single definition may be appropriate in all circumstances. However, given this persistent variability in the way risk is defined and applied across different disciplines, a common understanding still exists about how to define, identify, evaluate and manage it [3, 6]. Risk is mostly associated with an outcome for which one is uncertain, meaning there's an exposure and there's uncertainty [7]. Generally estimated in terms of likelihood and consequence [8], several authors have proffered different definitions for risk; Exposure to the possibility of an undesired outcome [9], prospects of damage or loss with estimated time of occurrence and significance of the unwanted impact [10], a measure of the degree of uncertainty surrounding the bad results of a decision [11], "*variance of the probability distribution of outcomes*" [12], "*variation of the actual outcome from the expected outcome*" [13], jeopardy, failure, injury, destruction, [14]. Kaplan and Garrick [15] introduced the triplet concept. Defining risk as a triplet, and noting that there may be many triplets, risk was denoted as follows:

$$R = \{< S_i, P_i, X_i >\} \qquad (1)$$

Where **Si** is a scenario identification or description, **Pi** is the probability of that scenario and **Xi** is the consequence or evaluation measure of that scenario. A triplet set can then be defined as:

R = {< Si, Pi, Xi >} where i = 1, 2,........,N. ***(2)***

Narrowing down the definition to supply chain risk as opposed to general risks, this study adopts risk definition by Kersten et al [16]:

"*The damage – assessed by its probability of occurrence – that is caused by an event within a company, within its supply chain or its environment affecting the business processes of more than one company in the supply chain negatively*"

This concept of risk is supported by Kaplan [17], William [18], and Ritchie [19]. Some authors have also classified supply chain risk into meaningful categories: Christopher and Peck [20], Ann and Els [21] classified supply chain risk as supply, environmental, process, control and demand risks while Sinha et al [22] classified it as standards, supplier, technology and practices risks. The Institute of Risk Management South Africa IRMSA [23] classified it as strategic, value based, process based, information based, people based, environmental based, and compliance and asset risks. In all cases, an underlying factor is the ability to detect, evaluate and manage risk with the aim of minimizing either the possibility of occurrence or impact of occurrence.

3.2 RISK MANAGEMENT

The ISO 31000 standard [6] simply defines risk management as structured and systematic activities to direct and control an organisation with regards to risk. Harwood [24] suggests that it is a choice among available options to reduce the impact of risk, while Norsworthy [25] expresses it as detecting threats and putting in place plans to deter its occurrence or impact should it happen and Borge [7] referred to it as conscious actions to increase the chance of good outcomes and reduce that of bad outcomes. Drawing from these definitions one can infer that the process of risk management involves structured application of policies, systems and practices to the activities of establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk. This is supported by Dave et al [26]. Many methods [7, 27] have been proposed for risk management but there is an underlying agreement that it should clearly identify risks in the entire product or project lifecycle, monetise the probable impact of a disruption and offer techniques to mitigate risks. In this regard Pritchard [28] gave management options as Tolerate (accept), Terminate (avoid), Treat (reduce), or Transfer (share). Because of its nature, risk management is of critical importance in the energy supply chain and cannot be attended to on an 'ad-hoc' basis. This paper presents a framework to achieve a continuous but systematic detection, assessment, prediction and management of historical and arising risks in the entire chain.

4 ARTIFICIAL NEURAL NETWORKS

4.1 INTRODUCTION

Artificial Neural Networks are powerful and versatile computing tool made up of highly distributed interconnections of adaptive nonlinear processing elements (PEs) called neurons [37]. As shown in figure 3, the network consists of three or more layers; the input, hidden and the output layers. By interconnecting the correct number of neurons in a specific manner and setting the connection strength or network weights to appropriate values, a neural network can provide output that matches a desired output whether linear or non-linear [31]. This arrangement of network nodes, connections and connections weights known as the network *topology* determines the network's final performance or behaviour [29].

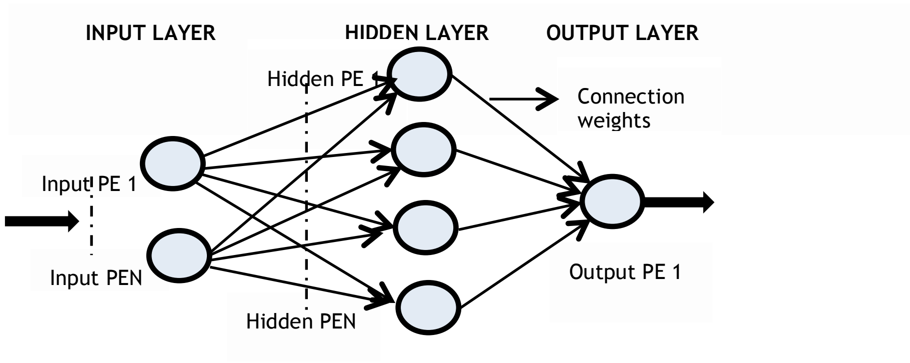

Figure 3: Building blocks of Artificial Neural Networks

This topology can be represented by

$$x_i = \sigma \left\{ \sum_j w_{ij} x_j \right\} \qquad \textbf{(3)}$$

where x_i is the output of unit *I*, σ is a nonlinearity, xj are the inputs to unit j, w_{ij} are the weights that connect unit j to unit i.

In practical terms, neural networks have been successfully applied across a diverse range of classification and prediction problems like classification of irregular patterns, prediction/forecasting, optimisation, associative memory, control applications and noise reductions [30]. These recorded successes are attributable to a few powerful yet unique features of the neural network [31, 32]:

a. Non Linearity: Neural networks can approximate both linear and non-linear functions. Modelling data with non-linear variables is beyond the scope of traditional linear models but neural networks produce powerful computation schemes and sophisticated modelling techniques capable of modelling complex functions and processes.
b. Adaptation: Artificial Neural Networks are adaptive systems. Adaptation enables a change of system parameters according to specific rules, for example the function, structure, training methods, extent of training, connection strength etc.

Some traditional methods that have been proposed for solving these classes of problems have done well only when applied in a well constrained environment, but implementation outside those boundaries has not shown good results [33, 31]

The two main phases of neural network operations are implemented in this study; the training phase and the recall phase. The training, also called the *supervised learning* phase, is the period when data is continuously passed through the network while the recall phase represents that period when the trained network is applied to a dataset it has never seen before. Based on their architecture, neural networks can be classified as 'feed forward' where the architecture has no loops or 'feedback network' where it consists of feedback loops. In this case, inputs to each neuron are modified via the feedback path to bring the network to a new state [38].

4.2 NEURAL NETWORK LEARNING, NECESSARY CONDITIONS AND STOP CRITERIA

4.2.1 Learning

Neural networks have the ability to learn from examples rather than following a set of rigid rules defined by human experts [34]. In this context, learning can be classified as supervised, unsupervised or hybrid learning. In supervised learning, the model developer gathers experimental data and gives the network a known, correct (desired) output for each input [34]. During training, network weights are adjusted to enable the networks generate a response to the input as close as possible to the desired output. Both the network output (x) and desired output (d) are compared to generate error (d-x) used for the network parameter adjustments. The correlation coefficient is a measure that shows how well this network output matches the desired output. Defined as:

$$r = \frac{\frac{\sum_i (x_i - \bar{x})(d_i - \bar{d})}{N}}{\sqrt{\frac{\sum_i (d_i - \bar{d})^2}{N}}\sqrt{\frac{\sum_i (x_i - \bar{x})^2}{N}}} \qquad (4)$$

It indicates a perfect positive linear correlation between x and d if r = 1, perfect linear negative correlation if x = -1 and no correlation between network and desired output should r = 0. On the other hand, unsupervised learning does not require a desired output to be defined and associated with each input in the learning data set while hybrid learning combines both supervised and unsupervised learning paradigms [34].

4.2.2 Necessary conditions

Although neural networks have been successfully implemented across many fields and have the powerful features earlier described, the full benefits can only be gained by ensuring some pre-requisite requirements are met:

a. A clear understanding of the problem to be modelled is required
b. Representative data from the right environment is a requirement and
c. Adequate data size for network training and testing is a necessity.

4.2.3 Stop criteria (Termination)

To prevent the network from overtraining, appropriate cross validation methods needs to be applied to terminate training at a point when the error begins to rise [37] as shown in figure 4. A termination point can be set by defining a threshold below which training must be stopped to prevent the network from overtraining.

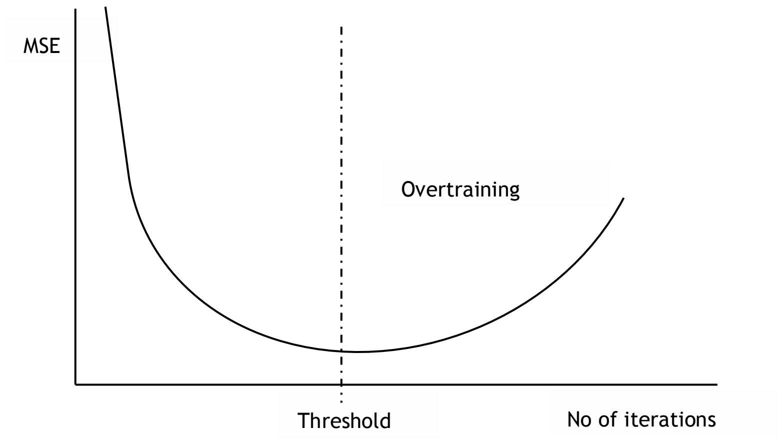

Figure 4: Mean Square Error (MSE) during training

4.3 NEURAL NETWORK MODEL FORMULATION AND METHODOLOGY

For the purposes of this study and neural network problem formulation, supply chain risk is categorised (Figure 5) into supply risk (purchasing/procurement), process (such as manufacturing, quality assurance) and demand (distribution, sales) risks.

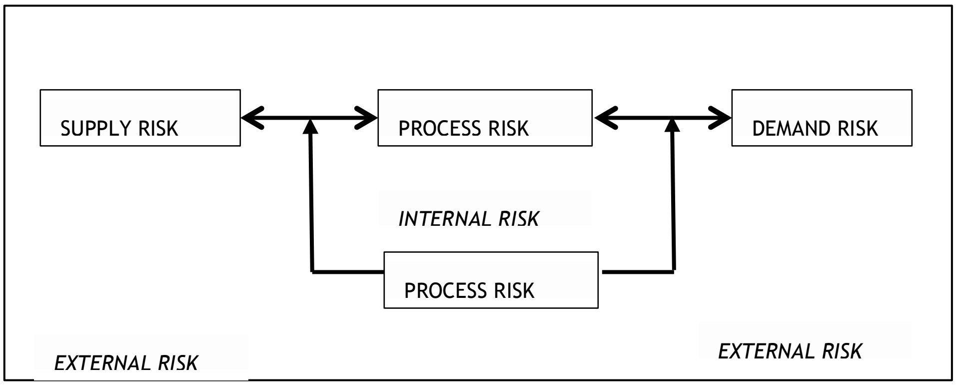

Figure 5: Categories of supply chain risk

(Source: Vlerick Leuven Gent Management School)

In order to formulate key risk indicators (KRIs) and metrics for each of these categories, interviews were conducted with Subject Matters Experts (SMEs) who served as key informants for this study. They emanated from production, engineering and technical departments. The interviews were set up as semi-structured interviews, and administered through questionnaires and verbal engagements. Some of the questions asked are on the production processes, process flow maps and plants' effectiveness. Table 1 is an extract from one of the questionnaires deployed:

Table 1: Sample questionnaire

Product ID: Date:	Separation OEE %	Conversion OEE %	Purification OEE %	Average OEE %
PTL	62	57	61	
DSL	39	62	58	
JTF	63	58	62	
LPG	56	55	61	
LUB	64	55	60	

Having, thus established the KRIs and metrics, they were used as input factors to the neural network model. Some of these are actual delivery times compared to target delivery times of different crude grades, actual versus expected delivery volumes, separation, conversion, treatment plants' overall equipment effectiveness (OEE), actual production, planned production etc. Using a neural network program, Neurosolutions [36], Figure 6 shows the procedure followed in formulating and training the network.

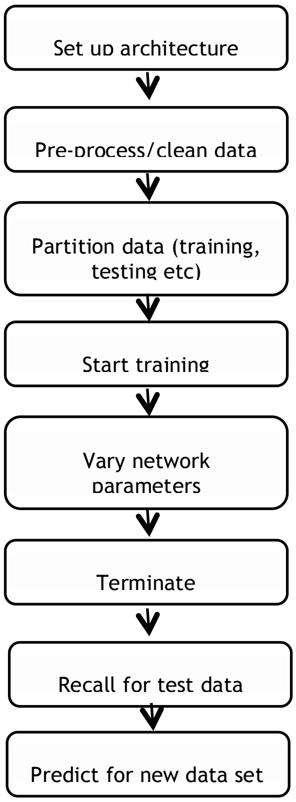

Figure 6: Neural network procedure

5 DISCUSSION OF RESULTS

Using risk metrics defined in section 4.3 as inputs to the network, one month data was gathered and modelled by the neural network. 60% of the data was used for training, 15% for cross validation while the remaining 25% was used as testing data set. To arrive at the best network topology, training was done for a few times with different random initial conditions but saving the best network weights each time for comparative analysis. Although the initial results were good but classification was not 100% correct hence genetic algorithms were also applied for learning which enabled genetic optimisation of the network choice of its parameters, like the number of PEs in the hidden layers, step sizes etc.

The supply chain covers crude import to delivery to end users (figure 1) hence disruption occurs when the right quantity of refined products does not get to the customer (retail centres) at the right time otherwise there is no disruption. Delivery of a line of product from a specific grade of crude at the right quantity and timing returns a 1 otherwise 0 is returned. Figure 7 (all columns not shown) is a screenshot of data feed to the network with initial network output while the confusion matrices in table 2 show final test result for both training and test data sets.

Crude Delay Time	Crude Quantity Shortfall	Separation OEE	Conversion OEE	Purification OEE	Production	Truck failure %	Undisrupted	Disrupted	Undisrupted Output	Disrupted Output	Output (Symbolic)
0	0	59	60	57	3814671	5	1	0	1.00000457	-4.573E-06	Undisrupted
0	0	63	65	58	77908	5	1	0	1.00000928	-9.283E-06	Undisrupted
0	0	58	55	56	3596593	5	1	0	1.00000282	-2.816E-06	Undisrupted
0	0	64	56	62	124537	5	1	0	0.99996655	3.3454E-05	Undisrupted
0	0	60	56	62	2031034	5	1	0	0.99998044	1.9563E-05	Undisrupted
24	0	56	57	59	3477052	5	1	0	0.99996363	3.6372E-05	Undisrupted
0	0	63	57	63	3047603	5	1	0	0.99993601	6.3986E-05	Undisrupted
0	0	55	58	60	3829161	10	0	1	3.9529E-05	0.99996047	Disrupted
28	0	0	64	63	2973942	5	1	0	0.07811905	0.92188095	Disrupted
0	0	43	35	44	2120009	5	0	1	-0.0001382	1.00013821	Disrupted
0	0	58	59	61	704813	5	1	0	1.00000899	-8.987E-06	Undisrupted
67	0	39	62	44	1999899	5	0	1	-0.0001345	1.00013448	Disrupted
0	0	64	57	61	0	5	1	0	0.99997695	2.3052E-05	Undisrupted
0	0	40	40	57	1869931	5	0	1	-4.919E-05	1.00004919	Disrupted
0	0	62	62	63	721384	5	1	0	0.99998425	1.5753E-05	Undisrupted
0	0	39	56	61	419891	5	0	1	-0.0001211	1.00012111	Disrupted

Figure 7: IO data for neural network

As can be seen in the tables, the network learned and classified the data very well although with less accuracy when tested with the production data set because the network hasn't been exposed to this data set before.

Table 2: Performance matrix (Training)

Output / Desired	*Undisrupted*	*Disrupted*
Undisrupted	27	0
Disrupted	1	13

Performance	*Undisrupted*	*Disrupted*
MSE	0.020728539	0.020728539
NMSE	0.095727126	0.095727126
MAE	0.022582288	0.022582288
Min Abs Error	2.52442E-06	2.52442E-06
Max Abs Error	0.921880949	0.921880949
r	0.954014403	0.954014403
Percent Correct	96.42857143	100

Table 3: Performance matrix (Testing)

Output / Desired	*Undisrupted*	*Disrupted*
Undisrupted	59	3
Disrupted	0	36

Performance	*Undisrupted*	*Disrupted*
MSE	0.068631986	0.029830436
NMSE	0.286458752	0.12450739
MAE	0.159067799	0.070028074
Min Abs Error	0.002541494	6.84984E-05
Max Abs Error	0.94226383	0.943464392
r	0.870558913	0.935933578
Percent Correct	100	92.30769231

A sensitivity analysis was further conducted to understand the cause and effect relationship between the inputs and outputs of the network. With this feedback it is possible to prune the input variables by removing those columns with very little or no impact on the output. This can significantly reduce training complexity and computing times. In this case (figure 8), the most significant input channels are the overall equipment effectiveness (OEE) of the separation lines and the delivery trucks failure rate.

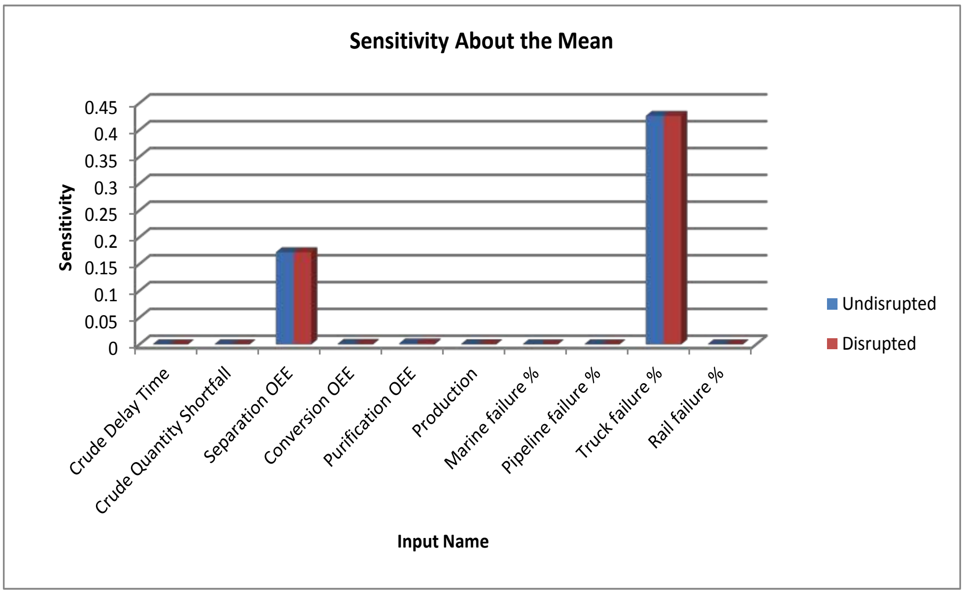

Figure 8: Sensitivity Analysis

Interestingly, crude supply failures are not very significant even though there are a couple of them lasting for many days. This is definitely because of the size of buffer kept in the underground storage facilities to feed the production lines in the event of supply failure.

6 RISK MANAGEMENT FRAMEWORK

Following the principle of Extract-Transform-Load (ETL), data acquisition can be done both manually and automatically, transformation done using artificial neural networks and loading done to target audiences via a central management portal or web interface. The cycle is usually as follows: cycle initiation, extract data (manual, automatic), verify and validate data integrity, transform data to fit operational needs, publish result. Figure 9 is a flow diagram of the recommended risk management framework, enabled by the ETL but powered by the neural network transformation engine. With sustained data feed to the neural network model, predictions are made of when disruptions are likely to occur. To ensure continuity in the supply chain, alerts (e-mail, sms alerts) can be set to inform responsible parties while each organisation needs to define their escalation procedure in case disruption calls are not heeded by the first line personnel notified of possible disruption.

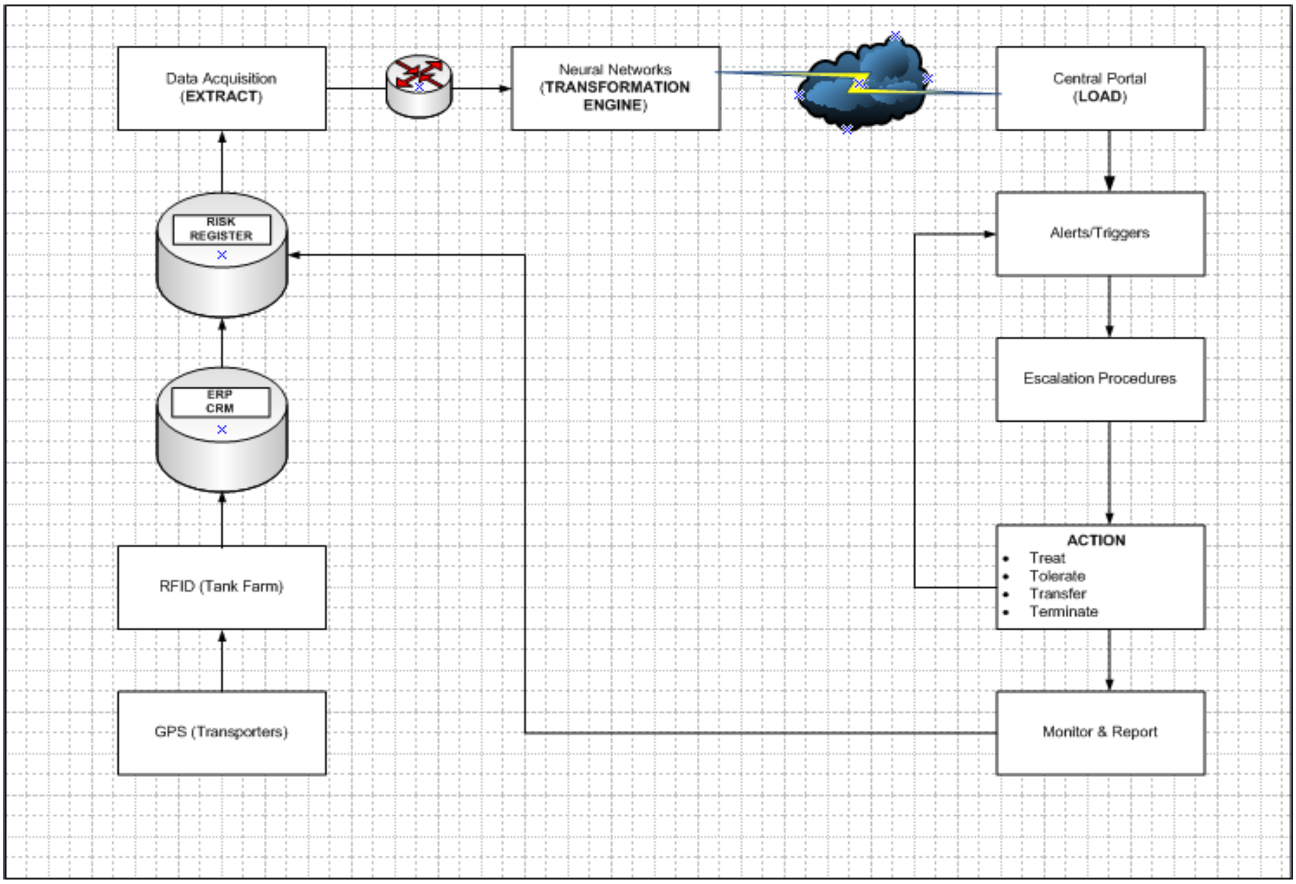

Figure 9: Risk Management Framework

7 CONCLUSIONS

The theories and application of supply chain risk management and artificial neural network have been exposed in this study. Building a neural network model to predict risk events in the energy supply chain is believed to be a good management tool for risk anticipation, avoidance and mitigation. The proposed framework was applied to a refinery where the chain initiates at crude imports and terminates with end users. Manual data capture was done, data transformed, fed through the neural model and result reported within the intranet. The model returned output that closely matches the desired output indicating it can be adapted to a very high level of confidence. It is, however, recommended that further risk indicators and metrics be defined in future and more representative data volume be applied to see what the performance of the NN model will look like when applied to the energy supply chain.

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EXPLORING ABRASIVE WATER JET CUTTING FOR NEAR NET SHAPE PROCESSING OF TITANIUM AEROSPACE COMPONENTS

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ABSTRACT

Establishment of a local titanium industry is the focal point of a broad South African initiative to exploit the country's reserves of this sought after material. In parallel to the process development, manufacturing technologies is being developed for competitive component manufacture. The high cost of both the titanium alloy and the machining of the material constrain the use and the market size for the material. Currently the use is limited to aerospace, medical implant and high value sporting equipment applications. The classic manufacturing method is to machine from a solid billet. In the light of titanium alloys being classified as difficult to machine materials, this is a high cost approach. Several initiatives are in development to address this challenge. Significant development is being devoted to technologies such as press and sinter powder metallurgy, metal additive manufacturing, investment casting as well as isothermal forging. In this study the possibility of abrasive water jet cutting is investigated as a near net shaping process. The capabilities and limitations of the process are presented. A case study of a typical aerospace part where the conventional method of machining is compared to a near net shape process utilising abrasive water jet cutting and final machining is discussed.

1 INTRODUCTION

The use of titanium in the aerospace industry has received attention from the 1950's, due to the material's high strength-to-weight ratio. As titanium has such favourable physical properties, it is also difficult to machine and process. It is also very reactive at elevated temperature, and readily reacts with oxygen in the atmosphere during machining; forming what is known as alpha-case on the surface of a part. This is a concern for the aerospace industry, as this reduces the metallurgical integrity of the part, serving as the source for crack propagation that can ultimately cause unexpected failure of a part. Additionally, aerospace parts typically require extensive machining, as the parts tend to have complex geometries and the need to be as light as possible. With the cost of machining titanium being especially high and hard to justify, near-net shape processing is becoming particularly attractive.

Near-net shape processing is currently receiving global attention, especially in the aerospace industries. These processes convert the raw material into a near-net shape of the final part. Secondary processing, such as milling, is then used to convert the near-net shape to the final functional part. It results in shorter lead times, improved quality and reduced costs to manufacture a part. Various established manufacturing techniques can be used to realise near-net shape processing, such as certain metal forming and material removal processes. As metal forming techniques generally require either large forces or elevated temperatures, the focus of this study is placed on material removal processes. More particular, the focus is placed on Abrasive Water Jet Cutting (AWJC), as this process is considered a cold process, with parts machined using this process typically having no heat-affected zone. This is particularly attractive to the aerospace industry, as it entirely eliminates the possibility of alpha-case forming, but many aspects about this cutting technology is still under development.

The goal of this study is to investigate AWJC for the purpose of near-net shape processing of titanium aerospace parts. This is done by means of an explorative case study of a typical aerospace component. A candidate aerospace part used by a major aircraft manufacturer is used as concept demonstrator. The argument is presented that AWJC is a suitable technology to reduce manufacturing cost and lead time for Ti-6Al-4V aerospace parts. This is achieved by reducing the amount of machining required by implementing AWJC as a near-net shape processing technique. This enables a more cost effective manufacturing technology that could improve the competitiveness of South African aerospace part manufacturers in global aerospace supply chains.

2 CHALLENGES OF TITANIUM MACHINING

Ti-6Al-4V is the most commonly used titanium alloy in aerospace applications. This is an alpha + beta alloy. The alpha-phase is stable below the transition temperature of 882˚C. Above this transition temperature the crystal structure changes from hexagonal close packed to a body centred cubic structure [1]. If the alloy is heated to beyond the transition temperature during manufacturing, oxygen is absorbed into the crystal structure causing severe microstructural change. The most important effect of this microstructural change is the severe degradation of fatigue properties. The failure mechanism is the formation of an oxygen enriched outer layer referred to as alpha-case. This alpha-case layer is hard and brittle and serves as crack initiation sites for fatigue cracking. It is therefore of critical importance to limit temperatures during manufacturing process to below the transition temperature [2] [3].

Titanium is regarded among machinists and researchers as a difficult-to-machine material. Its thermal properties contribute largely to this phenomenon. Table 1 illustrates that Ti-6Al-4V has a lower thermal conductivity than the referenced materials, namely 11% of that of

AISI 1018 steel and 1/25th of 6061 aluminium. In titanium machining the low thermal conductivity tends to accumulate heat in the cutting zone that leads to high local temperatures. This leads to a high risk for alpha-case to develop [4].

From Table 1 it can be seen that the specific heat (c), or heat storage capacity, of Ti-6Al-4V is relatively large, being 27% higher than for the referenced steels. The thermal diffusivity ($\alpha = \lambda/\rho c$) is the ability of the metal to adapt its temperature to that of its surroundings. Again it can be seen from Table 1 that the thermal diffusivity of Ti-6Al-4V is only 1/8th of that of AISI 1018 steel. This causes the alloy to accumulate heat locally, increasing tool wear and the risk of microstructural degradation. Titanium is an exceptionally reactive material at elevated temperatures. This reactivity with tool materials, such as Tungsten Carbide, is responsible for accelerated tool wear [5].

Table 1: Thermal properties of Ti-6Al-4V and comparative materials [6]

Material	Thermal conductivity	Density	Specific heat	Thermal diffusivity
	λ (W/m°C)	ρ (kg/m^3)	c (J/kg°C)	α (m^2/s)
Ti-6Al-4V	6.7	4430	586	0.0258
Inconel 718	12.1	8190	435	0.0340
AISI 4340 Steel	33.4	7830	460	0.0925
AISI 1018 Steel	59	7850	460	0.165
Al 2024	164	2780	883	0.666
Al 6061-T6	177	2710	892	0.733

Considering the challenges of titanium machining, especially the high strength alloys, the value of avoidance of machining by near-net shaping is considerably larger than in the case of other, less difficult to machine, alloys. In South Africa, techniques that are researched in Europe for near-net shaping application, such as rotary forging, have limited value, due to high capital costs and lack of subsequent support infrastructure. On the other hand, AWJC is well established in South Africa. Therefore this explorative study is considered to be valuable specifically in South Africa.

3 BACKGROUND OF ABRASIVE WATERJET CUTTING

AWJC is a non-traditional method of machining that offers a productive alternative to conventional machining techniques. AWJC uses a fine, high-pressure, high-velocity stream of water directed at the work surface to cause cutting of the work piece, with abrasive particles added to the stream to facilitate cutting. The cutting power is obtained by means of a transformation of a hydrostatic energy into a jet of sufficient kinetic energy to disintegrate the material [7].

Various variables have to be considered during machining, the most dominant being the waterjet pressure, the traverse speed of the nozzle and stand-off distance [8]. These variables are illustrated in Figure 1.

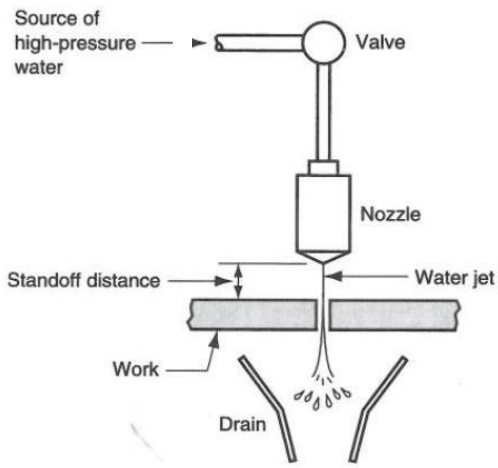

Figure 1: Waterjet cutting process [7]

3.1 Advantages

- No heat effected zones [9]
- Low machining forces [10]
- Current AWJC technology is a full-scale production process with precise, consistent results [11]
- Technology widely available [7]

3.2 Disadvantages

- Issues with dimensional accuracy due to cutting jet variation and striation, which is visualised in Figure 2 [12].
- Limited depth of cut, can cut material ranging from 1.6 to 300mm in thickness with a tolerance of ±0.05mm [11].
- Abrasive particle embedment in surface [13].
- Secondary processing usually needed to remove abrasive particles embedded in work piece surface [13].
- Disposal of the sludge of metal and abrasive particles after processing [11].

3.3 Profile of cut

There are three stages during the AWJC process, with each having different characteristics that have to be considered during the process design.

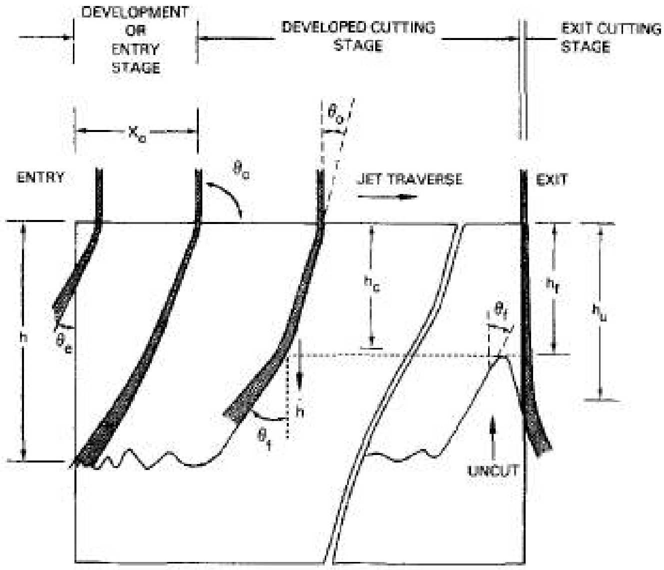

Figure 2: Profile of a cut using AWJC [14]

3.3.1 Profile of cut

3.3.1.1 Development of entry stage and penetration

The first step in the AWJC process is the entry, or penetration stage. The jet stream has to penetrate the material surface before linear cuts can be made. For material with a hard hardness, the penetration can be difficult. The upper hardness limit for material to be machined using AWJC is typically around 55-60 Hardness measured on the Rockwell C scale (HRC). The nozzle traverse speed has to be reduced to almost stationary, until the jet stream penetrates the entire required depth or thickness of the workpiece. After penetration, the jet stream will be deflected on the uncut material in the cut plane [14]. The entry stage lasts until the jet stream reaches the desired depth of cut.

3.3.1.2 Developed cutting stage

After the development stage, the nozzle traverse speed is kept constant and the jet stream is entirely contained in the cutting plane in the material. This results in a constant depth of cut and consistent surface quality.

3.3.1.3 Exit cutting stage

When the jet stream reaches the proximity of the exit face of the material, the jet stream will tend to exit the material before the full depth of cut is realised. This results in an uncut triangular shape on the material, where the jet traverse speed has to be reduced to remove the excess material to ensure consistent surface quality.

3.3.2 Different depth zones in the kerf

The kerf can further be described in 3 distinct zones, when viewed perpendicular to the cutting plane.

$$D = C\left(\frac{qP}{Va}\right) \qquad \textbf{(1)}$$

Equation 1 describes the full depth of cut for a single pass of the water jet. From literature it is seen that the depth of cut is primarily dependent on the waterjet pressure (P), nozzle traverse speed (V) and abrasive flow rate (q). Coefficient C and exponent a are a function of the abrasive and workpiece materials and the nozzle geometry. These constants can be determined through experimentation [15].

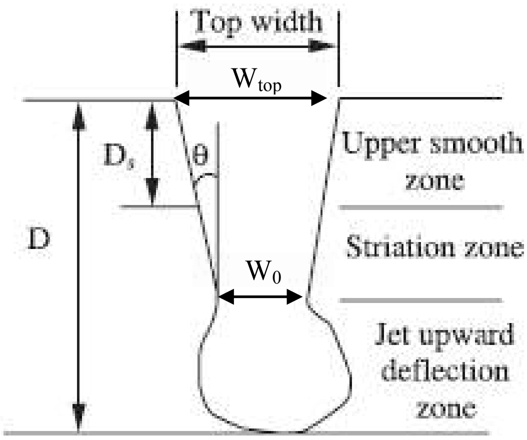

Figure 3: Schematic drawing of kerf geometry [16]

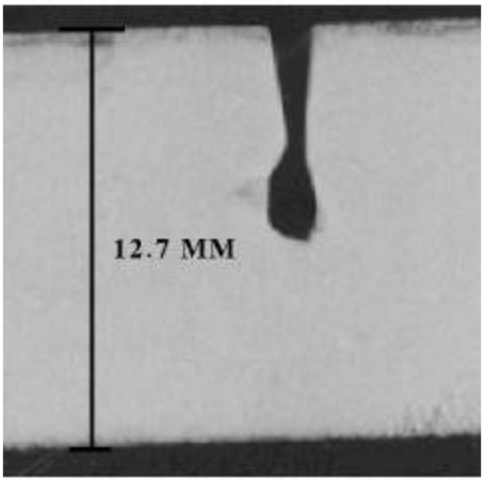

Figure 4: Kerf profile after single pass of AWJ at V = 200 mm/min and P = 345 MPa [16]

3.3.2.1 Upper smooth zone

The upper zone is characterised by a tapered zone from the surface of the part. The depth of the upper zone can be calculated using equation 2. The taper angle can be calculated using equation 3. W_{top} and W_0 can be taken as a constant, and vary little as water pressure, traverse speed and abrasive flow rate change.

$$D_s = C\left(\frac{qP^b}{V^a}\right) \quad \textbf{(2)}$$

$$\cot(\theta) = \frac{2D_s}{W_{top} - W_0} \quad \textbf{(3)}$$

3.3.2.2 Middle striation zone

The middle zone is characterised by perpendicular cuts, with visible striations originating here. W_0 remains virtually constant and surface roughness tends to be good [17]. As stated W_0 appears to remain constant as water pressure, traverse speed and abrasive flow are changed.

3.3.2.3 Jet upward deflection zone

The lower zone is characterised by a rough and fairly unpredictable surface finish. The lower zone tends to have visible jet striations and variation, which tend to increase as depth is increased. As traverse speed is decreased, the surface quality is increased, as seen in Figure 6. It is possible to eliminate this zone entirely, if the upper and middle zone is extended to the bottom of the cut, when making a through cut, as illustrated in Figure 1.

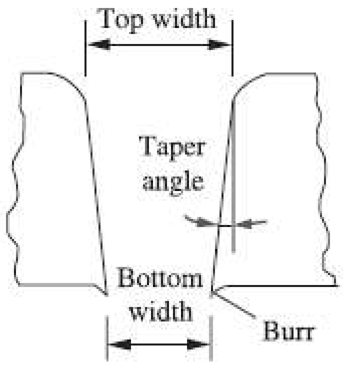

Figure 5: Through cut using AWJC [16]

4 MAIN FACTORS TO CONSIDER DURING AWJC

4.1.1 Traverse speed

The traverse speed is the speed of the nozzle of the waterjet cutter relative to the work piece. The choice of traverse speed is paramount, as it is the operative mechanism of material removal and thus influences the material removal rate. The traverse speed also has a strong influence on surface finish. The surface waviness can be reduced if the traverse speed is decreased and the surface roughness is not strongly dependent on traverse speed [18].

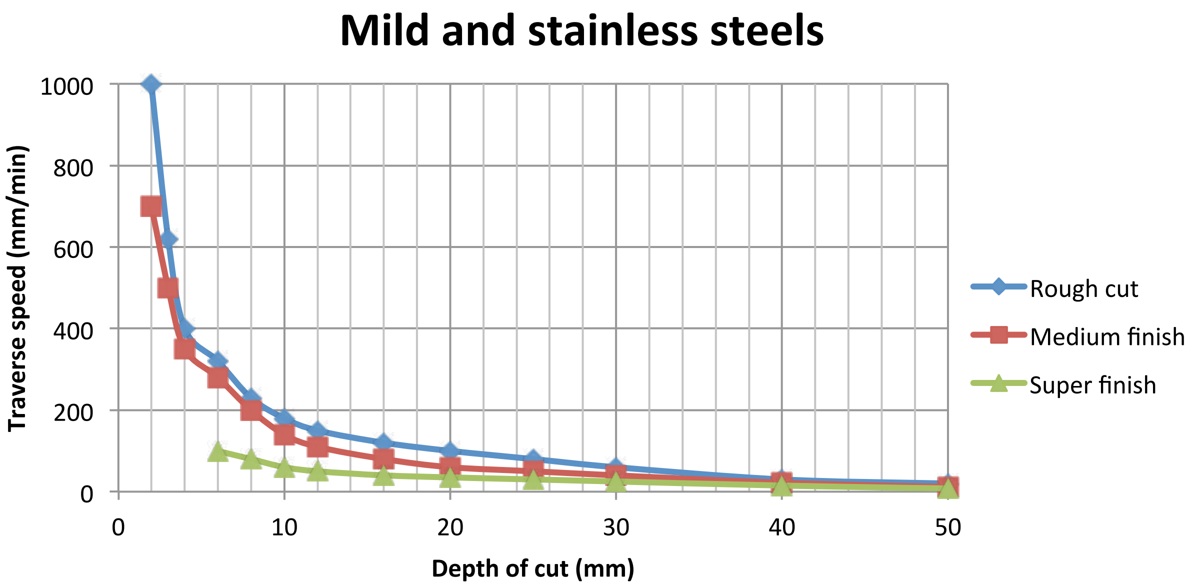

Figure 6: The traverse speed with different surface finishing and depth of cuts

4.1.2 Stand-off distance

The stand-off distance is the distance the waterjet has to travel from the nozzle to the workpiece. From work done by Fowler, et al [19], the material removal rate is insensitive to a stand-off distance between 2 mm and 5 mm and is at a maximum in this region. It should be noted that a decrease in stand-off distance results in an increase in the depth of cut with a smoother surface finish, and a decrease in kerf taper and surface roughness [16].

4.1.3 Abrasive particles and flow rate

There is a wide variety of abrasive particles available for AWJC, and the selection of particles is often based on economics rather than performance. The two parameters of abrasive particles that have the biggest influence on the process are grit size and hardness. Harder particles tend to have a larger material removal rate, but tend to embed into the surface of the work piece [13]. Examples of abrasive particles that can be used for AWJC include garnet, glass beads, AlO_3 (white), AlO_3 (brown) and steel shot.

4.1.4 Secondary processing

Secondary processing has a significant role in near-net shape processing. In most cases near-net shape processing is only used as a roughing operation, to eliminate the use of expensive roughing tools and extensive machining times on milling machines. A study done at an industry partner shows that approximately 73% of the time to machine the test part (Figure 7, left) on the CNC milling machine is spent on a single roughing operation. As the AWJC operation has certain quality concerns with respect to dimensional accuracy as depth is increased, material compensation has to be done that the part can still be machined to specification. The AWJC process also requires secondary processing to remove the embedded abrasive particles in the surface of part and localised surface hardening [20]. Figure 7 shows the difference between the finished test part, and the near-net shape part with material compensation.

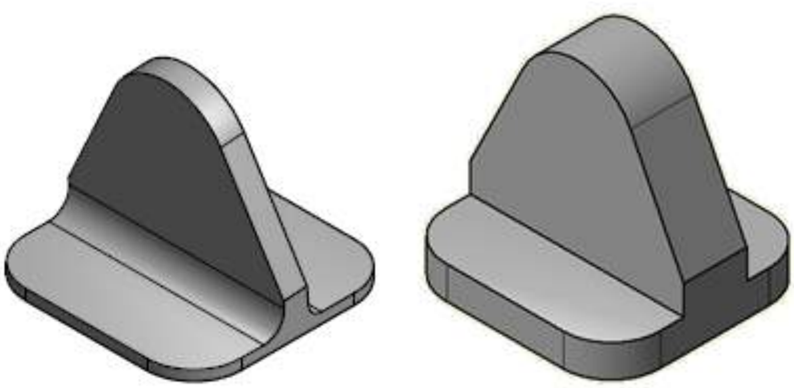

Figure 7: Finished test part (left) and near-net shape part (right)

The current process to create the test part requires 156 minutes machining time, of which 113 minutes is spent on the roughing process. When using AWJC it requires an estimated 23 minutes to produce the near-net shape part, with secondary processing taking an estimated 42 minutes. The result is an expected 42% reduction in lead time to produce a test part.

5 RESULTS

AWJC is a suitable candidate for the near-net shape processing of Ti-6Al-4V aerospace parts, provided that the geometric features of the parts do not require a depth of cut larger than 300mm [11]. The process has some tolerance issues when making deep cuts in some material, as well as impingement of abrasive particles in the surface of the workpiece. As the AWJC technology is intended as a near-net shape technology in this study, secondary processing is used to machine the part into its final shape. This processing also removes the impinged particles on the surface of the material, removes any localised surface hardening and removes all the geometrical issues with jet striation, provided adequate material compensation is provided [21]. AWJC results in a more energy efficient production method than conventional milling, as bulk sections of the material can be removed, whereas with milling the bulk sections of the material is simply converted to chips.

6 CONCLUSION

In the goal of this study and the introduction, the challenges of titanium alloy machining in aerospace applications have been discussed. A prominent challenge is to prevent heat degradation and related risk of fatigue failure of the final part. AWJC supports this objective by being a low temperature process with no risk of adverse microstructural change.

Replacing machining with AWJC results in inherent cost savings due to bulk section removal rather than reducing the workpiece section to chips. These inherent savings include the absence of cutting tool wear, with slag removal being similar to cutting fluid disposal. As energy is only applied to cut along specific lines and not to convert the entire material section to chips, energy is applied more effectively. For similar reasons the lead time for primary material removal is reduced.

As discussed in the paper the AWJC process also exhibits some disadvantages. The primary disadvantage is the limited depth of cut. At larger depths, the dimensional accuracy is adversely affected due to jet striation. Slag removal is a necessary disadvantage due to silicates as well as metallic compounds present in the slag. Another constraint to be considered is the impingement and embedment of silicate particles in the workpiece surface. This process requires secondary processing, namely machining, to create the final form of the part. Ultimately disadvantages such as dimensional accuracy and particle embedment become process constraints that are negated by secondary processing.

The conclusion can be reached that where part geometry enables AWJC as a near net shaping process for titanium aerospace parts, it is a suitable and more favourable alternative than machining processes.

7 RECOMMENDATIONS

It is recommended that the use of multiple passes of the jet stream be investigated, which has the possibility to improve surface quality and dimensional accuracy. This could reduce the amount of material compensation needed, resulting in less material being removed through secondary processing. Further experimentation is needed to investigate and validate the expected lead times and costs, to be able to study the economic feasibility of implementing this method in the industry.

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ECONOMIC MODEL FOR PRODUCTION OF ECO-FRIENDLY PRODUCTS FROM NATURAL FIBRE MATERIAL

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ABSTRACT

Petroleum-based synthetic materials such as polypropylene are normally not environmentally friendly. There is renewed interest in natural fibre as replacement for these. Agave, a natural fibre material that is locally available in South Africa, can be tapped into as it has a variety of applications in the manufacturing of eco-friendly products. About 98% of the agave plant that was previously not deemed useful now has a potential economic value and can be used as a biomass feedstock, yielding renewable and carbon neutral energy. Car manufactures and green product designers are also currently interested in agave and this has given the agave industry new vigor. This paper gives results from interviews carried out with various people involved in the research, production and processing of agave. A description of the processing of the plant is included. The input and output parameters as well as their inter-relationships are determined. The paper finally presents an economic model highlighting the feasibility of investing in agave industry. The model would be useful for decision making purposes by potential investors.

Keywords: eco-friendly, fibre material, agave, parameter, economic model, parameters

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1 INTRODUCTION:

Currently plastics are mostly used in the making of light weight components for example automobile parts. However, plastic's production requires a remarkable consumption of oil-based resources, which are non-renewable. Moreover, the use of plastic material makes the reuse and recycling quite difficult, and unsatisfactory because of the high costs, the technical difficulties and the environmental impact, La Mantia *et al* [1]. Research efforts are currently being harnessed in developing biodegradable 'green' materials and using natural fibres Netravali *et al* [2]. The fibres include sisal, flax, hemp, jute, kenaf, banana, pine apple, coir, cotton, and henequen, Miao M. *et al* [3], Li *et al*, [4], Bismarck [5] .These fibers are processed for a variety of applications, Riedel *et al* [6]. Mishra *et al*, [7] discussed the use of pineapple fibre and sisal reinforcements in low cost light weight composites. Sisal fibre claim a major participation as building materials as reinforced polymer composites, Joseph *et al* [8] and in manufacturing of twines, ropes, sacks, and carpets, Gao J *et al*, [9]. A few articles have been published on the potential that *agave americana* fibre has in producing eco-friendly products, Boguslavsky *et al* [10], Jaouadi *et al,* [11].

Natural fibre material form *agave americana*, that is locally available in South Africa, can be tapped into as it has a variety of applications in the manufacturing of eco-friendly products. The plants are medium to large, freely suckering, 1-2m tall rosettes, 2-3.7m broad and their leaves are 10-20 x 1.5-2.5decimeters, Gentry, [12]. According to the local Agricultural Research Council, [13], about 98% of the agave plant that was previously not deemed useful now has a potential economic value and can be used as a biomass feedstock, yielding renewable and carbon neutral energy. Car manufactures and green product designers are also currently interested in agave and this has given the agave industry new vigor.

Currently the plants are mostly used for animal feed and erosion restrictions. In this research the natural fibre material is investigated with respect to processes that the material goes through. This paper contains information about the eco-friendly products made from *the agave americana* natural fibre material which include industrial carpets, ropes, paper, and twines; and then finally presents an economic model for them.

2 BACKGROUND TO AGAVE PROCESSING

Agave industry is a multi-product industry. Agave plants are a valuable source of raw material due to its fibrous and complex sugar content of their leaves and core, and their bagasse waste can be used for several aims, Narvaez-Zapata, [14]. The requirements for agave processing are farms to supply the raw material and factories to produce products as well as logistics for products and plants. According to Franck, [15], fibre yield per hectare depends on the number of plants per hectare whilst total annual production of agave fibre varies, depending on demand, climatic conditions and cultivation.

To produce eco-friendly materials the cycle starts when agave is planted and ends when the final product has been made. The agave leaves whose weight are in the range of 0.5-1.5 kg, and the ratio (by weight) of fibre extracted from the fresh leaf is 4%-7%, Franck [15], are harvested after two years, Dalton, [16]) and decorticated into fibre. The dried fibre is classified according to length, cleanliness and moisture. Finally fibre is baled and transported to the market. Processed fibre is either carded, combed, drawn and spun into yarn for cordage or be cottonised and spun bonded into non-woven for technical textiles and composites, Franck [15]). Waste from these processes is further processed into biofertilizer, biofuel, paper or biogas among many other products.

According to the Council of Scientific and Industrial Research, 2011, [17], sustainability of the supply of raw material for fibre processing must always be established. This is determined by two conditions; the ability of the decorticator to supply the required quantities of the long and short agave fibre and the actual quantities of plants available for processing from the farms.

3 METHODOLOGY

Research on all potential products and by-products derived from the *agave americana* natural fibre material was done. However, due to the availability of data, only industrial carpets, A2 paper, ropes and twines are considered in this paper. Carpets are eco-friendly textiles used for floor covering. Production processes of agave industrial carpets, ropes, twines and paper products were studied based on input and output costs. In order to complete the task of developing an economic model for the production of eco-friendly products from natural fibre material the following was executed:

- Interviewing agave growing farmers to fully understand the growing process of the plant.
- Interviewing research experts on all aspects of processing the plant
- Consult local sisal committees for the potential of growing agave in South Africa
- Identifying relevant parameters for the model

Ultimately, the data was provided by the National Sisal Committee through their internal documents [13], farmers in Graaf Reinet, industrial experts at Rebtex Ltd and the research experts from the Council for Scientific and Industrial Research (CSIR) in South Africa, [17].The data assisted in identifying eco-friendly products considered in this article. The data show interpretation of events from experts' point of view; Kirzner [18][19], Yu, [20] and has influenced the creation and the dynamics of the economic model.

The data collected was used to develop models for each of the processes of producing value added products from the long fibre and tow. Variable costs and not fixed costs have been used as key factors to determine the feasibility of the project. The model was developed in excel spread-sheet to determine if the production of the biodegradable products (carpets, twines, ropes and paper) was feasible.

4 MODEL DEVELOPMENT

The model consists of a number of individual excel spread-sheet pages contained in Appendices A, B, C, D and E combined into a notebook by the use of arithmetic formulae, Rae, [21]. The appendices are supported by an excel program. The spread-sheet model provides an estimation of the cost and profit associated with the particular product or process as indicated in Appendix E. This enables a clear understanding and interpretation of the final results. Figure 1 shows the process flow diagram when converting long fibre to final products namely; twines, ropes and carpets as well as converting short tow fibres to A2 paper.

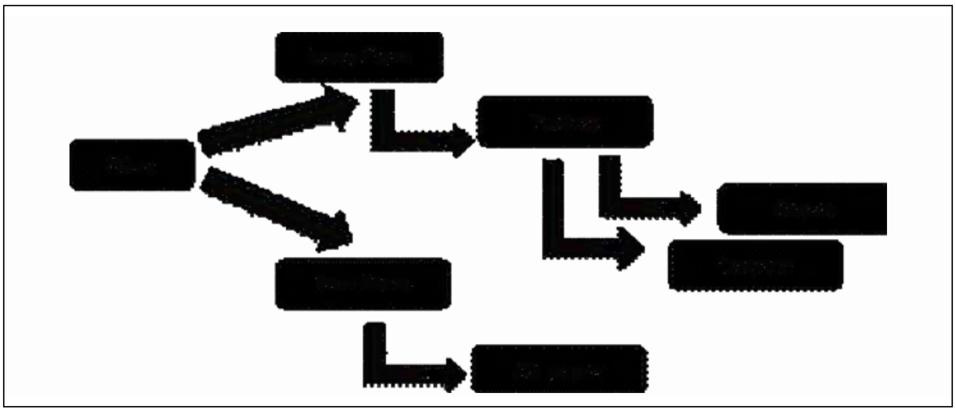

Figure 1: Process flow diagram

4.1 Variables

Most of the data, used by Rebtex Limited and quoted in Appendix E, is in values of the current Rand.

4.1.1 Inputs

The inputs in Appendix E include kilograms of long fibre material for twine, ropes, and carpet production whilst kilograms of tow fibre material are input for paper making. Both the former and the latter are both purchased from the agave farmers. Tow fibre consists of short fibres from the decortication process. Input cost elements considered are cost of raw material, labour, energy, capital equipment, building space, and maintenance . According to John 1994, [22], for each of these cost elements, an equation can be defined as a first order estimation. Therefore:

$$Long/short\ fibre\ cost\ (per\ unit)\ =\ Unit\ weight\ (kg)\ x\ Long/short\ fibre\ price\ (R) \quad \textbf{(1)}$$

The rest of the calculations based on kilograms of fibre to be processed are shown in Tables 2, 4, 6 and 8.Outputs

4.1.2 Outputs

The outputs are kilograms of ropes, twines, paper and carpets as well as net profit associated with each product as shown in Appendices A, B, C and D.

4.2 Production parameters

The major input parameters are shown in Appendix E. They include cost of energy, labour and fibre per kilogram of fibre processed. Conversion ratios of how many kilograms of fibre are converted into the end products are considered. The output parameter is the R/kg of processed goods obtained. The models' parameters are changeable to enable sensitivity analysis. Section 4.3 to section 4.6 give an outline of the input and output parameters and how they interact in the economic model for rope, carpet and paper production as also indicated in Appendix A to D.

4.3 Twine production parameters

Fibres are twisted to yarns that are in-turn twisted to form twines. Therefore the input into the model includes the number of kilograms of fibre to be processed from equation (1). The parameters for twine production are the kilograms of fibre to be processed, electricity cost, production cost, twine output efficiency of 97% per kg of fibre and their selling price as shown in Table 1, extracted form Appendix E.

Table 1: Twine production parameters

Parameter	Value	Unit
Kg per day	2000	Kg per Day
Electricity cost per Kg	0.8	R / Kg
Dyeing and finishing cost per Kg	6	R / Kg
Fibre cost	8	R/kg
Labour cost	1.2	R/kg
Selling price	22	R / Kg
Twine output	97%	Per kg of fibre

Table 2, is abstract from Appendix A and it shows the twine production output table. Total production cost is calculated by adding electricity cost, dyeing and finishing cost, labour cost and fibre costs.

Table 2: Twine output table

Parameter	Unit	Calculation
Fibre	Kg	Kg long fibre
Days required		Kg long fibre/Kg per day
Input cost	R	Dyeing and finishing cost + Labour cost + electricity cost + Fibre cost
Dyeing and finishing cost	R	Kg long fibre x Dyeing and finishing cost per Kg
Electricity cost	R	Kg long fibre x Electricity cost per Kg
Labour cost	R	Kg long fibre x labour cost per Kg
Fibre cost	R	Kg long fibre x purchasing price per Kg (from equation (1))
Twine	Kg	Kg long fibre x Twine output (97%)
Twine value	R	Twine x Selling price
Twine profit	**R**	**Twine Value - Input Cost**

4.4 Rope production parameters

Twines are twisted together to form ropes on a rope making machine. For a certain diameter of rope, the component twines required depend on the diameter and number of twines, Franck, [15]. Therefore, the input parameter is kilograms of twine to be processed. Table 3, extracted form Appendix E, shows the rope production parameters.

Table 3: Rope production parameters

Parameters	Value	Unit
Twine parameters		
Electricity cost per Kg	0.8	R / Kg
Cost of fibre	8	R / Kg
Labour cost	1.2	R /Kg
Dyeing and finishing cost per Kg	6	R / Kg
Twine output	97%	
Rope parameters		
Electricity cost per Kg	0.8	R / Kg
Labour cost	1.2	R / Kg
Spinning cost	5	R / Kg
Rope output	97%	Per kg of fibre
Selling price	30	R / Kg

Table 4 is an abstract from Appendix B. It shows the rope production output table. Electricity for rope production is a subtotal of electricity used on twine making and spinning of ropes. Total production cost is calculated by adding the input cost for twine production to the direct input cost of rope making as indicated in Appendix B.

Table 4: Rope output table

Parameter	Unit	Calculation
Input cost for twines	**R**	Fibre cost + Electricity cost + Labour cost + Dyeing and finishing cost
Fibre cost	R	Kg long fibre x purchasing price per Kg
Electricity cost	R	Kg long fibre x Electricity cost per Kg
Labour cost	R	Kg long fibre x labour cost per Kg
Twine	Kg	Kg long fibre x Twine output (97%)
Input cost of ropes	R	Input cost of twines + Input cost of ropes
Electricity cost per Kg	R	Kg of twine x Electricity cost per Kg
Labour cost	R	Kg of twine x labour cost per Kg
Spinning cost	R	Kg of twine x Spinning cost per Kg
Ropes	Kg	Kg of twine x Rope output (97%)
Rope value	R	Ropes x Ropes selling price
Rope profit	R	Rope value - input cost of ropes - input cost of twines

4.5 Carpet production parameters

The carpets fabric construction includes tufting, weaving or needle punching. For this model, the parameters to include are the production cost in R/kg, carpet output efficiency (approximately 90% per kg of fibre) and its selling price (R55) according to Rebtex Ltd, 2012. Carpets are a value added product of twines; therefore the twine parameters are applicable in carpet production as shown in Table 5 extracted from Appendix E.

Table 5: Carpet production parameters

Parameter	Value	Unit
Twine parameters		
Electricity cost per Kg	0.8	R / Kg
Cost of fibre	8	R / Kg
Labour cost	1.2	R /Kg
Dyeing and finishing cost per Kg	6	R / Kg
Twine output	97%	Per kg of fibre
Carpet parameters		
Electricity cost per Kg	2	R / Kg
Labour cost	1.2	R / Kg
Weaving cost	5.2	R / Kg
Carpet output	90%	Per kg of fibre
Selling price	55	R / Kg

Output values for carpet production are shown in Table 6, which is an abstract from Appendix C. Electricity for carpet production is a subtotal of electricity used on twine making and weaving of carpets.

Table 6: Carpet production output values

Parameter	Unit	Calculation
Input cost for twines	**R**	Fibre cost + Electricity cost + Labour cost + Dyeing and finishing cost
Fibre cost	R	Kg long fibre x purchasing price per Kg
Electricity cost	R	Kg long fibre x Electricity cost per Kg
Labour cost	R	Kg long fibre x labour cost per Kg
Dyeing and finishing cost	R	Kg long fibre x Dyeing and finishing cost per Kg
Twine	Kg	Kg long fibre x Twine output (97%)
Input cost for carpets	R	Electricity cost + Labour cost + Weaving cost
Electricity cost	R	Kg of twine x Electricity cost per Kg
Labour cost	R	Kg of twine x labour cost per Kg
Weaving cost	R	Kg of twine x Weaving cost per Kg
Carpet	Kg	Kg of twine x Carpet output (90%)
Carpet value	R	Carpet x carpet selling price per Kg
Carpet profit	R	Carpet value- twine input cost - carpet input cost

4.6 Paper production parameters

Market analysis, technical, financial and economic feasibility studies of agave based paper products was done by the Council of Scientific and Industrial Research, 2010, [23]. This covered the determination of production process, facility layout, specifications of raw material, establishment and production costs. The parameters considered in building the paper model were extracted from the Council of Scientific and Industrial Research, 2010 [23] and used in Appendix E. Table 7, shows the list of the parameters.

Table 7: Paper production parameters

Parameter	Value	Unit
Tow fiber / batch	0.50	Kg
Tow fiber Price	3.00	R/Kg
Hammer mill running cost	13.50	R/Hour
Hammer mill	280.00	Kg /Hour
Labour cost	8.00	R/Hour
Labours	10.00	
Caustic Soda	4.00	R/Kg
Caustic Soda / batch	0.20	Kg
Calcium carbonite	15.80	R/Kg
Calcium carbonite / batch	0.14	Kg
Water	0.00	R/l
Water / batch	185.00	l
Electricity / batch	1.36	kwH
Electricity	1.20	R/kwH
A2 Paper selling price	27.04	R/paper
A2 Paper / batch	3.00	A2

Batches per day	14.00

Table 8 is an abstract from Appendix D and it shows the paper production output

Table 8: Paper production output values

Parameter	**Unit**	**Calculation**
Tow fibre	Kg	Tow fibre Kg (input)
Batches	Batches	Tow fibre / (Tow fibre / batch)
Working Days	Days	Batches/Batches per day
Input cost	R	Hammer mill + Caustic Soda + Calcium Carbonate + Water Cost + Electricity Cost + Tow fibre cost + Labour
Hammer mill	R	(Tow fibre x Hammer mill running cost)/ Hammer mill
Caustic Soda	R	Batches x Caustic Soda Kg per batch x Caustic Soda (R4/kg)
Calcium Carbonate	R	Batches x Calcium carbonate x Calcium carbonate per batch
Water	R	Batches x Cost of water per litre x Water per batch
Electricity	R	Batches x Cost electricity per kg x Electricity per batch
Tow fibre cost	R	Tow fibre x Tow fibre Price
Labour	R	Working Days x Labour cost x No. of Labourers x hours per day (8 h)
Output		
A2 paper	Batches	Batches x A2 Paper / batch
Revenue	R	A2 paper x A2 Paper selling price{13}
Profit	R	Revenue - Input cost

The input box in the model (Appendix E) requires the amount of kg tow fibre allowed for paper production. This model focuses on the production of A2 paper sheets. These sheets may be further processed to produce more value added products capable of a higher selling price that include, but are not limited to: business cards, conference bag and document holder.

5 ECONOMIC FEASIBILITY

The excel model (Appendix A to D) shows that from 100hectares of the supply of fibre for each production process, approximately R11 million (from Appendix D), R2.5 million (from Appendix B) , R2.7 million (from Appendix A) and R940 thousand (from Appendix D) can be obtained after carpet, rope, twine and paper production respectively. However, the investor has to consider buying long fibre and tow fibre from the farmers at R10 and R4 per kg including transport cost, as producing fibre on rented land and hired labour is not profitable.

6 CONCLUSION

This paper has outlined the steps to the development of an economic model for agave fibre processing into eco-friendly products; twines, ropes, paper and carpets. The paper attempted to describe an economic model highlighting the possibility of profit making by evaluating four different production lines separately. Current commercial data was used as input to the model. The required quantities of raw materials were established to produce the most profitable products. Estimated net profit was obtained from each production line, and this determines the feasibility of producing ecofriendly products from natural fibre material. Sensitivity analysis can be done on the model to compare how different variables affect the outcome. The model may be used to determine the potential profit emphasising the unmet demand for *agave americana* products in South Africa.

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8 APPENDIX A: TWINE PRODUCTION

Period		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Income		**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**	**R 10 037 311.68**
Twine		R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68	R 10 037 311.68
Cost of sales		**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**	**R 7 525 632.00**
Finishing cost		R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00
Long Fibre		R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00
Overheads		**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**	**R 724 422.40**
Electricity		R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60	R 376 281.60
Rent		R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00
Maintenance and repair		R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00
Labour		R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40	R 564 422.40
Net Profit		R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28	R 1 787 257.28
Capital:		**R 1 250 000.00**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**
Carding machine		1250000														
Twine																
Long fibre	R/Kg	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Electricity	R/Kg	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Finishing cost	R / kg	6	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00
Labour	R/Kg	1.2	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20
Output	%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%
Long fibre	Kg	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352
Long fibre cost	R	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520
Carding cost	R	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112
Electricity	R	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6
Labour	R	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4
Twines	kg	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44
Selling price	R / kg	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Twine income	R	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68	10 037 311.68

9 APPENDIX B: ROPE PRODUCTION

Period		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Income		**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**	**R 13 276 625.90**
Ropes		R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90	R 13 276 625.90
Cost of sales		**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**	**R 9 806 839.20**
Carding cost		R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00
Long Fibre		R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00
Spinning cost		R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20	R 2 281 207.20
Overheads		**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**	**R 2 013 186.88**
Electricity		R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75	R 741 274.75
Rent		R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00
Maintenance and repair		R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00
Labour		R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13
Net Profit		R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82	R 1 456 599.82
Capital:		**R 1 250 000.00**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**
Carding machine		1250000														
Twine																
Long fibre	R/Kg	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Electricity	R/Kg	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Carding cost	R / kg	6	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00
Labour	R/Kg	1.2	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20
Output	%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%
Long fibre	Kg	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352
Long fibre cost	R	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520
Carding cost	R	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112
Electricity	R	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6
Labour	R	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4
Twines	kg	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44
Selling price	R / kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Twine income	R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ropes																
Electricity	R/Kg	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Spinning cost	R / kg	5	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00	R 5.00
Labour	R/Kg	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Output	%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%
Labour	R	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73
Electricity	R	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15	R 364 993.15
Spinning cost	R	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2	2281207.2
Ropes	Kg	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968	442554.1968
Selling price	R / kg	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Ropes income	R	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400	R 13 276 625.90400

10 APPENDIX C: CARPET PRODUCTION

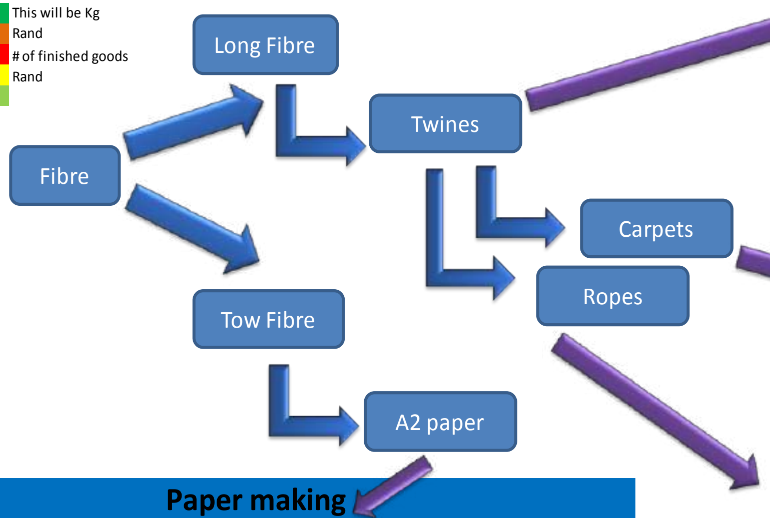
Period		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Income		**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**	**R 22 583 951.28**
Carpets		R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28	R 22 583 951.28
Cost of sales		**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**	**R 9 898 087.49**
Carding cost		R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00	R 2 822 112.00
Long Fibre		R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00	R 4 703 520.00
Weaving cost		R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49	R 2 372 455.49
Overheads		**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**	**R 2 560 676.61**
Electricity		R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48	R 1 288 764.48
Rent		R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00
Maintenance and repair		R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00
Labour		R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13	R 1 111 912.13
Net Profit		R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18	R 10 125 187.18
Capital:		**R 1 250 000.00**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**
Carding machine		1250000														
Twine																
Long fibre	R/Kg	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Electricity	R/Kg	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Carding cost	R / kg	6	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00	R 6.00
Labour	R / kg	1.2	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20
Output	%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%
Long fibre	Kg	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352	470352
Long fibre cost	R	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520	4703520
Carding cost	R	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112	2822112
Electricity	R	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6	376281.6
Labour	R	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4	564422.4
Twines	kg	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44	456241.44
Selling price	R / kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Twine income	R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carpets																
Weaving cost	R / kg	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Electricity	R/Kg	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Labour	R / kg	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Output	%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Labour	R	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73	R 547 489.73
Electricity	R	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88	R 912 482.88
Weaving cost	R	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488	2372455.488
Carpet	kg	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296	410617.296
Selling price	R / kg	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Carpet income		R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000	R 22 583 951.28000

11 APPENDIX D: PAPER PRODUCTION

Period		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Income		**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**	**R 1 557 504.00**
A2 pages		R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00
Cost of sales		**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**	**R 97 560.00**
Tow fibre		38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400
Hammer mill running cost		R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86
Caustic Soda		R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00
Calcium carbonite		R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14
Overheads		**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**	**R 515 545.05**
Water		R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48
Electricity		R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57
Rent Factory		R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00	R 60 000.00
Labour		R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00
Maintenance and repair		R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00
Net Profit		R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95	R 944 398.95
Capital:		**R 242 740.00**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**	**R -**
Hammer mill		25000															
Hollander beater		102 600.00															
Hydraulic press		6 840.00															
Mould and deckle A2		5 700.00															
Hollander Beater		102 600.00															
A2 pages																	
Tow fiber / batch	Kg	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Hammer mill running cost	R/Hour	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50	R 13.50
Hammer mill	Kg /Hour	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280
Caustic Soda	R/Kg	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00	R 4.00
Caustic Soda / batch	Kg	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Calcium carbonite	R/Kg	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80	R 15.80
Calcium carbonite / batch	Kg	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143	0.142857143
Water	R/l	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324	R 0.00324
Water / batch	l	185	185	185	185	185	185	185	185	185	185	185	185	185	185	185	185
Electricity / batch	kwH	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857	1.357142857
Electricity	R/kwH	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20	R 1.20
Labour cost / batch	R / Batch	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29	R 16.29
Cost of Tow fiber	R/Kg	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Tow fiber	Kg	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600
Cost of Tow fiber	R	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400	38400
Number of batches	number	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200
Hammer mill running cost	R	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86	R 462.86
Caustic Soda	Kg	3840	3840	3840	3840	3840	3840	3840	3840	3840	3840	3840	3840	3840	3840	3840	3840
Caustic Soda	R	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00	R 15 360.00
Calcium carbonite	Kg	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143	2742.857143
Calcium carbonite	R	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14	R 43 337.14
Water	l	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000	3552000
Water	R	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48	R 11 508.48
Electricity	R	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57	R 31 268.57
Labour	R	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00	R 312 768.00
A2 Paper / batch	A2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
A2 papers	Number of A2	57600	57600	57600	57600	57600	57600	57600	57600	57600	57600	57600	57600	57600	57600	57600	57600
A2 Paper selling price	R/paper	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04	R 27.04
A2 paper income	R	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00	R 1 557 504.00

12 APPENDIX E: INPUT AND OUTPUT PARAMETER VALUES

Input	This will be Kg
Profit	Rand
Products	# of finished goods
Input costs	Rand
Parameters	



Twines

Fibre	200000	Kg	Days required	100	
Input cost	R 3 600 000.00	R			Unit
Fibre cost	R 2 000 000.00	R	Kg per day	2000	Kg per Day
Electricity cost	R 160 000.00	R	Electricity cost per Kg	0.8	R / Kg
Labour cost	R 240 000.00		Cost of fibre	10	R / Kg
Dyeing and finishing cost per Kg	R 1 200 000.00		Labour cost	1.2	R /Kg
			Dyeing and finishing cost per Kg	6	R / Kg
Twine	193333.3333	Kg			
Twine value	R 4 253 333.33	R	Selling price	22	R / Kg
Twine profit	R 653 333.33	R	Twine output	97%	

Carpets

Fibre	200000	Kg			
Input cost twines	R 3 600 000.00	R	Twine parameters		Unit
Fibre cost	R 2 000 000.00	R			
Electricity cost	R 160 000.00	R	Electricity cost per Kg	0.8	R / Kg
Labour cost	R 240 000.00		Cost of fibre	10	R / Kg
Dyeing and finishing cost per Kg	R 1 200 000.00		Labour cost	1.2	R /Kg
			Dyeing and finishing cost per Kg	6	R / Kg
Twine	193333.3333	Kg	Twine output	97%	
Input cost carpets	R 1 624 000.00	R	Carpet parameters		
Electricity cost	R 386 666.67	R	Electricity cost per Kg	2	R / Kg
Labour cost	232000	R	Labour cost	1.2	R / Kg
Weaving cost	1005333.333	R	Weaving cost	5.2	R / Kg
			Carpet output	90%	
Carpet	174000	Kg			
Carpet value	9570000	R	Selling price	55	R / Kg
Carpet profit	R 4 346 000.00	R			

Ropes

Fibre	200000	Kg			
Input cost twines	R 3 600 000.00	R	Twine parameters		Unit
Fibre cost	R 2 000 000.00	R			
Electricity cost	R 160 000.00	R	Electricity cost per Kg	0.8	R / Kg
Labour cost	R 240 000.00		Cost of fibre	10	R / Kg
Dyeing and finishing cost per Kg	R 1 200 000.00		Labour cost	1.2	R /Kg
			Dyeing and finishing cost per Kg	6	R / Kg
Twine	193333.3333	Kg	Twine output	97%	
Input cost carpets	R 1 353 333.33	R	Rope parameters		
Electricity cost per Kg	R 154 666.67	R	Electricity cost per Kg	0.8	R / Kg
Labour cost	232000	R	Labour cost	1.2	R / Kg
Spinning cost	966666.6667	R	Spinning cost	5	R / Kg
			Rope output	97%	
Ropes	187533.3333	Kg			
Rope value	5626000	R	Selling price	30	R / Kg
Rope profit	R 672 666.67	R			

Paper making

					Unit
Tow fiber Kg	1122	Kg	Tow fiber / batch	0.50	Kg
			Tow fiber Price	4.00	R/Kg
Batches	2244	# of batches	Hammer mill running cost	13.50	R/Hour
Working Days	160.2857143	Days	Hammer mill	280.00	Kg /Hour
Input cost	R 118 984.75		Labour cost	8.00	R/Hour
Hammer mill	R 54.10		Labours	10.00	
Caustic Soda	R 1 795.20		Caustic Soda	4.00	R/Kg
Calcium carbonite	R 5 065.03		Caustic Soda / batch	0.20	Kg
Tow fibre cost	4488.00				
Water	R 1 345.05		Calcium carbonite	15.80	R/Kg
Electricity	R 3 654.51		Calcium carbonite / batch	0.14	Kg
Labor	R 102 582.86		Water	0.00	R/l
			Water / batch	185.00	l
Output			Electricity / batch	1.36	kwH
A2 paper	6732		Electricity	1.20	R/kwH
Revenue	R 182 033.28		A2 Paper selling price	27.04	R/paper
Profit	R 63 048.53		A2 Paper / batch	3.00	A2
			Batches per day	14.00	

DESIGNING OF AN INTELLIGENT FUZZY LOGIC SYSTEM FOR ACCRETION PREVENTION IN SPONGE IRON SL/RN ROTARY KILN BASED 100TPD DRI PROCESS

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ABSTRACT

Sponge iron is an intermediate product of steel formed during direct reduction of iron ore with aid of regulated temperatures and pressures within a rotary kiln. The greatest challenge is the direct measurement of kiln shell temperatures due to the catastrophic accumulation of sintered particles of solid bed which form rings at places along the length of the kiln thus hindering material flow. The accretion reduces productivity, damage kiln lining and reduces the production period as well as reduction in product quality. This process requires a controller which will be able to control with imprecise and partial data input; and be able to achieve the desired product quality under dynamic process conditions thus a Fuzzy Controller was used for the proposed design. The main goal of the research was to predict the rate of accretion build up within the kiln and minimize it with aid of a Fuzzy Control System cascaded to an already existing Programmable Logic Controller. A 16.2% build up rate was achieved as compared to the most appreciated 27% thus nearly a 10% decrease, a result which can improve the campaign period by approximately 48 hours which will be a 200 tons of sponge iron.

Key words: Sponge Iron, Fuzzy Logic, Accretion, kiln

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1 INTRODUCTION

The primitive methods of manufacturing, lack of process control and increased down-time has been the greatest effects experienced by manufacturing companies in developing nations. Fuzzy logic is useful just because of its low specificity; it allows a more flexible response to a given input. The output of a fuzzy system is smooth and continuous, ideal for the control of continuously variable systems such as electric motors or positioning systems. The process dynamics of sponge iron production depends largely on kiln rotation, temperature, pressure and feed control. Therefore the intelligence of process control architecture varies directly to the knowledge of the Knowledge Engineer. This research seeks among other things to control the manufacturing process of sponge iron with aid of a fuzzy controller which will be able to reason with imprecise or partial data hence making an informed decision. This controller developed demonstrated superiority in controlling the temperature, pressure and kiln rotational speed. Section 2 presents automation in sponge iron production, section 3 presents the sponge iron production process and section 4 the control parameters and section 5 the development of the fuzzy system.

2 AUTOMATION IN SPONGE IRON PRODUCTION

A report by Rockwell Automation [1] states that the plant floor has been in the past viewed as an "island" in isolation of other elements within the supply chain and the organisation itself. The developments in information technology and the development of e-commerce and e-manufacturing concepts have increased the need for the inventions of new and better methods to keep processes under control and providing information on the factory in the process industry. According to Saha and Grover [2] one of the enablers of e-manufacturing is automation. In developing automation systems based on fuzzy logic Booker [3] suggests one should first sit back and ask fundamental questions about what they are trying to do characterize the various forms of uncertainty and then develop mathematical models to quantify them.

The process of sponge iron making aims to remove oxygen from iron ore. According to Patra et al [4] the quality of sponge iron is primarily ascertained by the percentage of metallization (removal of oxygen), which is the ratio of metallic iron to the total iron present in the product. The characteristics of a kiln based system change significantly with respect to raw material quality, pressure and temperature conditions. In trying to apply the traditional methods of control, difficulties were encountered as the process working condition changes within a large operation range. Control methods such expert systems, fuzzy logic control, neural networks and knowledge-based systems, termed intelligent control were then considered as addition to conventional controllers. Fuzzy Logic (FL) is a nonlinear problem-solving control system methodology that lends itself to implementation in systems [5]. Sponge iron, also called Direct-reduced iron (DRI), is formed, when naturally available Iron Ore which is an oxidized form of Iron (magnetite (Fe_3O_4) or hematite (Fe_2O_3)) is reduced to its metallic form as stated by Kant and Shankar [6].

This reduction process occurs below the melting temperature of both metallic iron and its oxidized form. Though this process is carried out at lower temperature than melting point so that there is less volume reduction a large amount material get eliminated during reduction reaction. It is mandatory to get more understanding of parameters, such as the distributions of gas-solid flow, temperature, and composition of gases and particles within a rotary kiln through mathematical modeling as stated by Bhad et al [7]. The implementation of fuzzy control will enable the process to be optimized with imprecise or partial data hence achieving the desired product quality. However, only few expressions have existed so far for the processes in a cement rotary kiln to model the fuel combustion, heat transfer, and reduction chemistry. This is owing to the complexity of heat transfer that takes place simultaneously along with chemical and mineralogical reactions [7].

Zambak [8] states that in fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning. Everything is a matter of degree. Any logical system can be fuzzified thus knowledge is interpreted as a collection of elastic or fuzzy constraint on a collection of variables hence inference is viewed as a process of propagation of elastic constraints.

Fuzzy controller consists of a classifier, fuzzifier, rule base, interface engine. In the fuzzy rule base, various rules are formed according to the problem's requirements. The numerical input values to the fuzzier are converted into fuzzy values. The fuzzy values along with the rule base are fed into the inference engine which produces control values. As the control values are not in usable form, they have to be converted to numerical output values using the defuzzifier summarised by Jeganathan [9].

3 ACCRETION FORMATION

Experimental results done by the researchers revealed that accretion build up or ring formation in the kiln is caused by the deposition of low melting complex compounds on the refractory wall of the rotary kiln which gradually increases in thickness and takes shape of a circular ring, thus, reducing the kiln diameter and hence rate of production and a short campaign period is attained. Sarangi [10] states that, accretion build up occurs at a certain position in the second zone of the kiln when *Wustite* is the stable phase. When the ring formation is above 30% of the diameter of the kiln, the operation of the kiln becomes difficult. The kiln atmosphere must be properly regulated so as to achieve good metallization. The atmosphere above the bed is oxidising and within the bed is reducing. The inside conditions of the kiln are regulated in a manner that the oxidation potential within and just above the bed should be low which will assist in maintaining a strong reducing atmosphere for the reduction of iron ore. Within the second zone the CO: CO_2 ratio of the reducing gas should be more than 2:3. As for the conditions above the bed, the oxidising atmosphere may be controlled by controlled injection of secondary air using shell air fans mounted on the rotary kiln.

There are several factors which affect the isothermal condition in the reaction zone and heat transfer. The time of residence for preheating the charge and the chemical reactions essentially depends on the inclination speed of rotation, and granulometry of the raw materials. Heat release rate, poor heat transfer and lengthy reduction time account for low output of a rotary kiln and the campaign length. With a chosen retention time depending on the length and rotation, the output can be increased by increasing the diameter [11].

The degradation due to self-grinding increases with diameter, while exhaust gas velocity is decreased lowering entrainment of solids. For reasonable reaction rate, an appropriate temperature profile has to be maintained. The reaction temperature is dependent on softening temperature of solids. The reactivity of fuel and reducibility of the ore are the rate determining factors. The degree of metallization depends on the particle size and reducibility of the ore, temperature profile and reactivity of the fuel. All these factors should be considered in designing a model for minimizing accretion build up.

Dash [12] states that coal based process utilizes non-coking coal, lumpy rich grade of iron ore and dolomite as basic raw material. The non-coking coal acts as a reducing agent in this process. The reduction process is carried out in an inclined horizontal rotary kiln, which rotates at a predetermined speed.

Almost all direct reduction kilns operate on counter- current principle where the charge and the fuel are fed at opposite ends and, therefore, the raw materials travel in opposite direction to the flow of the kiln gases, while in co-current kiln the charge and the fuel fed at the same end and consequently the solids and the kiln gases move in the same direction.

The entrainment of fine particles of the charge in the exit gas depends on its velocity; the higher is the gas velocity, the larger will be the amount of fine particles carried away from the kiln. For identical quantity of gas leaving the kiln, the gas velocity decreases with the increase in the diameter of the kiln, which explains the higher length/diameter ratio of the commercial kilns. For gaseous reduction of iron oxide, the reaction rate depends on the flow rate of the gas to sweep away the product gas. Therefore, the rate controlling step of reduction depends on the gas velocity and it cannot be decreased below a definite limit. The velocity of exit gas of 20 m/sec. from a commercial kiln is sufficiently high to sweep the product gas. The extent of the pre-heating zone chiefly depends on the exhaust gas temperature, its volume and the exposed area of the charge. The temperature varies from 800 to 1050°C, while the gas volume varies from 3000 to 5000 Nm^3 ton sponge iron. Higher exhaust gas temperature decreases the thermal efficiency of the kiln and the temperature has to be lowered by admission of air using shell air fans dotted along the kiln length. The admission of the air with aid of shell fans at regular intervals lengthens the combustion zone.

The optimum temperature of operation inside the kiln mainly depends on the softening temperature of the ash of the reductant. As the output of the kiln increases steeply with increase in reaction temperature, the kiln should be operated at the maximum permissible temperature, which should preferably be about 100°C below the ash softening temperature. The softening of fusion of any constituent of the raw material and presence of fines lead to the major problems of balling up of the ingredients and "ring" formation or deposition of accretions on the kiln wall, progressive of operation.

In fact if the "ring" formation can be totally eliminated, a rotary kiln will be an ideal reactor for reduction of iron oxide of which that’s practically impossible. The ash softening temperature of the Zimbabwean non-coking coals is not very high, thereby limiting the maximum operational kiln temperature. The rate of removal of oxygen from iron ore depends on the temperature of reaction. The effect of temperature on gaseous reduction of an iron ore at identical gas flow rate is too complex and will not be used to develop the fuzzy model. A study of the kinetics of removal of oxygen by gaseous reductants reveals that the reaction rate progressively increases from 700°C to 1000°C and the time of 90% reduction, for a particular ore decreases from 145 min. to 70 min. In other words the kinetics of iron ore reduction by gaseous reductants like H_2 or CO at temperature below 800°C is exceedingly slow even when the product of the reaction is swiftly swept away from the reaction front. Consequently, the raw materials in the kiln are to be preheated to an appropriate temperature to assure a reasonable reaction rate as in the presence of large amount of carbon in the charge a significant part of reduction occurs through the agency of solid reductant.

4 CONTROL PARAMETERS

There are several factors and parameters which affect the production of sponge iron, however the research seeks to control only the following parameters so as to minimise accretion build up:

- Feed rate of raw materials from the raw material storage bin with aid of weigh feeder system.
- Kiln Temperature profile along the rotary kiln for both the preheating zone and the reduction zone.
- Kiln Gas pressure
- Kiln rotational speed

Parameters such as raw material quality are difficult to improve with automation; however they have a direct effect on the product quality. Therefore the quality aspect of raw materials is considered to be constant and the design shall seek to optimise the product quality based on the available raw material quality.

5 DEVELOPMENT OF FUZZY LOGIC CONTROL SYSTEM

According to Zadeh [9] and Al-Hadidi et al [14] a Fuzzy Logic Control System provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL's approach to control problems mimics how a person would make decisions, only much faster ted by as stated by Sivanandam and Deepa [15]. The FL model is empirically-based, relying on an operator's experience rather than their technical understanding of the system as stated by Priyono et al [16]. The terms are imprecise and yet very descriptive of what must actually happen. The trial-and-error basically formulates the back-bone of the empirical methods implemented during the design of fuzzy systems as shown in Figure 1.

Fuzzy set theory does not permit vagueness in our computations, but shows how to tackle uncertainty, and to handle imprecise information in a complex situation. Fuzzy sets are the core element in Fuzzy Logic. They are characterized by membership functions which are associated with input and output to the fuzzy logic system and terms or words used in the antecedent and consequents of rules as shown in Figure 1.

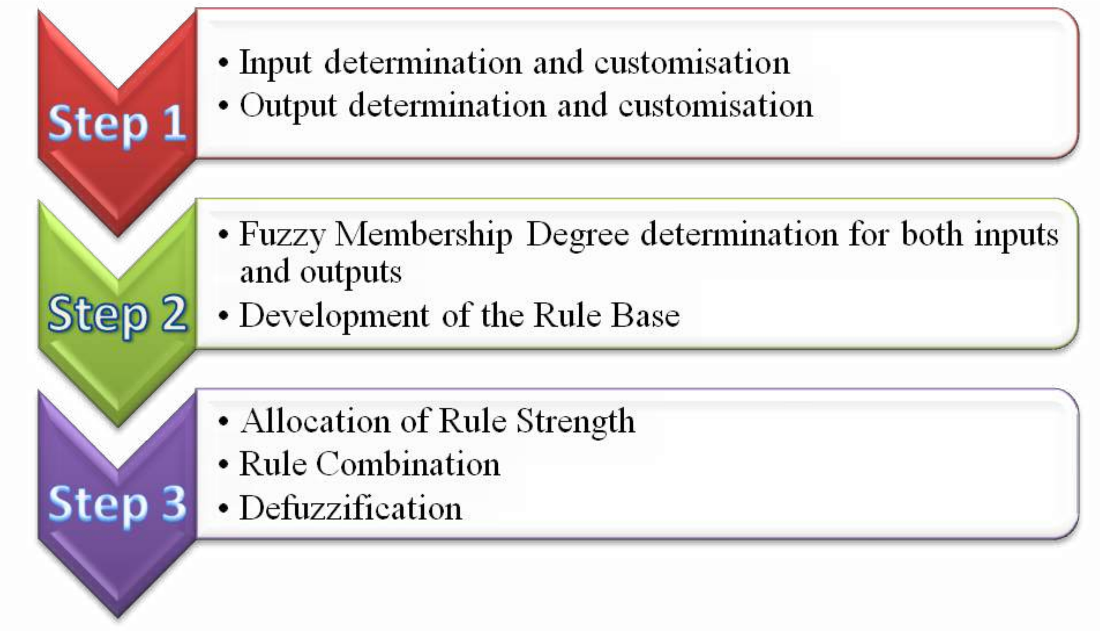

Figure 1 The methodology for designing a fuzzy controller [15]

Fuzzy set theory was originally proposed by Prof. Lotfi A. Zadeh [9] of the University of California at Berkeley to quantitatively and effectively handle problems involving uncertainty, ambiguity and vagueness. The theory, which is now well-established, was specifically designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision that is intrinsic to many real world problems [17].

The accretion regulation, prediction and prevention are achieved by regulation of the following sets of parameters:

1. Minimising accretion build up by monitoring the temperature profile (**T** /^{o}C) and gas pressure profile inside the kiln (**P** /*mBar*).

The linguistic description provided by the expert can generally be broken into several parts. There will be "linguistic variables" that describe each of the time-varying controller inputs and outputs. Linguistic variables assume "linguistic values". That is, they can be described by the following values:

"Negative High, Negative Low, Zero, Positive Low, and Positive High"

The convention that was used by was such that, a particular linguistic variable is considered positive if it is acting towards the right and negative if it is acting towards the left. Each of the three rules listed above is a *"linguistic rule"* since it is formed solely from linguistic variables and values. Since linguistic values are not precise representations of the underlying quantities that they describe, linguistic rules are not precise either. They are simply abstract ideas about how to achieve good control that could mean somewhat different things to different people. There is no underlying relationship between membership function and a probability density function; hence there is no underlying probability space. By definition "certainty" is the "degree of truth". Zadeh [9] proved that the membership function has no basis to quantify random behavior however it simplymakes less fuzzy the meaning of linguistic descriptions.

Takagi et al [18] explained that the premises (sometimes called "antecedents") are associated with the fuzzy controller inputs and are on the left-hand side of the rules. Note that there is no need to be a premise (consequent) term for each input (output) in each rule, although often there are.

5.1 The fuzzy set theory

Cox [19] summarised that there are two main types of fuzzy logic which are Type-1 and Type-2 fuzzy logic systems. The greater simplicity of implementing a control system with fuzzy logic can reduce design complexity to a point where previously insoluble problems can now be solved. Fuzzy systems typically result in a 10:1 rule reduction, requiring less software to implement the same decision-making capability.

5.1.1 Type-1 Fuzzy

Use full justification Type-1 fuzzy sets are not able to convey the uncertainties about the member ship functions as illustrated on Figure 2. Some typical sources of uncertainties are:

a) The meaning of the words that are used in the antecedents and consequents can be uncertain (words mean different things to different people),
b) Knowledge extracted from a group of experts do not all agree thus the consequents may have a histogram of values associated with them,
c) Inputs or measurements may be noisy

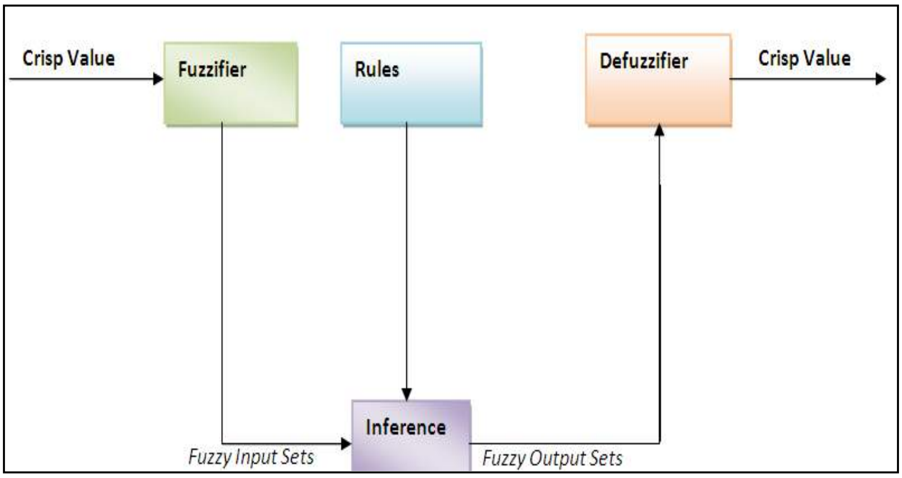

Figure 2: The Type-1 Fuzzy Logic System (FLS)

A type-1 fuzzy set, A for a single variable, $x \epsilon X$is defined as $A = \{(x, \mu_A(x)) | x \epsilon X\}$. Type-1 membership function, $\mu_A(x)$ is constrained to be between 0 and 1 for all $x \epsilon X$, and is a two-dimensional function as summarized by Cox [19]. A fuzzy logic system (FLS) that is described completely in terms of type-1 fuzzy sets is called a type-1 FLS. The system contains four components which are the fuzzifier, rules, inference engine, and defuzzifier.

5.1.2 Type-2 Fuzzy Sets

Unlike type-1 membership functions which are two-dimensional, type-2 fuzzy member ship functions are three-dimensional. The additional degree of freedom offered by the new third dimension enables type-2 fuzzy sets to model the aforementioned uncertainties as illustrated on Figure 3.

Type-2 fuzzy set is formally denoted as Ã and is characterized by a type-2 membership function $x, \mu_{\tilde{A}}(x; u)$ where, $x \epsilon X$ *and* $u \in J_x \subseteq [0,1]$ i.e.

$$\tilde{A} = \{((x, u), u_{\tilde{A}}(x, u)) | \forall x \in X, \quad \forall u \in J_x \subseteq [0,1]\}$$

in which $0 \leq u_{\tilde{A}}(x, u) \leq 1$. The domain of a secondary membership function is called the primary membership of x which is J_x.

For interval type-2 fuzzy set, J_x ,the primary membership of x is reduced to an interval set which is defined above and the secondary grades of Ã are all equal.

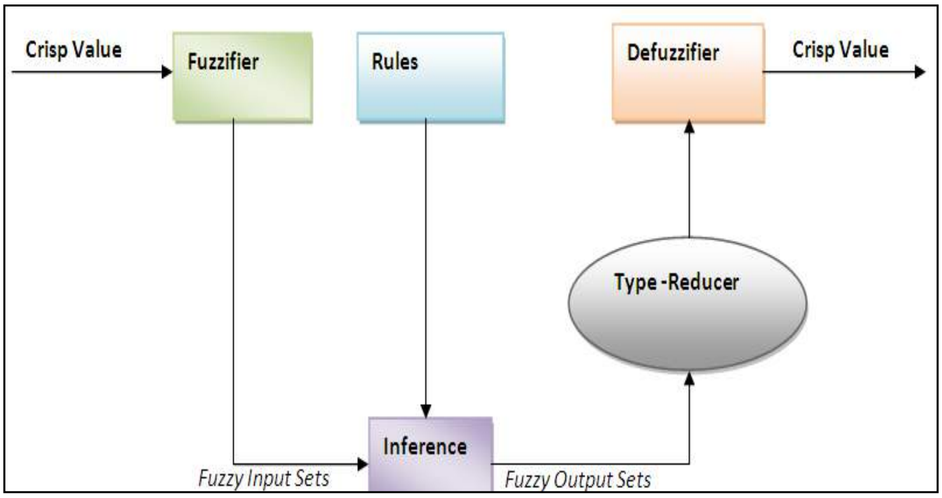

Figure 3: Type-2 fuzzy logic system (FLS)

A FLS that is described using at least one type-2 fuzzy set is called a type-2 FLS. A type-2 FLS is depicted in Figure 3. The first observation is that a type-2 FLS is very similar to a type-1 FLS. The major structural difference is that there exists a type-reducer block before the defuzzifier block. As the name suggests, type-reducer maps a type-2 set into a type-1 set before the defuzzifier performs defuzzification on the later set. Typical type-reduction methods are: centroid, center-of-sums, height, modified height, and center-of sets.

5.2 The fuzzy component design

The ability of Fuzzy Logic to deal with uncertainty and noise has led to its use in controls stated Self **Error! Reference source not found.**, hence sponge iron production is a very dynamic process with several intertwined control loops. Fuzzy logic is inherently robust since it does not require precise, noise-free inputs. It is not limited to a few feedback inputs and one or two control outputs. Fuzzy control is most reliable if the mathematical model of the system to be controlled is unavailable, and the system is known to be significantly nonlinear, time varying, or to have a time delay. Designing a fuzzy controller requires describing the operator's control knowledge/experience linguistically; process operators and control room operators played a major role in development of the control strategy. The controller captures these traits in the form of fuzzy sets, fuzzy logic operations, and fuzzy rules. Thus, Fuzzy logic control can be used to emulate human expert knowledge and experience illustrated Arsene **Error! Reference source not found.**.The fuzzy sets and fuzzy rules can be formulated in terms of linguistic variables, which help the operator to understand the functioning of the controller.

5.2.1 Fuzzification of inputs

The power and flexibility of fuzzy logic rests on its subjectivity, in that control statements are written in terms of imprecise ideas of what constitutes states of the variable. The values of a fuzzified input execute all the rules in the knowledge repository that as part of their premise have the fuzzified input as proven by Arsene **Error! Reference source not found.**.The process inputs to the fuzzy controller will be the mA from the 4-20mA control signal which will have been converted and conditioned from mV temperature values of the K-Type thermocouples by the 2-wire transmitter. The transmitter is used because millivolts are lost with distance as voltage drops therefore the mA are more accurate to use so as to avoid compensation irregularities. The crisp values from the sensors will be fuzzified accordingly so as to achieve the desired output. Load cell values from weigh-feeders and damper positions from control valves are all the crisp input values which will be fuzzified.

5.2.2 Membership function

Membership Function is a formula used to determine the fuzzy set to which a value belongs and the degree of membership in that set. The uncertainties associated with the membership functions are encapsulated by the footprint of uncertainty (FOU) and it is totally characterized by the upper membership function (UMF) and lower membership function (LMF). To enable designed membership functions (MFs) reflect the data, the researcher analyzed one type of FOU design strategy according to the dispersion of the data. The design comprise of Gaussian MFs with uncertain standard deviations.

5.2.3 Knowledge Base

Knowledge Base consists of a database and a rule base as illustrated on Figure 4. The greater simplicity of implementing a control system with fuzzy logic can reduce design complexity to a point where previously insoluble problems can now be solved. Fuzzy systems typically result in a 10:1 rule reduction, requiring less software to implement the same decision-making capability.

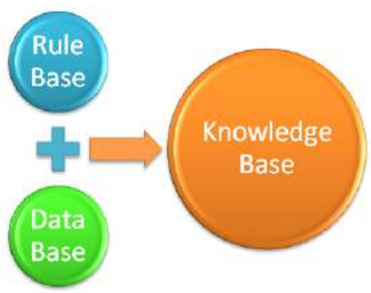

Figure 4: The knowledge base system

i. Data base

The basic function of a database is to provide necessary information for the proper functioning of the Fuzzy Membership (FM), the rule base and the defuzzification module. The basic information includes:

a) Fuzzy sets (membership functions) representing the meaning of the linguistic values of the process and the control output variable.

b) Physical domains and their normalised counter parts together with their normalisation and denormalisation (scaling) factors. For example the K-type thermocouples (temperature sensors) used for the process zone ranges between 0 to 1200 i.e. [0 1200] to be converted to [0 1] will use a scale factor of 0,0008

ii. Rule Base

The basic function of the rule base is to represent in a structured way the control policy of an experienced process operator and/or control engineer in the form of a set of production rules therefore it makes use of antecedent and the consequent.

IF <process state> THEN <Control Output>

E.g. IF <*The Temp is low*> THEN <*The accretion build up is High*>

The rule base is an important component of a fuzzy controller that captures the operator knowledge about the system in the form of fuzzy rules. Developing a rule base is one of the most time consuming part of designing a fuzzy logic controller. Usually it is very difficult to transform human knowledge and experience into a rule base of fuzzy logic controller. Moreover there is a need for developing efficient methods to tune membership functions i.e., to obtain optimal shapes, range and number of member functions.

A fuzzy control rule is a fuzzy conditional statement in which the antecedent is a condition in its application domain and the consequent is a control action for the system under control. The rule provides a convenient way for expressing control policy and domain knowledge.

The source and derivation of fuzzy control rules are:

- Expert experience and control engineering knowledge, achieved by means of heuristic approaches
- Control operator's control actions, as he employs consciously or subconsciously a set of rules to control the process.
- Fuzzy model of a process, used to generate fuzzy control rules.
- Based on learning, refers to self organizing controller (SOC) in which the FLC has the ability to create fuzzy control rules and to modify them based on experience.

Rules for regulating the accretion build up / ring formation:

```
IF (Temp is "zero") THEN (accretion is "average")
IF (Tempis "positive") THEN (accretion is "high")
IF (Pressureis "negative") THEN (accretion is "high")
IF (Pressureis "zero") THEN (accretion is "average")
IF (Pressure is "positive") THEN (accretion is "average")
IF (Temp is "negative") AND (Pressure is "negative" THEN (accretion is "high")
IF (Tempis "zero") AND (Pressure is "zero" THEN (accretion is "average")
IF (Temp is "positive") AND (Pressure is "positive" THEN (accretion is "high")
```

```
IF (Tempis "negative") AND (Pressure is "zero" THEN (accretion
is "high")

IF (Temp "negative") AND (Pressure_change is "positive" THEN
(accretion is "high")

IF (Tempis "zero") AND (Pressure is "negative" THEN (accretion
is "average")
```

Figure 5 shows the rule viewer for the rules developed in Matlab. The developed fuzzy rules were largely based on the Operator's discretion however a few rules were also added after investigation and research on recommended practices. The whole set of rules is imprecise hence partial, however the system will be expected to perform well and produce the desired product output.

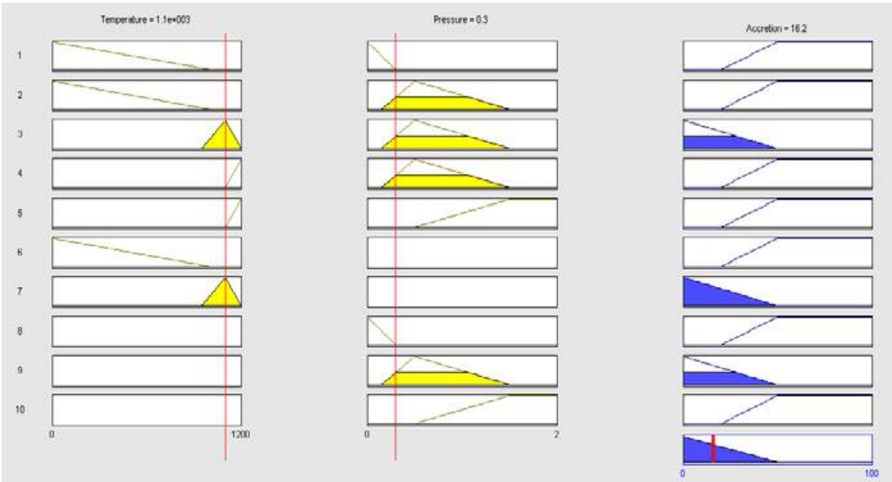

Figure 5: The Rule Viewer

6 MODEL RESULTS ANALYSIS

Accretion build up is an avoidable "evil" hence one cannot achieve total elimination but the rate of buildup can be regulated according to the process design parameters. The research revealed that the best possible rate of ring formation can only be 16.2% using the desired process parameters at the reduction zone of temperature 1100^0C and kiln outlet pressure of 0.3 Bars. Any value less than 16.2% would be achieved during *thermal shock* procedure which is the corrective measure and not a preventative measure hence it is beyond the scope of this research. From the surface view in Figure 6 we can deduce that as the temperatures increase from preheating values to the reduction values of 1100^0C the ring formation gradually decrease to a minimum value of 16.2%

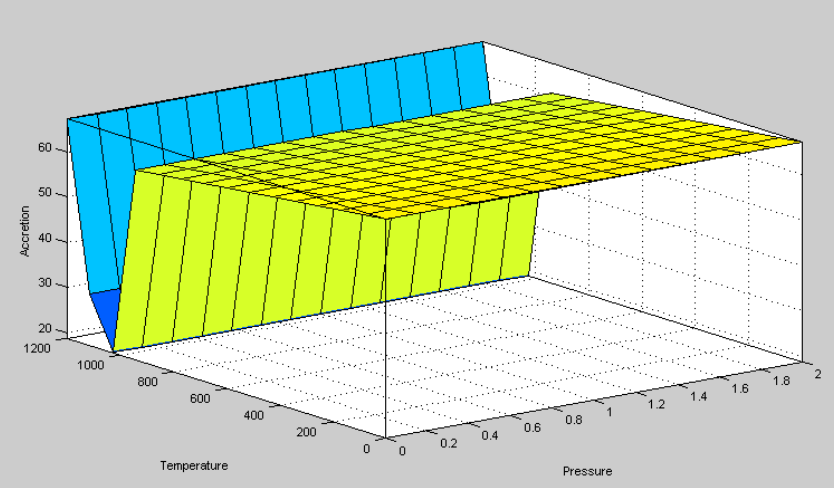

Figure 6: The Surface Model of the Reduction Zone

The results revealed that the most desired temperature of 1100^{0}C at the T7 thermocouple position or the reduction zone can result in high pressure build up. Therefore there is also ring formation, however the use of Induced Draft fan and the Stack Cap Opening and Closing system can be used to regulate the pressure build ups.

6.1 Process parameters

The proposed system was able to maintain the desired process parameters of T=1100 ^{0}C and P =0.3 Bars with a rate of 16.2% on ring formation as shown on Figure 7. Further decrease of the either temperatures or pressure set point was also performed.

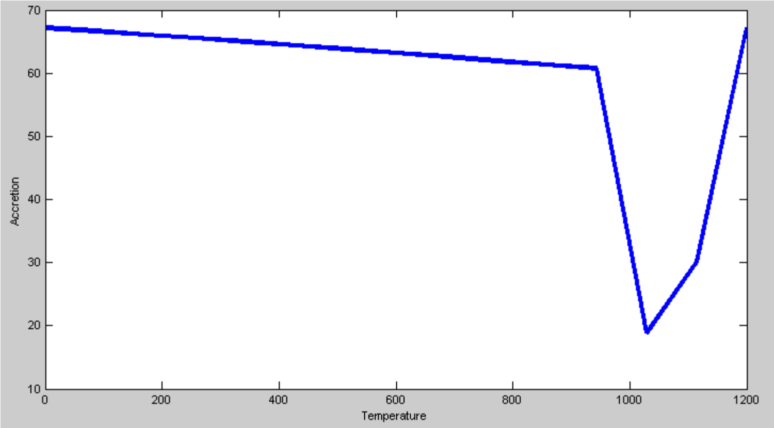

Figure 7 Effect of temperature on ring formation

6.2 The effect of temperature on ring formations

The research has revealed that the gradual change of temperatures from the preheating values to the reduction temperature values will certainly cause ring formation at an average of 63%, therefore there is need to facilitate rate of heat gain from the two zones so as to avoid ring formation. Also increase in temperatures above 1100 ^{0}C will result in sudden increase in accretion build up as sponge iron become steel and the coal fines and other minerals will be melt.

6.3 The effect of pressure on ring formations

The recommended pressure range was 0.3-0.5 mBars, while pressures above 1.5 mBars caused sudden increase in accretion build up as shown in Figure 8. Therefore there is need to have an efficient pressure regulating system such as automated stack cap movement and also variable speed induced draft fan. The central burning fans and the kiln shell air fans are also used to regulate the amount of pressure in the kiln.

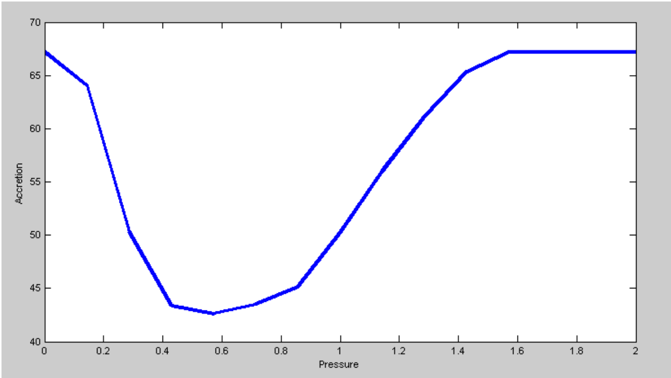

Figure 8:The relationship between pressure build up and accretion formation.

7 CONCLUSION

The fuzzy logic model for accretion build up was designed; however there is need to develop a cascade system of the predictive model and the regulating system. The research revealed that accretion build up was mainly due to pressure and temperature variations within the kiln. Although other factors such as raw material quality, kiln rotational speed and tilt angle had a contribution, it was of less significant. The proposed system managed to maintain the desired process parameters of T=1100 ^{0}C and P =0.3 Bars with a rate of 16.2% on ring formation with a recommended pressure range was 0.3-0.5 mBars. The current plant design consists of a lot of open loop control system with room for human intervention. The temperatures from the kiln zones are simply displayed and the control room operator will determine the best control action, however with the implemented fuzzy logic design, human intervention is minimized and complete automatic control is established.

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MODEL REFERENCE ADAPTIVE CONTROL SYSTEM FOR MOISTURE REGULATION IN COTTON GINNING

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ABSTRACT

Moisture content (mc) within the cotton fibre is an important aspect for all stages of the ginning process. However due to the process dynamics, mc is currently being controlled by regulating the water and air temperatures from the Humidifiers. Human intervention and lack of consistence on set-points determination has resulted in inconsistent mc during humidification. This procedure requires a control system which will be able to adjust the process set-points automatically by eliminating the need for human intervention. In this paper a robust Model Reference Adaptive Control (MRAC) system for a Samuel Jackson Humidifier is presented. This system improves upon the existing system by creating a closed loop controller with parameters that can be updated to change the response from reference model. The control parameters are then updated based on this error thus the parameters converge to ideal values that cause the plant response to match the response of the reference model.

Keywords: Model Reference Adaptive Control (MRAC), Moisture Content (mc)

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1. INTRODUCTION

The need to control dynamic processes and make informed decisions using imprecise and partial data has resulted in the emerging of intelligent systems. Hence there is need to design an on-line parameter estimator so as to minimize human intervention during the process operation. Over the years, control of processes and systems in the industry was customarily done by experts through the conventional Proportional, Integral and Derivative (PID) control techniques. Recently the logic controllers such as the Programmable Automation Controller (PAC) and the Programmable Logic Controllers (PLC) have managed to replace most process operations handling large quantities of inputs and outputs. This is as a result of their simplicity, low cost design and robust performance in a wide range of operating condition [1]. According to Khan [2] although the PID controllers have gained widespread usage across technological industries, it must also be pointed out that the unnecessary mathematical rigorosity, preciseness and accuracy involved with the design and tuning of these controllers have been a major drawback. This has made it difficult if not impossible for designers, engineers and technology experts to design intelligent complex systems, nonlinear systems, higher order and time-delayed linear systems that can satisfactorily behave as expected while operating in the human-machine interface [3].

The research is a case study based research on moisture control techniques and the challenges which the organization is currently facing on quality control of the lint product during gentle ginning. Due to the process dynamics it is very difficult to directly measure the moisture content within the lint during the ginning process, however it is possible to predict the moisture content using the water temperature, moist air temperature, fuel control valve and water control valve positions.

International Cotton Advisory Committee [4] stated that a ginner have two objectives: (1) to produce lint of satisfactory quality for the grower's classing and market system, and (2) to gin the cotton with minimum reduction in fiber spinning quality so that the cotton will meet the demands of its ultimate users, the spinner and the consumer. However the quality properties (staple length, moisture content and fibre colour) of the lint and the rate of production in ginning highly depends on the moisture content hence failure to regulate moisture content will also result in the creation of fires due to static charges.

According to Koo [5] and Shyu et al [6] apart from the MIT rule there are some other design techniques in Model reference Adaptive Control System, such as Lyapunov theory and the theory of augmented error, in this paper the emphasis is given to MIT rule only for developing the MRAC scheme. Simulation is done in MATLAB and results are shown for the first order system.

The estimation of process parameters by process operators during humidification has resulted in poor fibre quality and inconsistent moisture content. Thus intelligent systems simulate human thinking and behaviour. There is however not yet an Artificial Intelligence (AI) system that can truly replace human thinking, reasoning and creativity although each AI system mimics some specific aspect of human thinking.

The general idea behind Model Reference Adaptive Control (MRAC) is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model. The control parameters are updated based on this error. The goal is for the parameters to converge to ideal values that cause the plant response to match the response of the reference model.

In this paper, an improved MRAC system for moisture generation is presented. The rest of the paper is organized as follows; Section 2 introduces the problem domain of the moisture control system and the benefits for proper moisture regulation in gentle ginning system. Section 3 presents an overview of the MRAC system development procedure using the MIT-Rule, the review of already existing MRAC system and how the available system can easily be integrated with the designed MRAC. In section 4, the results of the developed system are described along with the explanation of its outstanding features and robustness relative to existing PID systems, followed by some concluding remarks in section 5.

2. MOISTURE CONTROL IN GINNING

The moisture content of seed cotton is critical for efficient gin operation and so as to preserve intrinsic fibre quality. The ideal moisture range for cotton ginning is 6.5-8% for upland cotton and 5-6% for Egyptian/Pima cotton. According to Gerald [7] when gin machinery is used in the recommended sequence, 75-85% of the foreign matter is usually removed from cotton. Cleaning is more efficient in dry cotton, but drying fiber lower than 4% moisture can cause increased static electricity problems and fiber breakage because fiber strength is inversely related to moisture content. On the other hand, cotton that is too moist doesn't separate into locks but remain in wads, which can choke the ginning machinery. A mathematical model that predict seed-cotton moisture content using the air (moist and hot)temperature, fuel valve , water pump speed to account for heat transfer from the conveying air, heat added to the room and the seed-cotton, and the heat added to the water in the seed cotton is presented in this paper. Byler [8] advocates that fibre quality is improved when lint moisture content at the gin stand is in the range of 6% to 7% wet basis compared to the lower levels. However the moisture content is variable to such an extent that the moisture at the lower levels such as the mixing floor and the distributor (screw) or overflow bins is even far much less than what Byler [8] has stated since the experiments done for the mixing floor and the distributor have revealed mc as low as 4%. Therefore moisture levels are greatly affected by outside gin temperatures thus the ginning period has a great impact on moisture levels. The overall quality of fibre produced by gins would be improved if the moisture control system will be able to add moisture to the lint as well as subtract it when necessary. The optimum moisture for fibre seed separation is 6.5% to 8% wet basis Griffith [9] or even higher ,Moore[10]; however due to the reduced cleaning efficiency the optimum moisture for ginning is considered to be in the range from 6-7 % wet basis . Moisture can be stored safely at a moisture levels below 8% [11].

The upper limit for safe storage of seed cotton is 12% moisture content [12]. If moisture is greater than 12% it should be ginned immediately to avoid fibre quality degradation. Lint represent about 35% of the seed cotton mass and cottonseed represents about 58% with the remainder being trash. Thus 635.03 Kg of seed cotton is required to produce a 217.72 Kg bale lint and about 371.95 Kg of cottonseed. Therefore at the maximum safe storage level of 12% seed cotton moisture, the lint is about 9% moisture and cotton seed about 13% moisture [11]. Cotton is dried at gins in order to increase cleaning efficiency of the machines and to improve the appearance of the cotton fibre. The Cotton Ginner's Handbook [13] recommends maximum fibre moisture at ginning of 7%. Thus an analysis of the ginning process will mean that there is need for moisture restoration at the lint slide, since they will be a loss of moisture during bale pressing. Ginners often add moisture at the lint slide so as to reduce bale-pressing packaging forces and to recover some of the weight lost during ginning at the gin stands. Experiments and process observations done have revealed that most humidifiers as shown in Figure 1 add approximately 2Kg-6Kg of water per bale if properly regulated.

Hot Air Humidification or Hot Air Moisture restoration in a cotton gin can have a huge impact on profitability. Some of the salient features are given below:

i. Instant humidification by easing out wax surface of the fibre and recuperation after humidification by cooling effect for retained moisture.
ii. Preserves fiber length, improves strength and uniformity and reduces short fiber content.
iii. Eliminates moisture condensation which is a general problem with all other moisturisation techniques.
iv. It increases the lint slide capacity and allows more cotton to enter the press box at each stroke of the tramper and hence higher density bale is obtained.
v. Improves the capacity of the bale press whereas dry cotton requires higher compression forces and more time to charge and compact it into the press box.
vi. Achieves better sliding of lint in the lint slide.

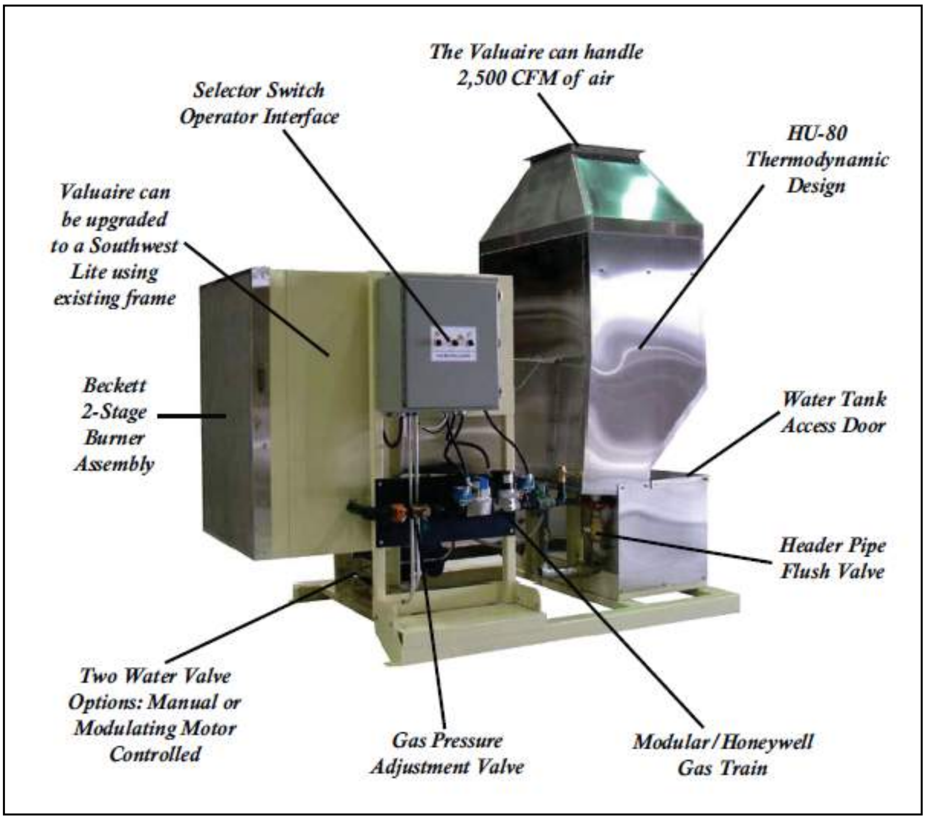

Figure 1: The Humidifier Unit © Samuel Jackson Humidair Units

Hot humid air is inducted in the lint on a lint slide with a set of louvers at temperature around 45 to 50^{0}C Degree Celsius. The hot air eases out the surface tension of the fibre and humidity is transferred to inner stem while air passes out.

The cooling down recuperates the fibre surface and maximum moisture contents are retained by fibre for a longer period.

3. THE MRAC SYSTEM DEVELOPMENT

According to Orkin *et al* [14] the computer revolution has also been a primary force in the expansion of quality activity into service businesses and functions. Adaptive control involves modifying the control law used by the controller to cope with the fact that the parameters of the system being controlled change drastically due to change in environmental conditions or change in system itself [15]. This technique is based on the fundamental characteristic of adaptation of living organism. In other terms the adaptive control process is one that continuously and automatically measures the dynamic behavior of plant process, compares it with the desired output and uses the difference to vary adjustable system parameters or to generate an actuating signal in such a way so that optimal performance can be maintained regardless of system changes.

Wong [16] defined adaptive control as the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. When applied to moisture restoration a control law is needed that adapts itself to such changing conditions such as temperature, flow rate and pressures. It does not need *a priori* information about the bounds on these uncertain or time-varying parameters, adaptive control is concerned with control law changes as the parameters changes. Hence the adaptive control is the attempt to “redesign” the controller while online, by looking at its performance and changing its dynamic in an automatic way. Adaptive control is that feedback law that looks at the process and the performance of the controller and reshapes the controller closed loop behaviour autonomously.

The foundation of adaptive control is *parameter estimation*. Common methods of estimation include recursive least squares and gradient descent. Both of these methods provide update laws which are used to modify estimates in real time (i.e., as the system operates). *Lyapunov stability* is used to derive these update laws and show convergence criterion (typically persistent excitation). Projection mathematics and normalization are commonly used to improve the robustness of estimation algorithms [17].

Usually these *recursive least squares* and *gradient descent* methods adapt the controllers to both the process statics and dynamics. In special cases the adaptation can be limited to the static behaviour alone, leading to adaptive control based on characteristic curves for the steady-states or to extreme value control, optimizing the steady state. Hence, there are several ways to apply adaptive control algorithms. Adaptive Control is made by combining online parameter estimator based on current measurements and control actions and control law that recalculates the controller based on those parameters. There are two main modalities of adaptive control; direct and indirect cases.

Indirect adaptive control, which is one of two distinct approaches for the control of dynamical plants with unknown parameters, as it is commonly used, consists of two stages. In the first stage, the parameters of the plant are estimated dynamically on-line using input-output information Kreisselmeier [18] and Middleton [19]. At every instant of time, assuming that the estimates represent the true values of the plant parameters, the control parameters are computed to achieve desired overall system characteristic. In contrast with this, in direct adaptive control the control parameters are adjusted continuously based on the error between the output of the plant and the output of the reference model. The latter results in the overall system being described by a set of non-linear differential equations, this in turn makes the formulation of the stability problems of such systems relatively straightforward. Duarte [20] concluded that while the two methods have continued to flourish for over two decades, very little is known about the precise relation between them.

The general idea behind Model Reference Adaptive Control (MRAC) is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system y_{plant} is compared to a desired response from a reference model y_{model}. The control parameters are updated based on this error. The goal is for the parameters to converge to ideal values that cause the plant response to match the response of the reference model. The design seeks among other things to control the position of modulating fuel valve and the water regulating valve as the temperature and changes. The research seeks to make quick motions with little or no vibration for the precise positions proportional to the error changes (error = y_{plant} - y_{model}). Using MRAC one can choose a reference model that respond quickly to a step input with a short settling time, and then build such a desired controller as shown in Figure 2.

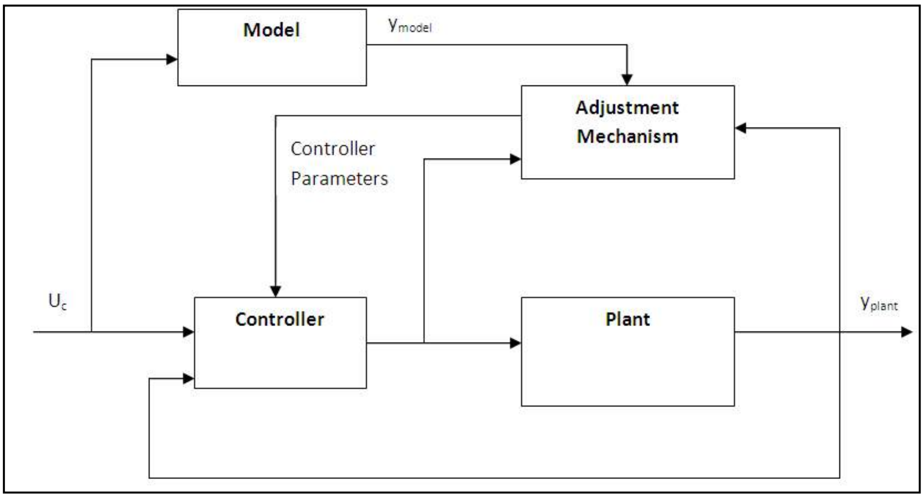

Figure 2: Model Reference Adaptive Control Schematic

Nowadays the adaptive control schemes are making their place where the conventional control system is not able to cope-up with the situation such as [15]:

- Loads, inertias and other forces acting on system change drastically.
- Possibility of unpredictable and sudden faults.
- Possibility of frequent or unanticipated disturbances.

4. DEVELOPING THE MODEL REFERENCE ADAPTIVE CONTROL (MRAC) -SYSTEM BASED ON THE MIT RULE

Moisture regulation is achieved by automatically regulating the position of valves .The moisture generation unit consists of a Honeywell Modulating hot-air valve with a 4-20mA signal card. The main purpose of this *hot-air flap valve* is to increase the temperature of the humid air so as to minimize condensation of the humid air before it reaches its intended destination. The flapping valve will be receiving an analog control signal (4-20mA) from the controller then continuously position the valve with reference to angle θ as shown in Figure 3.

The main function of the fuel valve is to regulate the fuel intake so as to increase or decrease the water temperature that will in turn increase or decrease the moisture content. The motorized valve rotates in the clockwise direction as shown in Figure 4 ; as the angle of rotation increase the flapping valve will change its position from 0^0 (fully closed) through 45^0 (half) to 90^0 (fully open).

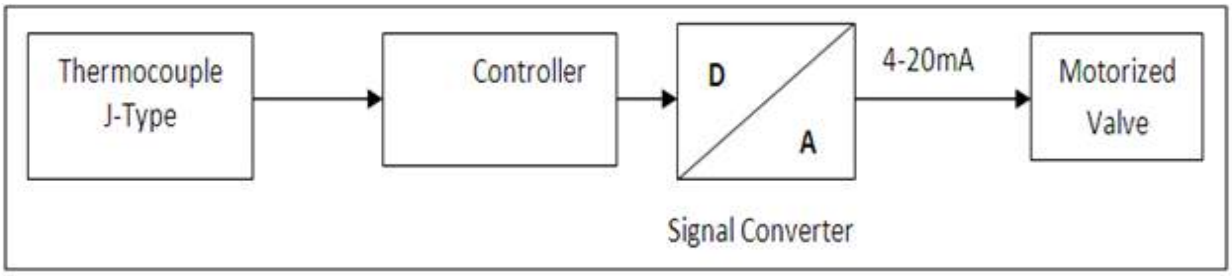

Figure 3: Signal flow for the control valve

The control signal depends on the temperature variations for the moist air temperature values and the hot air temperature. The valve position as shown on Figure 4 below is not monitored by means of any sensor; however the closed loop control system is accomplished by means of temperature sensors. Hence the valve has an embedded transmitter card for signal conditioning and conversion. There was need to create the initial linguistic rules for the control of the modulating valve, and the following rules were developed;

- If the moisture level is too high and the humid air temperature is low the valve opening angle will increase.
- If the moisture level is too high and the humid air temperature is high the valve opening angle will decrease.
- If the moisture level is moderate and air temperature is moderate the valve maintains its position
- If the moisture level is low and the air temperature is low then the valve opening will be increased.
- If the water valve opening is increase the hot-air valve will be increased.

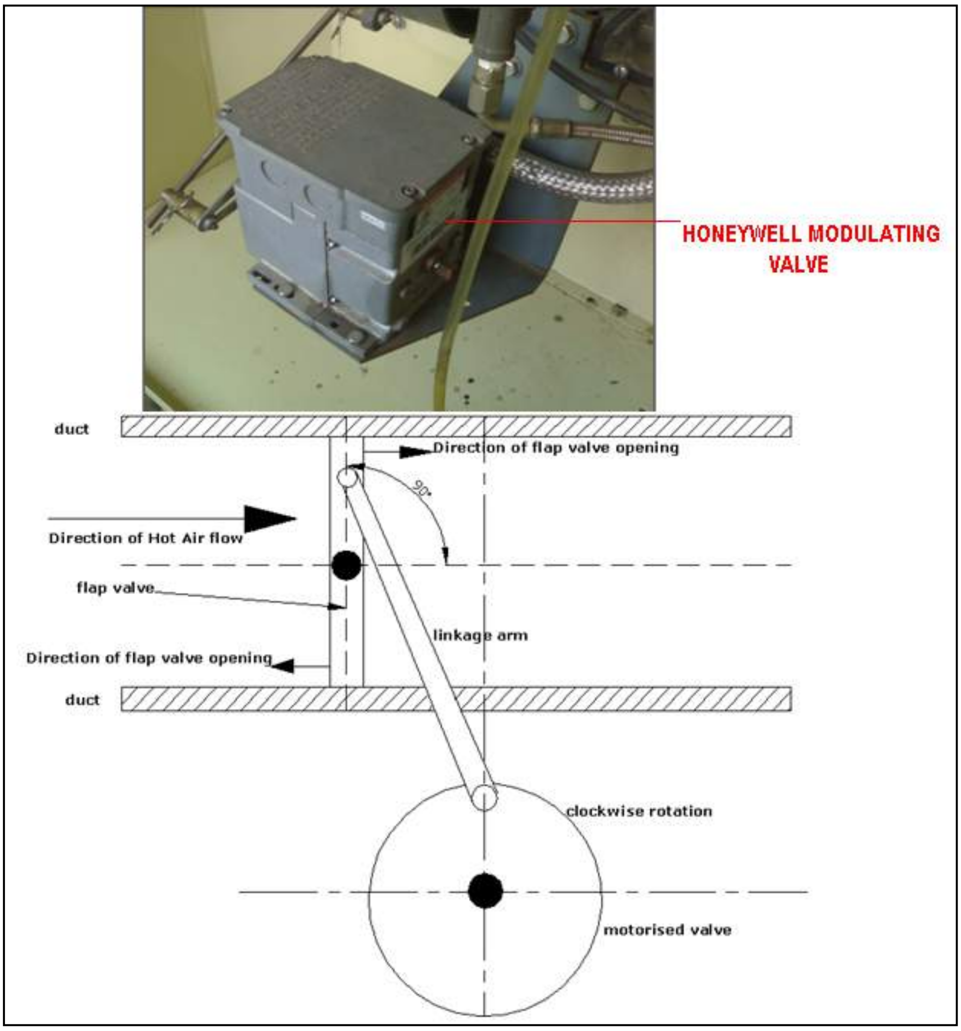

Figure 4: Schematic representation of the control valve

Model Reference Adaptive Control Modeling is a method of designing a closed loop controller with parameters that can be updated to change the response of the system to match a desired model. There were many different methods for designing such a controller; however we chose to use the MIT rule in continuous time. In the design of a MRAC using the MIT rule, the designers selected:

- The reference model,
- The controller structure
- And the tuning gains for the adjustment mechanism.

The first step to design MRAC is to define the tracking error, *e*. This is simply the difference between the plant output and the reference model output:

$$e = y_{plant} - y_{model} \tag{1}$$

From this error a cost function of *theta J (θ)* can be formed. *J* is given as a function of theta, with theta being the parameter that will be adapted inside the controller. The choice of this cost function will later determine how the parameters are updated. Below is the cost function displayed:

$$J(\theta) = \frac{1}{2}e^2(\theta) \tag{2}$$

To find out how to update the parameter *theta*, an equation for the change in *theta* was formed such that if the goal was to minimize this cost related to the error, it was sensible to move in the direction of the negative gradient of *J*. This change in *J* is assumed to be proportional to the change in *theta*. Thus, the derivative of *theta* is equal to the negative change in *J*. The result for the cost function chosen previously above is:

$$\frac{d\theta}{dt} = -\gamma \frac{\delta J}{\delta \theta} \tag{3}$$

Thus

$$-\gamma \frac{\delta J}{\delta \theta} = -\gamma e \frac{\delta e}{\delta \theta} \tag{4}$$

Where $-\gamma e \frac{\delta e}{\delta \theta}$is the sensitivity derivative of the system

This relationship between the change in theta and the cost function is known as the MIT rule. The MIT rule is central to adaptive nature of the controller. The sensitivity derivative is the partial derivative of the error with respect to *theta*. This determines how the parameter *theta* will be updated. A controller may contain several different parameters that require updating. Some may be acting on the input(s). Others may be acting on the output (s). The sensitivity derivative would need to be calculated for each of these parameters. The choice was made on the cost function above results in all of the sensitivity derivatives being multiplied by the error. The MRAC system can easily illustrated by the integration of the Reference Model, Adjustment Mechanism and the Plant Mechanism as shown in Figure5 below.

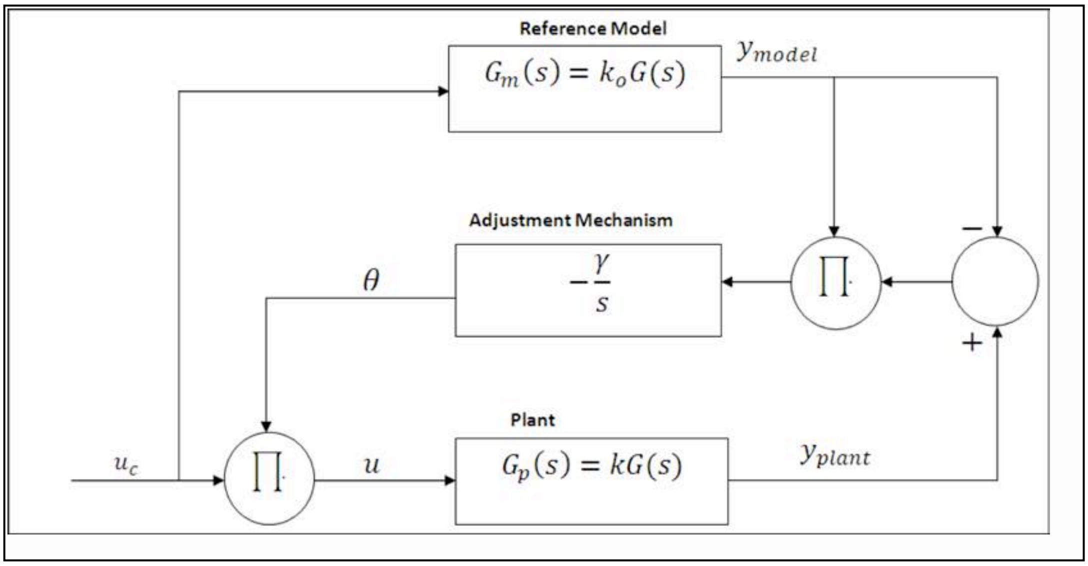

Figure 5: The developed MRAC system

G_m and G_p were implimented as the model and plant transfer functions hence k_o and k_p as the model and plant constants respectively. Determining the input to output relationship basing on the transfer functions within the feed-forward adaptive control strategy. The constant *k* for this plant was unknown. However, a reference model was formed with a desired value of *k*, and through adaptation of a feed-forward gain, the response of the plant can be made to match this model. The reference model was therefore chosen as the plant multiplied by a desired constant k_o:

$$\frac{Y(s)}{U(s)} = kG(s) \quad (5)$$

However using the same cost function in equation (2)

We have

$$\frac{d\theta}{dt} = -\gamma e \frac{\delta e}{\delta \theta} \quad (6)$$

The error in equation (1) is then restated in terms of the transfer functions multiplied by their inputs.

$$e = y - y_m \quad (7)$$

$$e = kGU - G_m U_c \quad (8)$$

$$e = kG\theta U_c - k_o G U_c \quad (9)$$

As can be seen, this expression for the error contains the parameter *theta* (Θ) which is to be updated. To determine the update rule, the sensitivity derivative was calculated and restated in terms of the model output:

$$\frac{\delta e}{\delta \theta} = kGU_c \quad (10)$$

But

$$kGU_c = \frac{k}{k_o} y_m \quad (11)$$

Therefore

$$\frac{\delta e}{\delta \theta} = \frac{k}{k_o} y_m \quad (12)$$

Finally, the MIT rule was applied to give an expression for updating *theta*. The constants k and k_o were combined into *gamma*.

$$\frac{d\theta}{dt} = -\gamma' \frac{k}{k_o} y_m e = -\gamma y_m e \quad (13)$$

To tune this system, the values of k_o and *gamma* were varied. The MIT rule by itself does not guarantee convergence or stability. An MRAC designed using the MIT rule was very sensitive to the amplitudes of the signals. As a general rule, the value of *gamma* was kept small. Tuning of *gamma* was crucial to the adaptation rate and stability of the controller. It was then assumed that the controller has both an adaptive feedforward Θ_1 and an adaptive feedback Θ_2 gain as illustrated in Figure 7. To derive expressions for the sensitivity derivatives associated with these parameters, the error function was restated to include Θ_1 and Θ_2. The equation for the error was first rewritten as the transfer function of the plant and model multiplied by their respective inputs. The input U_c is not a function of either of the adaptive parameters, and therefore can be ignored for now. However, the input U was rewritten using the feedforward and feedback gains. This was used to derive an equation for Y_{plant}.

The control valve will receive an analogue signal between 4-20mA from the main Omron PLC controller. The control valve is such that it will open from $\Delta\theta^0$ for temperature increase ΔT for time Δt seconds so as to achieve the control objective as shown on Figure 8. The valve will open up to 90^0 maximum, it is however not advisable to operate the system towards large values of θ^0. As $\Delta\theta^0$ increases with respect to the fuel intake the fuel consumption will also increase hence the cost of production will also increase such a system is not desirable. The design seeks to produce optimum moisture levels with minimum fuel consumption. The water pressure depends on the modulating valve opening within the water system as the pump will be rotating at a constant speed. As the valve opens from 0^0 (fully closed) to 90^0 (fully open) the water pressure at the nozzles will be increasing gradually. The increase in water pressure at the nozzles will cause build up of fog above the heating plate hence less water will be reaching the plate at a given time, also this will inhibit the creation of moisture within the Humidifier.

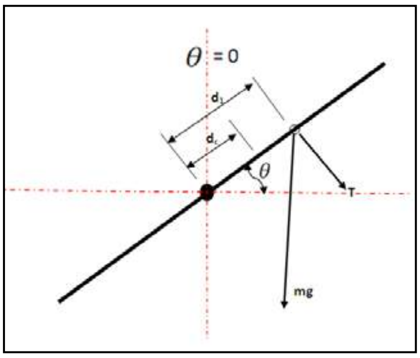

Figure 6: Valve Free Body Diagram

Newton's laws and conservation of angular momentum were used to derive the equations of motion. The Free Body diagram (FBD) is shown on Figure 6 and the equations and resulting transfer function for the linearized system were given below:

$$J\ddot{\theta} + c\dot{\theta} + mgd_c sin\theta = Td_1 \quad (14)$$

$$\frac{\theta(s)}{T(s)} = \frac{d_1}{Js^2+cs+mgd_c} \quad (15)$$

$$\frac{\theta(s)}{T(s)} = \frac{1.89}{s^2+0.0389s+10.77} \quad (16)$$

The adaptive controller for this system will take the form:

$$u = \theta_1 u_c - \theta_2 y_{plant} \quad (17)$$

$$e = y_{plant} - y_{model} = G_p u - G_m u_c \quad (18)$$

$$y_{plant} = G_p u = \left(\frac{1.89}{s^2+0.0389s+10.77}\right)(\theta_1 u_c - \theta_2 y_{plant}) \quad (19)$$

$$y_{plant} = \left(\frac{1.89\theta_1}{s^2+0.0389s+10.77+1.89\theta_2}\right) u_c \quad (20)$$

The error was later written with the adaptive terms included. Considering the partial derivative of the error with respect to θ_1 and θ_2 gives the sensitivity derivatives, having in mind that U_c does not include either parameter, and therefore is inconsequential when evaluating the derivative.

$$e = \left(\frac{1.89\theta_1}{s^2+0.0389s+10.77+1.89\theta_2}\right) u_c - G_m u_c$$
(21)

$$\frac{\delta e}{\delta\theta_1} = \left(\frac{1.89}{s^2+0.0389s+10.77+1.89\theta_2}\right) u_c$$
(22)

$$\frac{\delta e}{\delta\theta_2} = -\frac{1.89^2\theta_1}{(s^2+0.389s+10.77+1.89\theta_2)^2} u_c \quad (23)$$

$$= -\frac{1.89\theta_1}{s^2+0.0389s+10.77+1.89\theta_2} y_{plant} \quad (24)$$

The sensitivity derivatives obtained contain the parameters from the plant. The premise of design with MRAC assumes that the plant characteristics were not absolutely known. This seemingly places the design process at a dead end. However, the goal was to make the plant approach the model. If the model is close to the actual plant, the model characteristics can be substituted for the plant characteristics, giving the following sensitivity derivatives:

Substituting

$$s^2 + 0.0389s + 10.77 + 1.89\theta_2 \text{ with } s^2 a_{1m} s + a_{0m}$$

With

$$s^2 a_{1m} s + a_{0m}$$

Taking the derivative of the feedforward loop of the MRAC we have;

$$\frac{\delta e}{\delta \theta_1} = \frac{a_{1m}s+a_{0m}}{s^2+a_{1m}s+a_{0m}} u_c \quad (25)$$

$$\frac{\delta e}{\delta \theta_2} = -\frac{a_{1m}s+a_{0m}}{s^2+a_{1m}s+a_{0m}} y_{plant} \quad (26)$$

Then, applying the MIT rule, the update rules for each Theta was written. The block diagram for the system with the derived controller is shown on Figure 7.

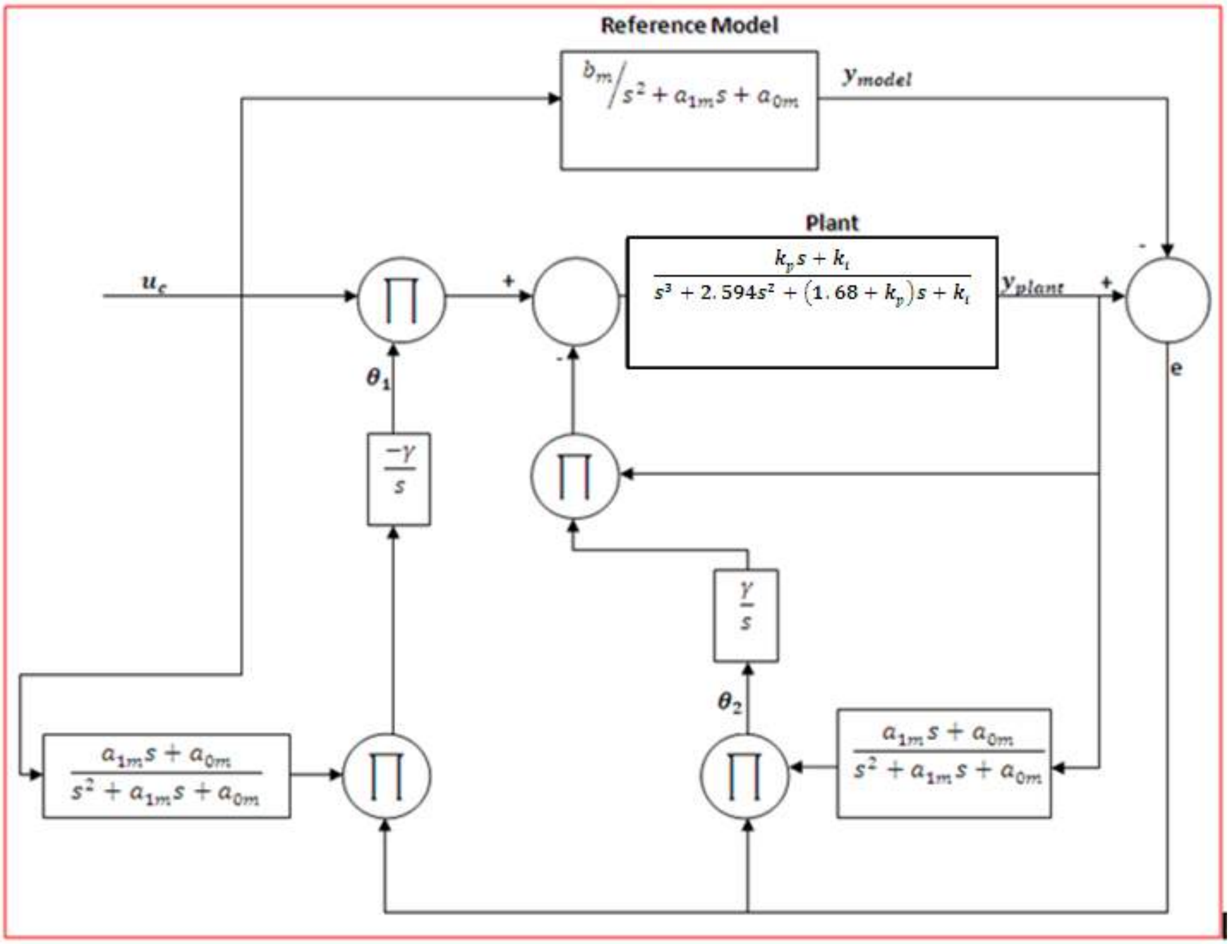

Figure 7: MRAC system with MIT-Rule

NB. The plant input and output measurements were filtered before being multiplied by the error and gamma.

$$\frac{d\theta_1}{dt} = -\gamma \frac{\delta e}{\delta \theta_1} e = -\gamma \left(\frac{a_{1m}s + a_{0m}}{s^2 + a_{1m}s + a_{0m}} u_c \right) e \quad (27)$$

$$\frac{d\theta_2}{dt} = -\gamma \frac{\delta e}{\delta \theta_2} e = \gamma \left(\frac{a_{1m}s + a_{0m}}{s^2 + a_{1m}s + a_{0m}} y_{plant} \right) e \quad (28)$$

The system was designed and tested for a constant 0f 49^{0}C since it is the desired air temperature for optimum moisture generation. However during the design stage the introduction of the PID algorithm was meant to reduce rise time, overshoots and transient response. The results were presented in the following section 5. The developed Simulink Model is shown in Figure 8.

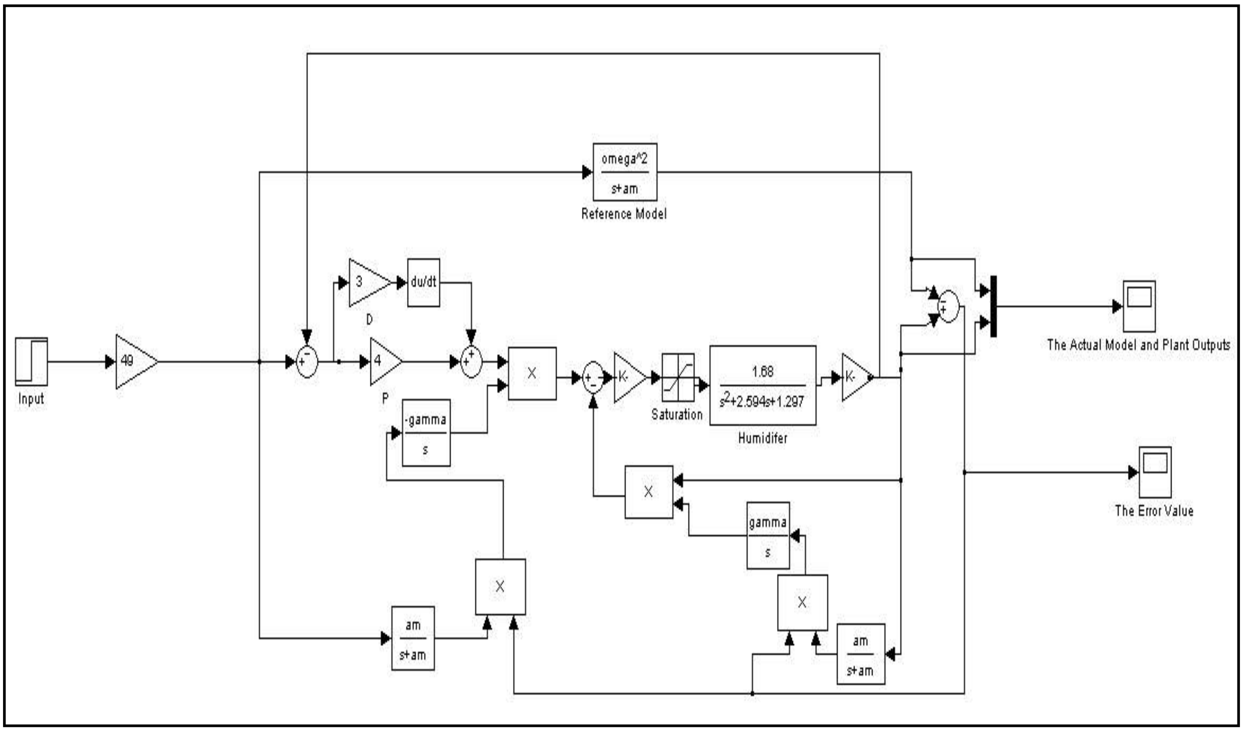

Figure 8: The Simulink Model of the MRAC

5. RESULTS

An optimal robust MRAC system with aid of PID algorithm technique was developed and integrated with existing moisture control system and other hardware components. It was also shown through simulation that the optimal MRAC is performing better than a conventional PID controller when both controllers are subjected to the same operating conditions. The performance metrics taken into consideration were the overshoot, rise time, settling time and steady state error. The PID system which gave the results shown on Figure 9 was embedded within the forward loop of the system as the main control algorithm; however the whole system highly depended on the performance of the adjustment mechanism.

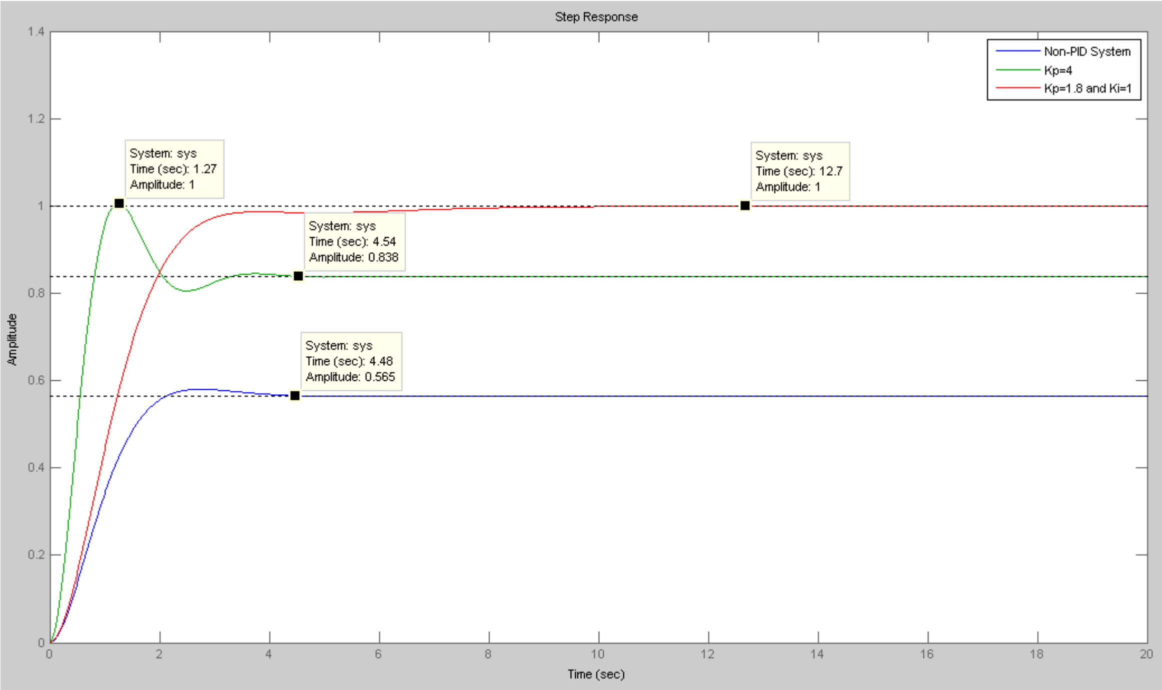

Figure 9: The Response of the system to unit step input

MATLAB/SIMULINK was used to simulate and fine-tune the controller models. The simulation results and the performance of the hardware implementation show that the optimal MRAC was functioning better than a conventional PID controller in terms of the rise and settling time. Although the main goal was to replace the existing PID system with MRAC system, the simulation results reviewed that an integration of the PID/MRAC systems will yield better plant performance.

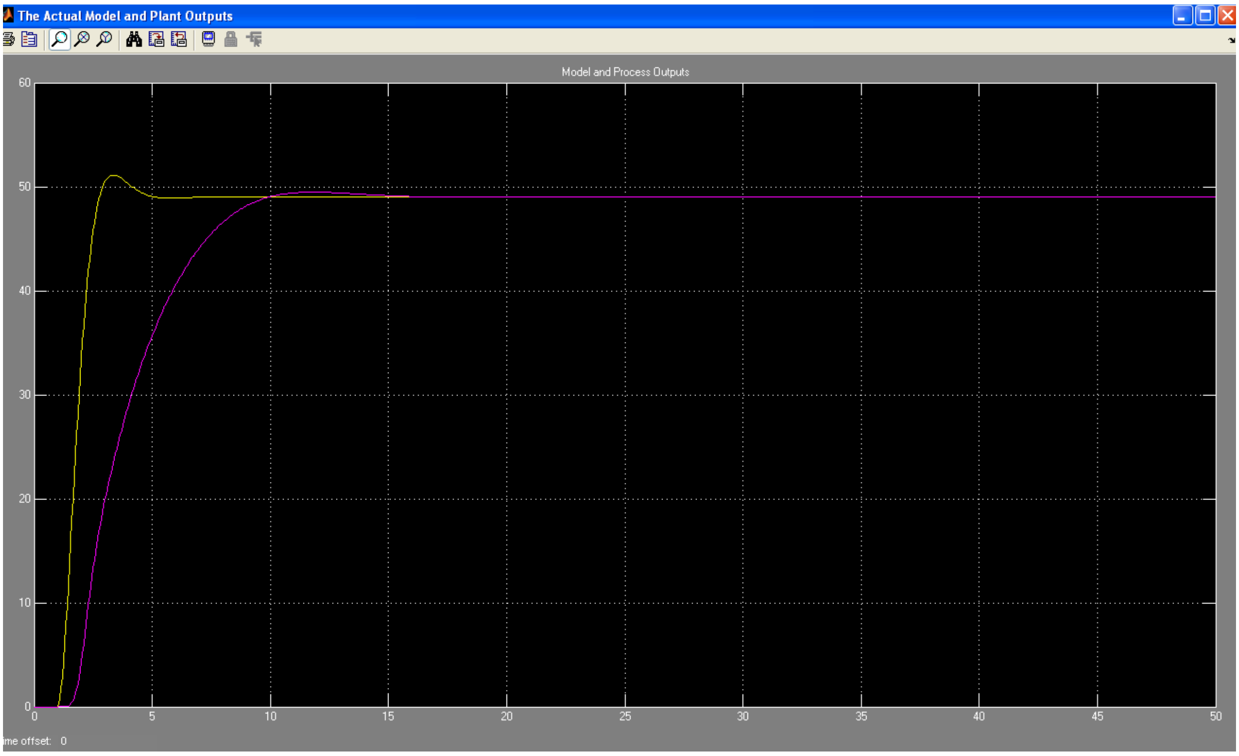

Figure 10: System output for the MRAC θ_r (purple) follows θ_d reference value (yellow)

The system showed a negative error difference as shown on Figure 10 which is mainly as result of the heating effect of the stainless steel flat plate heat exchanger. As the system temperature will be increasing the MRAC system will be comparing the Reference Model and the Actual plant output, therefore there is need to introduce a delay within the actual hardware components.

The system had a set-point of 49^0C hence the desired value was reached with an overshoot when using a PID system alone, however when integrated with a MRAC system the system achieved the desired set-point without any significant overshoots. However the settling time was 15 seconds as compared to the 5 seconds on the PID system. The deviation in settling time could not be further eliminated.

6. CONCLUSION

In this paper a MRAC system has been presented in this paper. The objective of achieving optimum moisture content within the lint and at the ginning point with minimum to no human intervention while updating system inputs on real time mode by direct comparison of the Reference Model output with the actual plant output was solved with aid of MRAC system in this paper. Furthermore, the MRAC approach improves many failures of the fixed-gains controller, such as: some large overshoots and undershoots lead to burnout of the devices at the transient, need to retune gains for different operation regions and pressed for robustness.

The experimental results have demonstrated that the proposed approach effectively eliminates the need for the process operators to measure the moisture after every five lint bales that is a sample after every twenty minutes which will in turn take between five to fifteen minutes (an average of to adjust the moisture value the implementation of the proposed design will mean that the system will be adjusted in real time with aid of moisture sensors at the gin stands and lint slide and the fuel and water modulating valves at the Humidifier Unit.

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THE APPLICATION OF THE PDSA CYCLE TO SOLVE PRODUCTION CHALLENGES AT THE ELECTRIC-ARC FURNACES

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ABSTRACT

The PDSA (Plan-Do-Study-Act) cycle was conducted at an Electric Steelmaking Plant (ESM) in an attempt to reduce production delays that are currently experienced at the electric-arc furnaces (EAFs). These delays have a negative financial impact on ESM. An analysis of the current furnace operations was done. It was established during the Plan stage, through Pareto analysis of EAF delays that the major contributor to downtime was when the furnace refractories are damaged which results in the the furnace being put offline for relining. Operators were requested to complete key performance indicator sheets (Do stage) and deviation reports to identify the root cause of the early failure of furnace refractories (be it temperature control or raw materials addition). The outcome of this investigation was a reduction in deviations while operating the furnaces by 84% (furnace three), a result of root cause analysis. In addition, an improvement in furnace refractory life of 78% resulted in improved furnace availability. This study resulted in the plant having a well-defined problem solving methodology for analysing and resolving any other challenges.

[*] This project was completed by the author in partial fulfilment of a Masters in Engineering degree at the University of the Witwatersrand.

1 INTRODUCTION

1.1 Background

Electrical steelmaking is a plant within ArcelorMittal that involves the recycling of steel scrap through an electric-arc furnace to produce desired flat steel products. This process also treats the sponge iron (also referred to as direct reduced iron, DRI) from the direct reduction plant, which is melted along with the scrap in the furnace. Electric Steel Making (ESM) consists of three major sections, namely, smelting in the Electric-Arc Furnaces, steel composition adjustment at Secondary Metallurgy and casting of the steel into required dimensions at the Continuous Caster. The process starts with loading of various types of scrap using two magnetized cranes where the scrap is attracted to the magnet and released into the scrap baskets. One basket is loaded per batch in each of the three furnaces.

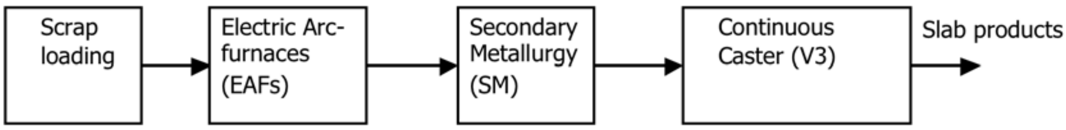


Figure 1: Overview of ESM

The EAFs is a batch process and each EAF has a capacity to produce 150 tonnes of steel into the ladle that is sent to SM and then to the Caster. The process essentially starts with melting at the EAFs and thus a delay at the EAFs has a negative impact on the entire ESM process. There are three Electric-arc Furnaces and each has a senior process controller (called the first smelter) and two assistant operators (second smelters) in a four shift operation indicating a manpower of 36 operators for the EAFs alone, not including the crane drivers who facilitate movement of ladles and scrap baskets at ESM.

1.2 Problem statement

ESM has not been producing the required amount of steel (failing to meet its production targets). The focus of this research is to address production challenges at the EAFs. It is thus necessary to investigate and apply a methodology that will enable the root cause of any production problems to be established, as this has a negative impact in the financial performance of the plant. The evaluations will yield recommendations that will improve the way furnaces are melted, thus improving production targets.

1.3 Objectives

The objective of this study is to apply the PDSA (Plan-Do-Study-Act) methodology to solve production delays at the EAFs in order to improve furnace uptime. After successful implementation, the PDSA cycle can thus be a problem solving methodology that will be rolled out to other sections of the ESM plant.

1.4 Current situation at ESM

Delays that occur at ESM are classified as production delays (delays due to process issues) and external delays (delays due to maintenance, upstream or downstream problems). The data presented below is for the period 20/02/2011 – 20/02/2012 and is extracted from the Management Information System (MIS), where all delays are entered into the system by the senior operator of each furnace for each of the four shifts and are verified by the production supervisor. Every delay or any kind of stoppage that requires the furnace or any other equipment to be stopped must be explained as all power-off data can be retrieved from the system hence the supervisor must ensure that all delays that occur during his shift are adequately accounted for on the MIS.

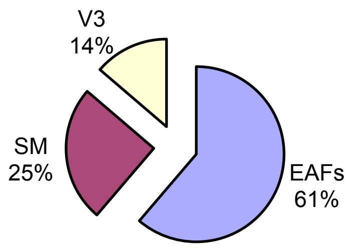


Figure 2: Breakdown of unplanned downtime at ESM

Figure 2 shows the total delays (downtime) that occurred at ESM over the 12 month period and the EAFs contributed 61% of the delays. SM production delays account for 25 % of the total ESM delays while V3 production delays account for 14 % of the total ESM delays. However, 61% of all ESM delays were due to production challenges at the EAFs.

2 LITERATURE REVIEW

The Plan-Do-Study-Act cycle was developed by Walter Shewart and is also known as the Deming wheel as it was W. Edwards Deming who promoted it very effectively from the 1950s [2].. The purpose of this cycle for Deming was to use the PDCA (Plan-Do-Check-Act) cycle in a continuous improvement process to help rebuild Japanese industries, so that they could compete in the world market in the future. The PDCA cycle is a dynamic model and assists in moving from 'problem-faced' to 'problem solved'. This cycle emphasizes and demonstrates that improvement programs must start with careful planning and result in effective action in a continuous cycle. The Act stage involves making changes a routine part of daily activities. The idea is to Act by involving other persons (other departments, suppliers or customers) affected by the changes and whose cooperation is needed to implement on a larger scale or those who may simply benefit from what you have learned [3]. The benefits of PDSA are to minimize the possibility of an 'error', ensure on-time corrective action, improve utilisation of time and improve productivity [4].

The PDSA cycle has been applied and proven successful in a vast number of industries. One instance where the PDSA cycle was applied was at a hospital to evaluate industrial engineering student's competency for process improvement [2]. In this study, the students started with quantitative data of how inefficient the processes at the hospitals were and the PDSA cycle was used to qualitatively analyse the system. The first stage required a plan to improve operations by identifying problems and formulating countermeasures. Stage two involved implementing the designed changes to solve the problems on a small scale and in stage three a study was done to analyse whether the changes were achieving the desired results. The fourth stage was to act by implementing the changes on a larger scale if found to be effective. Improvement was required in various areas in the hospital such as productivity, wasted time, number of errors, costs and patient care. The mapping to improve tool (M2I) was of particular interest as its application was used in this evaluation in the hospitals. The M2I tool has nine steps where the first seven steps are stage 1 of the PDSA cycle. These seven steps were applied as follows:

1. The problem area was identified
2. Describe the problem area
3. Draw a diagram or flowchart of the current state map where the problem exists
4. Describe why the current system is causing the problem
5. Describe what needs to be done to fix the problem
6. Describe when it needs to be done
7. Describe who is responsible.

Step three is comparable to the Do stage of the PDSA cycle which is to draw a diagram or flowchart of the future state map (targeted system) that will solve the problem and to describe the project success measurement plan. The Act stage involves creation of new organizational work routines when they are proved worthy. After this study was conducted, five evaluation questions were presented in the questionnaire in order to evaluate whether the M2I tool for process improvement was helpful to the students. The four questions are [2]:

- Was the problem clearly defined?
- Were the objectives met based on the identified major problem?
- Were the proposed improvement actions feasible?
- Were the implementation plans feasible?

The study showed that the PDSA Cycle (summarized in the M2I tool) was an effective qualitative tool for identifying root causes via linking the process flow with task characteristics and selecting improvement measures [2].

The PDSA cycle was also described as a tool leading to learning and improvement in any situation. This is because the Plan phase involves definition of the problem and a hypothesis about possible causes and solutions, basically, planning a change. The Do phase involves implementing the change through training and education. In the third stage, Study/Check, the results are evaluated establishing what have been the main learning outcomes. The final stage is the Act phase where either standardisation occurs if the results are satisfactory or it is back to Phase one until desired results are achieved which can then lead to standardisation [5].

The PDSA cycle also emphasizes the prevention of error recurrence by establishing standards and the on-going modification of those standards. Ishikawa stated 'If standards and regulations are not revised in six months, it is proof that no one is seriously using them'. It involves careful study before taking action. It is a model of improvement as it makes it necessary to answer the following three questions.

- What are we trying to accomplish?
- How will we know that a change is an improvement?
- What change can we make that will result in improvement? [3]

The PDCA cycle was also described as an important methodology to implement new ideas in a controlled way to make sure you get it right every time an improvement is proposed. It is therefore a scientific approach, where there is a process that needs to be followed when a change is made or when solving a problem. This process ensures that one plans, tests and incorporates feedback before committing to implementation [6].

The Act stage of the PDSA cycle is essentially about standardization of best practices if the outcome of the plan-do and study stages is positive. Standardisation has also been thoroughly discussed by Steven Spear, et. al. [5] that it is at the core of the Toyota process and results in creation of a community of scientists in that whenever Toyota defines a specification, it is establishing sets of hypotheses that can then be tested. When any change is made at Toyota, a detailed assessment of the current state of affairs is done and a plan of improvement (which is an experimental test of the proposed changes is documented). Thus, the rigid specification has been the very thing that makes flexibility and creativity possible at Toyota. This Toyota process is a cornerstone of the learning organization that Toyota is today. This will not create chaos at all as at Toyota it has been observed that though there are various improvements on a standard, the system remains stable at the same time [7].

Standardized work practices were also discussed by Hattingh T.S, et.al in that it results in reduced variability of the output and that it is the foundation that enables organizations to change and improve their processes. Eliminating the variation in the way operators do the same job will make it possible to identify root causes of problems. The PDCA (plan-do-check-act) Cycle was also commended in that it does not only result in less problems but the methodology is a platform for continuous improvement [8].

3 INVESTIGATIONAL PROCESS

The PDSA cycle will become a guideline to study any idea thoroughly before it is implemented to realise and measure the benefit of any improvement idea.

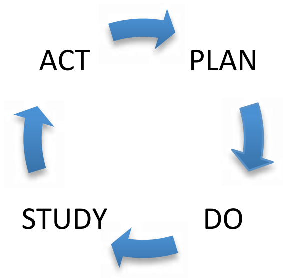


Figure 3: The PDSA cycle

The tools that will be used to identify the problems in the PLAN stage will be:

- Pareto analysis to identify the production delays which contribute eighty percent of EAFs production delays.
- A fishbone diagram will also be done to identify other production issues through ideas obtained from various stakeholders.
- The 5 whys analysis will be used in the Plan phase to determine the root causes of major production delays identified during the Pareto analysis with input from EAFs personnel as well.
- A cause-and effect diagram will also be constructed to compare ideas from the Fishbone diagram with the production delays with an aim of identifying the main causes to EAFs downtime.

In the DO stage a Key Performance Indicator (KPI) sheet will be given to all operators to complete during operating the furnaces to identify deviations and causes for the deviations. A deviation report sheet will also be handed out to the shift supervisor/foreman, which must be completed for every batch where a deviation occurred as a way to identify root causes and to avoid repeat cases.

Table 1: The KPI Sheet

Furnace KPI Sheet						
Date			Furnace		Heat	
Shift			First Melter		Cast	
Recipe			Ladle		Temp	
Fe Inputs			Other Consumptions			
Basket 1		Tons	Natural Gas		Nm3	
Basket 2		Tons	Oxygen		Nm3	
Basket 3		Tons	Foamy Carbon		Kg	
Hot Metal		Tons	Electricity		KWH	
Roof DRI		Tons	Tap Temp		C	
Plates		Tons	Tap Mass		Tons	
Total		Tons	Tap Time		Min	
Roof Addisions			If Deviated From Standard Give A Reason			
Dolomite		Tons				
Coal		Tons				
Lime		Tons				
Electrode	Slip	Change	Other			
A/phase						
B/phase						
C/phase						
	Delays >10 min					
Begin	End					
Deviation Be Specific			Type of deviation			
Signature First Melter					Signature Supervisor	

The data from the KPI sheets and deviation reports will be captured on an excel spreadsheet and feedback will be given to the supervisors on a daily basis with regards to the performance of their shift during the STUDY stage.

A study of the 12 process controllers will be done through assessing KPI reports for each batch processed and analysing whether there has been an improvement in the life of the furnace refractories. The life of the refractories is measured by the number of heats (batches) treated until the furnace refractories fail (burn through) and need to be replaced. A campaign will thus refer to the life of the furnace refractories, meaning the number of heats the furnace can produce before the refractories need to be replaced.

In the ACT stage, if all the previous three stages are successfully implemented then completion of KPI and deviation reports will be standardised to become part of daily routine. If possible entering of the data by the senior operator through an electronic system will be optimum to avoid time wasted during capturing of the logsheets. Recommendations given must be implemented with responsible persons identified.

4 RESULTS

The Pareto curve approach is applied to manage and improve operations performance. If managers rely on summarized data to focus improvement attention in their businesses, they lose much of the information necessary to identify and solve problems at their root cause. Sixty percent of common shop floor problems can be fixed quickly and cheaply [9].

The Pareto analysis, in Figure 4 below, indicates that two delays which are the furnace burn through and decanting of the furnace slag, contribute to 80% of the EAFs Top 20 delays. Thus it is necessary to minimize furnace burn throughs and the delay while decanting the furnace slag.

When a furnace burn throughs, the refractories lining gets destroyed (consumed) due to the chemical attack by the reactions occurring in the furnace. The furnace has to cool down for about 24 hours before the damaged refractory lining is removed and then rebuilding of new refractories can commence. If one furnace has a burn through then production is reduced to the other two furnaces for about a week until the other furnace is fully back online. The furnace burn throughs are also a result of operating the furnace at very high temperatures above the standard of 1630-1650°C, and the refractories can thus not withstand such high temperatures. As the process is not continuous but a batch process, other stoppages that result in the furnace standing and cooling down cause thermal shock when the furnace is restarted to the high operating temperatures. It is thus necessary to minimize any delays as the furnace which is a bottleneck has to be kept in operation as stoppages can result in extended delays during start-up.

The furnace slag is decanted at the end of every batch (called a heat) before the steel is poured (tapped) into the ladle from the furnace in order to send good quality steel to downstream operation. The slag makes it difficult to further treat the steel and thus its quantity in the steel must be as little as possible. However, though decanting cannot be eliminated, it is necessary to review the deviation from standard. Decanting of the furnace slag is supposed to be continuous during smelting in the furnace and thus at the end very little time, about three minutes is used to decant any remaining slag. More time is used at the end of the heat either due to incorrect melting practice or too much slag formation during melting.

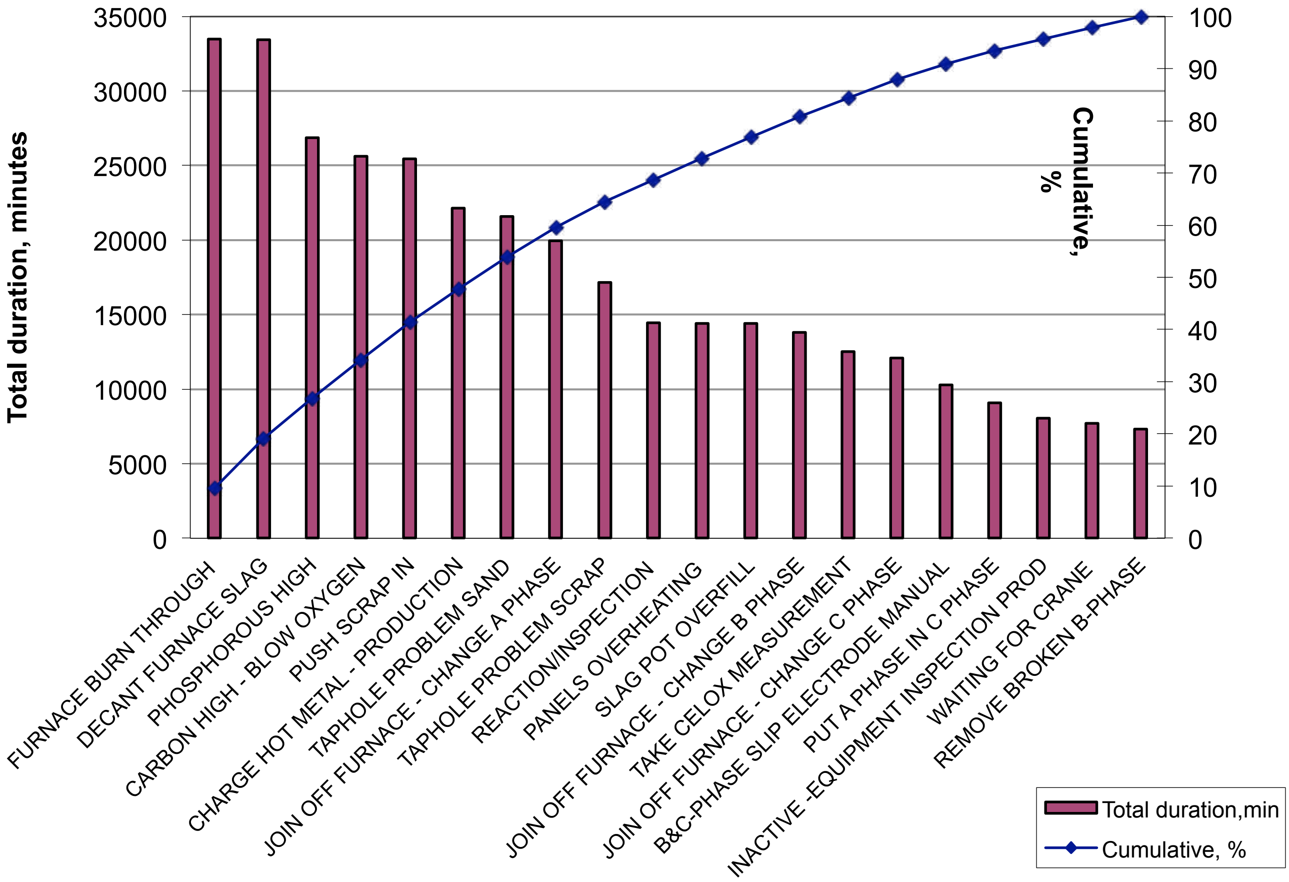


Figure 4: Pareto analysis of EAF delays

A Fishbone analysis of the five important parameters such as Man, Machinery, Methods, Measurement, Material and the Environment, was another tool used to evaluate what could be the root cause of EAFs production problems as well. This analysis is shown of Figure 5 below. It is important to note that most of the issues identified do not even need any capital investment from the company but can be done at no cost. The issues raised here are based on historical data, observations, experienced members of the EAFs technical team and also plant personnel (Supervisors and Operators) who were asked what they think could be the cause of EAFs production problems.

Man: The main issues highlighted in the people section were insufficient training, de-motivated employees and the different skills that the operators each have. The insufficient training issue can be addressed by discussing with the training department about better training methods. Currently, the training facilitator depends on each senior process controller at each furnace to train the junior operators. This results in individuals trained by a particular senior process controller operating the furnace the way he is taught and not necessarily the way the furnace should be operated. A solution is for the training department to implement a standard method for training by allowing the best 'operator' to train others. The best operator will be identified in the Do stage where the operator who has the least deviations, during completing KPI sheets in every batch, and thus train any new operators. This will also address the different skills the operators have as all will be trained by the same person and this might also result in employees being motivated as they will be more confident in executing their tasks without fear of doing the wrong thing.

Machinery: The frequent breakdown of machinery (such as cranes for loading scrap into the furnace, conveyor belt for feeding raw materials, carbon and oxygen injection equipment) was highlighted which in some cases was worsened by the absence of spare parts whereas in other cases is a result of the machinery having reached its end of life (old equipment). A breakdown of the machinery has a negative impact on the EAFs operation as it is the bottleneck and therefore should ideally be always in operation.

Blockages of equipment for injecting carbon into the furnace were also highlighted. This was observed to be a result of the absence of a lid in the carbon machine that was damaged some time ago and never replaced, resulted in other foreign particles entering and thus causing blockages. A decision was taken to have the lid fabricated at the workshop in the plant and also frequent sampling of the material was implemented, to analyse the moisture and particle size of the carbon material.

Methods: The issue of the standard operating procedures not well-defined will be addressed by the better training procedure already mentioned. This will result in a detailed process route which all operators will have to follow and there will be controls to minimise variation in the way the furnaces are operated.

Measurement: The measurement of temperatures and taking of samples in the furnace have been identified as a contributor to production challenge at EAFs. There is a perception that the quality of probes supplied is not good. The operators were thus required to put aside any faulty probes and the issue was taken up with the supplier. A delay in the analysis of the steel sample, taken from the furnace, at the laboratory also results in the furnace overheating which has a negative impact on the refractories. It was then necessary for the operator to contact the lab via a phone and get the results in case there is a system connection issue causing results not to be displayed as soon as they are analysed.

Material: There was also a general feeling about the poor quality of input materials. A decision was taken to take samples twice a week and analyse if the material received is within specification. This was done and the material quality was found to be according to standard. The early failure of refractories was also perceived to be due to poor workmanship during rebuilding of the furnace refractories. An inspection by the refractory specialist was thus done after every re-line to ensure that the refractories are up to the required standard to withstand the furnace processes.

Environment: The furnace environment is dusty ad high temperatures are generated as a result of the reactions taking place inside the furnaces. As some of the work is manual, such as taking of temperature readings and samples, this puts strain on the operator. It is thus necessary for the operator to wear the required safety clothing prescribed for the furnaces working area.

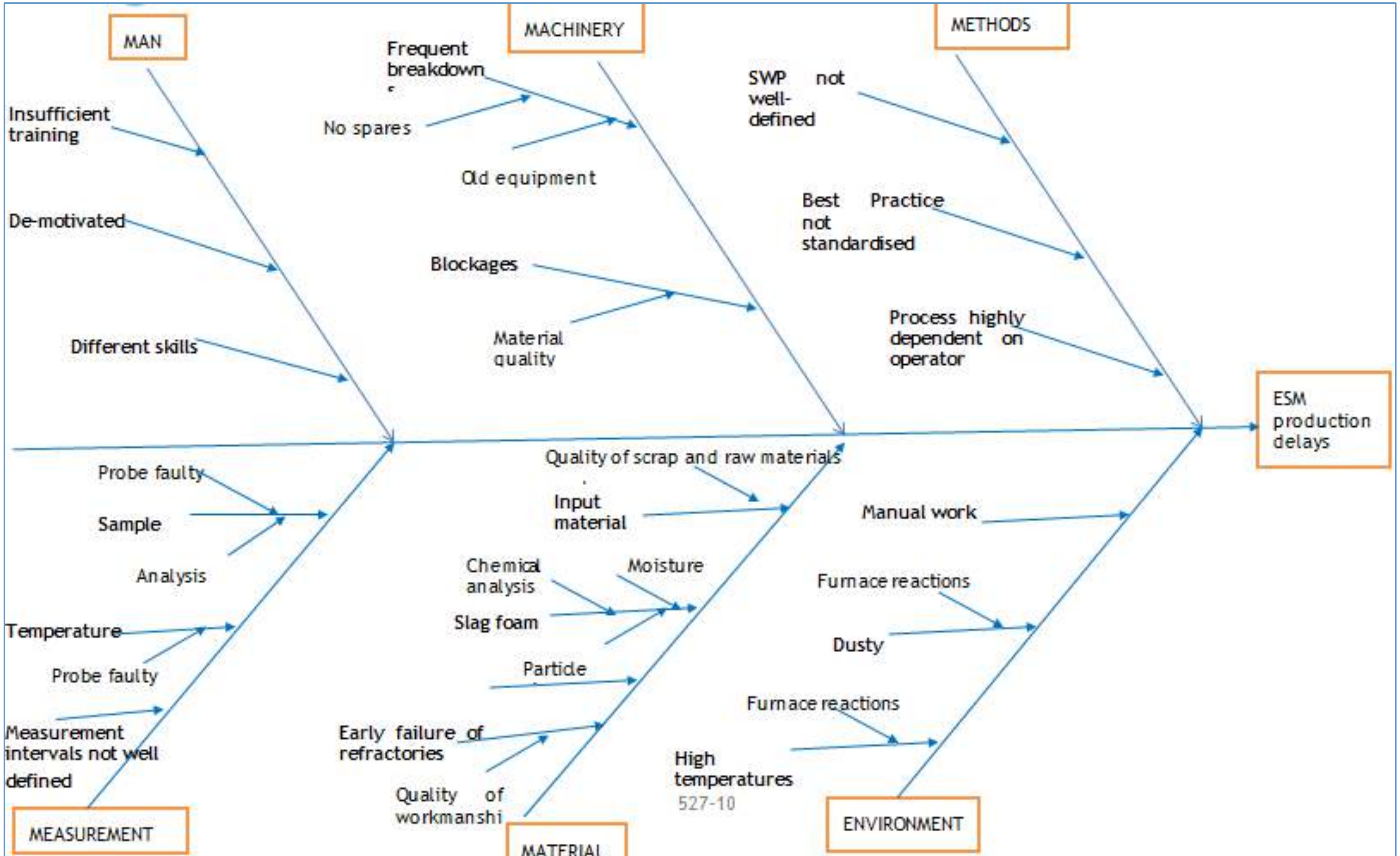


Figure 5: Fishbone diagram

The 5 Whys were then applied to the top three contributors of the EAFs production delays which were identified in the Pareto Chart. The answers to the 5 whys were obtained through technical information of furnace operations and observations in each furnace during melting. Spending time in each of the furnace control room gives insight into how each Operator is melting the furnace and through discussions in the production meetings; most of the answers to the 5 whys were also obtained.

Why	Why	Why	Why	Why
Furnce burnthroughs	Refractory failure	Too basic slag attacking refractories	Insufficient addition of MgO to protect refractories	Stabndard not followed
	Furnace overheating due to high temperatures	DRI (coolant) not feeding due to belt trip	Operator did not realise belt trip	Signal not audible
		Temperature probe faulty	Needs replacement	Incorrect handling Poor quality probe
Decant furnace slag	Slag removal to avoid slag being tapped	Impacts on quality of steel produced	Slag has negative impact on downstream processes	
Phosphorus high	Inadequate temperature control	Incorrect melting practice	Standards not monitored	
	Insufficient lime added	standards not followed		

Figure 5: 5 Whys analysis

From the 5 whys it was then apparent that certain steps had to be taken to ensure that correct melting standards are followed. For every batch of each furnace, the operator will thus fill in a KPI sheet where the key parameters for each batch will be recorded.

The Cause and Effect diagram [10] was constructed to evaluate the relationship between EAFs downtime (Top 20 delays) and the Fishbone Diagram issues identified. The outcome of this analysis is to identify the main causes to EAFs downtime and the effects can therefore be eliminated when the causes are addressed.

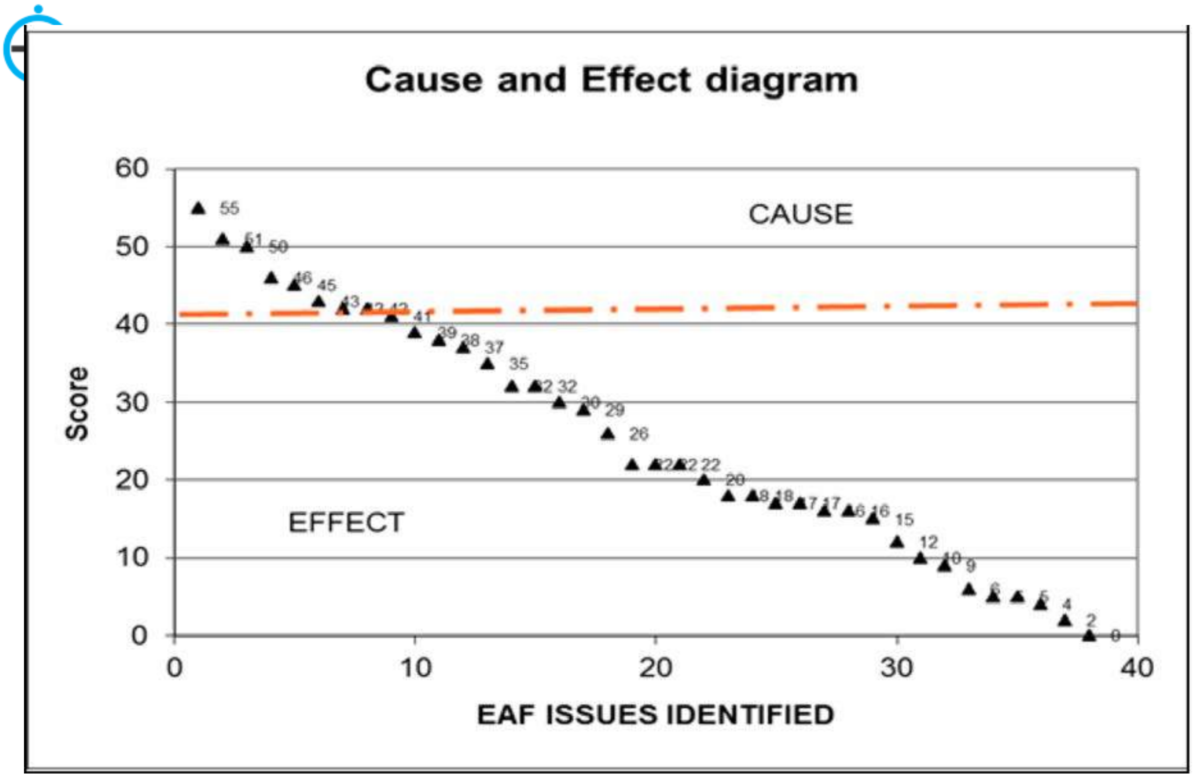


Figure 6: Cause and effect analysis

Eight main causes were identified according to their scores as shown Figure 7 where the dotted line is drawn at the first point where the graph is horizontal at a score of 42. This diagram basically says that if the CAUSES are corrected, most of the EFFECTS are also corrected as a result. Corrective actions for these causes are shown in Table 2.

Table 2: Corrective Actions for the causes

Score	EAF CAUSES	Corrective action	Responsible Person
55	High Temperatures	Correct melting temperature standard to be followed by Operators	Supervisor and Engineer
51	Manual Work	Re-training to be done once a month during Training Day	Supervisor and Engineer
50	Quality of Input Materials	Submission of samples to the Lab	Engineer
46	Temperature Probe Faulty	Proper handling of probes and quality monitoring to be done	Supervisor and Engineer
45	Best Practice not Standardised	Best Operator melting profile to be on display at each control room	Engineer
43	Process Highly Dependent on Operator	Furnace power to stop when any feeding belt trips(pokayoke)	Process Control Dept
42	Measurement Intervals not Well-Defined	Deviations to be addressed on KPI report	Supervisor and Engineer
42	Slag Foam Quality	Submission of samples to the Lab Fabricate lid to close slag foam silo	Engineer Maintenance Dept

- After three campaigns (of each of the three furnaces), there was a decline in deviations (Figure 8) from standard during melting as a result of the root cause analysis by the operators.

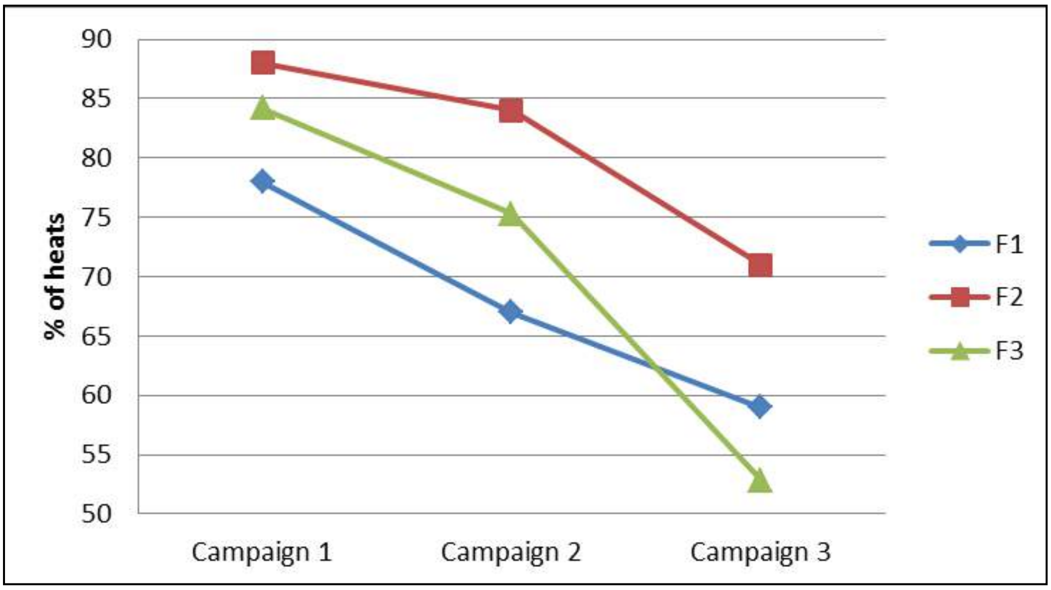
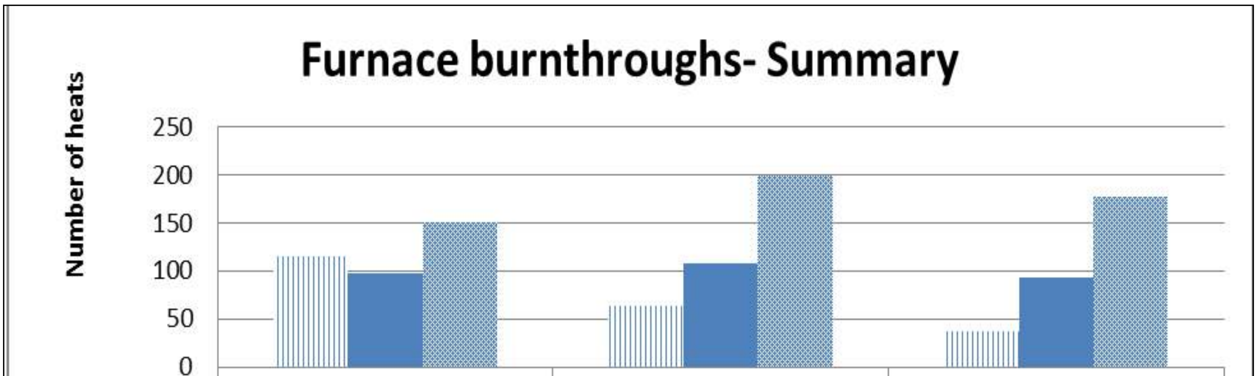


Figure 8: Deviations per furnace



	1	2	3
Campaign 1	116	64	38
Campaign 2	98	108	93
Campaign 3	151	200	178

Figure 9: Furnace refractory performance

5 DISCUSSION

The results showed an improvement in the refractory life of all three furnaces (measured by the number of heats to failure) with furnace three showing the most improvement followed by furnace two and then furnace one. This was through better conformance to the operating standard (temperature control was the critical parameter) and minimizing deviations thereof. The recording of key parameters for every batch made the Operators to really think about the way they operated the furnaces and if there is any deviation to evaluate the cause and corrective action to be taken. This helped minimize the negative impact on the furnace refractory that was a result of operating blindly without really looking at what the operator can control. It is thus now possible to evaluate other technical issues that affect metallurgical processes occurring in the furnaces in order to improve the number of heats per furnace to its design limit of about 250 heats.

A summary of the results is presented below:

- Two types of delays contribute to 80% of the Top 20 EAF delays (Figure 3). A 5 Whys analysis was applied to these delays to establish the root cause. It was found that the main cause was not adhering to the operating standard.
- The recording of key parameters on the KPI sheet for every batch required the operators to give reasons for deviating from the operating standard.
- Figure 8 shows that there was a decrease in the amount of heats with deviations, i.e. furnace three heats with deviations decreased from eighty four percent during campaign one to fifty two percent in campaign three.
- An improvement in the refractory life of all three furnaces (Figure 9) with furnace three showing the most improvement.
- Emphasis on standardization resulted in reduced deviation from operating standards at the EAF. An A3 problem-solving sheet was developed to be on display in each furnace control room with the major Pareto delays and corrective actions explained.
- Improved training by making use of the 'best operator' as a trainer was also initiated.
- The operating process was standardised based on the best performing operators' method, as previously each senior operator at a specific furnace trained his successor.

6 CONCLUSIONS AND RECOMMENDATIONS

- The PDSA cycle was proven to be an effective problem solving process as problems were identified and dealt with in a logical way.
- Furnace availability increased as a result of the improvement in the furnaces refractory life (furnace 2 refractory life improved from 64 heats in campaign 1 to 200 heats in campaign 3).
- The PDSA cycle has been successfully applied at the EAF and a recommendation that this is rolled-out to other sections of the Electric Steel Making Plant. This will have a positive impact as ESM production delays will be minimised therefore reaching production targets.

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EMPIRICAL COMPARISON OF VECTOR BOOTSTRAP METHODS FOR MULTIVARIATE SCENARIO GENERATION

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ABSTRACT

Stochastic simulation models require input scenarios, which may be generated from observed data using bootstrap methods. If a model's input variables are auto- and/or cross-correlated, these dependencies must be preserved in the generated scenarios. Three bootstrap methods were tested empirically: (1) the vector moving block bootstrap method, with a block length of one timeframe, (2) the vector moving block bootstrap method, with an optimised block length, and (3) the vector nearest neighbour bootstrap method. They were applied to data observed from processes at a petro-chemical plant: 28 numerical, multivariate, stationary time series, with a variety of auto- and cross-correlations. The quality of the generated scenarios was measured using a Turing test procedure, which balances fidelity to the observed data and natural variety. Method (2) performed best, followed by method (3), and then method (1).

1 INTRODUCTION

Stochastic simulation modelling is used to study the behaviour of complex systems, as follows:

1. A model is built, which is a simplified representation of the system that contains its essential features. The complexity of the model depends on the scope and the required accuracy, which depends on the purpose of the modelling exercise.
2. Stochastic (random) input scenarios are generated, which are sets of inputs to the model of the system. These inputs scenarios must mimic the natural level and variation of the actual system inputs, which have been observed.
3. The scenarios are fed into the model, which simulates the behaviour of the system.
4. The response of the system model is observed and analysed statistically.

To get meaningful results, the model must be appropriate and the input scenarios must be plentiful and realistic. The process of generating realistic input scenarios from observed data is the focus of this research.

The usual approach is to fit a parametric statistical distribution to the observed data for each input variable, and then to generate input scenarios by sampling randomly from the fitted distributions. However, this method assumes that the input variables are independent. This assumption often breaks down for simulations in the petro-chemical industry, where the input variables are physical quantities like temperatures, pressures, flow-rates and concentrations. These variables usually depend on each other (cross-correlation), and on their own recent history (auto-correlation).

The standard parametric method destroys these correlations in the generated scenarios, because each variable is sampled independently at each timeframe. This means that although the generated values match the fitted distributions, they occur in combinations and patterns that wouldn't occur in reality. For example, figure 1 shows an example of two observed input variables that are auto- and cross- correlated, while figure 2 shows how these correlations have been destroyed in the generated input scenarios.

This can sometimes make a big difference to the simulation results (Civelek *et al* [1]). Imagine, for example, using a simulation model to determine the required size of a tank. If tank inflow and outflow are positively correlated, tank level variation will be reduced, and so a smaller tank will be required. Conversely, if the inflows come in bursts rather than randomly, a bigger tank will be required.

A method is required for generating input scenarios that are stochastic, while at the same time preserving the observed correlation structures. With the petro-chemical industry in mind, the method must be able to handle a variety of multivariate numerical time series, which vary about a steady mean (stationary), and display short-memory auto-correlation and simple cross-correlation.

2 METHODS AND MEASURES

2.1 Non-Parametric Bootstrap Methods

Non-parametric bootstrap methods are good candidates for the data-rich petro-chemical industry. Unlike parametric methods, they do not try to understand or model the observed data, but just to mimic it. They generate input scenarios by drawing samples directly from the observed data. This random *re-sampling* is done with replacement, so that the observed scenarios can be sampled repeatedly as input scenarios. In essence, non-parametric bootstrap methods try to replay the observed data in a realistic way. This means that they are robust, and can be applied to observed data whose underlying processes are poorly understood. It also means that they function in relatively simple, intuitive ways.

To describe the way they work, some terminology must be introduced. The measured data is called trace data, and can be visualised as a panel (or matrix), where each column represents an input variable, and each row represents the timeframe during which the input variables were measured, as illustrated in table 1. The input scenarios generated from the measured data also have this panel format. These two panels are called the *trace series* and the *generated series* respectively.

For bootstrap methods, there is a simple way to preserve cross-correlations. Instead of sampling each variable separately, all the variables are sampled at once from the trace series, as a vector. This guarantees that cross-correlations are preserved in the generated series, because it then consists of values that were observed to occur together in the same timeframe in the trace series. Preserving the auto-correlations is a bit more complicated, and the two main approaches are described below.

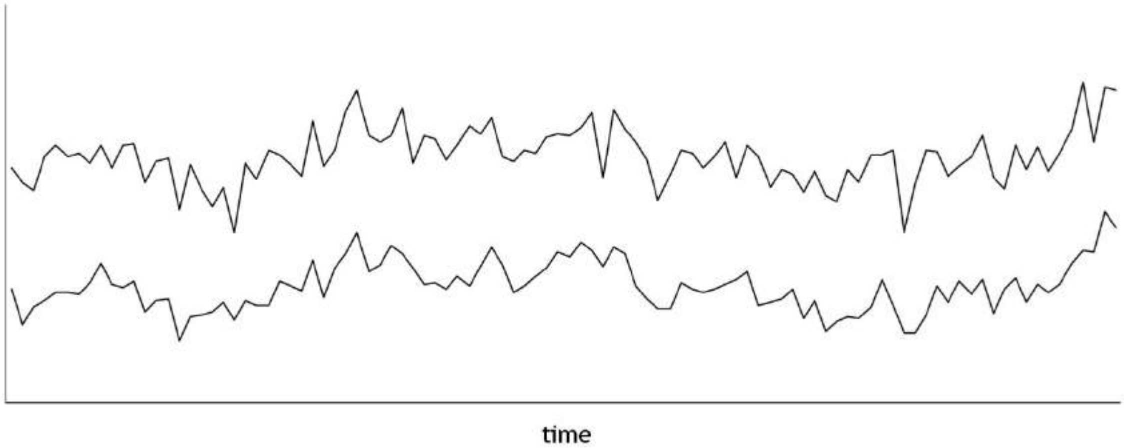

Figure 1 – Observed input variables showing auto- and cross-correlation

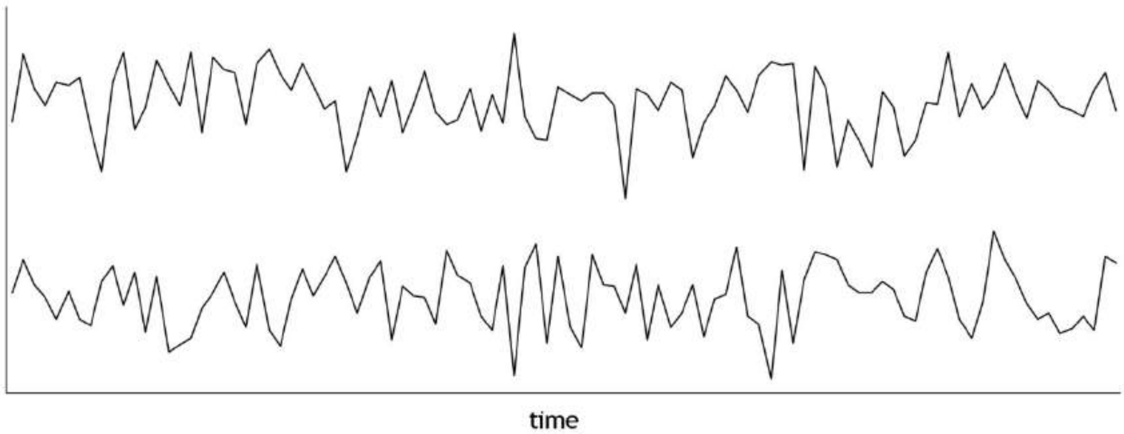

Figure 2 – Generated input scenarios with the correlations destroyed

Table 1 - Panel data format

	Input variable 1	Input variable 2	Input variable 3	etc.
Timeframe 1				
Timeframe 2				
Timeframe 3				
etc.				

2.1.1 *Vector Moving Block Bootstrap Method (VMB)*

The *block* approach involves sampling a number of successive timeframes from the trace series at once, instead of just one at a time. The idea is that the auto-correlation pattern is preserved within each block, although there are discontinuities at the block boundaries in the generated series, as shown in figure 3.

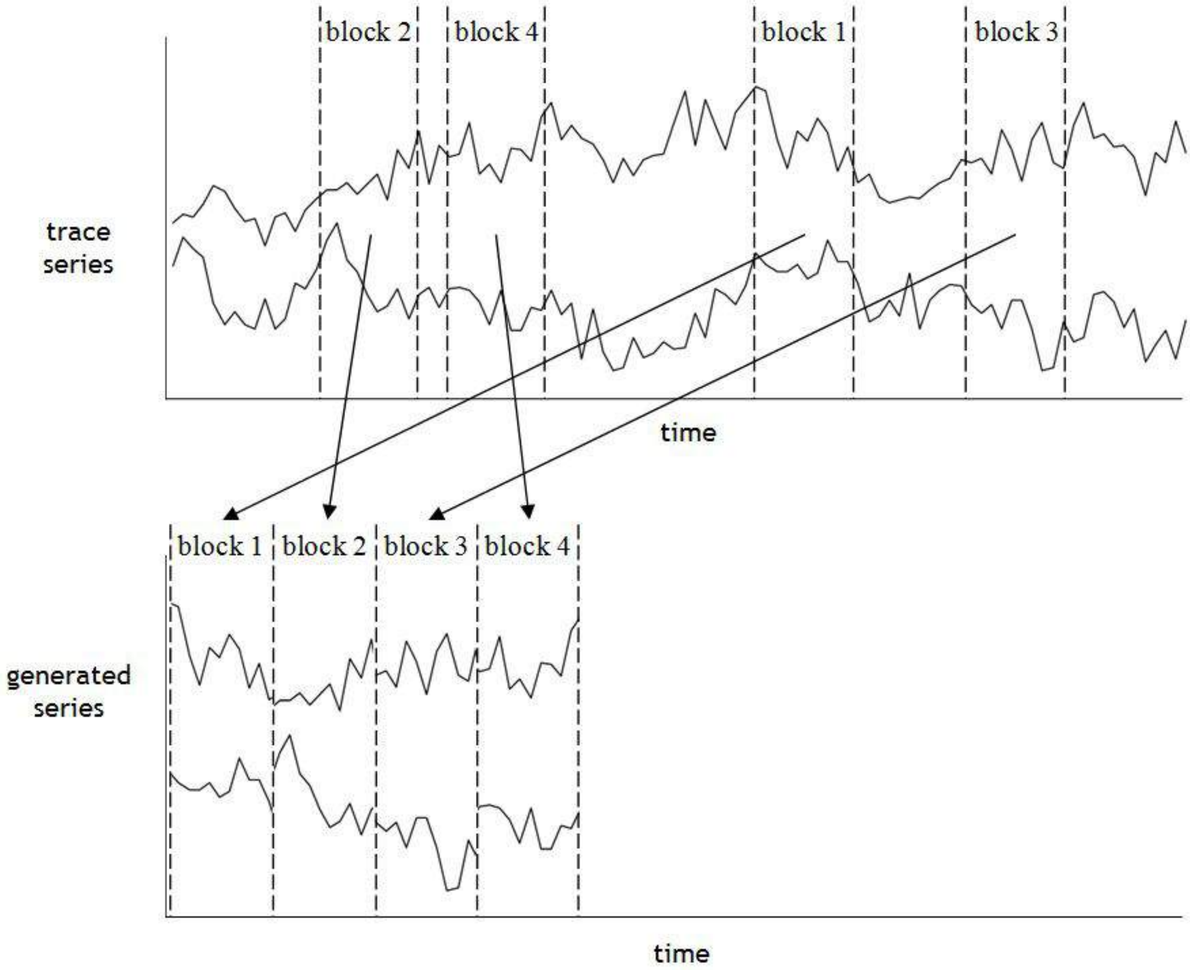

Figure 3 - The block bootstrap re-sampling approach

Of the many block bootstrap varieties, the moving block bootstrap by Kunsch [2] and Liu & Singh [3] was chosen for the research. It samples overlapping blocks of fixed length, and is recommended by Willemain *et al* [4] *"because of its simplicity, prominence, and good performance"*.

The VMB bootstrap method is executed according to the following algorithm. Given a trace series with *p* variables and *n* timeframes, produce a generated series of any length as follows:

1. Choose a block length, *b*.
2. Randomly choose a timeframe from the *n* timeframes in the trace series.
3. Starting at this timeframe, sample a vector block from the trace series (*p* variables × *b* timeframes). If the sampling block overlaps the end of the trace series, let it continue at the beginning.
4. Repeat steps 2 and 3 until the generated series exceeds the required length.
5. Truncate the generated series to the exact length required.

The method has one parameter, the block length (*b*), which is the number of timeframes sampled from the trace series at once. Hall *et al* [5] show that the performance of the moving block bootstrap depends critically on block size. Demirel & Willemain [6] find that the optimal block size for scenario generation is proportional to the square root of the trace length, but that this proportionality constant depends on the auto-correlation structure of the particular trace series at hand. Two cases were considered for the research:

- Block length of one timeframe (VMB_1) - This is the simplistic case appropriate for when there is no auto-correlation in the trace series. It is used as the control case.
- Optimised block length (VMB_{opt}) - The VMB bootstrap method is applied to each trace series at every possible block length. The block length with the best overall performance for a given trace series is chosen.

2.1.2 The Vector Nearest Neighbour Bootstrap Method (VNN)

The *nearest neighbour* approach tries to preserve the auto-correlation by re-sampling such that each new sample 'fits' after the previous one. Each time it samples it asks, *"What does the generated series look like right now?"* and, *"When did it look similar to this in the trace series"*, and then, *"At those times, what happened next?"* It then samples from one of these candidate successors.

The methods that follow the nearest neighbour approach (nearest neighbour methods) differ in the way they choose each new sample. The areas in which they differ and the options that were chosen for this research are summarised in table 2.

Table 2 - VNN bootstrap version

Area of difference	Option chosen for the research
Number of previous timeframes compared - when determining similarity	Only the most recent timeframe is compared.
Vector distance measure – To find nearest neighbours, the 'current state' of the generated series must be compared to the trace series for all the variables at once.	Ranked weighted city block distance measure.
Number of candidates considered – All the timeframes in the trace series are ranked according to how well they resemble the current state of the generated series. Only the successors of the best few matches are considered as candidates.	The number of candidates considered is the square root of the number of timeframes in the trace series, as recommended by Lall & Sharma [7] and Rajagopalan & Lall [8] for long trace series with short-memory auto-correlation.
Successor selection method – The successor (next sample) can be chosen from the candidates randomly, or by weighting the candidates so that the more closely the neighbour resembles the current state of the generated data, the better the chances of its successor being chosen.	The following weighting scheme advocated by Lall & Sharma [7]: • Let the number of candidates be K. • Rank these candidates from 'best match' to 'worst match'. • Assign a probability P_j to the j^{th} candidate as follows: $P_j = \frac{1/j}{\sum_{i=1}^{K}(1/i)}$. • Sample from these candidates with probabilities P_j.

The VNN bootstrap is executed according to the following algorithm. Given a trace series with *p* variables and *n* timeframes, produce a generated series of any length as follows:

1. For each variable, calculate the Spearman [9] correlation between each value in the trace series and its previous value. This is the lag-1 auto-correlation for that variable (r_a).
2. Sample a timeframe randomly from the trace series. Set this as the start of the generated series. It serves as the 'warm-up' period.
3. Then, for each subsequent timeframe in the generated series:
    - Compare the previous timeframe in the generated series to every timeframe in the trace series, calculating the absolute difference between each of the variables.
    - For each variable, rank the timeframes in the trace series according to this absolute difference, in ascending order.
    - For each timeframe, calculate the weighted sum of these ranks, weighting each variable according the magnitude of its r_a.
    - Rank the timeframes in the trace series according to this weighted sum, in ascending order.
    - Choose randomly from the best $\sqrt{n}$ candidate timeframes (rounded down to the nearest whole number), according to the probabilities defined by Lall & Sharma [7], as described in table 2.
    - Sample the successor timeframe of the chosen candidate as the new timeframe in the generated series.

2.2 A Quality Measure

To compare the performance of the bootstrap methods objectively, a quantitative statistical measure of the quality of the generated scenarios is needed. High quality scenarios are realistic scenarios. To be realistic, they must satisfy two criteria:

1. *Fidelity* - Obviously, the generated scenarios must be similar to the observed data, with the same essential characteristics. The auto-correlation structure of each variable in the trace series must be preserved in the generated series.
2. *Variety* - However, the generated scenarios must not be identical to the observed data, because the process creating the trace data is stochastic not deterministic. Successive realisations of this process would produce different observed data. Therefore, the generated data must also have some realistic variation. (To illustrate the point, imagine that the whole trace series was just replayed repeatedly to make the generated series. The statistics would then be identical, but there would be no variety. This is certainly not realistic.)

An appropriate quality measure must reconcile these two competing objectives. Demirel & Willemain [10] propose that the correct approach is to phrase the quality measure as a Turing test, which says that a high quality generated series is as similar to the trace series as independent realisations of the trace series are to each other. This test is performed *for each variable* in the trace series by answering three questions:

1. *How similar are independent realisations of the trace series to each other?*

Usually for real-world simulations, only one realisation of the trace series is available. To get around this problem, the trace series is divided into a number of subseries, and these are compared to each other. The degree to which the auto-correlation structures of these subseries differ is quantified using the *delta* difference measure recommended by Demirel & Willemain [6].

2. *How similar are the generated series to the trace series?*

A large number of generated series are produced. Their auto-correlation structures are compared to that of the trace series, using the same *delta* difference measure.

3. *How closely do these similarities match?*

The distribution of *delta* values calculated in step 1 is compared to the distribution of *delta* values from step 2, using the Kolmogorov-Smirnov test. The quality measure Q is then defined as $Q=ln[(1-D)/D]$, where D is the Kolmogorov-Smirnov D-statistic. The higher the Q value, the better the distributions match, the better the quality of the generated series for that variable.

3 EXPERIMENTATION

3.1 Objective

The objective of the research is to compare the performance of the VMB_1, VMB_{opt} and VNN bootstrap methods to determine which method generates the most realistic input scenarios for simulations in the petro-chemical industry. The testing is empirical, using trace series that have been observed from a petro-chemical plant.

3.2 Hypotheses

The first step was to do an overall test to determine whether performance depends on the method used, so the following null hypothesis was tested. *H_0: Q does not depend on the bootstrap method that is used*. The alternative hypothesis was *H_A: Q depends on the bootstrap method that is used*. The test was done at the 5% significance level.

3.3 Sampling

28 empirical trace series were observed from processes at a petro-chemical plant. They were selected such that the variables in each trace series were known to be linked in a physical way, and were more-or-less stationary time series (from visual inspection). The 28 trace series contained between 2 and 8 input variables each, yielding a total of 96 input variables, each of which gave an estimate of Q.

3.4 Results

All three methods were applied to each trace series, so the appropriate parametric statistical test to compare their performance is repeated-measures Analysis of Variance (ANOVA). However, the assumption of normally distributed residuals was violated, so the non-parametric Quade test was used instead (Derrac *et al* [11], Borokowski [12]). The overall null hypothesis was rephrased more specifically as *H_0: There is no median difference in Q between the bootstrap methods*. The alternative hypothesis was then *H_A: There is a median difference in Q between the bootstrap methods*.

Figure 4 shows box-and-whisker plots of the differences in Q between the three bootstrap methods. A Quade F-value of 88.6 and a p-value of less than 2.2×10^{-16} were calculated. This p-value is much less than the cut-off of 0.05, so H_0 was therefore rejected, with the provisional conclusion that there is a median difference in Q between the bootstrap methods. In other words, the bootstrap method that is used does have a statistically significant effect on performance.

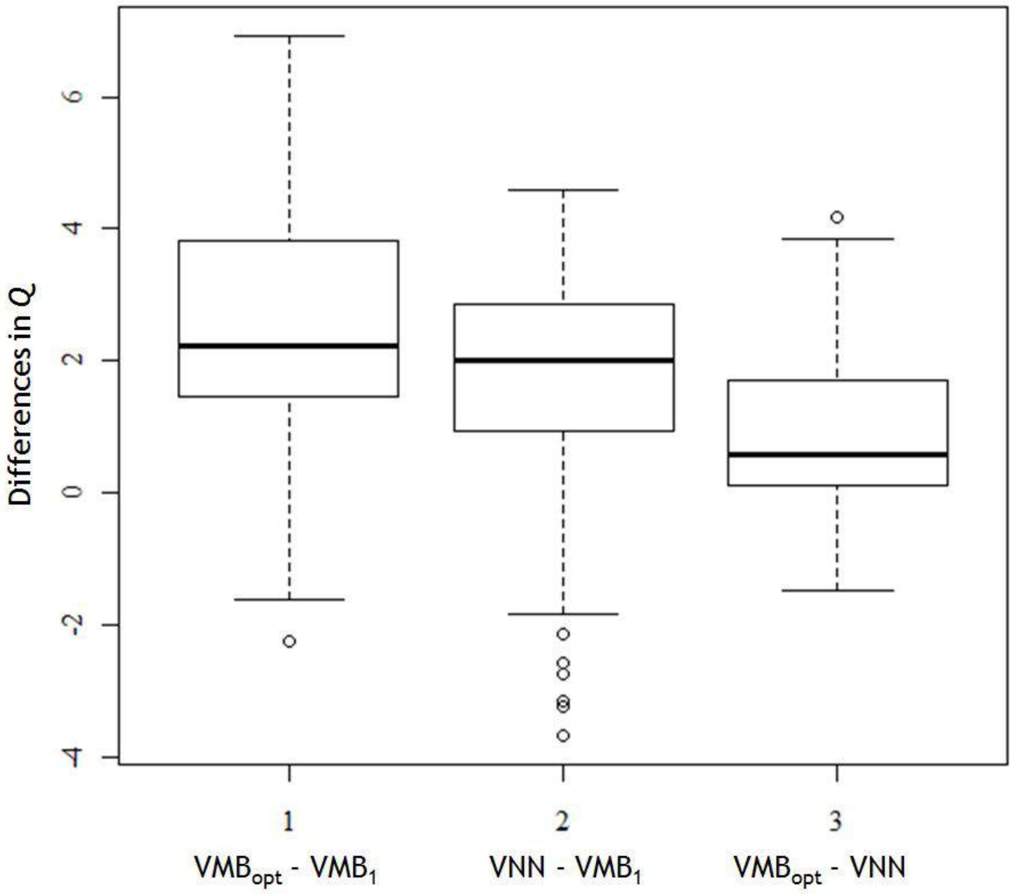

Figure 4 - Differences in performance between bootstrap methods

The next step was to determine where these differences lie, to find out which method performed best. Quade multiple comparison tests were used to reveal differences between the methods. The pair-wise difference hypotheses and the test results are shown in table 3, along with the sample median difference between each pair of methods. Because every null hypothesis was rejected, the provisional conclusion was made that the VMB_{opt} bootstrap method performed significantly better than the VNN bootstrap method, which performed significantly better than the VMB_1 bootstrap method, when tested at the 5% level of significance.

Table 3 - Quade multiple comparison tests results

Null hypothesis	**Alternative hypothesis**	**Median difference**	**1-sided *p*-value**	**Conclusion**
There is no median difference in Q between the VMB_{opt} and VMB_1 bootstrap methods.	*There is a median difference in Q between the VMB_{opt} and VMB_1 bootstrap methods.*	2.2	7.3×10^{-11}	Reject null hypothesis
There is no median difference in Q between the VNN and VMB_1 bootstrap methods.	*There is a median difference in Q between the VNN and VMB_1 bootstrap methods.*	2.0	3.9×10^{-4}	Reject null hypothesis
There is no median difference in Q between the VMB_{opt} and VNN bootstrap methods.	*There is a median difference in Q between the VMB_{opt} and VNN bootstrap methods.*	0.59	4.6×10^{-4}	Reject null hypothesis

4 CONCLUSION

The vector moving block bootstrap method, with an optimised block length (VMB_{opt}) performed better than the vector nearest neighbour bootstrap method (VNN). This could be because of the simplistic nearest-neighbour matching algorithm used, which only compared one previous timeframe. It may also be that the general approach of re-sampling data in blocks is just a more effective way to preserve auto-correlations than by trying to make each new re-sampled timeframe 'fit' after the previous one.

Both the VMB_{opt} and VNN bootstrap methods performed much better than the control vector moving block bootstrap method, with a block length of one timeframe (VMB_1). This is not surprising. The VMB_1 method destroys the auto-correlations in the trace series by definition, because it samples individual timeframes in random order. As the block length increases, fidelity to the auto-correlation structure of the trace series increases. If the block length increases too much, though, the generated series loses variety, and starts looking too much like the trace series. The optimal block length is a compromise between the two. This is illustrated in figure 5, which plots performance Q versus block length for an example trace series containing four variables. The optimal block length is at the overall peak.

It is recommended that practitioners in the petro-chemical industry use the VMB_{opt} bootstrap method, rather than the VNN or VMB_1 bootstrap methods, to generate multivariate input scenarios for simulation models if the presence of auto- and cross-correlation is suspected.

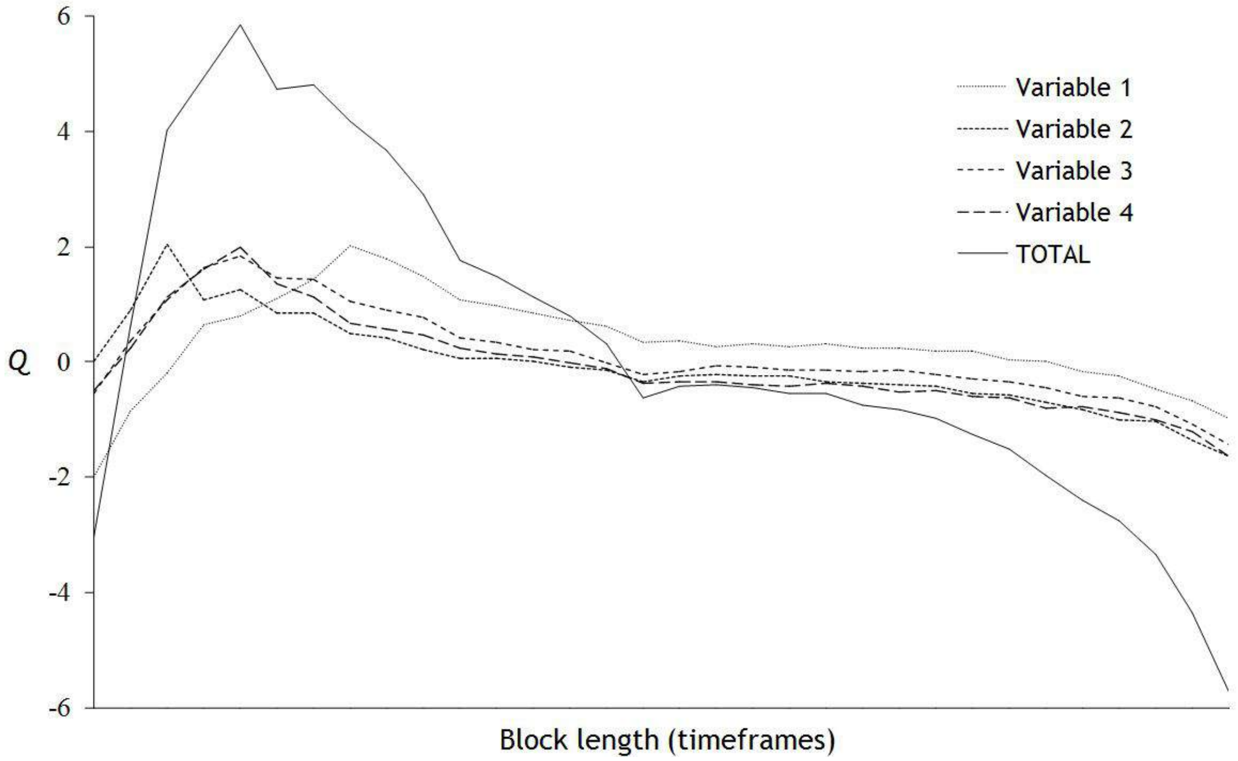

Figure 5 - Performance versus block length for an example trace subseries

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DEVELOPMENT OF A RESOURCE AGENT FOR AN E-MANUFACTURING SYSTEM

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ABSTRACT

Due to globalisation and distributed manufacturing systems the development and manufacture of products is no longer an isolated activity undertaken by either one discipline or a single organization but has become a global process. Using e-manufacturing companies can now outsource to manufacturers outside their geographical area and make them dependent on the production capabilities and responsiveness of the suppliers. Hence there is need for the suppliers to provide reliable information on the state of the orders being processed. E-manufacturing promises companies to exchange the required information with their suppliers by increased visibility to the shop floor and providing a platform for information interchange. The paper discusses the development of an e-manufacturing resource agent to enable manufactures to predict the probability of their outsourced machinery being available and the probability to complete an order without having a breakdown. The Maintenance Free Operation Period (MFOP) method is used to develop the agent. This means that the manufacturer will be expected to have a guarantee that no unscheduled maintenance activities will occur during each defined period of operation with the predefined level of confidence.

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1 INTRODUCTION

Manufacturing companies have shifted from the traditional mass production strategy to lean and agile manufacturing strategies. Globalisation and distributed manufacturing systems have enabled companies to overcome the limitation of dealing only with companies in their geographical manufacturing process but have extended the manufacturing process into a global process. To enable these concepts to be a success there needs to be a more reliable platform for information exchange between the customers and suppliers in the supply chain which E-manufacturing seeks to provide. In this paper we develop a framework for a resource agent for an E-manufacturing system proposed by Nyanga et al [1]. The agent enables manufacturers to predict the availability of their machinery at the time when they are required to perform a specific job before outsourcing it or when it is being outsourced to them. The Maintenance Free Operation Period (MFOP) method is used to develop the agent by extending one cycle of MFOP into many cycles using the alternating renewal theory. The structure of the paper is as follows, MFOP methodology is discussed followed by the alternating renewal theory. We then give the framework for our proposed resource agent. We conclude the paper by giving the current status of the research and future work to be done.

2 INFORMATION GAP AND E-MANUFACTURING

According to Koc et al [2] competition in manufacturing industry no longer depends on lean manufacturing only, but also on the ability to provide customers with total solutions and life-cycle costs for sustainable value. Manufacturers are now under a pressure to improve their responsiveness and efficiency in terms of product development, operations, and resource utilization with a transparent visibility of production and quality control. A report by Unifi Technology Group [3] states that a survey of the top 50 global manufacturing executives carried out by Forrester revealed that the number one problem the executives have is poor visibility into the shop floor. In trying to improve the responsiveness and efficiency of the manufacturing plant the main challenge these manufacturers face is the existence of an information gap exists between the factory floor and the corporate systems that govern business and supply chains. Enterprise Resource Planning (ERP) systems have been developed to bridge the information gap in the manufacturing companies and have become the financial backbone of many corporations. As observed by Rockwell Automation group [3], ERP systems still have their own shortcomings as they cannot include the dynamics of the factory floor conditions such as unpredictable machine downtime, machine utilization, variability and reliability of suppliers and customers. Lee [4] states that the crucial link between Manufacturing Execution Systems (MES) which provides a higher-level view of production and ERP systems is hindered by the lack of integrated information coming from and flowing to control systems on the plant floor.

E-manufacturing fills the gaps between product development and supply chain consisting of lack of life cycle information and lack of information about supplier capabilities which exist in the traditional manufacturing systems as stated by Koç and Lee [5]. E-manufacturing enables information exchanges among various plant level systems with business systems to eliminate data bottlenecks that can occur in conventional enterprise IT architectures as stated by Kovacs [6]. This enables the decision makers in an organization to make informed management decisions, efficiently respond to changing business conditions, and reply to customer inquiries in a timely manner. Koç and Lee [5] state that the intrinsic value of an e-Manufacturing system is to enable real-time decision making among product designers, process capabilities, and suppliers as shown in Figure 1. In the context of this research e-manufacturing is used to enable sharing of manufacturing resources to enable Small, Medium and Micro-sized Enterprises (SMMEs) to overcome their limitation in resources, increase their capacity and machine utilisation by implementation of capacity and technology subcontracting machines and jobs using the internet as a medium of communication.

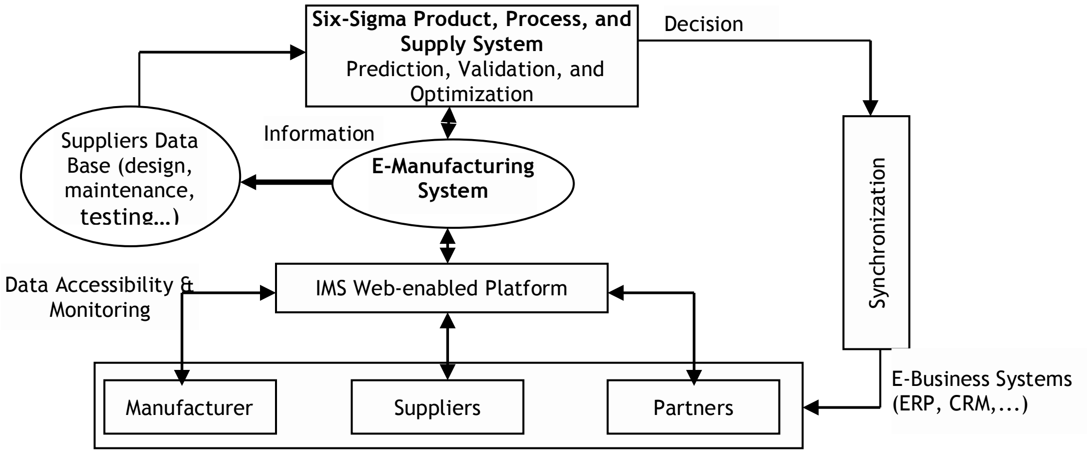

Figure 1 Intrinsic value of an E-Manufacturing system

3 PROBLEM ENVIRONMENT

The proposed framework seeks to enable manufacturers intending to subcontract machinery uploaded on an online registry proposed by Nyanga et al [1] to be able to predict the availability of machinery at the time the machinery would be used. The names of manufacturers and machinery available for different operations at any given time are uploaded on to a public registry which gives information on the manufacturing capabilities and capacities of manufacturers. Manufacturers send Request For Quotes (RFQs) for operations they require to subcontract or machinery available which they want to use and are replied with quotes. A Multi Agent System (MAS) is utilised to analyse the quotes and issue out orders based on machine availability, capabilities and cost of use. Unlike most of the e-manufacturing systems which uses e-diagnosis [7],[8],[9], to predict machine availability the proposed system uses the concept of Maintenance Free Operating Period (MFOP) as a way of reducing the complexity of the system, set and operational costs of the e-manufacturing system. The aim of the framework is to increase visibility into the shop floor and enable managers to make informed decisions when subcontracting machinery. The proposed resource agent predicts the availability of machinery from the machine schedule developed by the job scheduling agent and the maintenance module using the Maintenance Free Operating Period (MFOP) concept.

4 RELIABILITY-CENTRED MAINTENANCE (RCM)

A reliability-centred maintenance (RCM) strategy can be used to increase the operational reliability of the system and decrease both downtime and maintenance cost [10]. Using Graber's [11] approach, reliability is expressed as the probability that a machine will perform its function or task under stated conditions for a defined observation period (mission time). Considering the drawbacks of Mean Operating Time Between Failure (MTBF) or its reciprocal – the 'failure rate' which makes it almost impossible to demonstrate reliability. Hockley and Appleton [12] state that the Royal Air Force (RAF) are considering maintenance free operating period (MFOP) as the prime reliability and maintainability requirement for their future generation aircraft. According to Relf [13] the RAF set a target to have MFOP replace its fleet of strike aircraft in approximately 2015.

5 MAINTANCE FREE OPERATING PERIOD (MFOP)

Dinesh-Kumar et al [14] defines the MFOP as a period of operation during which an item will be able to carry out all its assigned missions without the operator being restricted to system faults or limitations, with the minimum of maintenance. Every MFOP is followed by a Maintenance Recovery Period (MRP). This is the downtime during which the equipment is recovered to such a level that the next MFOP can be achieved successfully. Unlike the mean time between failures and Mean Time To Failure (MTTF) approaches which accept that failure cannot be accurately forecast and avoided, MFOP focuses on enabling equipment to achieve operational success with minimal within-MFOP maintenance intervention, through combined use of failure avoidance, failure anticipation, and maintenance delay as stated by Warrington [15].

According to Wu et al [16] MFOP is an extension of warranty period extended throughout the life of the system which reduces direct maintenance costs (DMC). The machine owner is guaranteed that no unscheduled maintenance activities will be required during each defined period of operation with the predefined level of confidence. Not all Maintance Recovery Periods (MRPs) will have same duration because of the different maintenance activities for individual Line Replaceable Unit (LRU). Brown and Hockley [17] state that the length of the MRP varies depending upon the previous and subsequent MFOP and also the depth of maintenance required hence a flexible approach to the duration of the MRP is required. However the authors do not explain how to deal with the differences in the MRP. Fritzsche [18] shows how the MFOP concept is to reduce maintenance costs by replacing unscheduled corrective maintenance with more scheduled activities. The focus this paper is to show how MFOP can be used to predict machine availability.

5.1 MFOP models

Todinov [19] presented models for limiting the risk of failure below a maximum acceptable level, guaranteeing an availability target and guaranteeing a minimum failure-free operating interval before each random failure in a finite time interval. Chew et al [20] proposed the use of a Petri net (PN) to model the reliability of the MFOP and phased missions scenario. A mission is taken in phases with a combination of several sequential phased missions without maintenance considered to produce a maintenance-free operating period.

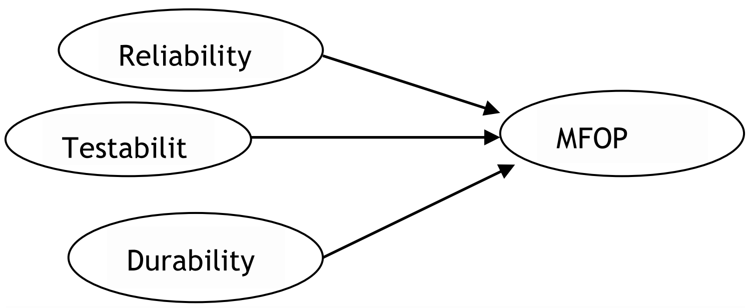

Figure 2 MFOP fundamental elements [17]

Using Knezevic's toasting fork model Brown and Hockley [17] came up with three elements fundamental to the philosophy of MFOP, which are reliability (increased reliability over existing platforms), testability (ability to diagnose faults and failures efficaciously) and durability (redundancy and fault tolerance) as shown in Figure 2. They also state that MRP is of specified duration dependent upon the maintenance task required. Maintenance would be carried out on the platform to ensure that the probability of completion of subsequent MFOPs would be the same as that given for the previous MFOP. Thus the duration and content of each MRP would be predicated by the duration and content of the MFOP.

According to Guertin and Bruhns [21] an MFOP-enabled system is inherently reliable with continuous health monitoring status to provide confidence that the tactical application availability requirement is highly likely to be met. To achieve this in their Navy ships MFOP system design the following design enablers were incorporated (1) Fault Tolerant Design (2) Data Collection, and (3) Remote Connectivity as shown in Figure 3.

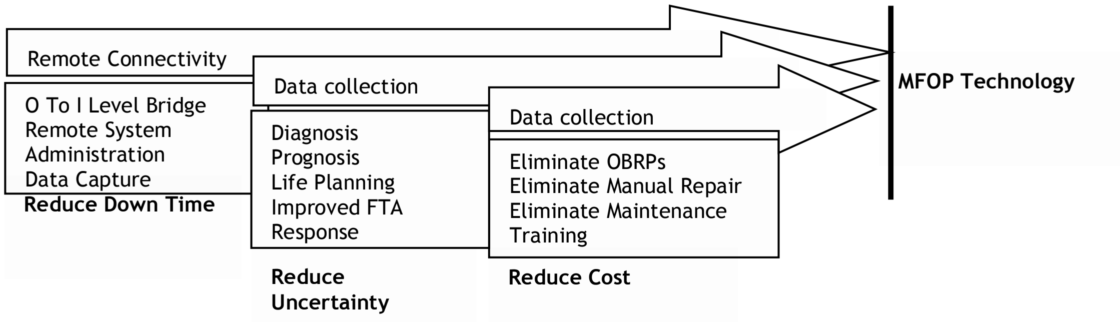

Figure 3 MFOP design enablers [21]

5.2 MFOP Analysis

The MFOP analysis for the system follows the 5 step methodology proposed by Shaalane [22]:

1) Identification of System
2) Setting System Boundaries
3) Identification of Correct Failure Data
4) Data Collection and Management
5) Determination of Data Set Trends

The steps for data analysis are shown in the schematic diagram in Figure 4. The data is tested if it is a Homogenous Poisson Process (HPP) or Non-homogenous Poisson Process (NHPP) using the centroid test or the Laplace test as recommended by O'Connor et al [23].

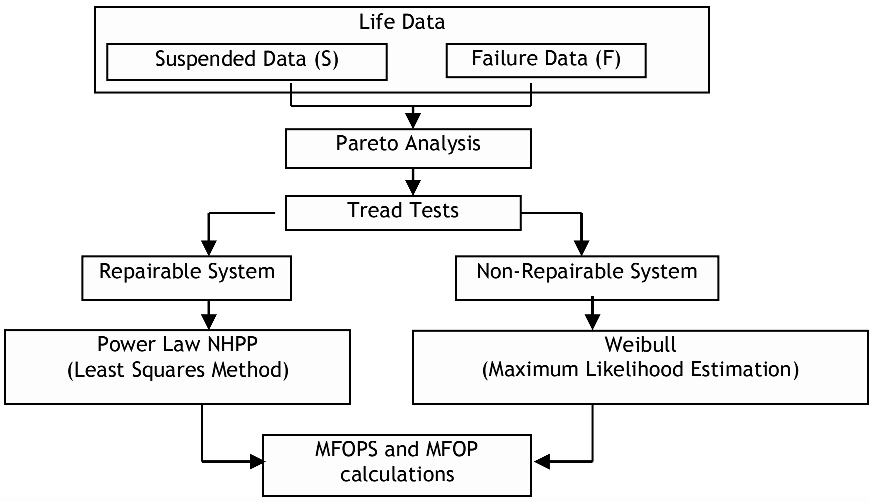

Figure 4 MFOP data analysis [21]

Using the Laplace test the following hypothesis is tested:

H_0 : HPP

H_a : NHPP

The test Laplace test equation is given by Equation (1):

$$U_L = \frac{\sum_{i=1}^{n-1} T_i/_{n-1} - T_n/_2}{T_n\sqrt{1/_{12(n-1)}}} \quad (1)$$

Where U_L approximates a standardised normal variate at a 5 % level of significance when $n \geq 4$, n is number of failures, and T_i is the i^{th} failure arrival time.

If $U_L \geq 2$ there is reliability degradation. If $U_L \leq 2$ there is reliability improvement. If $-1 \leq U_L \leq 1$ there is no evidence of an underlying trend. A test for dependencies between the inter arrival times should be performed as discussed by Cohen [24] and Gretton et al. [25]. A positive result on a test for dependence would mean that a Branching Poisson Process (BPP) would be applicable. The test for dependence is however omitted as stated by Cox and Lewis [26] since approximately 30 failure observations are required to perform such a test with reasonable confidence. In reality it is rare to have more than 30 observations in reliability data

If $-2 \leq U_L \leq$-1 or $1 \leq U_L \leq 2$ the Laplace test cannot provide indication with certainty that a trend is present in the data set hence the Lewis-Robinson will be used.

In the Lewis-Robinson test following hypothesis is tested:

H_0: renewal process

H_a: not a renewal process

The Lewis-Robinson test is given by Equation (2):

$$\boldsymbol{U_{LR}} = {}^{\boldsymbol{U_L}}/_{\boldsymbol{CV}} \tag{2}$$

where $\boldsymbol{CV}$ is the estimated coefficient of the variation of the inter-arrival times, $\boldsymbol{U_L}$ is the Laplace test statistic.

CV can is calculated by Equation (3):

$$\boldsymbol{CV}[\boldsymbol{X}] = \frac{\boldsymbol{V\hat{a}r}[\boldsymbol{X}]}{\widehat{\boldsymbol{X}}} \tag{3}$$

where X represents the variable of inter-arrival times. The results of the Lewis-Robinson test are interpreted the same way as the Laplace test.

5.2.1 Distribution parameters

If U_L falls in the region $-1 \leq U_L \leq 1$ there is no dependence of the data hence the non-repairable systems theory will be applied. The pdf for non repairable systems which shows the probability of system failure $f(x)$ at the exact instant x, is given by Equation (4):

$$f(x) = \frac{\beta}{\eta}\left(\frac{x}{\eta}\right)^{\beta-1} \exp\left(-\left({}^{x}/_{\eta}\right)^{\beta}\right) \tag{4}$$

Where β is the shape parameter and η the scale parameter of the Weibull distribution, where $\beta > 0$.and $\eta > 0$.

If $U_L \geq 2$ or If $U_L \leq 2$ there is a data trend hence the repairable systems theory has to be used. For repairable systems the power law Non-homogenous Poisson Process (NHPP) is used to model the repairable system using Equation (5):

$$\rho_1 = \lambda\delta t^{\delta-1} \tag{5}$$

Where λ is *scale* parameter and δ is a *shape* parameter. The parameters λ and δ are determined using the using the least-squares method i.e. difference between the observed number of failures and the number of failures expected.

For a failure

$$\mathbf{min}(\hat{\lambda},\hat{\delta}) : \sum_{r=1}^{r}[\boldsymbol{E}[\boldsymbol{N}(\mathbf{0} \rightarrow \boldsymbol{T_i})] - \boldsymbol{N}(\mathbf{0} \rightarrow \boldsymbol{T_i})]^2 \tag{6}$$

For a suspend

$$\mathbf{min}(\hat{\lambda},\hat{\delta}) : \sum_{r=1}^{r-1}[\boldsymbol{E}[\boldsymbol{N}(\mathbf{0} \rightarrow \boldsymbol{T_i})] - \boldsymbol{N}(\mathbf{0} \rightarrow \boldsymbol{T_i})]^2 \tag{7}$$

5.2.2 Maintenance Free Operating Period Survivability (MFOPS)

The MFOPS of non repairable systems will be calculated as shown by Denish-Kumar et al [14] and Denish-Kumar [27]. The MFOPS of non repairable systems is given by Equation (8):

$$\boldsymbol{MFOPS_{(t_{mf})} = exp\left(-\frac{t^{\beta}-(t+t_{mf})^{\beta}}{\eta^{\beta}}\right)} \tag{8}$$

Where η is the scale parameter and β is the shape parameter of the Weibull distribution.The reliability of the system *R(t)* in Equation (9) is given by Long et al [10] and Moss [28]:

$$R(t) = exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \tag{9}$$

For repairable systems the MFOPS is given by Equation 10:

$$MFOPS(t_{mf}) = e^{-\lambda((t_{mf}+T_r)^{\delta}-(T_r)^{\delta})} \tag{10}$$

Where T_r is the global time unit of the last known failure event and the parameters, λ and δ are the system parameters found through the least squares

5.2.3 Determine Maintenance Free Operating Period (MFOP)

In order to calculate the MFOP period for a non-repairable system for a given level of confidence Equation 8 is rearranged to the form of Equation (11):

$$\boldsymbol{t_{mf} = \left[t^{\beta} - \eta^{\beta}\ln\left(MFOPS_{(t_{mf})}\right)\right]^{1/\beta} - t} \tag{11}$$

The MFOP duration for a specified MFOPS requirement is given by Equation (12):

$$\boldsymbol{MFOP = \eta * \left\{\ln\left(\frac{1}{MFOPS}\right)\right\}^{1/\beta}} \tag{12}$$

The probability of achieving MFOP length at a confidence MFOPS can now be found by plotting MFOPS against MFOP. The MFOP methodology implemented by Shaalane [22] and has been preferred more than the MTBF.

6 ALTERNATING RENEWAL THEORY

To incorporate the MRP after an MFOP for a repairable system Denish-Kumar et al [14] and Nowakowski et al [29] derive MFOPS for a repairable item using renewal theory by allowing a maintenance recovery period after an MFOP. Considering a repairable item and assuming that:

1. The time to failure distribution of the item follows arbitrary distribution with density function represented by $f(t)$.
2. Maintenance recovery time of the item follows some arbitrary distribution with density function represented by $g(t)$.
3. The item can be in one of two states {1, 0}, where "1" is up state and "0" is down state.

Let $P_1(T)$ be the probability that the item will have t_{mf} hours of maintenance free operating period throughout the mission T. Maintenance is carried out as soon as the item fails. The expression for $P_1(T)$ can be written as:

$$\boldsymbol{P_1(T) = R(t_{mf}) + \int_0^T f(\mu|t_{mf})\, P_0(T-\mu)d\mu} \tag{13}$$

and

$$\boldsymbol{P_0(T) = \int_0^T g(v)\, P_1(T-v)dv} \tag{14}$$

where $f(\mu|t_{mf})$ is the probability that the system fails at time u, given that it has survived up to time t_{mf}.

Various approaches have been used to solve the integral equation of renewal type like Equation 13. Yevkin and Krivtsov [30] state that in repairable systems reliability analysis the four states to which a system can be repaired to following a failure (1) good-as-new, (2) same-as-old,(3) better-than-old-but-worse-than-new and (4) worse-than-old should be considered. After a failure if a repairable system is restored to a “good-as-new” condition, and the time between system failures can be treated as an *independent and identically distributed* (*i.i.d.*) random variable, then the failure occurrence can be modelled by the Ordinary Renewal Process (ORP) indicated by equation 13. If upon a failure the system is restored to the “same-as-old” condition, then an appropriate model to describe the failure occurrence is the Non-Homogeneous Poisson Process (NHPP) given that the time to repair can be neglected. ORP and NHPP can be treated as special cases of Generalized Renewal Process (GRP). They use two-point pade approximants to solve the ordinary renewal equation. Politis and Pitts [31] use approximations for the renewal density based on the derivatives of the renewal density functional. The derived explicit formulae for approximations can then be easily implemented on computer algebra software. Tortorella [32] uses the trapezoid rule and Simpson-like rules to solve the integral equation of renewal type. Taking note that equation 13 is a system of integral equations, we find the numerical approximation proposed by Gopalan and Dinesh-Kumar [33] most appropriate to use in developing our resource agent.

7 MULTI AGENT SYSTEM

An agent can be defined an object of a program, which has its own value and means to solve some sub-tasks independently and finally communicate its solution to a large problem solving process to achieve the objective [34] or as any piece of software or object which can perform a specific given task [35]. Properties of agents include autonomy, socialability, responsiveness, adaptability, mobility, and protectiveness [36]. Agents also have reasoning capabilities [37] have the ability to make a plan to achieve the goal [34]. A group of agents existing in the same environment which collaborate with each other to achieve common goals forms a Multi Agent System (MAS). These agents share information, knowledge and tasks among themselves.

The proposed multi agent system consists of functional agents which are managed and supervised by the Managing Agent (MA) through the internet as shown in Figure 5. The functional agents are Order Agent (OA), Mediator Agent (MdA), Job Agent (JA), Manufacturability Agent (Mfg A), Job Scheduling Agent (JSA), Process Planning Agent (PPA) and Resource Agent (RA).

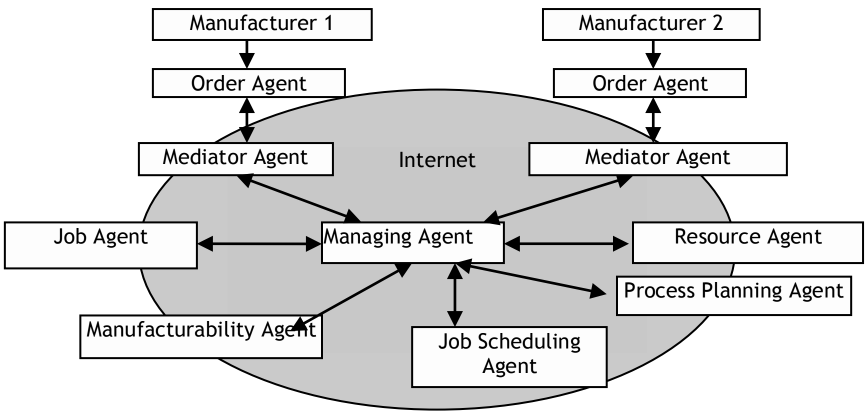

Figure 5 Multi-Agent System

The multi agent system makes decisions in allocating orders to machines registered on an online registry for capacity and technology subcontracting as shown in Figure 6. A manufacturer prepares a product process plan for the product one wants to manufacture. The manufacturer's mediator agent then searches for machines which are capable of carrying out the required manufacturing processes from the machines with sufficient capacity available the online registry. Once the machines have been identified the mediator agents from the manufacturer with the part to be manufactured or process to be done enters into negotiations using the Contract Net Protocol (CNP) to allocate jobs to the machines available.

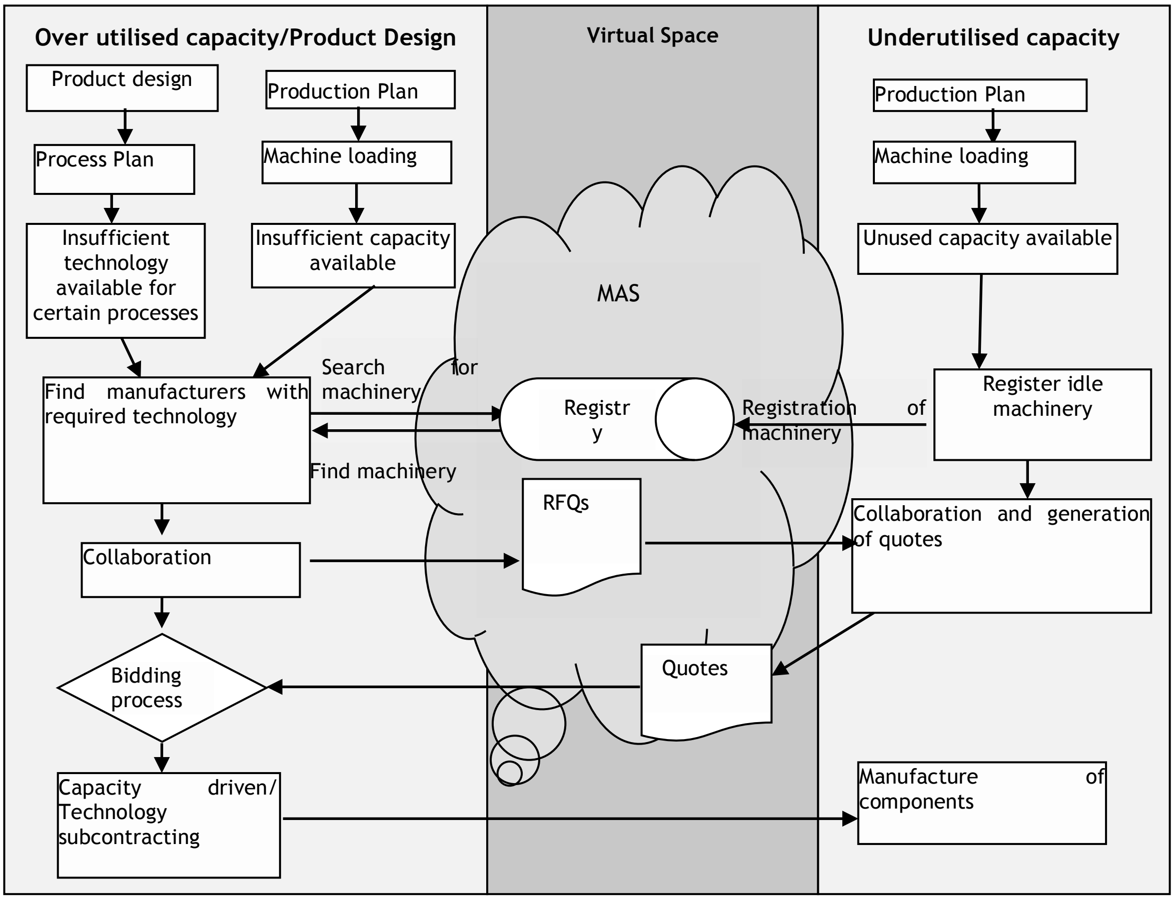

Figure 6 Framework for Capacity and Technology Driven Subcontracting

8 RESOURCE AGENT

The physical hierarchy for the resource agent is shown in Figure 7. The agent consists of three main modules: Machine schedule Module, Maintenance module and Communication module. The machine schedule module contains the machine schedule updated by the Job scheduling agent and maintenance module. The job agent determines the availability of the machinery from the scheduled workload for the machine. The maintenance module determines the probability of the availability of machinery from the maintenance point of view. The communication module enables the resource agent to communicate with the other agents in the multi agent system. The functionality diagram for the resource agent is shown in Figure 8.

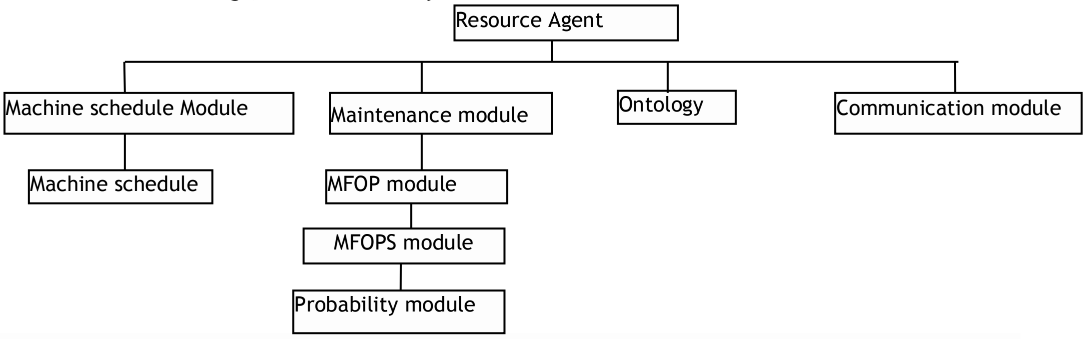

Figure 7 Physical hierarchy for the resource agent

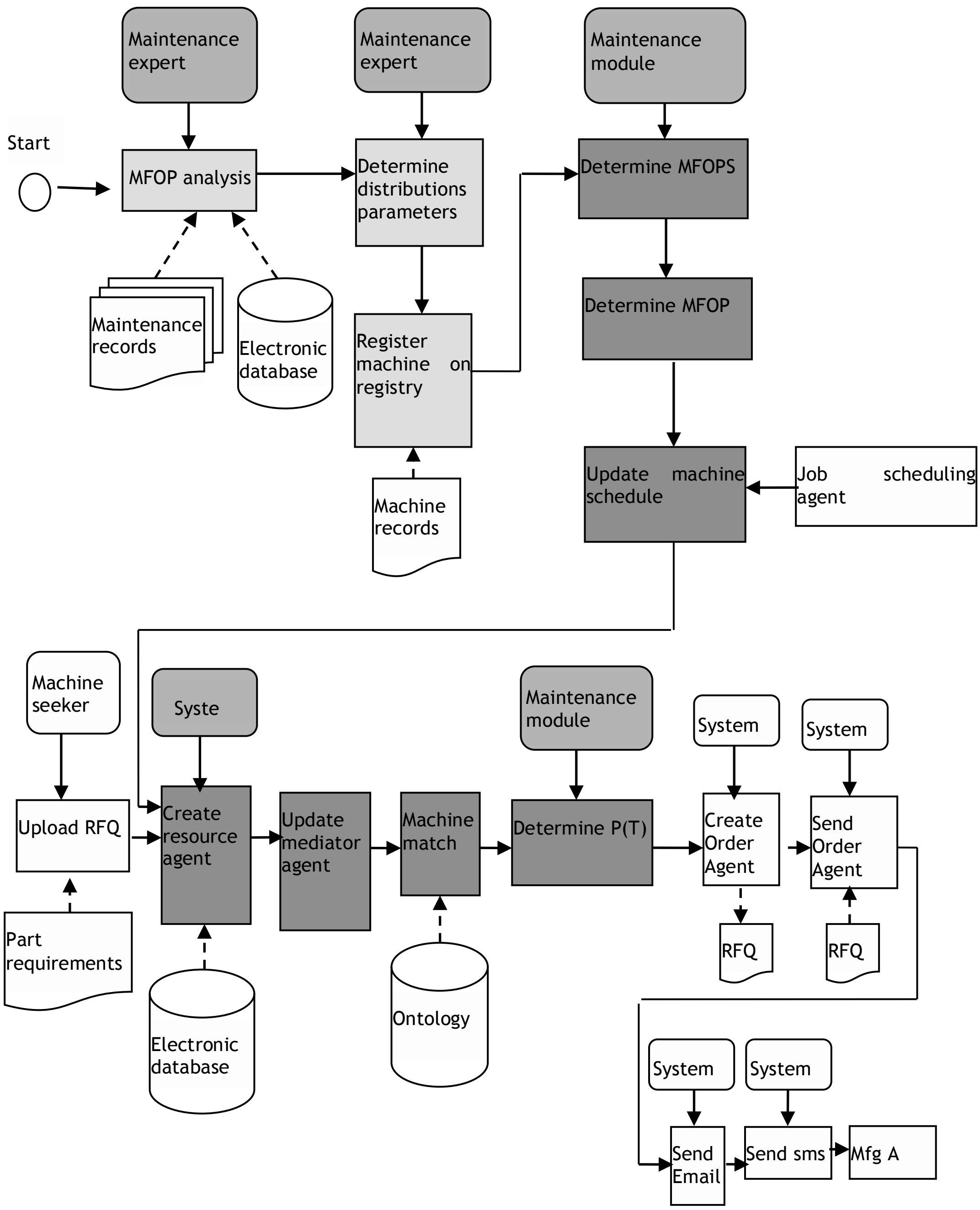

Figure 8 Functional Flow Diagram for Resource agent

A maintenance expect in the company will be responsible in carrying out the MFOP analysis in order to determine the using historical of machine maintenance. Data trends, MFOP and MFOPS will be determined as shown in Section 5.2. The distribution of MRP is sought and the alternating recovery theory discussed in Section 4 is used to determine the probability function of machine availability with many MFOP cycles. The MFOP analysis is used to update machine schedule developed by the Job processing agent by removing the machine workload where the machine is under MRP. When a Request For Quote (RFQ) has been raised a resource agent is generated. It updates the Mediator Agent (MA) on the states of machine availability during the period the machine is being requested. If the machine will be available at the time of request the machine is made available on the ontology to for process and machine matching. The probability of machine availability is calculated and the information is passed on to the Order Agent and then sent to the Manufacturability Agent (Mfg A). The machine selection process is represented by the process definition in an extended Business Process Modelling Notation (BNMN) shown in Figure 9.

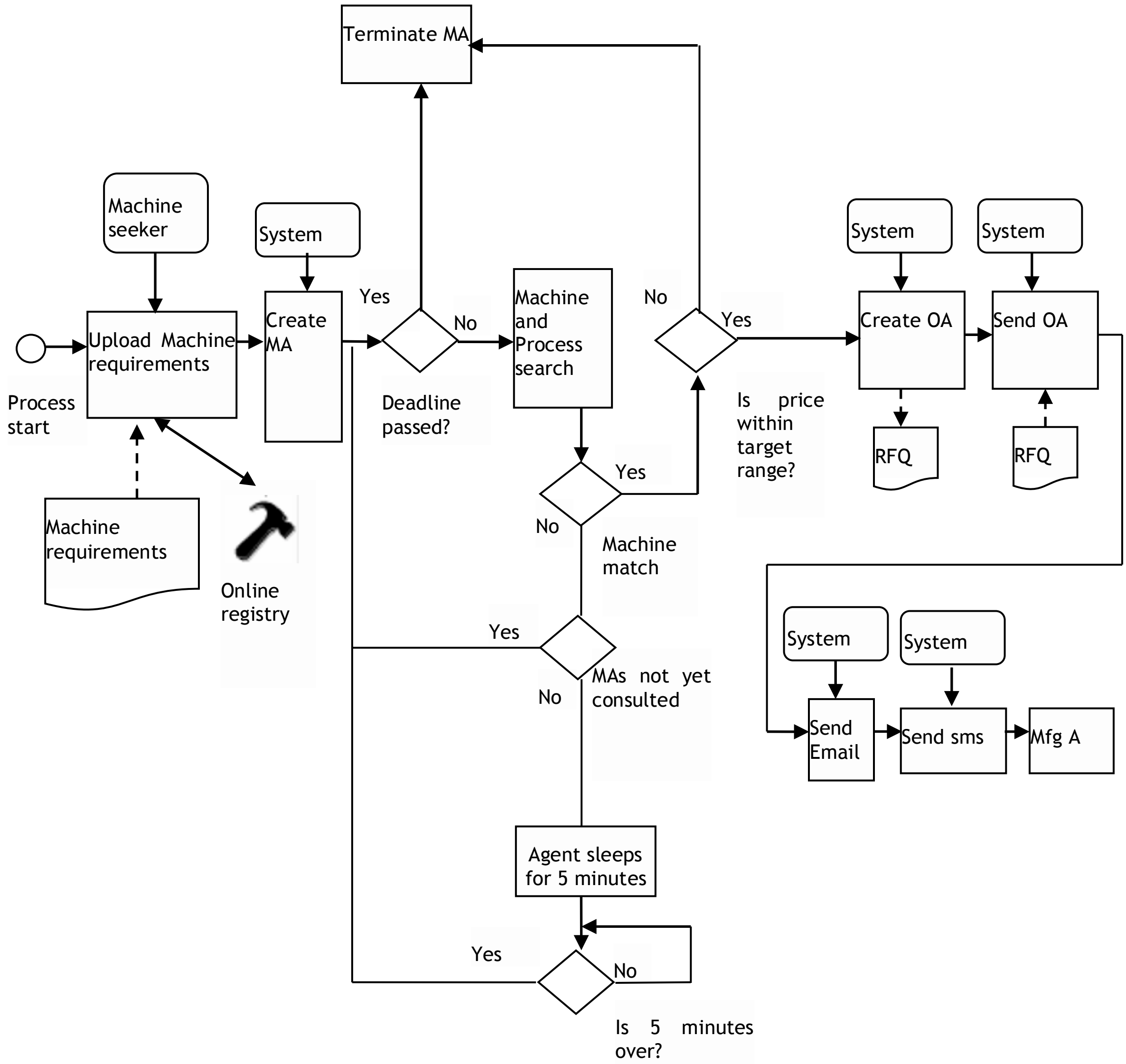

Figure 9 Machine and Process definition in extended BPMN notation

9 CONCLUSION

The paper discussed a framework for a resource agent for a multi agent system of an e-manufacturing system. The MFOP and alternating renewal process methodologies were looked at. Unlike the MTTF which accepts that failure cannot be accurately forecast and avoided the MFOP gives the machine owner a guarantee that no unscheduled maintenance activities will be required during each defined period of operation. The MFOP and alternating renewal process methodologies are then used to develop a framework for the resource agent which seeks to predict the availability of machinery at a given time requested in a request for quote. The agent also updates the machine schedule generated by a job agent.

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TOWARDS ENERGY MANAGEMENT DURING THE MACHINING OF TITANIUM ALLOYS

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ABSTRACT

The manufacturing industry needs to address challenges as regards to the machining process in the multifaceted context of sustainability. The current cost of energy and the reduction in material reserves highlights the need for machining systems to be more energy-efficient. This paper aims to provide a systematic overview of advanced approaches to manage energy and resource efficiency in cutting operations. The research experimentation focuses on the machining of a selected titanium alloy, Ti6Al4V, using carbide cutting tools. Tool wear, chip formation, cutting force and energy use were measured and analysed for selected cutting parameters. The experimental results illustrate the importance of selecting optimum cutting parameters and machining strategy. The results further help to define the boundary conditions for the various input parameters. Future research is also discussed.

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1 INTRODUCTION

Energy efficiency of production systems, especially machining operations, is becoming increasingly relevant and is a key focus of all developing nations [1]. The growing demand, and continued rise in the value of energy, serve to emphasise the importance of enhancing the energy and material-related efficiency of all manufacturing processes. Efficient energy management therefore forms an integral part towards sustainable production systems [2]. Optimising machining processes will also significantly help to address the sustainable manufacturing requirements set by various governing bodies. Efficient energy management also helps to cut the operational costs of manufactured products and to reduce the ecological impact [3].

Titanium alloys are subdivided into *α*-alloys, *β*-alloys and *α*/β-alloys. These alloys form part of the light metals group, due their low density of ρ = ±4.5g/cm^3. These alloys also display elevated high temperature strength and can therefore be used at temperatures [4] up to approximately 600°C. This temperature is much higher than the 350°C considered as the operating temperature [5] of a typical application such as compressor blades for example. Titanium alloys are used in the aerospace and biomedical industries, due to this exceptional strength-to-weight ratio and superior corrosion resistance [6]. In general titanium alloys are also characterised by a low thermal conductivity of λ = ±7W/m.K, combined with a high melting point (1650°C). These properties lead to high cutting temperatures [5] at the tool's cutting edge during machining. Ti6Al4V (Grade 5) is the most specified high strength titanium alloy currently used and was therefore selected for use during the current experimental work [8]. According to the material certificate the specific alloy used has an ultimate tensile strength of 969 MPa, a fracture toughness of 100 kJ/m^2 [7] and yield strength of 847 MPa.

Many of the same superior properties that enhance titanium's appeal for most applications also contribute to its being a challenging material to machine. The material's machining difficulties can be divided into thermal and mechanical tool demands. Chemical or more accurately 'tribo-chemical' wear may be considered a thermally activated process, whereby the Ti-alloys and tool material react in such a manner as to remove material from the tool on an atomic scale [9]. In High Speed Machining (HSM) the cutting tool mostly fails catastrophically, due to chipping preceded by extensive crater wear. In High Performance Machining (HPM) the cutting tool typically fractures, when the mechanical load exceeds the physical properties of the tool material. The mechanical demands include the chip load and the influence of different types of vibration.

The recommended cutting speeds (v_c) for titanium alloys are typically 30m/min and up with high-speed steel (HSS) tools and over 60m/min with carbide tools. These low cutting speeds may lead to reduced productivity [10]. This is aggravated by the fact that Titanium alloys have a melting point of 1650 °C/1930 K which concentrates high cutting temperatures [11]; at the tool - work piece interface. Furthermore, Ti-alloys have high temperature chemical reactivity with most known cutting tool materials such that at temperatures in excess of 500^{o}C it displays sufficient chemical stability to exhibit low wear rates, low thermal conductivity (K_{Ti} = 7.3 W/mK versus K_{Steel} = 50.7 W/mK) and low modulus of elasticity [8].

Figure 1 illustrates the various levels available for energy management in manufacturing systems. It also shows the input and output between levels and focuses on the energy transformation at process level. Electrical energy is supplied to the CNC lathe and converted in kinetic energy that is used to cut the material at different cutting speeds and feeds and; move the conveyer at a constant speed. At the same time energy is used to supply lubrication at the cutting interface to transport the heat from the cutting tool and to reduce friction.

During the cutting operation at process level the kinetic energy is transformed into various energy outputs. Cutting is a process of high localised stresses and extensive plastic deformation and shearing, in which the high compressive- and frictional contact stresses on the cutting tool, result in the various cutting forces. The specific energy required to produce the chip is a function of the mechanical energy to produce shear in the work piece and the frictional energies consumed by the chip tool interaction on rake and flank faces of the tool. During this transformation a significant fraction of the energy in the form of heat is transferred to the chip and tool from the shear-plane- and tool-chip interface respectively. This interaction between the cutting tool and work piece at different cutting conditions also affects chip formation, surface quality of the work piece and tool wear.

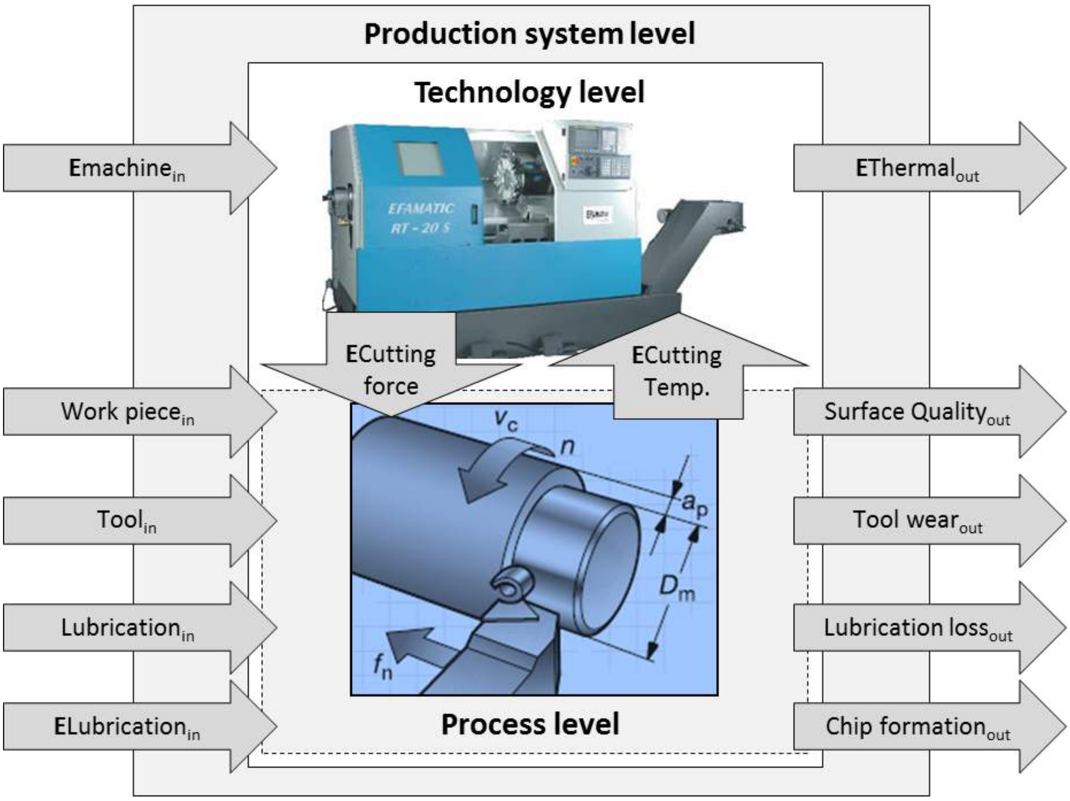

Figure 1: The input and expected output at different levels of a machining operation that effects energy management [2]

The main objective of this research is therefore to investigate this interaction and transformation to eventually be able to optimise the machining process with regards to energy efficiency for machining in general but more specifically for the machining of titanium alloys.

2 CURRENT UNDERSTANDING OF MACHINING TITANIUM ALLOYS

Machining is an important manufacturing process and is mostly involved where high precision components are required [12, 13]. Machining is one of the main cost drivers of manufactured products, especially when hard-to-machine materials (e.g. Ti-alloys) are formed. The cost of titanium alloy components is increased further because of the common practice in the aviation industry of overall material removal rates in excess of 90%. Tribo-chemical and impact related wear mechanisms are important aspects that tool materials need to deal with. Titanium's chemical reactivity becomes problematic at temperatures above 500˚C. Apart from diffusion wear, it has a strong affinity to adhere (weld) to the tool cutting surface. Once a built up edge develops, tool failure follows rapidly [14]. Tool failure can be initiated by one or a combination of several types of wear, which in an advanced stage usually leads to failure [15]. Further challenges may arise when other important production factors, as displayed in Figure 2, are taken into account. Productivity will always be a compromise between tool life and the material removal rate (MRR) and the manufacturers need to utilize HSM and HPM effectively and efficiently.

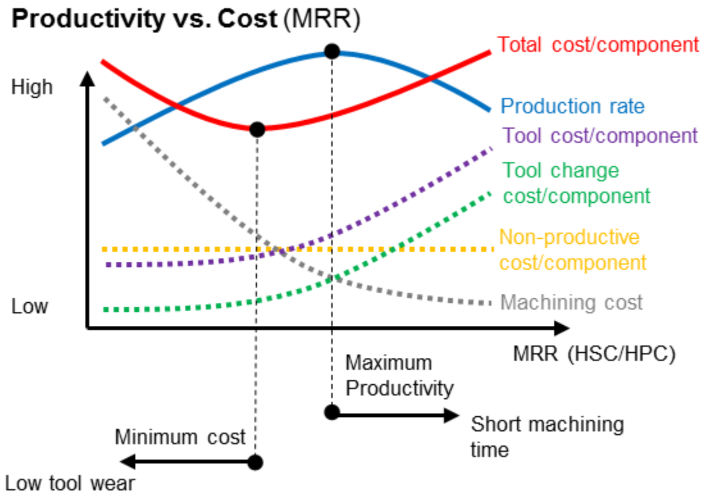

Figure 2: The trade-off between tool life and material removal rate to increase productivity

Figure 3 illustrates the effect of varying cutting speed (thermal load) on various productivity parameters with the eventual goal of optimizing energy use [16]. One of the important objectives is to increase the v_c as high as possible without adversely affecting the surface integrity of the Ti-component. Surface integrity (quality) refers to the outermost surface layers of a machined component. It consists of topography effects such as surface roughness (R_a), changes in the metallurgy (phase transformations and inclusions) and the introduction of other surface layers such as oxides and contaminants. Mechanical effects such as voids and cracks and deformation layers that induce mechanical property changes (typically hardness) also play a role. Since Ti-alloys are used in the aerospace industry the characteristics of the machined surface have to conform to aerospace regulations [17]. If the work piece is exposed to oxygen and nitrogen at high temperature (high v_c), these elements will diffuse into the base material and make the components brittle.

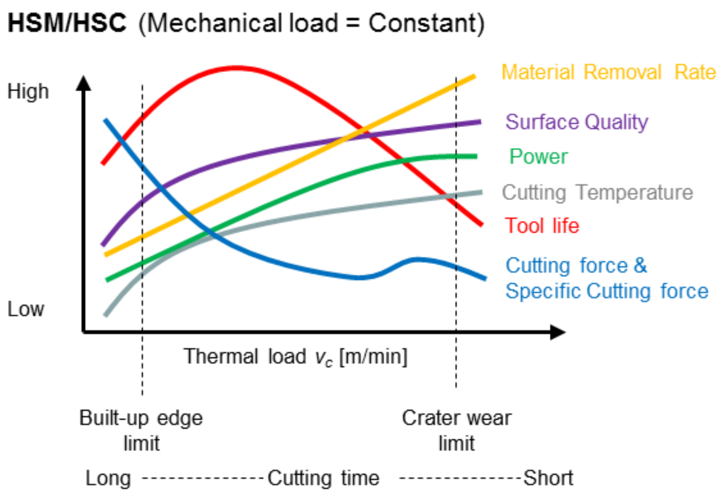

Figure 3: The effect of thermal load (cutting speed) on various productivity parameters (Adapted from [16])

The cutting tool will fail catastrophically when the cutting speed (v_c) is too low due to chatter and/or the effect of increased cutting force due to diminished thermal softening; or when v_c is too high due to chipping preceded by extensive crater wear. Figure 4 illustrates the effect of a varying chip load (mechanical load) on various productivity parameters [16]. Cutting forces are mainly determined by the maximum un-deformed chip load, the cutting speed (v_c) and the average flank wear (V_B). Still, little consideration is given with regards to an energy perspective.

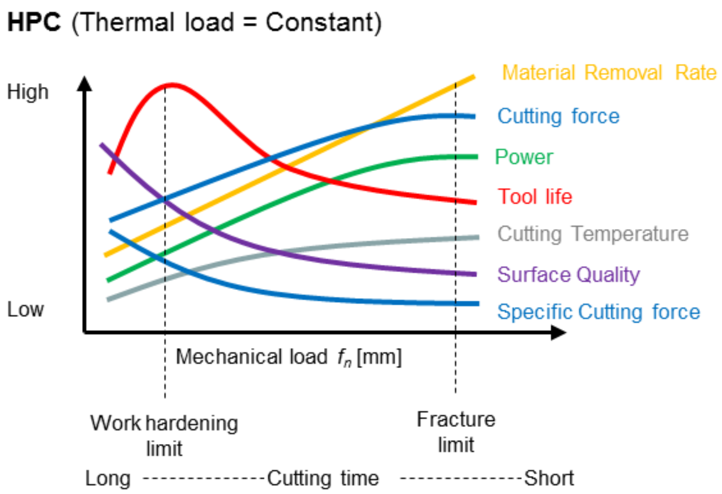

Figure 4: The effect of mechanical load on various productivity parameters (Adapted from [16])

The specific energy as related to cutting may be determined by a number of approaches as summarised in Figure 5. Specific energy is used as the fundamental indicator of energy efficiency in machining [18]. The most effective indicator of green machining lies in the consideration of the total energy used by the machine tool and necessary auxiliary equipment in relation to the volume of total material removed (in effect is specific energy).

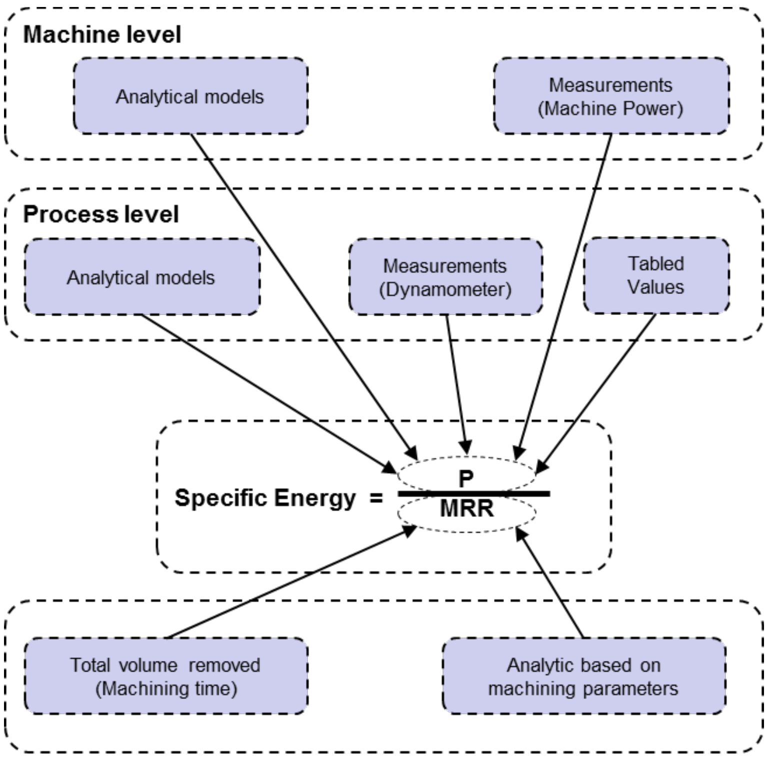

Figure 5: Various approaches for defining Specific Energy [18]

A process level specific energy definition necessitates an efficiency (ή) factor for the machine tool that needs to be taken into account. The specific energy may therefore be defined relative to cutting force (F_c), power (*P*) and total energy (*E*) [18]:

$$U_1 = \frac{F_c}{b * t} \quad (1)$$

$$U_2 = \frac{P}{MRR} \quad (2)$$

$$U_3 = \frac{E}{V} \quad (3)$$

Where U_i is the specific energy, F_c the cutting force, b is width of cut, t is feed rate, *P* is power and MRR is Material Removal Rate. The total energy definition (eqn. 3) tends to be the most comprehensive as it encompasses the total energy (*E*) and relates it further to the total volume (*V*) of material removed. Segmented chips are semi-continuous and saw-toothed in appearance. It is usually closely associated with difficult-to-machine metals such as titanium alloys or machining at high cutting speeds [24]. Segmented chip formation is believed to be due to adiabatic shear band formation which is caused by the localized shear deformation resulting from the predominance of thermal softening over strain hardening [19]. Strain softening has been introduced in a flow stress model in order to explain the segmented chip formation [21]. Serrated (segmented, inhomogeneous) chips have zones of high and low strain and occur in metals with low thermal conductivity and strength that decreases sharply with temperature [22]. The heat generated and dissipated in segmented chip formation is illustrated in Figure 6. Periodic crack initiation at the free surface of the work material ahead of the tool and the subsequent propagation pathway toward the tool tip may also have a role to play in the formation of segmented chips [20].

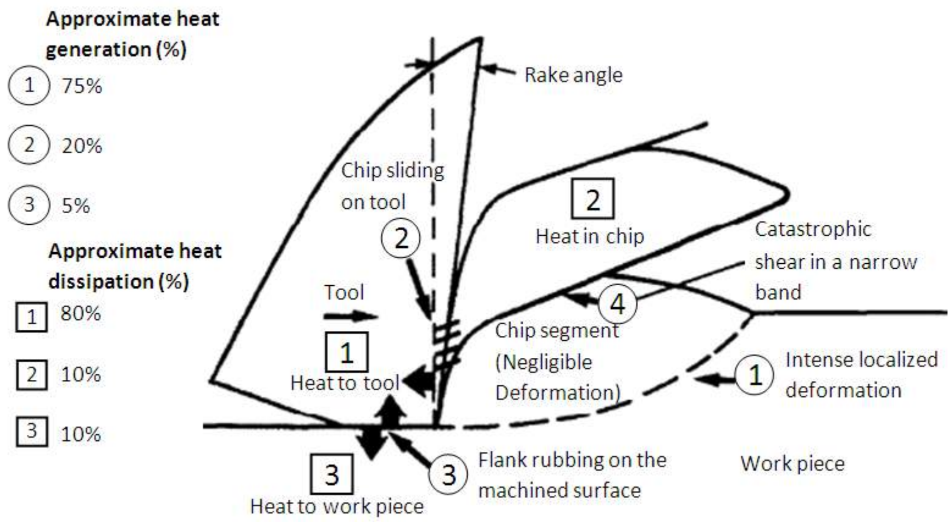

Figure 6: Segmented chip formation: Heat generated and dissipated in segmented chip formation (Adapted from [23])

Segmented chips may also be formed when hard brittle materials are machined at high speeds and feeds [20].

3 EXPERIMENTAL SETUP AND DESIGN

Turning experiments were performed on an Efamatic CNC lathe (model: RT-20 S, Max. 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 (see Figure 9). 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 data acquisition system was used to the output the data to a windows based personal computer via USB.

Figure 7: Dynamometer data acquisition

A solid carbide tool (CNXMX 12 04 A2-SM with coating) in 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 180 mm long). The work piece chemical composition and mechanical strength characteristics (as per materials certificate) are presented in Tables 1 and 2 respectively.

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***

Mechanical Characteristic	Treatment Condition	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Reduction of Area (%)
State/Value	Annealed	969	847	13	28

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. To conform with the ISO Standard 3685-1977 (E) for single point turning tools a wear criterion of V_B=300 μm [25] was used for all the machining experiments.

Tool wear was observed and measured using a Mitutoyo Optical tool makers 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 and read off an Acer Aspire 5551 Laptop running on Windows 7. The experimental set-up is shown in Figure 8.

Figure 8: Experimental set-up

4 EXPERIMENTAL RESULTS AND DISCUSSION

Optical measurements of the tool wear and chip formation were taken at different cutting speed and feed rate conditions. Cutting forces were also monitored during cutting operations. The effect of cutting speed and feed rate on tool wear is graphically illustrated in Figure 9. The dominant wear mechanism was flank wear, followed by crater wear. As the cutting speed increased the crater increased on the rake surface of the tool. An increase in mechanical load (f_n) caused an increase in fracture mechanisms.

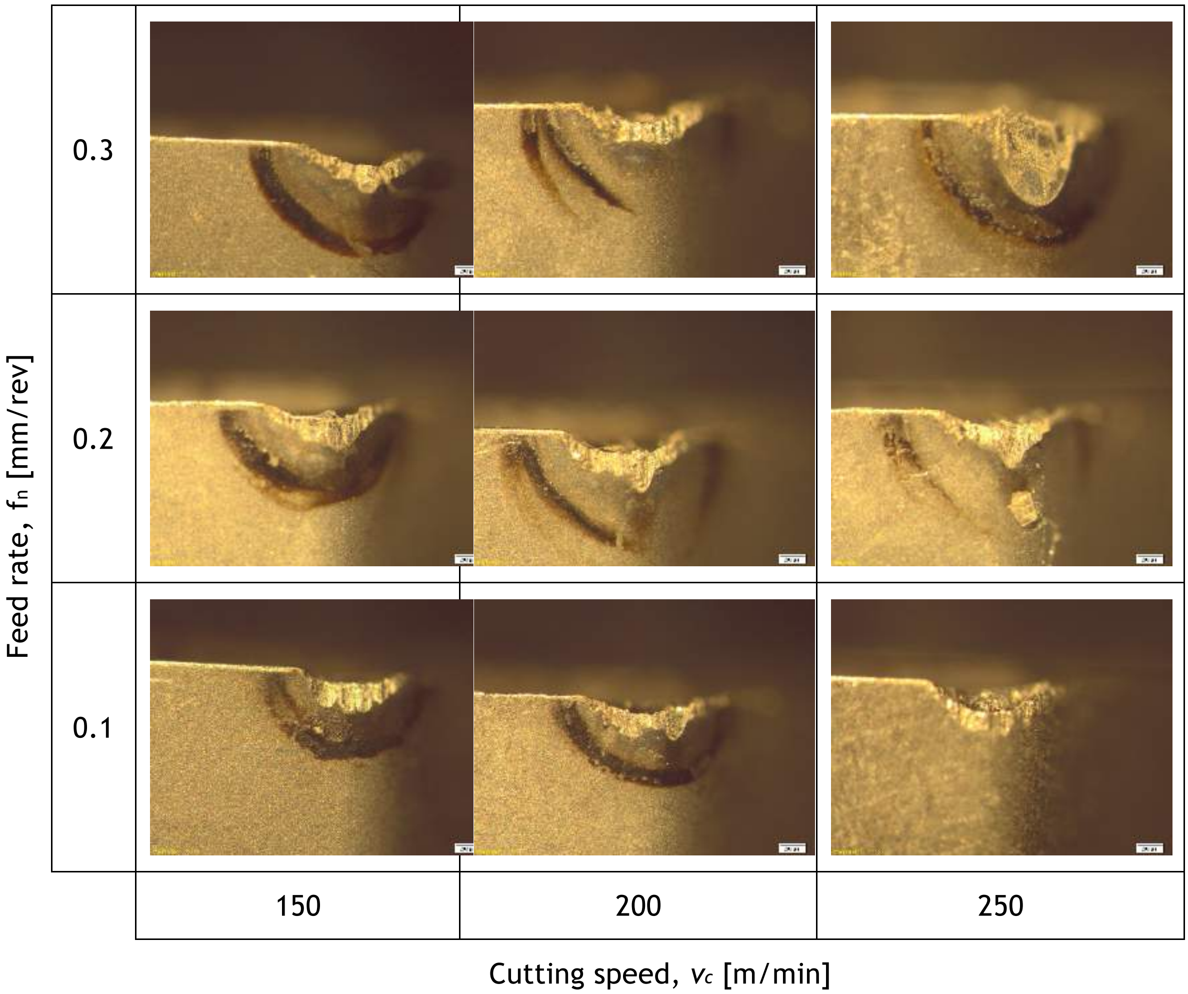

Figure 9: The effect of cutting speed and feed rate on tool wear

The total power consumption of the lathe as a function of cutting speed for the different feed rates is presented in Figure 9. This data was obtained during the first pass (l_m=170mm) and therefore assumes minimal tool wear. As expected the data clearly shows that an increase in cutting speed and feed rate leads to increased power consumption. Increasing the cutting speed and/or feed rate implies an increased material removal rate that will translate to an increased power requirement. These relationships are not linear. An increase in cutting speed from 100 m/min to 250 m/min implies an increase of 67% in material removal rate. The power consumption only increases on average for the three feed rates by 24%. The same is true for an increase in feed rate from 0.1 mm/rev to 0.3 mm/rev which imply a 200% increase in material removal rate but this only translates to an average increase in power of 27%. This clearly indicates the importance and effect that the ancillary support systems associated with the turning process on a typical CNC lathe has. These include the coolant system, overall mechanical losses (bearing friction etc.), electronic control, hydraulic drive system and the compressed air system. The energy usage associated with these is significant and remain largely constant during the machining operation.

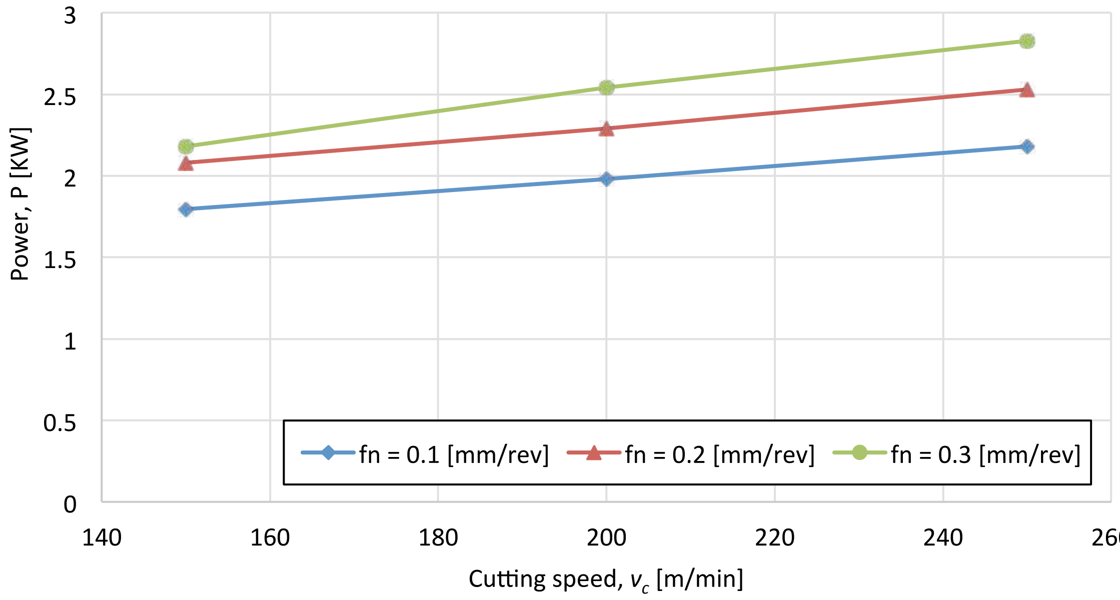

Figure 10: The effect of cutting speed for various feed rates on the measured power

The total energy consumed to cut one pass (length of cut, l_m=170mm) as a function of cutting speed and feed is displayed in Figure 11. The data clearly shows that energy use decreases 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 5.6 × 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. The data points towards possibly large energy savings related to high speed machining on typical CNC machine tools.

This is further emphasised in Figure 12 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.

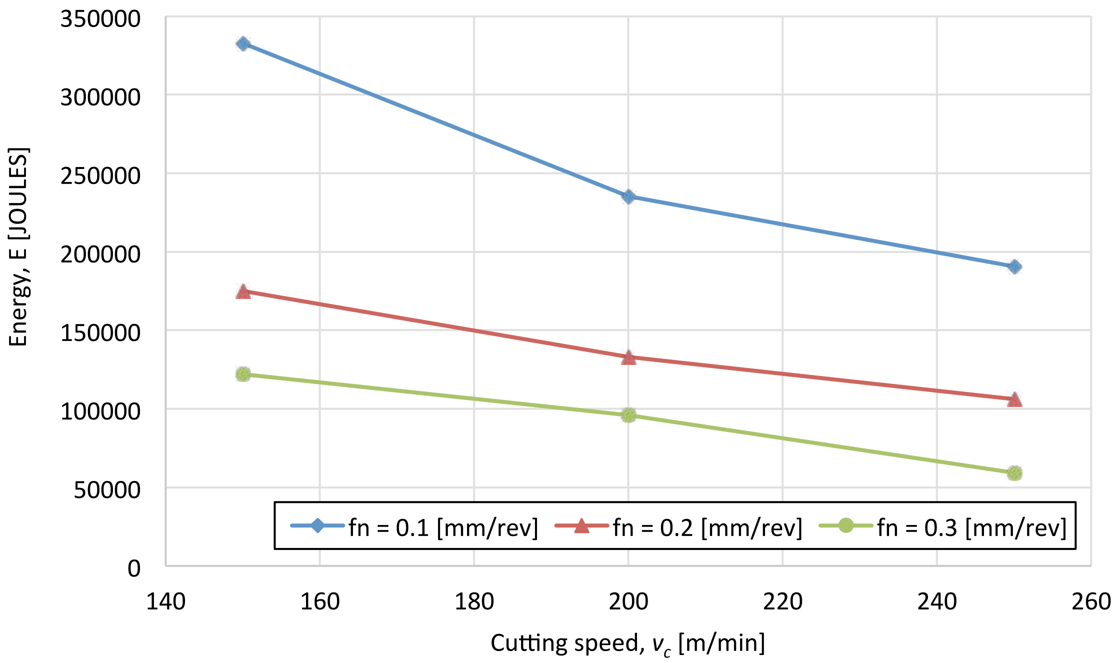

Figure 11: Total machine energy use as a function of cutting speed and feed rate to conduct one full pass (l_m =170 mm)

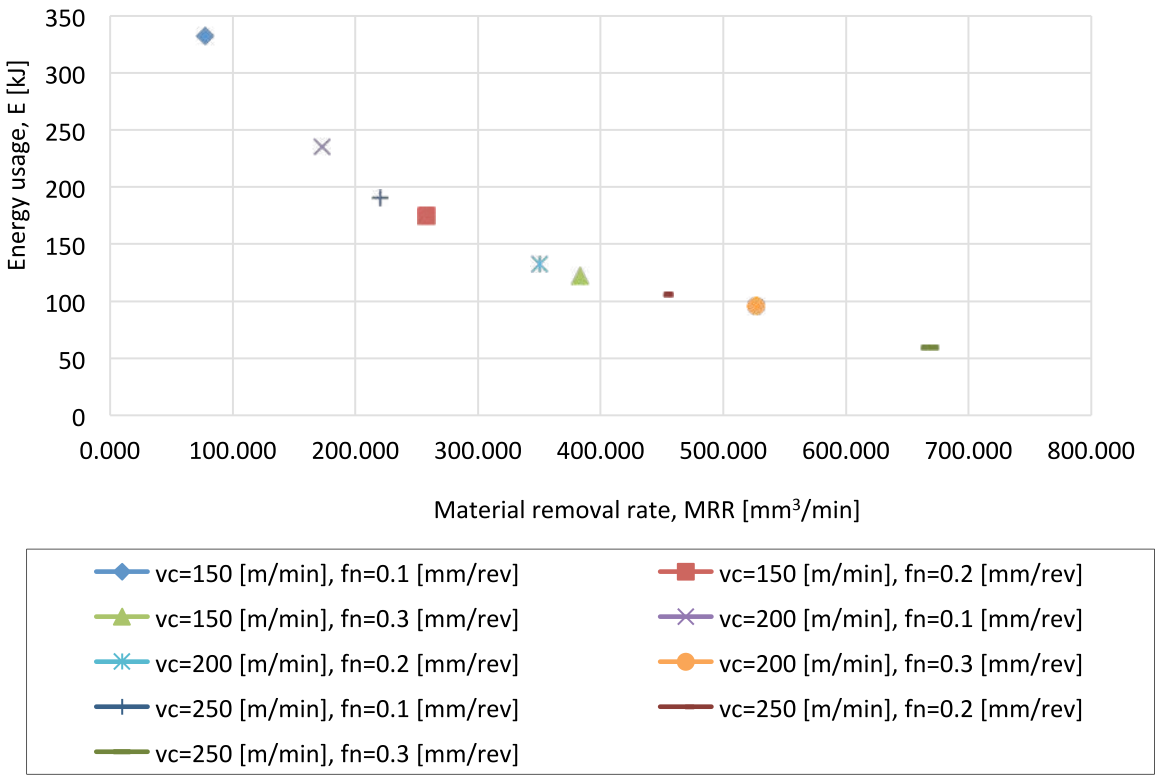

Figure 12: The effect of material removal rate on energy usage for different cutting conditions

The progression of flank tool wear as a function of cut length for the various cutting parameter sets investigated is presented in Figure 13. The data clearly show that tool wear is strongly influenced by the cutting speed and feed rate. An increase in either cutting speed or feed rate increases the tool wear rate. An increase in cutting speed increases the thermal loading by essentially increasing the rate of heat generation and therefore leads to higher tool-work piece interface temperatures that increase the tool wear rate.

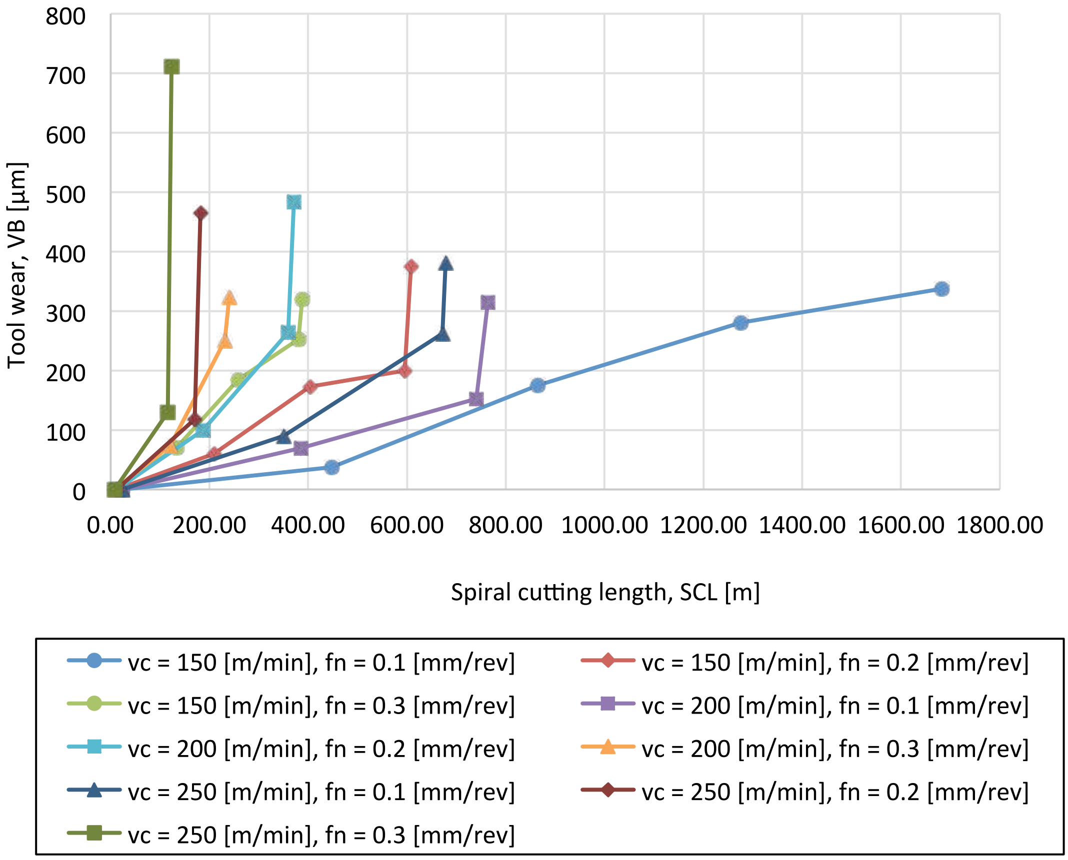

Figure 13: The spiral cutting length until a tool wear of V_B=300µm is reached for different cutting speeds and feed rates

These higher temperatures along with titanium's low thermal conductivity and high chemical affinity leads to increased localized welding and chip adhesion that increases the tool wear rates on the flank and rake faces. The same is essentially true for an increase in feed rate except that the higher thermal loading is now a function of the higher cutting forces induced by the higher feed rates. In both cases an increased thermal loading is induced that cannot be effectively controlled by the cooling technique (flood cooling) employed.

Micrograph images of the chip formation are presented in Figure 14. It shows mainly segmented chip formation with the chip segmentation frequency tending to increase with a decrease in the feed rate. Considering the images, cutting speed does not have a significant effect on the segmentation. As expected the width of these chips also increases with an increase in feed rate.

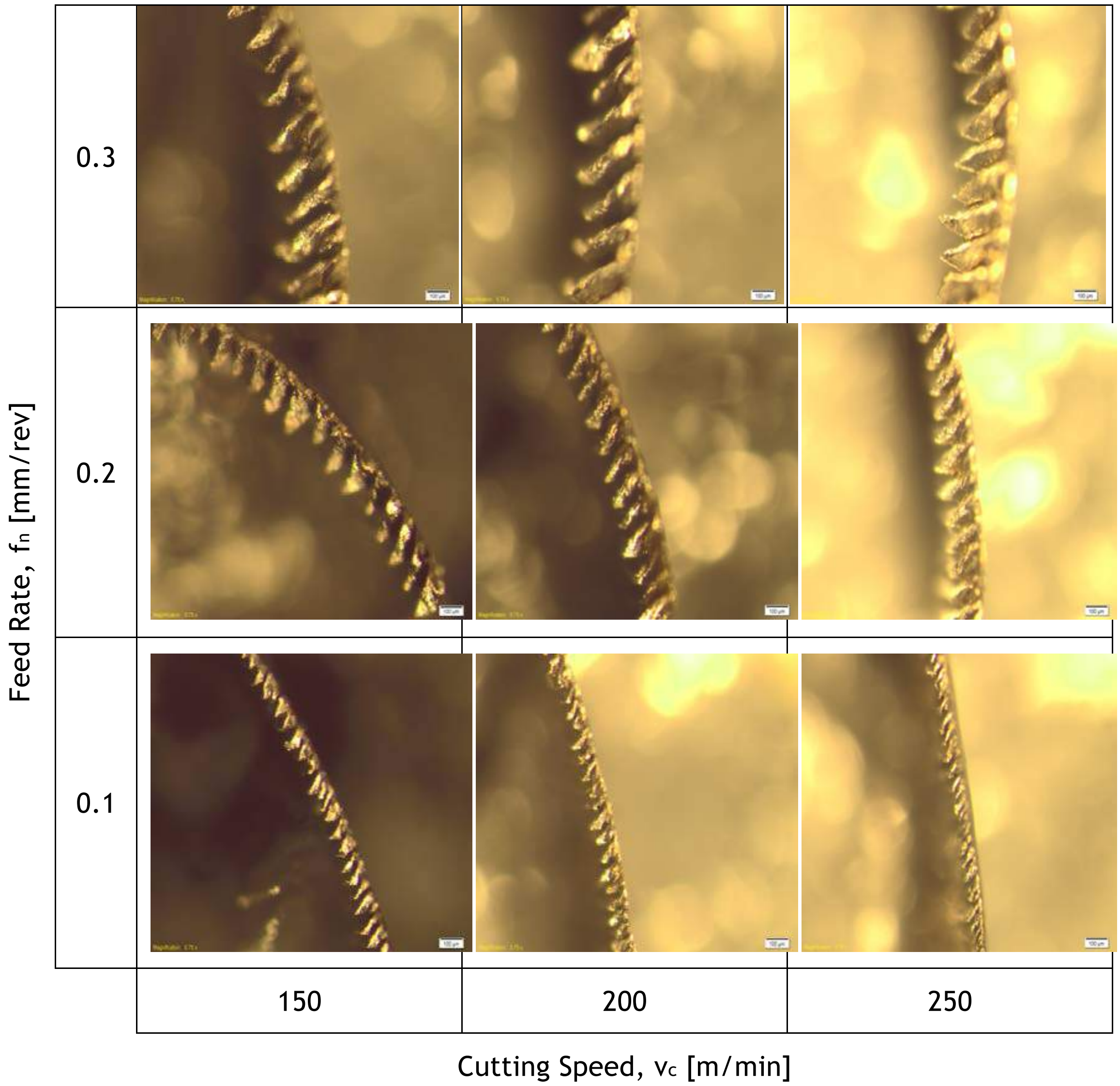

Figure 12: The effect of different cutting conditions on chip formation

Cutting forces were measured in 3 dimensions using the Kistler Dynamometer. Forces were measured normal and horizontal to the work in the depth of cut feed direction axis (F_x), parallel to the work axis (F_z) the cutting feed force and tangential to the work rotating diameter (F_y). Although the results are not published in this paper, the forces tend to increase with an increase in feed rate and display a small decrease with an increase in cutting speed.

5 CONCLUSION

The concept of energy management in machining operations is discussed. The research experiments focused on the machining of titanium alloys using carbide cutting tools. The experimental results illustrate the importance of selecting optimum cutting parameters and machining strategy. 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 with essentially 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. Further analysis of the experimental data and additional work aims to expand on the current investigation with the eventual aim of intelligent management of the machining process as far as energy usage is concerned. The experimental results show that there is significant scope for improved energy management during machining and more specifically during machining of Ti-alloys.

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MANAGEMENT AND CONTROL OF COMPLEXITY IN CLUSTERING FOR VALUE CREATION IN SUSTAINABLE SOCIETIES

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ABSTRACT

The global production challenges we face need to be addressed in the multifaceted context of sustainability. Startup enterprises need to be both creative and innovative in order to survive and realize growth. Production clusters are usually formed as a result of common geographical location and/or similar economic activity. Clustering can support distributed manufacturing incubators to overcome social, economic and technological challenges through sharing resources. As these clusters must contribute socio-economically to its community, without compromising the ability of future generations to meet their own needs, complex systems exist. The aim of this paper is to encourage ourselves to direct our research towards concepts which reduce production complexity and support simplicity. This research evaluates several production clusters toward sustainable value creation in developing communities. Key elements of a clustered based growth framework are identified to support manufacturing incubators in South Africa.

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1 INTRODUCTION

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. South Africa is facing severe poverty levels especially in underdeveloped regions. Manufacturing is seen as the sector which could create work, but it requires innovative development concepts.

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. Therefore, manufacturing deserves strong and continuous endeavor of all actors in a modern society to ensure prosperity, better life and sustainable development [3].

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].

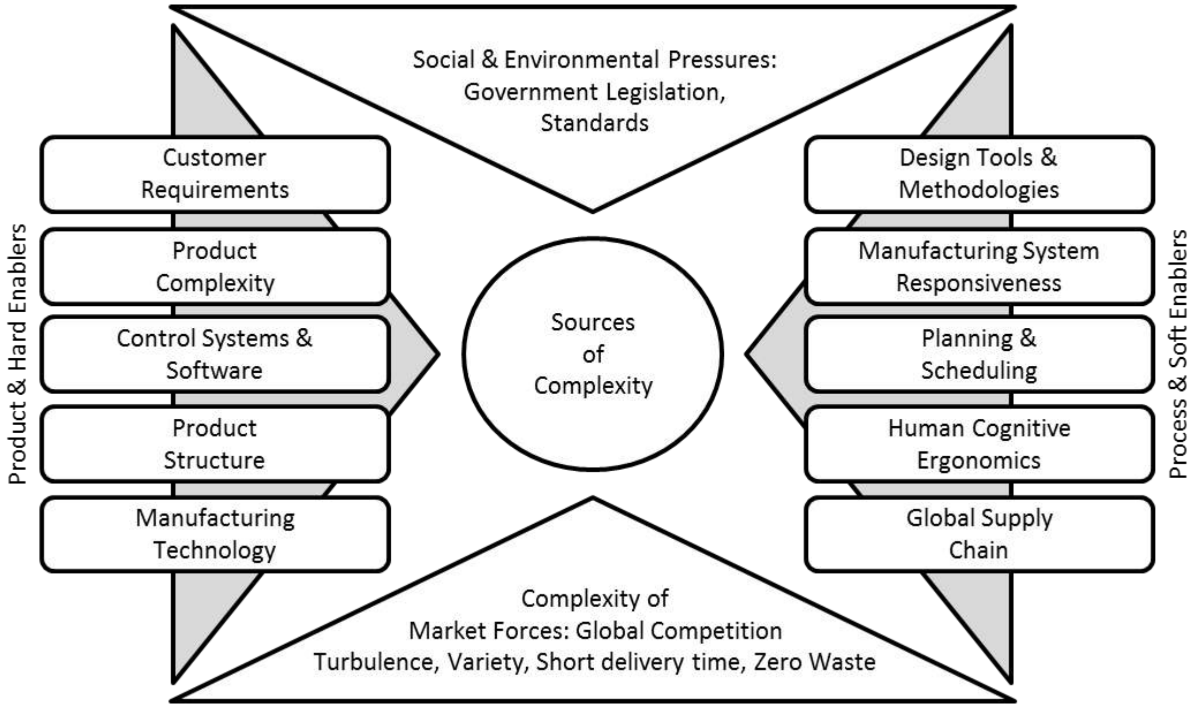

Figure 1: Drivers of manufacturing complexity (Adapted from [5])

Business incubators 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) [6] defines the business incubator as a dynamic process of business enterprise development. Its main task is to support development of supported small and medium-sized enterprises (SME's), by providing management services and financial resources. The wider task of the incubator concept would be to support macro-economic related (e.g. employment) and micro-economic related (e.g. implementation of technology) objectives.

In the 1950's a very large industry in New York (US) closed down, leaving vacant a complex of multistory buildings with a total area of almost 80 000 m^2. The building was then successfully divided into smaller units to house new entrepreneurs. One of the first tenants was a chicken processing company, thus the origin of the name "incubator" with this successful model of promoting SME development [7]. The United Nations Industrial Development Organization (UNIDO) also adopted this incubator model in order to create a support environment for entrepreneurship to expand SME's in developing countries [8]. 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.

The concept [3] of Open Collaborative Manufacturing (OCM) incubators include infrastructure in community centres designed to support the development of visionary entrepreneurs, using an array of support systems. These are developed and orchestrated by management and offered both in the incubator and through its network of open design contacts [3]. The core part of an OCM incubator is its ICT infrastructure, which facilitates the creation, operation, and eventual disintegration of the virtual organisations it contains. The OCM incubation concept can also be integrated into the country's national innovation system as proposed by [9]. A consortium approach with a stage-gate management model is proposed as illustrated in Figure 2 [3]. Thereby, a clustered-based support system can manage progress of specific tasks, where the decision is based on the information available at the time. Clusters and innovation networks are promising and powerful instruments in promoting research and development, which in turn supports productivity and can create work opportunities.

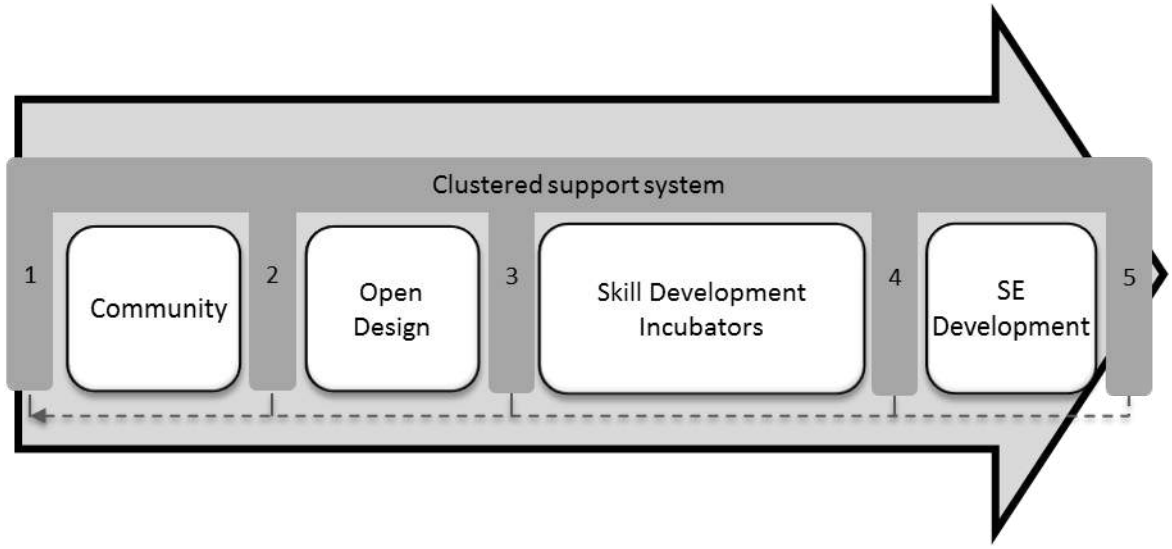

Figure 2: Building blocks for OCM incubators with the proposed clustered based support system managing the stage-gates elements (Adapted from [3])

In this favourable ecosystem, innovative enterprises can flourish by interacting with different innovation actors and across sectorial boundaries [10]. 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 [4]. 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. 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 [10].

Current success stories in the US include the Silicon Valley and Massachusetts's *Brainpower Triangle* clusters. Both are in close proximity to well established technology institutes. The collaboration of small and medium enterprises (SME's) with each other and the research sector can be seen as an opportunity to renew the economy and the society [10]. 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 [11]. 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 [12].

In Europe, the clustering policies towards cluster development are generally issued by national governments, with the co-operation of regional or local governments. National authorities focus on designing and coordinating cluster policies to create the general framework conditions and developing research and development programs [13]. Still, clusters are geographic concentrations of interconnected companies and institutions in a particular field that compete and collaborate at the same time [11]. 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.

In Sub-Saharan Africa (SSA) the South African Petrochemical cluster around Sasol near Witbank, is one of the most successful clusters [14]. This cluster supports various industries and downstream linkages were created. Around East London and Uitenhage (Eastern Cape in South Africa), the motor vehicle industry cluster that exists produced around 40% of the country's vehicle output [14].

The establishment of international cluster policy collaboration bodies and benchmarking of cluster organisations and programmes helped to develop these policies significantly [10]. Although scientific methods (e.g. agent theory, neural network, genetic algorithms, fuzzy logic [15, 16]) 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. This research evaluates several production clusters in developing communities to identify key elements for a clustered based growth framework that can support manufacturing incubators in South Africa.

2 CASE STUDIES ON CLUSTERED BASED PRODUCTION

The methodology used in this research was a case study review. This involved reviewing several cases from different parts of the world. Thereafter, it was decided to specifically focus on developing countries where complexity has been managed. 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.

2.1 The Suame manufacturing cluster in Ghana

The Suame cluster site was created in the 1950's when its entrepreneurs were relocated by the Kumasi City Council. A key turning point in the cluster's history occurred in the mid-1970s, when the government placed tight restrictions on the importation of new vehicles and parts [17]. This crippled large enterprises, which were capital-intensive and relied on imports. Small enterprises filled the gap by producing the spare parts that had been previously imported. Though the importation of spare parts and even whole vehicles resumed under the Economic Recovery Program in the 1980s, large enterprises did not regain their previous dominance [18].

According to research [19] the adoption of basic technologies and relatively complex machinery such as tool-making machines has raised the engineering capability of companies. The assistance rendered by the Suame Intermediate Technology Transfer Unit (ITTU) of the Technology Consultancy Centre (TCC) increased the number of machine tools. The ITTU was established by the government of Ghana to raise the technical competence of the cluster by providing technology advisory services and machinery upgrades. There is a development from recent studies that the trade in engineering materials and spare parts was more profitable than manufacture and repair work [19].

The market of the Suame cluster currently includes the government, private companies and individuals. The products of its enterprises are also popular in other West African countries such as Burkina Faso, Cote d'Ivoire, Mali, and Togo. 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) [19]. The government of Ghana has also come up with policy incentives to support the growth of the cluster. The products and services of the Suame cluster are shown in Table 1.

Table 1: Products and services of the Suame Cluster [19]

Major Sectors	Products and Services
Manufacturing	Food-processing equipment and farm implements; cooking stoves and utensils; foundry products. Metal fabrication and plant construction; angle irons, channel iron bars.
Sales	Sheet metal, bars, iron rods, steel sections, hand tools, fasteners, electric motors, pumps. Second-hand engines and parts; car-decorating materials. Foods and beverages of all kinds.
Maintenance	Engine overhauling; auto electric works; vehicle interior upholstery; auto body work (straightening and painting).
Communication & business centres	Telephone and fax services, photocopying, computer typesetting; internet and e-mail services, mobile phone cards, barbering and sales of soft drinks.

The Suame cluster is one of the biggest in Africa, with a long history of craftsmanship and entrepreneurship. It has been the object of a sustained attempt to provide public support for small business development. The role of formal and informal associations has been important to the sustainability of the cluster [19].

In the early 1980s, the government launched a major national initiative to repair all state-owned vehicles, particularly those being used for transporting commodities such as cocoa and other food crops from the hinterland to urban areas. A new crop of young workers joined the cluster's labour force. The artisans of Suame and similar clusters were contracted to carry out the initiative using unsalvageable vehicles to repair others. This particular state policy led to the formation of the Ghana National Association of Garages, as a unified association of artisans. With its permanent national secretariat in the Suame cluster in Kumasi, the association later opened offices in Accra and other regional capitals to pursue its aims. The aspirations and needs of motor vehicle repairers have dominated the activities of both the Ghana National Association of Garages and the Magazine Mechanical Association in almost all clusters. By contrast, little has been done for manufacturing enterprises, or for enterprises that have upgraded their activities to manufacturing. To refocus the direction of metalwork manufacturers in the cluster, the clients of the Suame ITTU assembled in the late 1990s to form the Association of Micro and Small Metal industries. The aim of the association was to address the constraints and challenges faced by the metalwork manufacturers [19]. Considering the available literature [17, 18, 19] and data, influential governmental support to the Suame cluster are shown in Table 2.

Table 2: Strategic governmental support to the Suame cluster [17, 18, 19]

Commercialisation	Available Skilled Manpower	R & D	Intellectual Property Protection	IT Support	Venture Capital
	x	x	x		x

Since 2001 the challenges posed by globalization local economic hardship, and growing political awareness have diminished the effectiveness of the Ghana National Association of Garages and the Magazine Mechanical Association. It appears that the majority of enterprises began to favour regrouping into trades - foundry men, sprayers, auto electricians, engine reborers to promote their enterprises [19].

2.2 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. 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 [20]. Business activities carried out in the cluster were restricted to small and micro enterprises 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. During this period, the cluster served as the economic centre for burgeoning settlements. It 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 [20]. Considering the available literature [20] and data, influential governmental support to the Kamukunji cluster are shown in Table 3.

Table 3: Strategic governmental support to the Kamukunji cluster [20]

Commercialisation	Available Skilled Manpower	R & D	Intellectual Property Protection	IT Support	Venture Capital
x	x				

This cluster still enjoys a location advantage and the role of the Kenyan government in this cluster has been minimal. However, the government has been actively involved in the agricultural sector [21].

2.3 The Nnewi automotive components cluster in Nigeria

The Nigerian automotive and component industry is publically known to be important to the national economy. Few industries allow for self-manufacturing, or use so many different raw materials, tools, machinery, and equipment. Consequently, the automotive industry serves as a stimulus for the development of other industries (e.g. machine tool production, iron and steel, and transportation). In 2002 there were 12 automotive vehicle assembly plants, 5 of which are partially state-owned (e.g. Peugeot Automobiles Ltd., Lagos; Anambra Motor Manufacturing Co. Ltd., Anambra; Volkswagen Nigeria Ltd., Lagos; National Trucks Manufacturing Ltd., Kano; and Steyr Nigeria Ltd., Bauchi), the rest being privately owned. 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 [22]. Considering the available literature [22, 23] and data, influential governmental support to the Nnewi cluster are shown in Table 4.

Table 4: Strategic governmental support to the Nnewi cluster [22, 23]

Commercialisation	Available Skilled Manpower	R & D	Intellectual Property Protection	IT Support	Venture Capital
	x	x		x	x

The Nnewi automotive components cluster is made up of four villages - Otolo, Umudim, Uruagu, and Nnewichi. 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. Colocation is evident [23]. According to reviewed literature all the firms in the cluster obtained their Intellectual property technology from Taiwan [23].

2.4 Handicraft and furniture clusters in Tanzania

Micro and small enterprises (MSEs) are dominant actors in the economies of many developing countries, and even more so of the least developed countries, such as Tanzania. These enterprises accommodate a workforce largely characterized by low levels of education and skill. Major challenges include low productivity, lack of capital accumulation, and labour-intensive (though capital-saving) production [18].

In a research [18] it was established that although the Tanzanian government had tried different economic development models since the country's independence (1961) it recently recognized the potential socioeconomic contribution of MSE's. This policy change was justified by studies that estimate that one-third of Tanzania's GDP originates from the informal sector, and particularly from MSE's. According to the Informal Sector Survey of 1991, there were 1.7 million businesses operating in the informal sector and employing about 3 million people (20%) of the Tanzanian workforce.

The informal sectors were long neglected and therefore systemic and institutional issues tend to define the sector's vision. This include the heavy costs of compliance with government regulations and taxation standards, inadequate working premises, limited access to finance, lack of entrepreneurship skills, lack of marketing expertise and business training, low technology levels, and lack of information. There are also weaknesses in the institutional structures that support the informal sector, such as business associations. These are for the most part weak, fragmented, and uncoordinated. The sector also lacks clear policy guidance from government authorities [18]. In spite of these challenges, MSEs have survived over time and at times have even produced relatively good-quality products despite intensified competition following import liberalization.

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.

2.5 The Lake Victoria fishing cluster in Uganda

Fish processing and exporting are important to the economy of Uganda [24]. In 1997, the European Union (EU) applied to Ugandan fish exports a set of sanitary and phytosanitary (SPS) 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 standards, the industry was plunged into a severe export crisis, as fish processors were locked out of their largest and most lucrative market for three long years. At the time, the country was still recovering from a troubled past and remained dependent on a few traditional agricultural exports, notably coffee.

The processed fish were still the most important non-traditional agricultural export and therefore swift and decisive action to induce the European Union to lift the ban was imperative. The industry had no choice but to become compliant with the EU standards. This case proved to be an interesting example of a technologically weak cluster in Africa that overcame a serious challenge through networking, linkages, learning, and upgrading [24].

These clusters in Uganda are not all clustered in a particular geographical city or sub-region, but are found in several cities surrounding Lake Victoria. Of the 17 plants in the country, 10 are located near two major cities, Kampala and Jinja, the latter being about 80 kilometres east of Kampala. There are important locational differences between the Jinja cluster and Kampala cluster. While the distances between plants in the Jinja cluster are very small, three of the five firms in the Kampala cluster are located in different suburbs or parts of the city, for a total cluster area of more than one square kilometre. The Kampala-Entebbe sub-region (3x plants), and the Masaka-Kyotera sub-regions (4x plants), may also be considered agglomerations.

Clustering is often associated [25] with four key advantages for members, namely: market access, labour-market pooling, intermediate input effects, and technological spill-overs. All fish-processing firms in Uganda have had to provide intensive training for their workers to create a pool of local skills in factory-based fish preparation. The establishment of that skill base has benefited both new and old firms in the clusters, both through labour mobility and through the diffusion of ideas often associated with the routine interaction of workers. However, the clusters are marked by an acute absence of workers highly skilled in the more sophisticated aspects of fish processing. Considering the available literature [18, 24, 25] and data, influential governmental support to the Lake Victoria Fishing cluster are shown in Table 5. For more complex tasks such as product development, some firms have obtained technical expertise from buyers and other experts outside Uganda, as such skills are unavailable locally [24].

Table 5: Strategic governmental support to the Lake Victoria fishing cluster [18, 24, 25]

Commercialisation	Available Skilled Manpower	R & D	Intellectual Property Protection	IT Support	Venture Capital
	x		x		

Formal technical and vocational institutes in Uganda have not provided adequate numbers of graduates qualified in industrial food processing. For their personnel needs, therefore, firms have relied on in-house training, usually of persons with only a few years of formal schooling. An additional benefit of clusters is that they often induce the emergence of suppliers who benefit from dealing with a group of customers located near one other. Suppliers sometimes even receive support from their customers. Both phenomena have been observed in Uganda’s fish-processing clusters, but those benefits have been undermined by the failure to resolve the problem of reliance on a natural resource that cannot be harvested limitlessly. Research–industry linkages in fish processing are scarce even where research institutes can be found near the clusters [18].

2.6 The Textile and clothing sector in Mauritius

Over the last three decades Mauritius has recorded impressive economic achievements that have improved the living standards of its citizens, modernized the nation, and provided a window into the developed world. Mauritius is now categorized as an upper-middle-income economy. Within a very short period of time, outward-oriented strategies have transformed this small island with low agricultural productivity into a significant exporter with a manufacturing-based economy. The two sectors that have boosted the manufacturing performance of the Mauritian economy are sugar milling and textiles and clothing. However, the textile sector is now at risk [26].

The textile and clothing sector appeared in the government's agenda as a solution to over-reliance on a sugar-based, mono-crop economy. Being labour intensive, it became a solution to unemployment as well. The clothing sector in Mauritius therefore plays an important role in the economy in terms of employment, foreign exchange earnings, and share of the GDP. In 2003 around 65,000 people - more than 60 percent of the manufacturing labour force were engaged in the manufacture of clothing. In 2002 the sector accounted for 22.4 percent of GDP. In 2001 apparel accounted for some 56 percent of Mauritius' total exports of goods, and some 82 percent of its total manufactured exports [26]. Although the bulk of activities in the textile and clothing sector of Mauritius are geared toward the manufacture of ready-made garments (94 percent of total textile and clothing exports in 2004), the importance, though minimal, of spinning and weaving firms in the local market should not be left out. In 2004, as in all years since the beginning of the 1990s, most Mauritian clothing exports were geared toward the United States, United Kingdom and France.

One of the strategic approaches to surviving in the apparel market is to move up-market into high-end, high-value-added products, where price competition is less severe. Lall and Wignaraja studied [27] the export competitiveness of the Mauritian economy, found Mauritius to be exceptionally vulnerable because of its heavy dependence on a few products, and because more than 80 percent of its manufactured exports come from one product group: clothing. They argued that once clothing exporters' wage-cost advantage was exhausted, export growth would depend on the ability to add value through backward integration (into textiles) and, within clothing, to upgrade quality and flexibility. To upgrade garment quality, investment is required not only in equipment, but also in organizational and labour skills, quality management, and design, marketing, and response capabilities. In 2002 firms had to cope with a limited pool of available skilled labour, but since then the textile and clothing sector had to lay off employees. A lack of investment incentives and government support may now be the main factor causing firms to think about relocating.

2.7 The Wine Cluster in South Africa

South Africa's wine producers can be divided into four segments, each with a different structure and focus. The four segments are the established producers, new producers, cooperative producers, and wholesalers (some of which produce wine, in addition to buying and selling it). Development in the different segments has been influenced by changes in the political and economic landscape of South Africa, as well as by changes in the industry. Wine estates and none state wine farms are mostly small producers of quality wines. Table 6 shows the changes in production volumes by industry segment in the wine producing cluster of South Africa.

Table 6: Change in volume of production by industry segment, 1998-2003 (Cases of Wine Produced) [28]

	% Increase (1998-2003)
Producing Wholesalers	400.0
New Producers	698.7
Co-operatives	1166.7
Established Producers	104.5
TOTAL	403.2

There is wide disparity in performance between the different industry segments and considerable diversity within each industry segment. South African producers have been effective at innovation in product and production, by introducing new varieties that are in demand, particularly in export markets, and in improving the quality of output [28]. An under resourced but relatively effective network of technical support and research closely aligned to industry needs has aided these processes. The network is most intensively used by less well-resourced producers, with better resourced producers more inclined to turn to the private sector for the required expertise, in the form of consulting viticulturists and winemakers [28]. Considering the available literature [28] and data, influential governmental support to the Wine cluster are shown in Table 7.

Table 7: Strategic governmental support to the wine cluster [28]

Commercialisation	Available Skilled Manpower	R & D	Intellectual Property Protection	IT Support	Venture Capital
x	x	x			

In comparison with other New World producers, growth in export value has been less impressive. South African producers have had limited success in exporting quality wines. The critical constraint on performance throughout the industry is not in the technical or research areas, not in production or in winemaking, but in marketing [28].

2.8 The Film Production and Distribution Industries in Nigeria

Nigeria is the third-largest film producer in the world after the United States and India. The sector is dominated by SMEs [29]. The diffusion of digital and communication technologies in the 1990s has accounted for its fast growth. Currently, around 300 producers release between 1,000 and 1,500 movies per year. Nigerian directors are known to adopt new technologies as soon as they become available at an affordable price [29]. Considering the available literature [29] and data, influential governmental support to the Film Production and Distribution cluster are shown in Table 8.

Table 8: Strategic governmental support to the Film Production and Distribution cluster [29]

Commercialisation	Available Skilled Manpower	R & D	Intellectual Property Protection	IT Support	Venture Capital
x	x	x			

According to the UN report, lack of funding, lack of organized industry and business associations, inadequate skills & lack of professionalism are some of the problems experienced. Some upcoming clusters also have challenges with infrastructure and a weak distribution system.

3 SUMMARY OF CLUSTERED BASED PRODUCTION

The reviewed case studies show a common set of challenges faced by clustered-based growth frameworks in developing economies. As the world moves towards complete globalisation and the promotion of free trade, existence of industrial clusters will continue to face stiff competition from cheaper imports as a result of improved production methods from other developing countries. As a result, simple and less complex production methods become a survival prescription for players in the developing countries. Sustainable growth is achieved through cost competitiveness and continual creation of value [1]. Key concepts, models and tools for managing and controlling complexity in clusters are summarized in Table 9 [4, 15, 16]

Table 9: Controlling complexity in manufacturing clusters [4, 15, 16]

Models	Tools	Concepts
Object-oriented Analytical IDEF 0 Funnel Petri-nets	Performance measurement Monitoring diagnostics Simulation Production planning and control Decision support	Open Design collaboration Agile or Fractual factories Value engineering Ubiquitous Manufacturing Systems (UMS) Distributed Manufacturing Systems (DMS) Group technology

Clustering supports enterprises to overcome capital, skills, technology, and markets constraints. Enterprise clusters help their constituents grow and compete by encouraging more effective knowledge and technology diffusion and product specialization, leveraging local comparative advantage, fostering production value chains, and achieving collective efficiency. In so doing, they contribute significantly to Africa's economic growth. They provide jobs for the continent's growing population, thus enabling families not only to survive, but also to educate their children and perhaps move out of poverty. But in today's increasingly knowledge-intensive and globalized economy, these clusters also face serious challenges in the areas of technology, natural resources, infrastructure, skill acquisition, and quality control. Evaluating these cluster case studies, the following elements were found to be common characteristics in most:

- Physical proximity of enterprises ensure concentration of resources
- Core competencies of enterprises are complementary
- Collaborating these enterprises have a collective growth potential
- Collaborating as an production system with long-standing coordinating mechanisms

In order to ensure sustainable development and value creation, these clustered ecosystems attempt to manage complexity by:

- Concentrating resources in an specific geographic area and streamlining supply chains by identifying gaps earlier
- Long-term collaboration among cluster enterprises helps to improve performance with trusted buyer-seller relationships
- Interdependence and the mutual believe in the speed of trust also strengthens commitment levels and reduces conflict through faster access to specialized information
- Shorter feedback loops helps to modify supply chains faster, which can also result in cost savings
- Flexibility can be increased, while reducing risk with partners of a supply chain are clustered

In order to manage the complexity and performance of clusters a standardised clustered based business process framework need to be established among stakeholders. This sometimes includes changes in the nature and mix of activities carried out at each link in the value chain. These changes cover process, product, functional and chain upgrading.

Product improvement includes the ability to produce components or retail innovative products developed by product leaders. Product quality is enforced through value chain relations, given that the final value-adding entity is held accountable for compliance.

Process upgrading aims to increase cluster productivity by increasing throughput, reducing inventory and lowering operating cost. It includes both processes within individual links in the chain (e.g. increased inventory turnover, lower scrap) and between the links in the chain (e.g. more frequent, smaller and on-time deliveries). Successful adoption of such standards is an important means of industrial upgrading, one that in part protects firms from lower-cost competitors who are not able to comply with these standards. Functional upgrading seeks to increase the value added by changing the mix of activities conducted within the firm (e.g. taking responsibility for outsourcing accounting, logistics and quality functions) or moving the locus of activities to different links in the value chain (e.g. from manufacturing to design). Chain upgrading creates opportunities for suppliers that have developed competencies and skills to move to a new value chain.

Trust and accountability need to be recognized as the cluster's foundation. Increased competitiveness can be realized through analysing the value chain and identifying opportunities to make it more efficient. Waste management and recycling activities are key elements to ensure sustainable production systems.

4 CONCLUSION

The aim of this paper was to encourage ourselves to direct our research towards concepts which reduce production complexity and support simplicity. This research evaluated several production clusters in developing communities. Key elements of a clustered based growth framework are identified to support manufacturing incubators in South Africa. Concepts for managing complexity in clustered ecosystems are discussed and various possible changes mentioned.

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THE SOCIAL DIMENSION OF OPEN DESIGN

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ABSTRACT

The sustainability of the quality and rate of the design process has always posed challenges. Initial open design concepts evolved from the need for an even faster rapid product development process and the desire to have co-creative platforms. Innovative open design platforms and toolkits ensure a continuous interchanging of knowledge between many and diverse stakeholders from a community with a common vision. Companies continuously research social strategies to get volunteers' attention and keep their interest to contribute to the company's objectives. Doing this can create significant value for the company's customers and shareholders. Therefore, the objective of this research study was to understand the main reasons for contributing to these open design platforms. Both community- and company driven open design platforms were studied and; the benefits and challenges for utilising these platforms discussed. As a result boundary conditions were identified to exploit, without compromising the constraints of current design systems. Plans for further investigations are also given.

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1 INTRODUCTION

Sustainable design processes requires the reconciliation of environmental, social equity and economic demands. Numerous sustainability standards and certification systems are developed from these sustainability spheres, which are also known as the triple bottom line (TBL). Economically motivated design for manufacturing (DFM) and assembly (DFA) aligns the design process with the organization's manufacturing capabilities and assemble processes, needed to reduce operating cost and increase throughput. Environmentally, design for recycling (DFR) and disassembly stems from the pressure of recycling and refers to the product design that takes into account the ability to disassemble a used product to recover the recyclable parts. Eco design is also the incorporation of environmental considerations and is an extension of the other important economic requirements considered in the design process [1].

Social design relies on the premise that personal and social networking relationships and ties provide value to organizations in a network by allowing them to tap into the resources embedded within the network for their benefit [2]. Real economic value is created out of these new principles simply due to concurrent, mass collaboration where people are living, experiencing and expressing gradually more within digitally enabled social- and peer networks. The idea of open design systems is to change the way we construct knowledge around manufacturing itself, as the ability to generate new knowledge can play an integral role to stay competitive [3]. Throughout the 1980's Sony had an impressive track record for being innovative, but by the 1990's the company's engineers started to suffer from a damaging "not invented here syndrome". Even as competitors introduced next-generation products such as the iPod and Xbox the engineers were insular. As a result of their belief that outside ideas were not as good as inside ones, they missed opportunities in such areas as the MP3 players and flat-screen TV's. Therefore, a company's success should be increasingly based on knowledge-seeking and knowledge creation [4]. In today's highly competitive industrial environment, no individual can accomplish production tasks alone.

Collaboration is necessary at every technical and organizational level [5]. OD has its roots in the open source software movement, which is described in [6] and can be understood as a change in the value creation process [7, 8]. Open design, virtual-reality environments, digital collaboration as well as web 4.0 technologies allow customers to be more closely involved early in the product design cycle. OD means that all information, which is related to the product, is available without obstacles, as well as that the developer community is open to every interested participant [9]. It breaks up this traditional point of view and involves a community, which has free access to the knowledge of the company [10]. This level of openness can be influenced by various factors, including the level of proprietary information sensitivity, the purpose of the challenge and the decision whether the product is fit for the platform. OD is based on the principles of open source, network manufacturing and social networks in order to ensure sustainable development. This way leads to new methods for solving problems and accelerate the process of co-creation [11].

In the past the economy was not as sophisticated and organisations not as complex with the rapid changes and knowledge workers at the core. In the industrial economy, attention wasn't the scarce resource that it is in today's connected world [12]. Information was scarce, and so virtual communities pursued open hardware and software strategies that made vast amounts of information freely available. Open design also embraced these new ways of sharing information, ideas and risks, so as to create the most collaborative environment possible. It is becoming the norm in once traditional companies, where intellectual property and production capacity is shared among hundreds of specialized companies. Together, with the enormous boost from the Internet of Things (IoT) megatrend, the information generation succeeded in sharing ideas via rapid communication. At the same time it made human attention a scare commodity [12]. In the attention economy, it is critical to evaluate actions with regard to how much attention it consumes and how we can get people to contribute to a company's needs. Still, it is critical to realize that an open design system can only become ubiquitous if a critical mass of elements is achieved. Research [12] suggests that one of the most important factors for gaining attention and keeping contributors' interest is engaging with the users' emotions. There are four linked lessons from psychobiology:

- Survival instinct are strongly present in everyone sub conscience – a contributor's attention can be gained through this natural reaction;
- Natural competitiveness is common across most people – open design platforms utilise this competitive urges that are part instinct, part cultural conditioning and eminently exploitable;
- Attention deficiencies leads to easy distraction - some platforms and toolkits exploit these distractions by offering to help users with their personal challenges; and
- Personal engagement encourages people to participate conscious – various open design platforms get people to invest something of their own, making them more committed than if they feel like observers. This co-creation dynamic also attract people to contribute.

Getting design communities to contribute to designs on open platforms and to keep contributors interest (stickiness) is crucial to stay competitive in the current corporate innovation field. Idea challenges adapt an idea suggestion system to be more competitive by rewarding successful value (from inside or outside) financially, or in other forms related to the organisation. Innovation networks also incorporate the input from a network of contributors in the form of solutions to identified problems, with the difference relating to the proposed problems. Whereas challenges are orientated to gain new ideas for innovations, networks are used to find solutions for more specific problems within a product design process [13].

Customer immersion platforms harness customers' inputs as to product requirements in a customer-product interaction process with the assistance of new technologies [13]. To succeed, companies must respond to changing customer needs and the move of their competitors [11]. The ability to identify opportunities co-creatively and bring innovative products to market effectively in an efficient way will enhance a manufacturer's competitiveness. Therefore, as shown in figure 1, desired products should be brought to market on the right time at the desired quality level. Managers naturally look first inside their own functional groups or business units 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 individuals across units brainstorm or when companies tap external partners for ideas [13].

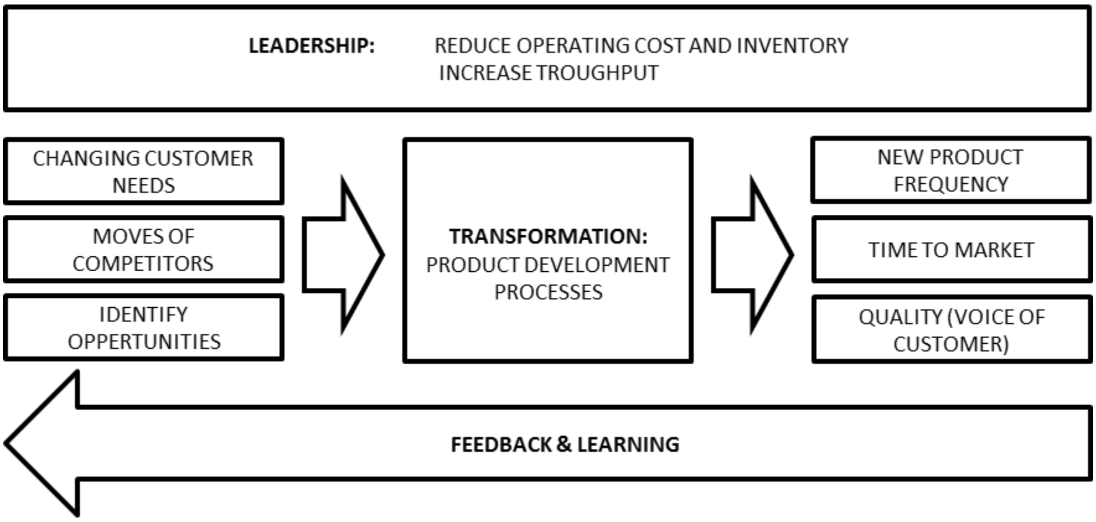

Figure 1: Measures of product development success (Adapted from [1])

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 [1]. 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 [14]. When organisations decide to collaborate in open innovation, the level of governance and level of participation should be decided [15]. Platforming uses co-creation tools for developing and introducing a base product with the purpose of providing a basis for contributors to access and co-create more value as the creative exploitation part of the product is left to the imagination. Collaborative product design and development is the technique of increasing the importance and responsibility of suppliers' and customers' role in the product design process. Thereby, increasing productivity to the benefit firstly the organisation, and eventually the customer [13].

In this research the main reasons for contributing to these open design platforms were studied. Factors that contributed to keeping interest and capturing designers 'attention were also investigated. Understanding the social dynamics of these platforms can help to increase the steady stream of new products to market in order to enhance the competiveness of companies.

2 OPEN DESIGN PLATFORMS AND ENTERPRISES

Similar to the open source information revolution, open design platforms could eventually put the means to produce physical objects in the hands of every individual and community. Local Motors is the first disruptive entrant in the US automotive industry in decades, also applying OD principles. Co-creation and collaborative (peer) production of hardware is coming of age, and advanced production corporations are getting with the program as shown in Table 1. Open design creates opportunities for internal related work or with corporate partners to have seamless access to relevant information, transfer and share documents and to automate manual tasks that can accelerate processes and decision making. OD is also evident in China's growing motorcycle manufacturing industry. The approach has been so successful that motorcycle production has quadrupled from 5 million to more than 20 million vehicles a year since the misd-1990s, giving China about 50% of the global share [16].

Highly collaborative design and manufacturing ecosystems isn't unique to the motorcycle industry. Although the success is questionable, Boeing replaced its traditional manufacturing systems for the Boeing 787 Dreamliner, with innovative international collaborations. This modern aircraft consist of many specialized parts, sourced from hundreds of suppliers. For companies managing these cross-pollinating ecosystems of value creation, innovation is less about inventing and building physical things and more about cultivating and matching good ideas [17].

Value creation of Open Design cannot be described as a traditional process, where the consumer and the producer are separated from each other. Instead the consumer changes his role into a consumer with development competence (prosumer) [18]. The Open Design principle for value creation follows a bottom-up approach [19]. It is characterized by collaboration as a form of interaction between the actors. Due to the collaborative possibilities of amateurs, they are superior to single professional designers [7]. For the implementation of an open design project in particular open source web-based collaboration platforms are suitable. They are a subset of so-called computer supported cooperative work systems, which are typically used in the cross-company collaborations [20].

Web-based collaboration platform refers to computer-based work environments that facilitate collaborative work, especially in the unstructured and non-recurring tasks [21]. Furthermore, the product can be built in so-called open-access factories which are contacted via platforms (e.g. Alibaba). Open source software programs (e.g. Linux) 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 [11].

LinuxCNC has many features and brings a lot of new functionality (a flexible and powerful hardware abstraction layer that allows you to adapt it to many kinds of machinery, a software PLC controller and a new trajectory planner. LinuxCNC is precompiled with Ubuntu LTS (long term support) versions for ease of installation and longevity and is a descendent of the original NIST enhanced machine controller software, which is also in the public domain. Often free, OSS products are distributed under many public licenses, are more reliable, and provide greater flexibility and choice. The system also leads to fascinating competitive and cooperative relationships among companies and communities [17].

Table 1: Examples of open design platforms and networks

	Logo	Platforms	Website
1.	3DVIA	3DVIA.com	http://www.3dvia.com
2.		Sketchchair	http://diatom.cc/sketchchair
3.	SketchUp	SketchUp	http://www.sketchup.com
4.	Autodesk 123D Beta	Autodesk 123D	http://www.123dapp.com/
5.	Open CASCADE TECHNOLOGY	Open Cascade	http://www.opencascade.org/
6.	TINKERCAD	Tinkercad	https://tinkercad.com/
7.	blender	Blender	http://www.blender.org/
8.	eMachineShop machine custom parts online	eMachineShop	http://www.emachineshop.com
9.	open source ecology	Open Source Ecology	http://opensourceecology.org
10.	OpenStructures	OpenStructures	http://www.openstructures.net/

Recently, there are open design initiatives to provide open source hardware (e.g. Open Source Ecology). The idea of this platform is to provide license free product documentation to be downloaded for a do-it-yourself realization.

Open project management tools help people organise their work using cards on a virtual task board that the interface is easy to understand also exist (e.g. Kerika). Despite these success stories of open design platforms and toolkits, some platforms like the Design byMe experience form LEGO® struggled to live up to the quality standards for a LEGO service. As a result, the Design byME service was closed in January 2012 [22].

In order to define the various OD platforms better it were divided into design toolkits, projects, education and learning initiatives and enterprises.

2.1 Open Design Toolkits

3DVIA.com, also known as the 3DVIA Cloud, hosted online to provide a specialised 3D service, a suite of SaaS (Software as a Service) applications for interactive viewing specifically designed to help 3D professionals communicate, market and sell more effectively. SketchUp also helps people to model anything they can imagine, like to redecorate their living room, designing a new piece of furniture or to Re-model a city for Google Earth.

Autodesk 123D helps turn ordinary photos into extraordinary 3D models or to convert 3D models into cut patterns for creating build-your-own projects. Open CASCADE Technology is a software development platform freely available in open source and includes C++ components to model in date exchange, 3D surfaces, visualisation, and rapid application development.

Open CASCADE Technology can also be applied in development of specialized CAD/CAM/CAE applications. Blender utilises OpenGL for drawing all interfaces but is available across platforms.

2.2 Open Design Projects

SketchChair is an open-source software tool that allows anyone to easily design and build their own digitally fabricated furniture. The program allows users design chairs, structures is automatically generated and the stability can be tested, by using a simple 2d drawing interface. Open Source Ecology is an open source, cost effective technological platform with high performance and consisting of a network of farmers, engineers, and supporters that has been creating the Global Village Construction Set for the last two years. The 50 different Industrial Machines that it takes to build a sustainable civilisation which includes modern comforts allows for the easy DIY manufacturing in this Construction Set.

The OpenStructures (OS) project initiates a construction system where everyone designs for everyone. Exchange of experiences, parts, components and ideas serves as motivation to build things together is stimulated by utilising a shared modular grid and common open design principles in this on-going. Riversimple is a UK based Car Company, with a single goal of producing efficient vehicles for personal transport and Oscar’s goal is to develop a car according to OD principles. WIKISPEED is a volunteer based, green automotive-prototyping company, working in a virtual, collaborative team of skilled individuals who volunteer time to creating cost effective, safe, road-legal efficient vehicles. WIKISPEED is invests all money earned back into the company as a donation to assure movement forward with WIKISPEED's vision.

2.3 Open Design Education and Learning

Tinkercad enables people to enjoy learning about design and 3D printing, as one can work collaboratively either with close friends or as part of the community. eMachineShop’s open CAD software is also developed specifically to ease learning. The software commands are included for the automation of quotation, ordering, the creation evaluation of designs. Time and money can be saved because expensive engineering support is minimised due to the fact that feedback and advice is instantly provided via a built-in automated analysis tools. Adafruit was created for online learning of electronics and making the best designed products for makers of all ages and skill levels.

2.4 Open Design Enterprises

Local Motors is a crowd-powered automotive design, distributed manufacturing and technology to enable the creation of potential game-changing vehicles. Local Motors helps solve local problems, locally through open-source principles, by making transportation more sustainable globally; and utilises innovative distributed manufacturing to co-create vehicles and components with its virtual community of role-players around the world.

Arduino is an open-source electronics prototyping platform based on user friendly, flexible, software and hardware. Arduino programming language (based on Wiring) and the Arduino development environment (based on processing) uses the microcontroller on the board for programming. SparkFun is an online retail store that sells the bits and pieces to make your electronics projects possible.

Innovation of organisations in the rapidly-growing *Internet of Things* (IoT) market is aspired by Bug Labs, a cloud-based platform. It abstracts the raw functionalities (e.g., sensors, actuators, transceivers) of any hardware device and exposes them as web services. No matter how heterogeneous hardware is the simple drag-and-drop design of the application helps to overcome this challenge.

3 EXPERIMENTAL APPROACH

The objective of this research study was to understand the main reasons for contributing to these open design platforms. This research was divided into different phases as illustrated in Figure 2. The first step constituted of a thorough literature study on sustainable manufacturing and open design.

Several case studies were studied in order to understand the various tools found on these platforms and; also their respective social integration. This evaluation helped to understand which platforms and toolkits to use during the different phases of the product development process.

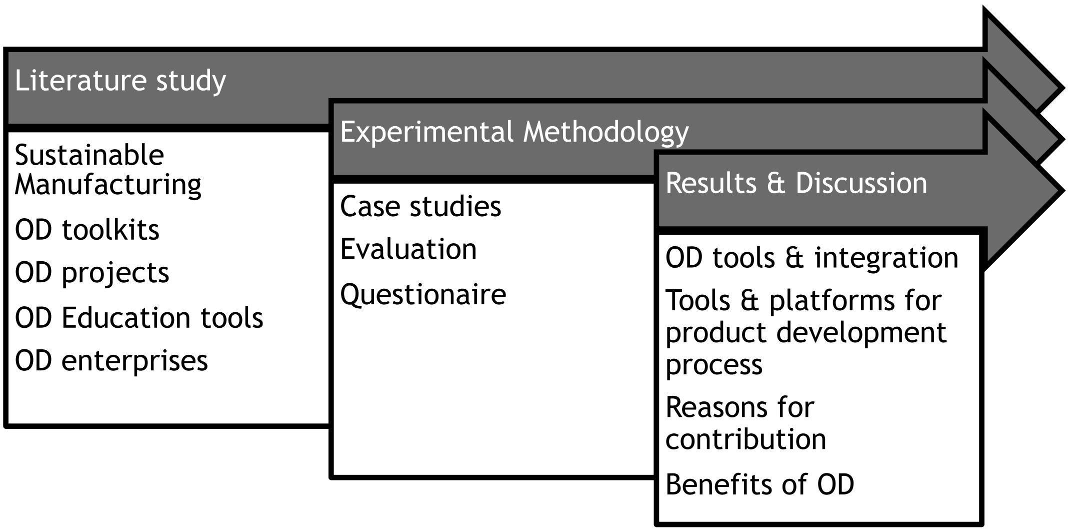

Figure 2: Experimental approach followed to better understand the dynamics of open design

Thereafter, a questionnaire was conducted with a group of fifty net generation (contributors born after 1981) open design users to understand the benefits of using open design. The main reasons behind contribution to these open design platforms, together with the benefits that open design poses were studied. Both community- and company driven open design platforms were studied and; the challenges for utilising these platforms discussed.

4 EXPERIMENTAL RESULTS AND DISCUSSION

In order to gain the competitive advantage, companies optimise research strategies to get volunteers' attention and keep their interest to contribute to the company's objectives. The main reasons for contributing to these platforms are illustrated in Figure 3. Most of these open design platforms offer no financial compensation to the contributors. Rather, most of the contributors rely on practical solutions which are freely available; or intrinsic motivated social rewards.

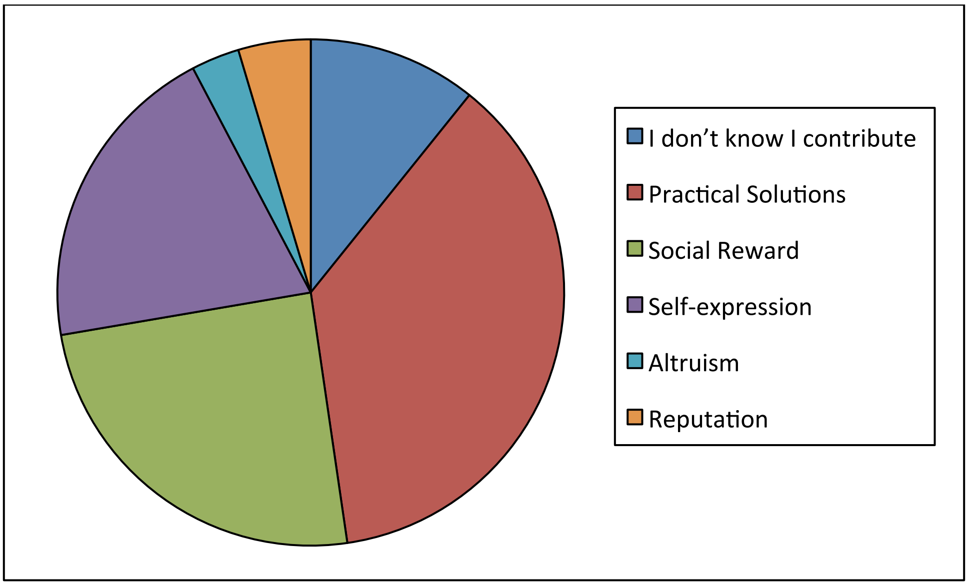

Figure 3: Reasons for contribution to open design platforms

Some contributors enjoyed participation to express themselves and exhibit skills, while few were unaware that they contribute; or simply want the truth to be heard. Most contributors use open design platforms due to the rapid product development process as shown in Figure 4. Overwhelming of the understanding that the net generation have a collaborative approach to design solutions, contributors find it beneficial to capitalise on the knowledge of others rather than redesigning the wheel.

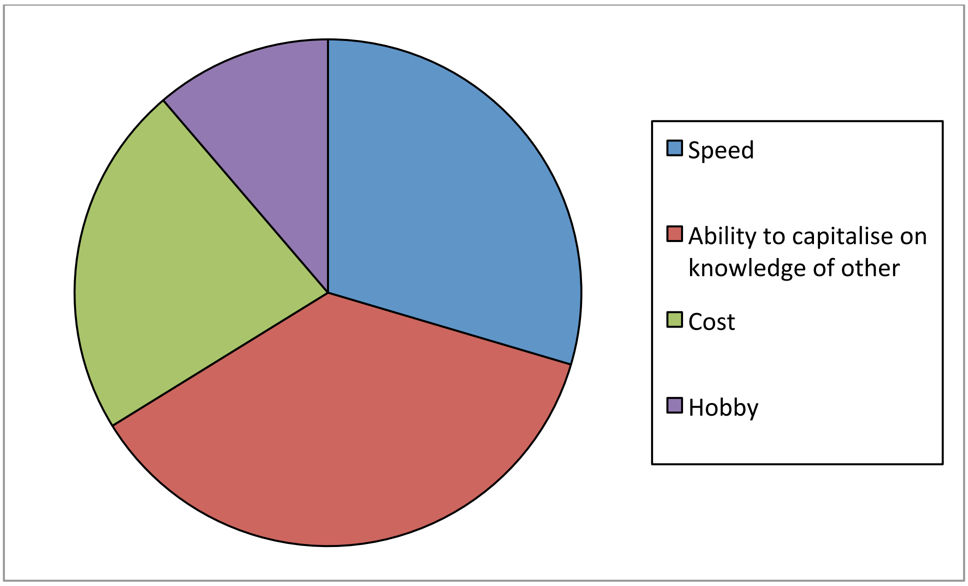

Figure 4: Benefits of open design

The most popular open design platforms and toolkits according to the selected group of users are illustrated in Table 2. These open design platforms and toolkits were evaluated to understand the tools and social integration used to get attention and ensure contribution. The free computer-aided systems (e.g. CAD/CAM) help users to modify existing designs or create new ones. The bill of materials signifies a freely available list of materials required for the specific product.

Table 2: Tools and integration of open design platforms and networks

Platforms	Free CAD/CAM software	Product bill of Materials	Videos & Education	Social Network integrated
3DVIA.com	x		x	x
Sketchchair	x		x	x
SketchUp	x		x	
Autodesk 123D	x		x	x
Linux CNC	x			
Open Cascade	x		x	
Tinkercad	x		x	x
eMachineShop	x		x	
Open Source Ecology	x	x	x	x
Local Motors	x	x	x	x
Wikispeed	x	x	x	x
Riversimple		x		
OScar	x	x	x	x
OpenStructures	x	x	x	x

Some platforms offer educational videos and training on their respective websites in order for users to familiarise themselves with the features of the specific platform. In most instances the design platforms is attractively integrated with social networks for increased visibility.

Most of these platforms use a concurrent engineering approach to unite design- and manufacturing contributors early in the design phase. Thereby, these platforms collaboratively drive the product development process shown in Table 3. After studying these platforms it was possible to group them into specific phases of the product development process.

Table 3: Examples of platforms along the Product Development Process [23]

Idea generation & challenges	Concept development	System Level Design	Detail Design	Testing and refinement	Production ramp-up
IdeaCONNECTION InnoCentive MycroBurst	Autodesk 123D 3DVIA.com Tinkercad SketchUp	Linux CNC Open Cascade	Sketchchair Oscar Riversimple OpenStructures	Arduino Adafruit Buglabs DIY DRONES	eMachineShop FabLab MakerBot Industries Alibaba

In the idea generation and challenges phase, platforms like IdeaCONNECTION and InnoCentive can be used. MycroBurst is also a community of graphic and logo designers from around the globe who can compete on new design challenges as competition drives results. Autodesk 123D, 3DVIA.com, Tinkercad and SketchUp are typical platforms for use during the concept development phase, while the eMachineShop and FabLabs can be used to ramp-up production.

5 CONCLUSION

Both community- and company driven open design platforms were studied and; the opportunities and challenges for utilising these platforms discussed. Most open design contributors rely on practical solutions or social rewards. The benefits of open design platforms include the speed and co-creation benefits. The biggest challenge still remains the quality standards set by the voice of the customer. Future open design investigations will include the economic dimension behind these platforms.

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THE COMBINED AHP-QFD APPROACH AND ITS USE IN LEAN MAINTENANCE

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ABSTRACT

The approach of using Quality Function Deployment (QFD) with techniques such as the Analytic Hierarchy Process (AHP) is gaining wide acceptance in many decision-making problems. This combined approach is followed in order to enhance the effectiveness of the decision-making process and is also used to deal with the sometimes subjective linguistic judgements that arise when expressing relationships and correlations required in the QFD approach. Previous uses of the QFD-AHP approach have been made in areas such as facility location problems and evaluation of hardware for mobile stations. Rarely has this approach been used in the field of Lean Thinking and in particular, lean thinking in the maintenance environment. The work presented here broadens the use of this approach by applying it in evaluating the importance of a set of Maintenance Excellence criteria and how they can be addressed by applying lean thinking. A survey, carried out at a maintenance organisation in the railway environment, acts as the foundation of the study. This exercise results in a set of prioritised lean tools used to address a set of ranked maintenance excellence criteria specific to the organisation in question.

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1 INTRODUCTION

The approach of using Quality Function Deployment (QFD) with related techniques such as the Analytic Hierarchy Process (AHP) is gaining wide acceptance in many decision-making problems. This approach is usually followed in order to enhance the effectiveness of the decision-making process and is also used to deal with the sometimes subjective linguistic judgements that arise when expressing relationships and correlations required in the QFD approach. Previous uses of the QFD-AHP approach have been made in areas such as facility location problems and evaluation of hardware for mobile stations. Rarely has this approach been used in the field of Lean Thinking and in particular, Lean Thinking in the maintenance environment. In the work presented here, the scope of use of this approach is broadened by applying it in evaluating the importance of a set of Maintenance Excellence (ME) criteria and how they can be addressed by applying lean thinking. A survey, carried out at a maintenance organisation in the railway environment, acts as the foundation of this study. The results of the survey are used as the input of a QFD model. The other set of input necessary for the model is obtained from a literature study of lean thinking and its potential application in addressing the ME criteria. A relationship matrix is then formed from the two sets of input. The AHP process is then used to carry out pairwise comparisons in order to establish the consistency and subsequent ranking of the various relationships according to importance. The organisation of the paper is as follows; there is a brief discussion on the QFD and AHP procedures and how they have been used in previous studies. A description is also made of the concept of lean thinking and its use in maintenance operations, through the concept of lean maintenance. A QFD House of Quality (HOQ) consisting of a set of ME criteria and a set of possible lean tools to meet the criteria, is developed. This is followed by the application of the QFD-AHP approach to evaluate and rank the relationships in the HOQ in order to determine the consistency of the comparisons. Implications of this approach in the area of lean thinking in maintenance operations are then discussed and concluding remarks and recommendations are made.

2 LITERATURE REVIEW

2.1 The Quality Function Deployment Technique

Quality Function Deployment (QFD) was first proposed and used by Mitsubishi Heavy Industry's Kobe shipyards to design super tankers ReVelle [1]. It is a widely used customer-driven, design and manufacturing tool, and is commonly used in the new product development field to translate customer requirements (WHATs) into appropriate engineering characteristics (HOWs) Zarei & Jamali [2]. Toyota Auto Body developed a quality table that had a "roof" on top, which was later passed on as the House of Quality (HOQ). The HOQ is essentially a matrix that is used to display the relationship between the WHATs and the HOWs and demonstrates how quality characteristics satisfy the customer requirements. The QFD technique is mostly used in conjunction with other techniques in order to enhance its effectiveness and applicability. It is also combined with other techniques in order to deal with the subjective linguistic judgements that arise when expressing relationships and correlations required in the HOQ. One such adaptation is through the use of Fuzzy Logic Bottani [3], which is used to minimise the vagueness frequently represented in decision data. Another approach that is gaining wide acceptance is that of combining QFD with the Analytic Hierarchy Process.

2.2 The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a systematic decision-making approach that was first developed in 1971 by Thomas L Saaty Saaty [4]. A very detailed literature review of the many applications of AHP is given by Vaidya & Kumar [5] 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 Ho [6]. The process does however have its critics with the earliest being Belton & Gear [7], 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 Aiqing & Jinli [8] who propose a new method of rank preservation based on what they call the judgement matrix consistency. However, in spite of these perceived shortcomings, AHP in its original form still remains very powerful, especially when it is used in conjunction with other decision making techniques.

2.3 The QFD-AHP Approach

Quality Function Deployment (QFD) has been used extensively in conjunction with AHP to give better solutions. Partovi [9] carries out one such combination where instead of using a standalone AHP approach, an AHP-QFD approach is used for evaluating decision alternatives in a facility location problem. Another QFD-AHP study used in a facility location problem is found in the work done by Chuang [10]. AHP is used to measure the relative importance weighting for each location requirement and also to assess the evaluating score for each candidate location for a particular set of location criterion. Dziadak & Michalski [11] use QFD and AHP in the evaluation of hardware for a mobile station and find that the results of these methods are better than those obtained using quality/price ranking methods. Ho [6] gives many another examples where the AHP-QFD approach has been used including, amongst others:

- Improving the education quality for a higher learning institution.
- Project selection.
- Determining the composition of an army deployment.
- New product development.

2.4 Lean Maintenance

The term "lean maintenance" is relatively new having only been coined in the last decade of the 20th Century, well after lean manufacturing Smith & Hawkins [12]. An abbreviated definition of the term is given by Clarke, Mulyran, & Liggan [13] who state that it is the delivery of maintenance services to customers with as little waste as possible hence promoting achievement of a desirable outcome with fewest inputs possible. Definitions are few and hard to come by as most simply prefer to refer to it as the application of lean to maintenance, repair & overhaul (MRO). Whatever expression is used, whether it is "lean maintenance" or "lean in MRO", the underlying focus for the application of lean is in the reduction of waste, as indicated by Ayeni, Baines, Lightfoot, & Ball [14]. This view is also shared by Ghayebloo [15] who states that the main purpose of lean maintenance is to eliminate all forms of waste in the maintenance process without taking into account serious reliability issues. Lean Tools are the various tools that can be used to increase the leanness of a function. These tools are designed to prepare for, plan and execute the function using lean thinking. And when referring to the maintenance function, these lean tools will allow lean thinking to be applied with the end result that maintenance excellence is attained. Davies & Greenough [16] state that there is no clearly defined lean practice framework which can be referred to for the maintenance function. Table 1 gives a brief overview of tools that have been used or have been determined to be effective in performing lean thinking in the maintenance environment. As can be observed from the table, most of the lean tools have been applied in a manufacturing context.

Table 1: Lean Tools/Enablers Used in Maintenance Functions

Lean Tool (s)	Application/Industry	Author (s)
5S, TPM, OEE, Standards, Mapping, Inventory Management, Visual Management, Root cause problem solving, Continuous improvement, Kaizen Activities, Poka Yoke, Process Activity Mapping, Self-Audits, Story boarding, Kanban, Scenarios, Takt Time, Lead Time mapping, Value Focused Thinking, Supplier Associations, Open Book Management	General - Manufacturing Origins	Davies & Greenough [16]
5S, 7 Deadly Wastes, Standardised Work, Value Stream Mapping, Kanban, Jidoka, Poka Yoke, JIT	General - Manufacturing Origins	Smith & Hawkins [12]
Jidoka, Just-in-time, Heijunka, Kaizen	Maintenance Repair and Overhaul	Zwas [17]
Value Mapping, Criticality Analysis, Hidden Lost Cost Model, Best Practice Development, Lean Maintenance Standards, Focused Improvement	Pharmaceutical Manufacturing	Clarke et al [13]

3 IMPLEMENTATION OF AHP-QFD APPROACH

In order to investigate the use of the AHP-QFD approach in lean, a maintenance organisation in the railway environment is used as a case study. This investigation forms part of a broader initiative by Tendayi [18] to develop a framework for applying lean thinking in a non-manufacturing oriented maintenance function. Given in Table 2 is a list of maintenance excellence criterion ranked in terms of their importance to fulfilling the objectives of the maintenance organisation in question. These importance weightings are the result of an earlier exercise that involved the use of AHP in a maintenance excellence survey conducted by Tendayi [18] at the case study.

Table 2: Maintenance Excellence 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

After having identified a set of maintenance excellence criteria that are imperative if a maintenance organisation is to achieve best maintenance standards, the next step is to identify lean tools that will allow the organisation to meet those standards in a manner that eliminates waste and adds value. The lean tools are identified from literature and are then used as input (HOWs) in an HOQ that has the ME criteria as the WHATs as shown in Figure 1. The numbers shown in the 'Importance Degree of Lean Approach' row are derived from the absolute importance, $\boldsymbol{AI}_j$ ($j = 1, \dots m$) formula of the QFD approach as shown below:

$$\boldsymbol{AI}_j = \sum_{i=1}^{n} W_i R_{ij}, \quad j = 1, \dots, m \qquad \textbf{(1)}$$

Where:

$\boldsymbol{AI}_j$ is the absolute importance of the jth engineering characteristic ($j = 1, \dots m$), and m is the total number of characteristics.

W_i is the relative importance of the $\boldsymbol{i}$th Customer Attribute,

R_{ij} expresses the relationship between the ith customer attribute and the jth engineering characteristic with a numerical scale.

In our case, the numerical scale of the relationships between the lean tools and the ME Criteria is 1-3-9 for the Weak, Medium and Strong relationships respectively and the importance weightings of ME criteria are taken from Table 2. The 'Normalised Importance Degree' figures in the HOQ are derived from the relative importance, $\boldsymbol{RI}_j$ formula as shown below:

$$\boldsymbol{RI}_j = \frac{\boldsymbol{AI}_j}{\sum_{j=1}^{m} \boldsymbol{AI}_j}, \quad j = 1, \dots, m \qquad \textbf{(2)}$$

The last row in the HOQ shows the rankings of the various lean tools according to importance weighting.

	Kaizen	Kanban	Visual Management	Just In Time	Variability Reduction/Standardisation	Hoshin	Balanced Scorecard	Jidoki/ Poka-Yoke	5S	Importance Weighting of ME Practice
Continuous Improvement Efforts	●		□		●	●	●	●	●	0.03
Use of FMMS/SAP	□	□	○	○			○	○	□	0.15
Schedule Complaince	○	●	□	●	○	□	●	□	□	0.01
Detailed Operating Procedures			●		●	○		□	●	0.01
Management Support			□			●	□		□	0.04
Spare Parts and Material Availability	○	●	○	●	□		○		□	0.26
Comprehensive Work Orders	○	□	□		□	○		□	●	0.04
Maintenance Organisation & Structure	○		□			●	□		□	0.06
Personnel Skills Training	●		○		□	□	●	○	□	0.02
Policy and Strategy	□		●		□	●	□		●	0.06
Maintenance Contracting	○	○		●	○		□	□	□	0.08
Key Performance Indicators	●		●		●	□	●	□	□	0.12
Workforce Involvement	●		●		○	●	●		□	0.03
Conformance Quality	●		○	□	●	○	●	●	●	0.03
Importance Degree of Lean Approach	2.99	3.04	2.93	3.33	2.85	2.45	3.11	1.35	3.74	
Normailsed Importance Degree	0.12	0.12	0.11	0.13	0.11	0.09	0.12	0.05	0.14	
Rank	5	4	6	2	7	8	3	9	1	

Key
- ○ Weak relationship
- □ Medium relationship
- ● Strong Relationship

Figure 1: ME Criteria vs. LE HOQ Matrix

A Pairwise comparison of each of the lean tools is then made using AHP in order to see if there is any consistency in the judgements of the importance degrees derived from the HOQ. Figure 2 shows a pairwise comparison matrix of the importance degrees of the lean tools. It is constructed according to the following AHP matrix, $\mathbf{A}$:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \quad (3)$$

Where, a_{ij} 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 a_{ii}=1 and $a_{ij} = 1/a_{ji}$. The possible assessment values of a_{ij} with their corresponding interpretation is shown in Table 3.

	KAI	KAN	VIS	JIT	STA	HOS	BAL	PKY	5S
KAI	1	1/3	3	1/3	3	5	1/3	7	1/5
KAN	3	1	3	1/3	3	5	1/3	7	1/5
VIS	1/3	1/3	1	1/3	3	3	1/3	7	1/5
JIT	3	3	3	1	3	5	3	7	1/3
STA	1/3	1/3	1/3	1/3	1	3	1/3	7	1/5
HOS	1/5	1/5	1/3	1/5	1/3	1	1/5	7	1/7
BAL	3	3	3	1/3	3	5	1	7	1/5
PKY	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1	1/7
5S	5	5	5	3	5	7	5	7	1

KEY:

KAI	Kaizen
KAN	Kanban
VIS	Visual Management
JIT	Just In Time
STA	Standardisation
HOS	Hoshin
BAL	Balanced Scorecard
PKY	Poka-Yoke
5S	5S

Figure 2: LE Pairwise Comparison Matrix

Table 3: Assessment of a_{ij}

Value of a_{ij}	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 j
9	Objective i is absolutely more important than objective j
2,4,6,8	Intermediate values

This matrix is then normalised and gives the new Matrix shown in Figure 3 which is derived from the following AHP matrix, A_w:

$$A_w = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{11}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \cdots & \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & \ddots & & \\ \vdots & \vdots & & \ddots & \vdots \\ \frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \cdots & \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix} \quad (4)$$

	KAI	KAN	VIS	JIT	STA	HOS	BAL	PKY	5S
KAI	0.06	0.02	0.16	0.06	0.14	0.15	0.03	0.12	0.08
KAN	0.19	0.07	0.16	0.06	0.14	0.15	0.03	0.12	0.08
VIS	0.02	0.02	0.05	0.06	0.14	0.09	0.03	0.12	0.08
JIT	0.19	0.22	0.16	0.17	0.14	0.15	0.28	0.12	0.13
STA	0.02	0.02	0.02	0.06	0.05	0.09	0.03	0.12	0.08
HOS	0.01	0.01	0.02	0.03	0.02	0.03	0.02	0.12	0.05
BAL	0.19	0.22	0.16	0.06	0.14	0.15	0.09	0.12	0.08
PKY	0.01	0.01	0.01	0.02	0.01	0.00	0.01	0.02	0.05
5S	0.31	0.37	0.27	0.50	0.23	0.21	0.47	0.12	0.38

Figure 3: Normalised LE Pairwise Comparison Matrix

The importance weighting, as shown in Table 4, of each lean enabler is then derived from this matrix according to the AHP formula shown below:

$$\boldsymbol{C} = \begin{bmatrix} c_1 \\ \vdots \\ \vdots \\ c_m \end{bmatrix} = \begin{bmatrix} \dfrac{\frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{m} \\ \vdots \\ \dfrac{\frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{m} \end{bmatrix} \quad (5)$$

Where c_i is the average of the entries in row i of $\boldsymbol{A_w}$ to yield column vector $\boldsymbol{C}$

Table 4 also shows the consistency measures of these importance weightings where these consistency measures are derived from the following AHP expression, which is essentially the product of $\boldsymbol{A}$ and $\boldsymbol{C}$:

$$\boldsymbol{A} \cdot \boldsymbol{C} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_m \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{bmatrix} \quad (6)$$

Table 4: LE Importance Weightings

Lean Enabler	Importance Weighting	Consistency Measure	Rank
5S	0.32	10.96	**1**
Just In Time	0.17	11.24	**2**
Balanced Scorecard	0.13	11.32	**3**
Kanban	0.11	10.93	**4**
Kaizen	0.09	10.45	**5**
Visual Management	0.07	10.04	**6**
Standardisation	0.05	9.87	**7**
Hoshin	0.04	9.52	**8**
Poka-Yoke	0.02	9.59	**9**

The Consistency Index $\boldsymbol{CI}$ is then calculated from the following equation:

$$\boldsymbol{CI} = \frac{\delta - m}{m-1} \quad (7)$$

Where δ is called the maximum or principal eigenvalue and is equal to the average of the consistency measures calculated above **(=10.43)** thus giving:

$$\boldsymbol{CI} = \frac{10.43 - 9}{9 - 1}$$
$$= \mathbf{0.179}$$

According to Saaty [4], for m = 9, the random index, $\boldsymbol{RI}$ is 1.45. This gives a Consistency Ratio, $\boldsymbol{CR}$ of:

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \quad (8)$$

$$= \frac{0.179}{1.45}$$
$$= \mathbf{0.12}$$

The value of 0.12 is a little over the commonly accepted threshold of 0.10. By following a procedure given by Saaty [4], which involves replacing all a_{ij} in the initial matrix in question by the corresponding priority ratios, w_i/w_j and recalculating the priority vector, convergence to a consistent case is possible. This procedure is carried out on the lean tools and it is observed that the consistency ratio can be improved to $\mathbf{0.04}$ with the revised importance weightings as shown in Table 5.

Table 5: Revised LE Importance Weightings

Lean Enabler	Importance Weighting	Consistency Measure	Rank
Balanced Scorecard	0.25	10.40	**1**
Visual Management	0.18	10.59	**2**
5S	0.15	11.28	**3**
Kaizen	0.15	10.03	**4**
Standardisation	0.10	9.69	**5**
Hoshin	0.08	9.66	**6**
Just In Time	0.04	7.74	**7**
Kanban	0.04	8.50	**8**
Poka-Yoke	0.02	7.04	**9**

4 DISCUSSION

The changes that occur in the importance weightings when the judgements are revised, in order to make them more consistent are illustrated in the chart shown in Figure 4. These new weightings are more useful to the decision-maker than those obtained initially. There is need, however, not to excessively force the values of the judgements in order to improve consistency as this may distort the results. A more advisable approach, given time and resources, would be to go back to the HOQ and investigate what caused the inconsistencies in the first place. One possible reason for these inconsistencies can be attributed to the rather subjective correlations made in the HOQ when allocating lean tools to specific maintenance excellence criteria. The number of lean tools used in this exercise is by no means exhaustive or exclusive as the concept of lean thinking is very broad and subject to a number of external factors that determine its usefulness or otherwise. In further studies that were carried out using this same scenario, additional lean tools were also discovered to be essential in helping the organisation in question meet its maintenance excellence objectives. It would also be useful to compare the results obtained in this study using the AHP-QFD approach, against other integrated AHP approaches. This would help determine if this is indeed the best approach or there are some that can provide a more accurate representation of the real world scenario.

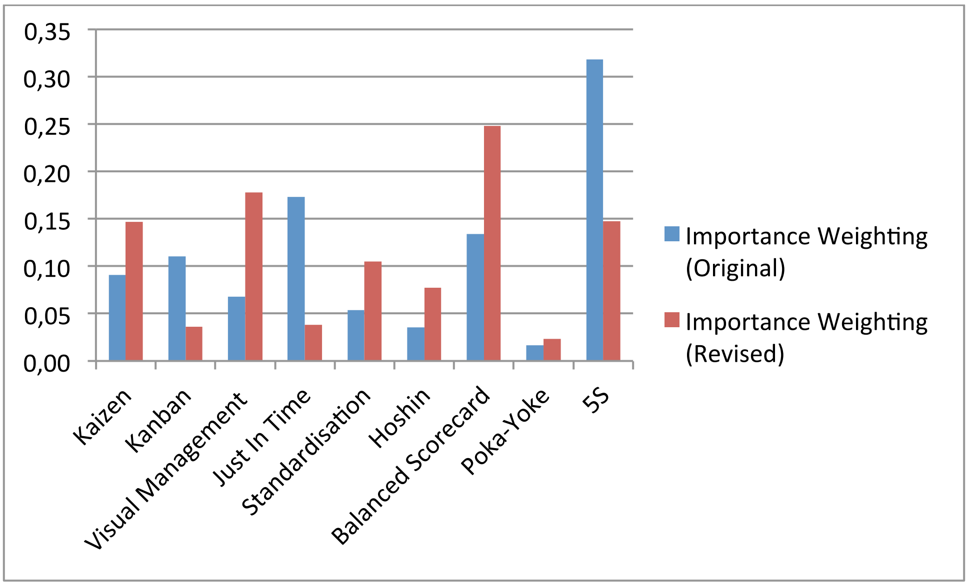

Figure 4: Revised vs. Original LE Weightings

5 CONCLUSION

In this paper, the use of the combined Analytic Hierarchy Process (AHP) and Quality Function Deployment (QFD) approach in the field of lean maintenance has been studied. First, an overview was given of the separate AHP and QFD approaches before exploring the work carried out in the combined AHP-QFD approach. A review of the concept of lean maintenance and its most common uses was also given. The combined AHP-QFD approach was then investigated by using it in a rail maintenance organisation seeking to adopt lean thinking in its operations. A QFD House of Quality (HOQ) consisting of a set of maintenance excellence criteria measured against a set of possible lean tools that can be used to attain maintenance excellence, was then developed. The AHP process was then used to check the output of the HOQ for consistency and to give judgements on the importance of each of the lean tools. The original judgements had to be revised as there was some inconsistency and the result of this revision was a set of ranked lean tools that can be used to attain maintenance excellence in the organisation. The last section involved a discussion that highlighted some of the significant observations and recommendations arising from the study. These included the possibility of revisiting the HOQ decisions, the use of further lean tools and comparing the AHP-QFD approach to other similar decision-making tools available.

Based on the results of this study, it can safely be concluded that the AHP-QFD approach is useful in the field of lean maintenance for decision-making purposes. This further broadens the scope of use of this powerful decision-making tool and also helps maintenance practitioners make informed judgements on which lean tools to prioritise in their endeavour to achieve lean maintenance.

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APPLICATION OF POLYURETHANE MATERIALS IN THE ASSEMBLY OF MICRO-COMPONENTS

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ABSTRACT

The efficient assembly and manufacturing of micro-components are becoming ever more important with the technological industry becoming larger and the electronic components in this industry decreasing in size. This is why the efficient handling of micro-parts is becoming a great challenge, with micro-parts with dimensions less than 20 mm being handled during the assembly process. Mechanical and vacuum grippers currently utilized in this field pose a risk of the micro-parts being strained or broken during the handling process. Therefore, this paper presents a solution through using a single polyurethane gripper, actuated only by Van-der-Waals forces. This polyurethane gripper is more efficient than conventional micro-grippers, and can handle and assemble simultaneously up to 10 micro-parts without leaving residual stresses, charges and strains on the micro-components. Polyurethane micro-grippers do not require a power supply or pressurized air to be operated. A motoman robot coupled with different polyurethane grippers was utilized to perform the simultaneous pick-up, transfer and placement operations of up to 10 micro-elements of less than 20 mm dimensions in an assembly operation.

1. INTRODUCTION

The efficient handling of micro-materials such as piezoceramic elements which takes place during the assembly of piezoelectric components involves certain challenges. These challenges include the accurate pick and place operations of the parts, as well as handling the micro-parts without causing unnecessary strain or breaking them. The reasons behind the aforementioned challenges are that the elements are of an extremely small size and fragile, which means that these parts are prone to break easier than in the case of normal size materials. Mechanical and vacuum grippers that are currently used in the handling of these micro-parts can in some cases exert unnecessary strain or even break the fragile micro-parts ([16]). Accuracy is another shortcoming in some gripper cases when utilizing the above mentioned grippers. The amount of parts handled at one time is another problem. Matope et al. [17] have managed to use a polyurethane micro-gripper to assemble one piezo-ceramic element at a time. This paper takes this further and explores how ten piezoceramic elements can be assembled simultaneously.

Since polyurethane grippers are soft, they are able to pick up and place parts without exerting excess strain or stress ([11]). Furthermore, these polyurethane grippers do not leave any residual electrical charge on the handled parts ([5]), making the grippers suitable for sensitive piezoelectric components. Van-der-Waals forces are the fundamental gripping force of polyurethane grippers ([9]).

The aim of this paper is to propose a gripper made of polyurethane material which can handle up to 10 micro-parts at a time. This would increase the efficiency as well as the precision of the pick and place operations during the assembly of piezo-electric components.

2. BACKGROUND

The research on polyurethane material as a gripping material in micro-material handling operations has become a growing field, due to the advantages and effectiveness of the material. The usage of polyurethane for gripping purposes has origins in the research of gecko inspired adhesion. Geckoes can move over surfaces with the pads on their feet rapidly adhering and releasing from the surface without leaving any residue ([1]). Tests carried out by Murphy et al. [9] state that a 1cm x 1cm cross-sectioned polyurethane flat material can exert over 1 N of Van-der-Waals forces on smooth and flat surfaces. These Van-der-Waals forces occur when objects are sufficiently close together. According to Debrincat et al. [3] these forces are caused by a naturally fluctuating electromagnetic field between surfaces of interacting objects.

Murphy and Sitti [7] proved the effective use of polyurethane as an adhesive material by implementing fibrillar adhesive footpads on a tetherless wall climbing robot called Waalbot. These fibrillar adhesive footpads allowed the robot to move vertically on a wall consisting of rough and smooth surfaces whilst supporting the mass of the robot of 0.1kg. The forces were proven not to be suction forces by hanging a 0.5kg weight onto a 1cm^2 polyurethane pad in a 0.01 atmosphere vacuum chamber ([8]). Polyurethane materials can firmly grip both micro- and macro-parts whose root-mean-square surface roughness values can be as high as 35μm ([9]).

3. POLYURETHANE GRIPPER

The polyurethane material chosen to produce the gripper that was utilized to perform the necessary experiments was sourced from a local company AMT Composites in Cape Town, which is a distributor of Smooth-On Company (USA) ([15]). The polyurethane product forms part of the VytaFlex Liquid Urethane Rubber Series. VytaFlex polyurethane was chosen because it was shown to be viable for large scale use in the application of Van-der-Waals force based adhesion ([7]; [2]) and has been implemented in wall climbing robots as mentioned earlier. VytaFlex is available in shore hardness range of 10A – 60A. For the purposes of this paper, VytaFlex 30 and VytaFlex 60 were chosen because they were readily available locally. The VytaFlex sourced from AMT Composites comes in 2 parts. The two parts were mixed thoroughly with a ratio of 1:1 for 3 minutes, and thereafter poured into moulds and were left to cure for 18 hours before the grippers were removed. The moulds used were of diameters 9mm and 10mm as well as thicknesses of 1.5mm and 3mm, so as to test out the effect it would have on the parts handled if the sizes of the grippers differ. An example of the moulds as well as the grippers after removal can be seen in Figure 1 and Figure 2.

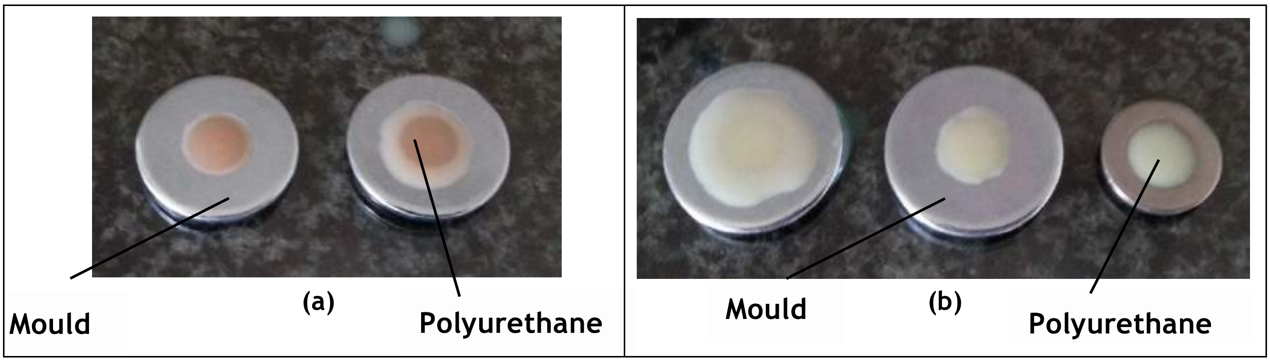


Figure 1: (a) VytaFlex 30A in 10mm x 3mm mould (b) VytaFlex 60A in 10mm x 3mm and 10mm x 1.5mm moulds

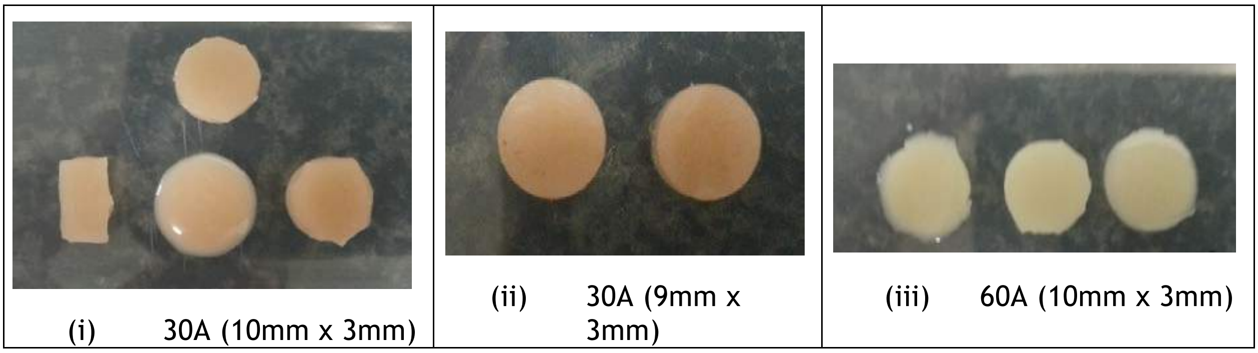


Figure 2: Polyurethane grippers after removal from moulds

4. PIEZOCERAMIC ELEMENTS

The micro-elements that were handled for the purposes of this paper were piezoceramic elements as mentioned earlier. These piezoceramic elements are integrated into piezoelectric components which are used in vibration and structural monitoring of materials ([4]). The piezoceramic elements are rod-shaped. These piezoceramic rods are to be accurately inserted into the micro cavities formed in the carrier material (aluminum), as seen in Figure 3 ([10]). The dimensions of the piezoceramic rods are 250µm by 250µm by 10mm, while the micro cavities are 300µm by 220µm by 10mm. The machined micro cavities in the aluminum alloy carrier can be seen in Figure 4. It should be mentioned that these piezoceramic rods are fragile and susceptible to damage if mishandled.

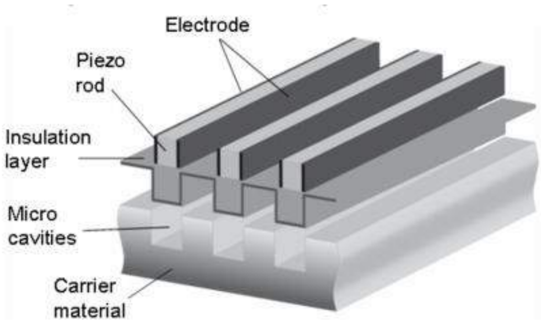


Figure 3: Schematic of piezo-metal module ([10])

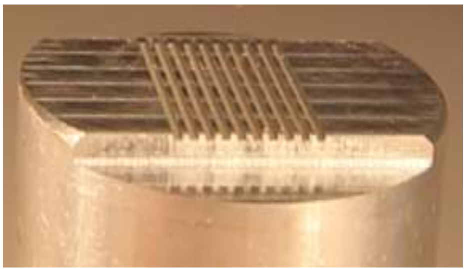


Figure 4: Dimensions of the micro-cavities in aluminum alloy carrier

5. SURFACE ROUGHNESS TESTS

Analysis of the surface roughness of the piezoceramic rods as well as the polyurethane gripper was done at iThemba labs in Cape Town. These tests were carried out on the Veeco NanoMan V Atomic Force Microscope with Nanoscope version 7.3 software. The area of the scan was 10µm x 10µm. The results of the 3D surface roughness scan for the piezoceramic rod, as well as the polyurethane gripper can be seen in Figure 5 and Figure 6. A summary of the characteristics of the surface roughness scan for the piezoceramic rod, as well as the polyurethane gripper, is shown in Figure 7 and Figure 8 respectively.

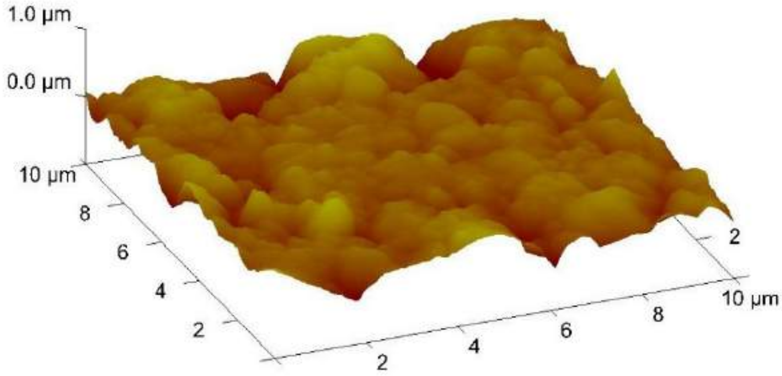


Figure 5: 3D surface roughness scan for piezoceramic rod

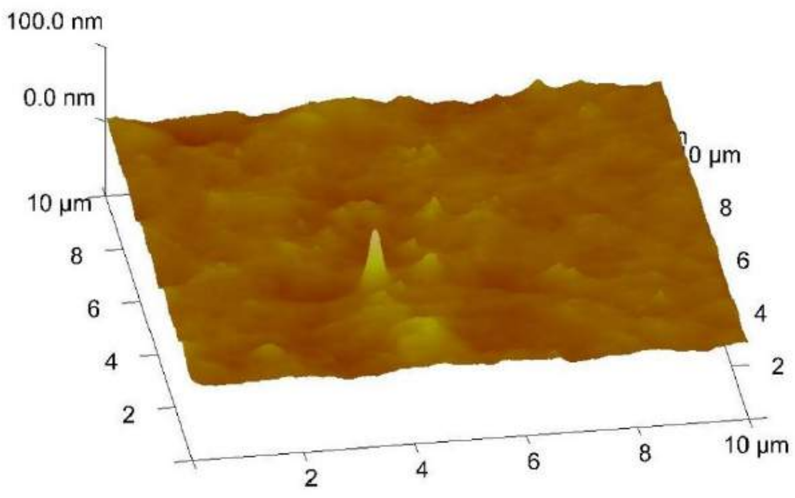


Figure 6: 3D surface roughness scan for 30A polyurethane gripper

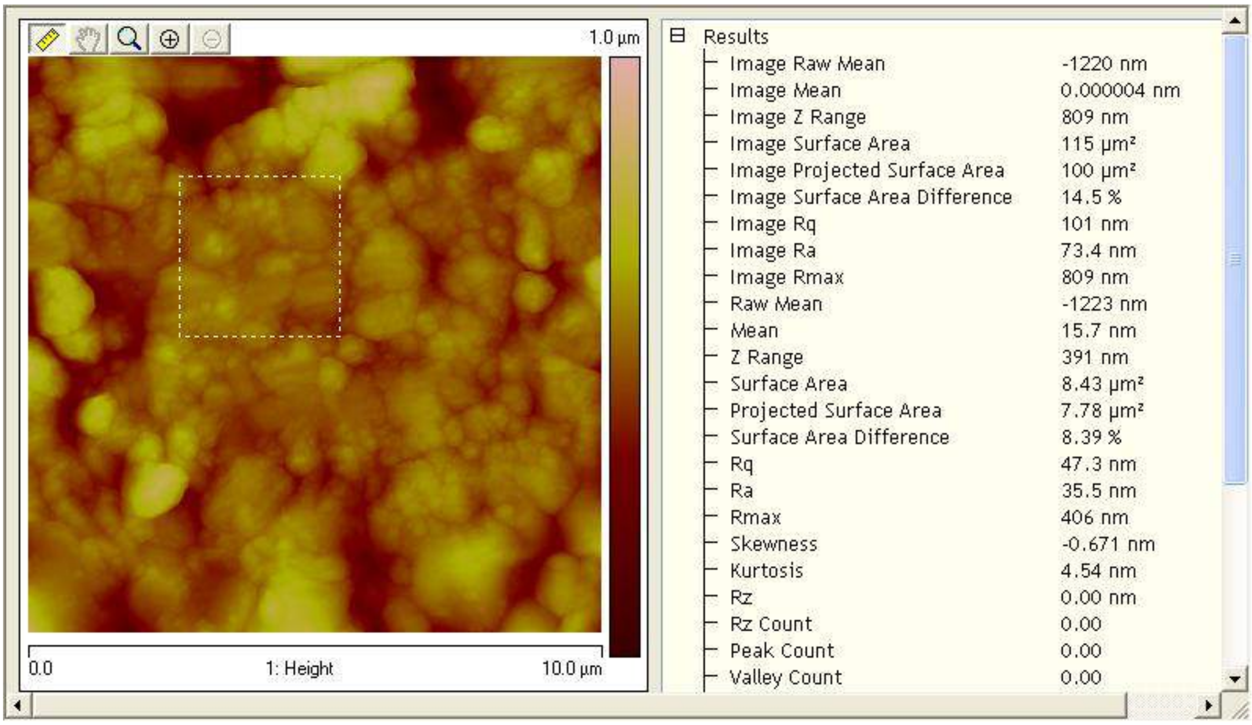


Figure 7: Surface roughness scan for piezoceramic rod with characteristics

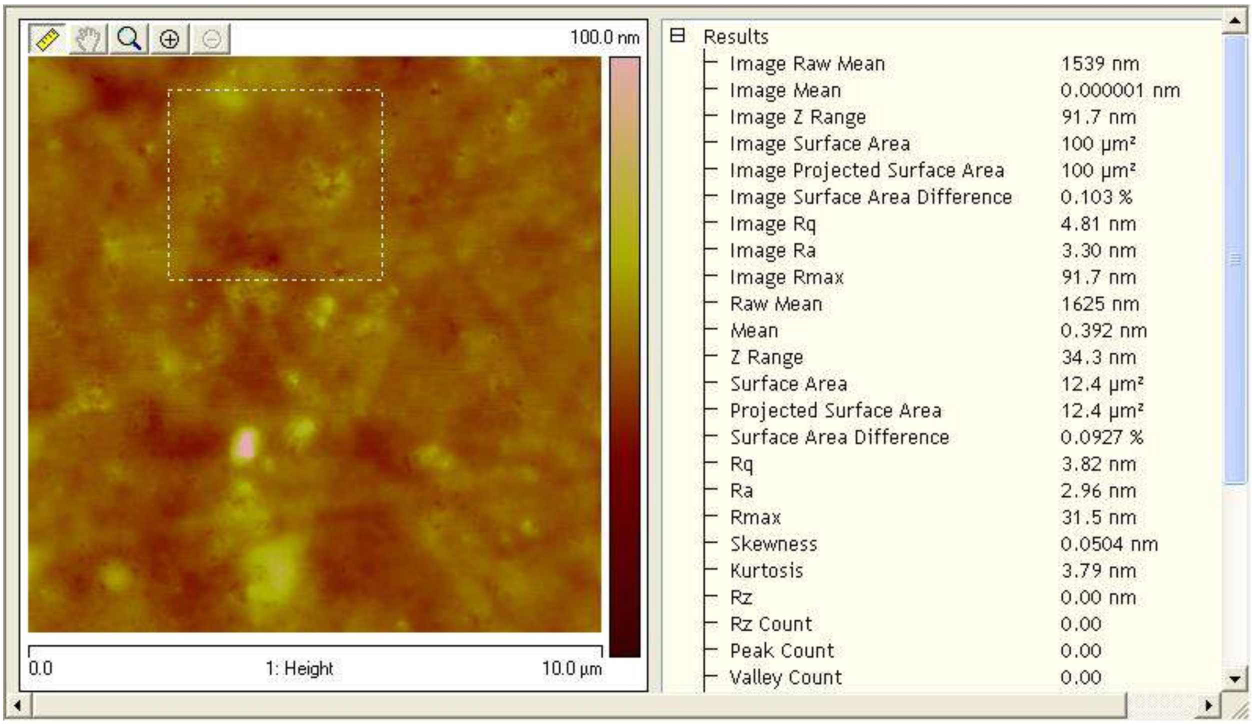


Figure 8: Surface roughness scan for 30A polyurethane gripper with characteristics

The roughness of the material being handled plays a pivotal role in calculating the Van-der-Waals forces needed to pick up the piezoceramic rods. According to Matope et al. [6] a lower root mean squared value allows for higher Van-der-Waals forces and therefore better picking capability. The root mean square (rms) surface roughness value of the piezoceramic rod was found to be 101 nm, as can be seen in Figure 7 by looking at the value "Image R_q". The root mean square (rms) surface roughness value of the 30A polyurethane gripper was found to be only 4.81 nm, as can be seen in Figure 8 by looking at the value "Image R_q". In the case of the piezoceramic rod, the rms surface roughness value is suitable for the pick-up operation by the polyurethane gripper, seeing as this value is far less than the value of 35 µm, which according to Murphy et al. ([9]), is the highest surface roughness value where Van-der-Waals forces may be applied for micro-material handling purposes. In the case of the polyurethane gripper, the rms surface roughness value is extremely small, which indicates that the surface with which the gripper will pick the elements is smooth, which will increase its ability to pick more than one piezo rod at a time.

6. FORCE MEASUREMENT

The force measurement was done by making use of a Motoman SDA10D 15 axis robot. An ATI multi-axis force/torque feedback sensor was used in conjunction with the robot to measure the Van-der-Waals forces exerted by the polyurethane micro-gripper. An electrostatic mat was placed on the workstation so as to cancel out any static electricity. An anti-static crocodile clip was attached to the end effector of the robot to ground the robot and the gripper of any electrostatic forces. The aluminum carrier with micro-cavities was securely attached onto a workbench. The gripper attached to the end effector was then aligned 5mm above the aluminum carrier by means of the control tablet. The next movement towards the aluminium carrier was done via a computer program. This control program was written by Andrè Smit, a Masters student at the Industrial Engineering Department at Stellenbosch University, for controlling the Motoman robot. This program was written in Microsoft Visual C#. The gripper was brought into contact with the aluminium carrier and then the gripper lowered until a force reading reaches the desired preload value. The gripper was then raised in increments of 0.2 mm. This was done to record the maximum Van-der-Waals force when releasing. The force tests with the 30A polyurethane gripper were repeated 8 times to allow for a reliable data set. The results can be found in Table 1.

Table 1: Van-der-Waals forces recorded during force measurement

Test	Preload (N)	Max Van-der-Waals force when releasing (N)
1	0,234	1,184
2	0,249	1,142
3	0,238	1,401
4	0,233	1,358
5	0,243	1,414
6	0,217	1,580
7	0,239	1,386
8	0,217	1,354
Mean	0,234	1,352
Std. Dev.	0,0615	0,137

The average preload force on the aluminium carrier was calculated as 0.234 N (Table 1). The average maximum Van-der-Waals force exerted when the gripper was released from the aluminium carrier rods was calculated as 1.352 N (Table 1). The standard deviation for the maximum releasing force was calculated as 0.137 N (Table 1) which indicates that the operation is repeatable. The desired preload force used during the force measurement tests was 0.2N which was the preload force used by Matope et al. [17] during their handling tests of 1 piezoceramic rod which were successfully done. This was proven to be the optimal force to be used so as not to damage the piezo rods or the micro-gripper.

7. EXPERIMENTATION AND ANALYSIS OF RESULTS

A Motoman SDA10D robot was used to perform the necessary tests. This robot is a 15-axis robot which consists of 2 arms with 7 degrees of freedom each. The Motoman robot was equipped with an ATI multi-axis force/torque sensor, which was used to measure the preload force necessary to pick up the piezoceramic rods. The robot can be controlled via the control tablet or on a computer connected to the robot via an Ethernet network. Control via the computer is necessary to be able to receive data transmitted from the force/torque sensors. The robot is rated to a repeatable positional accuracy of 0.1mm while handling a 10kg mass payload ([12]).

The polyurethane gripper that was prepared, was attached to the end effector of the robot, with the end effector being attached to the force/torque sensor. In this case a rectangular cross-sectioned gripper was attached to the end effector using double sided tape as shown in Figure 9. An anti-static crocodile clip (shown in Figure 9) was attached to the end effector to ground the robot and the gripper of any electrostatic forces.

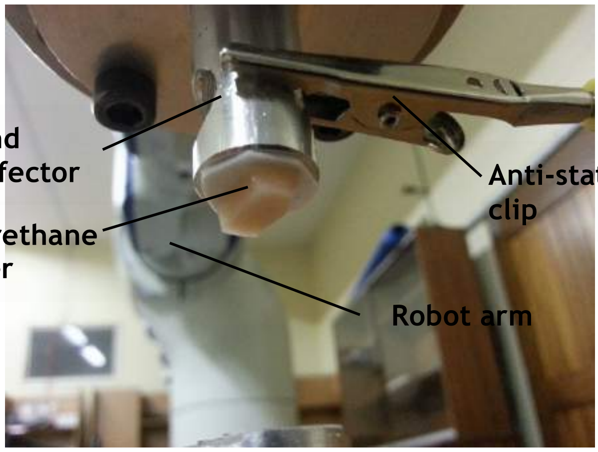
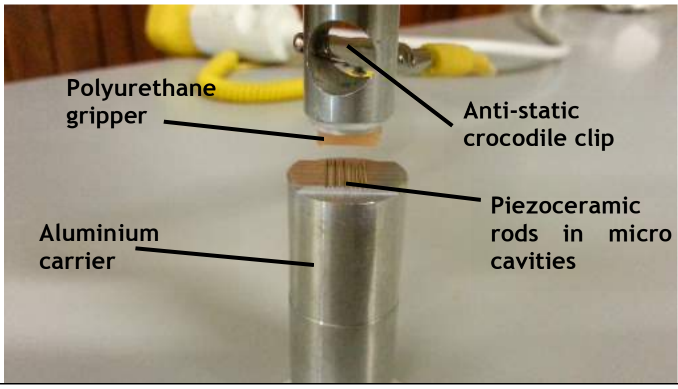


Figure 9: Polyurethane gripper attached to end effector

The steps followed with the pick-up operation of the piezoceramic rods can be seen in Figure 10. The aluminum carrier with inserted piezo rods was secured to the workbench. Next the gripper attached to the end effector was aligned above the aluminum carrier by means of the control tablet. The operations to follow were done by means of the control program (as mentioned in section 6). The gripper was lowered onto the 10 piezoceramic rods until a force of 0.23N was registered by the force sensor. The gripper was then raised with the 10 piezoceramic rods successfully attached to the polyurethane gripper as can be seen in parts (iii) and (iv) in Figure 10. A 10 mm x 5 mm x 3 mm polyurethane gripper reliably performed the operation as seen in Figure 10. This rectangular shaped gripper was used because it afforded an improved view of the handled piezoceramic rods, enhancing accuracy in the placement operation.

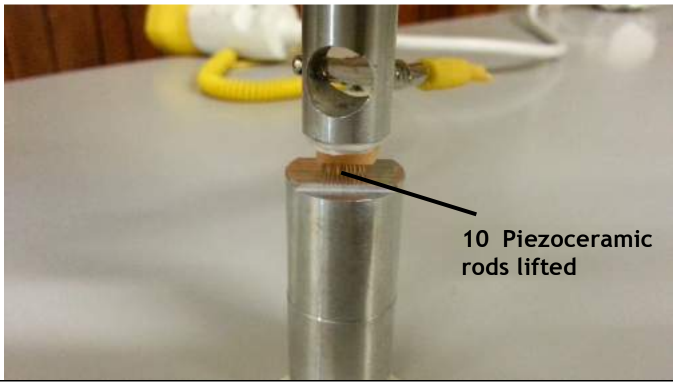
The steps followed with the placement operation of the piezoceramic rods can be seen in Figure 11. The gripper attached to the end effector was aligned above the second aluminium carrier by means of the control tablet. As mentioned earlier the next operations were performed by means of the control program. The gripper was lowered into the micro cavities with the 10 piezoceramic rods attached. The gripper was then raised until a preload force of 0N was registered on the force/torque sensor. The gripper was then moved horizontally to release the piezo rods.

It was proven that the polyurethane gripper used in these experiments was successful in picking and placing the piezo-ceramic rods (Figure 10 and Figure 11) without causing any damage or exerting unnecessary charges or strains to the piezo rods.

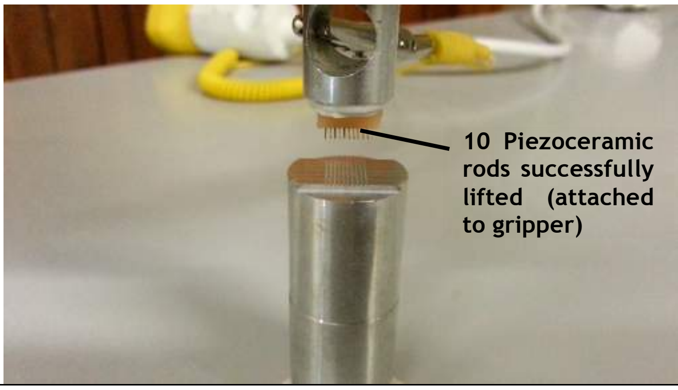


(i) Gripper aligned and ready for pick

(ii) Preload force of 0.23N applied to piezo rods

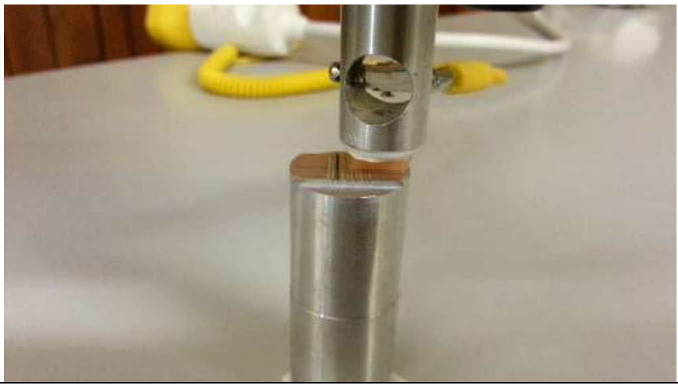


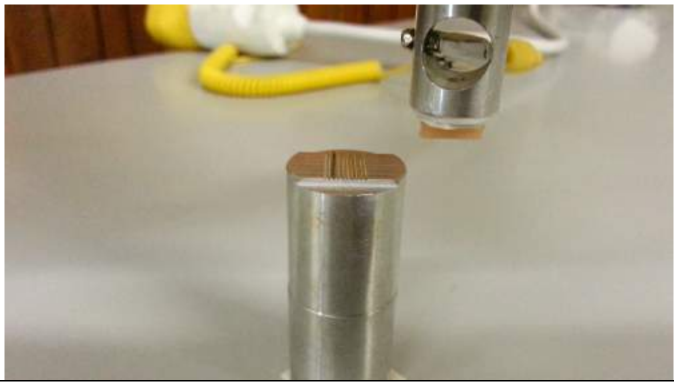
(iii) Piezo rods removed from micro cavities by vertical movement



(iv) Piezo rods successfully removed

Figure 10: Pick-up operation of piezoceramic rods from micro cavities

	(i) Gripper aligned and ready for placement operation
	(ii) Rods placed back into micro cavities
	(iii) Gripper raised until preload force of 0N is read by force sensor
	(iv) Gripper moved in a horizontal direction to release rods



(v) Gripper successfully removed from piezo rods, piezo rods successully placed

Figure 9: Placement of piezoceramic rods

8. CONCLUSION

This paper presents Van-der-Waals force actuated polyurethane micro-grippers as a viable option in the handling of fragile piezoceramic elements. In this case a rectangular 10 mm x 5 mm x 3 mm polyurethane micro-gripper with a shore hardness of 30A reliably handled the piezo-ceramic elements. This rectangular polyurethane gripper successfully handled 10 piezoceramic rods simultaneously. The rods were of size 250µm x 250µm x 10 mm dimensions. These were handled from micro cavities of 300µm x 220µm x 10mm. The gripper presented in this paper improves the assembly efficiency by about 10 times as compared to the Matope et al 2013's [17] gripper which could only assemble one piezoceramic rod at a time.

9. ACKNOWLEDGEMENTS

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AN INVESTIGATION OF INDUSTRY EXPECTATIONS ON INDUSTRIAL ENGINEERING GRADUATES: A CASE STUDY OF GRADUATE DEVELOPMENT PROGRAMMES IN SOUTH AFRICAN UNIVERSITIES

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ABSTRACT

During the year 2008 and 2009, post apartheid South Africa and the global community experienced major economic turbulence with poverty, unemployment and skills shortage affected by poor productivity in most manufacturing and other economic sectors leading to a subsequent downsizing of the labour work force. The government and business communities at large realized the necessity for skills development across the major economic sectors in order to resuscitate the failing economy. The solutions lay in organisations re-evaluating their current operational strategies by streamlining their organisations and adopting aggressive lean and cost saving approaches in order to remain competitive.

Two things became apparent; one was the need for skills growth and two the need for a cost cutting, cost saving and optimisation skill, a skill descriptively and applicably seen in industrial engineering. The role of graduate institutions facilitating the growth of the human capital development in the work environment has become a critical factor in South Africa, aiming at improving the productivity and economic growth of the country. In this paper, the focus confines itself on the following main areas of discussion, the institution environment with the students-lecturer relationship explored and the work environment. The study highlights the influence these environments have on industrial engineering skills and competencies attained by industrial engineering university student graduates and how this ultimately creates a way out for the South African economy.

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1. INTRODUCTION

Since the 1970s and 1980s, skills development was and still is a contentious issue within the work industry. The skills shortage in South Africa is one of the main impediments to reaching the stated economic growth targets of the Government. This has advertently made skills development crucial to South Africa's growth and progress [9]. Two major challenges addressed during the post apartheid era, poverty and unemployment [23], called for an aggressive approach to skills development. This aggressive approach is evident by the governments' efforts in the creation of the department of higher education and training. This has incorporated various institutional entities such as human capital development under the Human Resource Development Strategy for South Africa and the higher education bodies in cooperation with the South African Qualifications Authority in fostering skills development aiming at realising a systemised post school education and training structure.

The South African Qualifications Authority Act [18, 24], passed into law in October 1995. The act prescribed the establishment of, amongst others, the South African Qualifications Authority, the National Qualifications Framework and the Sectoral Education and Training Authorities. In addition, the introduction of the Joint Initiative for Priority Skills Acquisition together with the higher education bodies has created a renewed approach in the economic 'skills' needs required for improving the economic growth reaffirmed by Mlambo-Ngcuka:

"In a country such as ours where skills shortage and skills inadequacy is so glaring...In South Africa, we have missed so many opportunities because of skills. We import artisans, welders...concurrently we also need a skills revolution in the curriculum of tertiary education, as well as in the quality of public education. Human Resource Development. The biggest crosscutting constraint. The skills that we lack and desperately need are engineering skills, planning and management skills, artisans..." [9].

The evolution of industrial engineering in South Africa as discussed by MyFundi [11], began in the early 1960s with the learning 'student' being equipped with subjects like work-study, method studies, production, material handling, layout planning and a few financial subjects. During the 1970s, it was realised that the environment of industrial engineers was changing and that the student was entering the era of planning and scheduling. As a result, the academic syllabi changed accordingly, and the inclusion of additional subjects like Control Systems, Material Science, Operations Research, Statistical Quality Control and Computers and Programming was necessary. Industrial engineers began to emerge as engineers trained to see the 'bigger picture' in a systems perspective. It was also realised that this engineer could perform outside the arena of hard production and would enter the world of the service sectors [11]. According to Statistics South Africa [28], in 2008 and 2009, South Africa underwent a trying economic slump losing a major percentage of their manufacturing labour force. As a result, most manufacturing firms' competitive edge pegged on re- evaluating their operational strategies by undertaking leaner more aggressive cost saving approaches. This signalled a revival for the industrial engineering field as most companies delved into streamlining their organisations by employing industrial engineering practices, techniques e.g. six sigma, continuous improvement, and taking on industrial engineering professionals. Industrial engineering was slowly gaining attention as a means to cut cost and maintain a cost effective business approach. This course of events, created a niche for industrial engineering as a much-needed value-adding component for business excellence.

Industrial engineering is a necessary skill in any developing and developed country. The need is evident by the increase in the cost saving approaches South African companies are employing. This study explores the correlation between industry skills expectations and the academic ability to meet this need. The study needed to satisfy the researchers' enquiry in as far as the level of graduating South African industrial engineers who are actually employed within the relevant job market and the expected growth. In addition, the needs of the job industry are ideally expected to be met by the various learning institutions i.e. universities in this case, placing responsibility on both the industry and the universities to ensure that students learn what is relevant and useful for job performance and development. It is thus imperative to investigate this relationship between industry and graduate industrial engineers with emphasis on the skills expectations as emphasised by the government and the academic capacity to meet these skills expectation in today's competitive professional arena as iterated by Nel [13].

The combined impact of the economic strain experienced by the South African economy, shows that there is a lack of adequate communication between industry and institutions, the result of which, the skills level and academic qualification attained by graduating industrial engineers do not meet industry expectations'. In making this statement, we are in fact asking ourselves the following; "Are the graduate industrial engineers able to meet the minimum demands and skills level expected by the relevant industrial engineering industry?" In answering this question, several objectives are derived and explored further in order to elucidate the bridge behind this assumed gap between the student's skills level acquired from academic knowledge and the application of this skill within the industrial engineering environment. The objectives for this study were as follows:

- To determine the significant roles played by industrial engineering graduates in industry;
- to identify the minimum skills level of an industrial engineering graduate;
- to identify the existing academic national qualification framework for industrial engineering curricula, as defined by the South African Qualification Authority; and
- to define effective mechanisms to ensure high quality levels of industrial engineering graduates capable of meeting industry expectations.

2. LITERATURE REVIEW

2.1. Skills level and the significant role of industrial engineering on productivity

Since 1994, the skills shortage in South Africa has been of concern triggering various discussions forum in an effort to understand and articulate its dynamics and impact towards economic development [25,30]. Poverty, inequality and unemployment are continuously under debate with skills scarcity being topical [30]. Iterating further, South Africa [27], describes the gap between income inequalities in the various sectors of industry in South Africa plays a major role in the skills shortage arena. Results obtained from the 2005/6 Income and Expenditure survey, show a resounding gap between income earners in industry. Despite ten percent of the population earning more than fifty percent of household income, eighty percent of this population earns less than eight and a half percent of the household income, negating the need for skills as a source of income [25]. In addition, the unusually high unemployment rate manifests itself with a low youth count in the labour market and the education and training system [4]. The poor and ineffective educational outcome is evident in the poor results seen in the current Annual National Assessments literacy and numeracy levels [31].

This challenge, calls for a more effective approach towards the education system and balance between labour supply and demand if there is to be an improvement in the socio-economic growth and development. Articulation of the link between the education sector and industry creates a platform for development of quality programmes in the education sector that caters directly for the needs of industry [22,32]. The department of trade and industry iterates this in the National Industrial and Policy Framework stating that '...the skills and education system form a fundamental pillar for the success of an industrial policy. There is currently insufficient integration between industrial policy objectives and skills in the education system. There is therefore a need for a much closer alignment between industrial policy skills and education development, particularly with respect to sector strategies...' [26]. In light of these revelations of inequality and poor pre-schooling outcomes, an understanding of the importance of effective post schooling and supporting training systems is worth exploring in order to improve South Africa's developmental growth and sustainability.

Industrial engineering is a branch of engineering that focuses skills knowledge geared towards effective systems development and optimisation in both product engineering and service related fields [11]. In the South African engineering context, industrial engineering is a skill viewed in various forms such as industrial technologists, industrial technicians and industrial professional engineers [19,20]. The department for Home Affairs listed industrial engineering as a national scarce and critical skill in 2006 substantiating the need for industrial engineering as a highly sort after skill [26]. According to Nel and Mulaba-Bafubiandi [12], the current number of professionally registered South African engineers in the engineering database since 2006, was five thousand for engineers, one thousand six hundred for technologists, six thousand seven hundred for technicians and as of March 2005 only two hundred and twenty five registered industrial engineers.

A 2008 statement by the Southern African Institute for Industrial Engineering, iterated that the varied characteristic of the industrial engineering profession has shifted beyond the conventional engineering applied in the manufacturing sector prior to 1950 and has widened to feature in non-manufacturing areas, which include consulting, banking, healthcare, and government. [12]. The Business Times of March 2007. The article, cited in Project2010 [15], stated "…companies are buckling under the increasing demands of a growing economy and in the face of fierce competition from international businesses, companies 'creaking under the strain' of a 'skills crisis' and the need to deliver bigger volumes of goods to increasingly diverse customers. This is compromising SA's global competitiveness and is spurring 'poorer' service across various industries"...“due to the shortage of skills in engineering, supply chain management, warehousing and distribution, and network analysts...” all skills relevant to industrial engineering [15]. In addition, the discussion forum held by the SAIIE industry forum in 2008 estimates that about one thousand industrial engineers are needed every year in order to meet this level of industrial engineering demand for South Africa.

2.2. Curriculum requirements and skills level

Industrial engineering focuses on the following areas of business; efficiency, or, more precisely, how to design, organize, implement and operate the basic factors of production (materials, equipment, people, information, and energy) in the most efficient manner possible. The typical focus is on optimising industrial manufacturing operations, although the skills learned are applicable to other non-manufacturing settings [33]. The following highlight a few key areas an industrial engineer must meet; both in academia and the relevant linked industry skills:

- Ergonomics / Human Factors Engineering (designing the workplace to better accommodate "human factors" (human abilities and behaviours'), thereby yielding more efficient operations and fewer accidents or injuries).
- Facility Design (aimed at operational efficiency)
- Applied statistics (using statistics and other forms of data analysis to aid in making management decisions and analysing work.)
- Manufacturing Engineering (concerned with all aspects of manufacturing operations – materials, parts, equipment, facilities, labour, finished products, and delivery, among others).
- Quality Control (using sampling, statistical analysis and other techniques to assess and maintain the quality of products or services provided by a business or other organisation)
- Work Design (defining jobs that individual workers do in performing the overall work of the organisation, with the typical focus being on optimising manufacturing operations).
- Worker Productivity (conducting time and motion studies, setting work performance standards, and proposing new/improved work methods)

In fitting the various roles of industrial engineering fields, the following main engineering disciplines in industrial engineering stand out [35]:

- **Enterprise engineering:** This is the engineering of enterprises as a whole, which evolved from systems engineering. In order to achieve this, industrial engineers make use of their ability in the application of knowledge, principles, and disciplines related to the analysis, design, implementation and operation of all elements associated with an enterprise.
- **Systems engineering:** This is the approach to design, creation, and operation of systems. It entails the identification and quantification of system goals, with the aim of integrating the needs of each related subsystem to fit the purpose of the main system. The need arose with the increase in system complexity, due to poor subsystem integration, and subsequently unstable system reliability.
- **Operations management:** Operational industrial engineering focuses on the design and improvement of operations and activities related to the functions delivered by the system role players. One such area is in the supply-chain-management operation that aims to link the organisations role players internally and externally in the system.
- **Applied industrial engineering:** This is the application of industrial engineering in specific industries. These industries may be dictated by the national economic growth needs. In South Africa, the current industrial needs fall under production and productivity growth.
- **Engineering management:** Engineering management is a specialised form of management that is concerned with the application of engineering principles to business practice. Engineering management is a career that brings together the technological problem-solving practical understanding of engineering and the organisational, administrative, and planning abilities of management in order to oversee complex enterprises from conception to completion.

2.3. Curriculation, quality assurance and academic qualification levels of industrial engineering

Higher education bodies responsible for curriculation of industrial engineering as a study programme, tasked with the mandate to formulate, standardize and monitor the current and emerging academic and non-academic qualifications, brought about a means to steer skills level towards a more productive focal point. These bodies are the South Africa National Qualifications Framework and the Engineering Council of South Africa. One body that is not included under the higher education statutory bodies but contributes immensely, by its own right, towards fostering economic growth in the business and other economic sectors, is the Southern African Institute for Industrial Engineering. SAIIE as the name implies, is an organisation made up of industrial engineering members from various disciplines drawing upon specialised knowledge and skills in the mathematical, physical, behavioural, economic and management sciences focused on finding optimal and practical solutions, which contribute to the success, prosperity and the creation of wealth in the Southern African economy. SAIIE aims to be a vibrant, learned society, representing and promoting all industrial engineers, while maintaining a high level of standard for all industrial engineers within Southern Africa [16].

The academic qualifications currently attainable in South Africa by an industrial engineer are:

- National diploma in industrial engineering with an NQF level 6,
- Bachelor of technology in industrial engineering with an NQF level 7,
- Master of technology in industrial engineering with an NQF level 9,
- Doctor of technology in industrial engineering with an NQF level 10,
- Bachelor of engineering in industrial engineering with an NQF level 8,
- Master of engineering science: Engineering management with an NQF level 9 and
- Doctor of engineering with an NQF level 10

In highlighting these broad areas of literature, the study is able to show the alignment of the two components i.e. curriculum requirements and the skills level of the graduate industrial engineer thereby narrowing the gap between the student's skills level acquired from academic knowledge and the application of this skill within the industrial engineering environment.

2.4. Quality and Total Quality Management of industrial engineering

Total quality management is a philosophical management approach developed by several management professionals one of whom was the quality guru W. Edward Deming through his fourteen points on how to implement quality improvement. Organisations use total quality management to implement quality policies and objectives through directing and controlling a set of integrated elements in order to achieve a high level of overall operational excellence. Deming's fourteen points were developed further into seven effective concepts namely, continuous improvement, six sigma, employee empowerment, bench marking, just in time, taguchi concepts, and the knowledge of the total quality management tools [36].

"Trends in Public Higher Education in South Africa: 1995 to 2004" [21] is a report that demonstrates the quantity of learners who have successfully passed to graduate during the period 1995-2004 and the number of qualifications registered since the inception of the outcome based National Qualifications Framework initiative. The report defines a national higher diploma in industrial engineering as a qualification with a national qualifications framework rating of seven, which will serve as an example or basis of reference throughout this study. As mentioned previously, the outcome-based accreditation of undergraduate engineering programmes has been under discussion since the mid 1900s [8]. The accreditation emphasizes the need to produce graduates that adequately meet the needs of industry and as such, it is important to explore whether the outcomes of such engineering programmes do indeed match the needs of industry [5, 8]. It is however important to mention that alignment of the curriculum requirements and the skills level of the graduate industrial engineer is of no consequence if value is not proffered. The study proceeds to show an effective mechanism to ensure high quality levels of industrial engineers capable of meeting industry expectations in a cross section study of what it means to have quality represented in industrial engineering.

Just as any other organisation that utilises quality to gain optimum throughput through total quality management, higher education requires a quality component. Viewing industrial engineering in institutions of higher learning as a system with interrelated components, with the 'customer' being the product of interest such as the graduate industrial engineer, quality becomes an aspect that one is hard pressed to ignore just as in any other manufacturing process. Chikumba [3], iterates that the organisational transformation model, emphasizes that understanding organisations as a model is important for successful execution of corporate strategy and that viewing the organisation as a transformation process, which satisfies customer needs through maximizing value added to inputs producing outputs through routine and repetitive or programmable decisions is important. In defining value, the dimensions of quality should not be ignored; value accrues through the creation of the products' function. This ideology is better described mathematically in figure 1 [10]:

$$VALUE = \frac{\text{FUNCTIONALITY (as a Product or Service or System)}}{\text{COST}}$$

$$\therefore VALUE = \frac{\text{QUALITY, SPEED, and FLEXIBILITY (Drivers of value)}}{\text{RISK, WASTE, and CASH FLOW (Drivers of value)}}$$

Figure 1: Operational value drivers [10]

The three main groups responsible for creating this value are considered in this paper as falling within three domains, one the industry, two the institutions of higher learning and three the student. The study measures these groups against the effectiveness and efficiency model [10]. Being effective allows an individual the ability to achieve a task given certain pertinent tools and resources. However, achieving the task in the shortest time and in the least effort relies on how efficient one is, see figure 2.

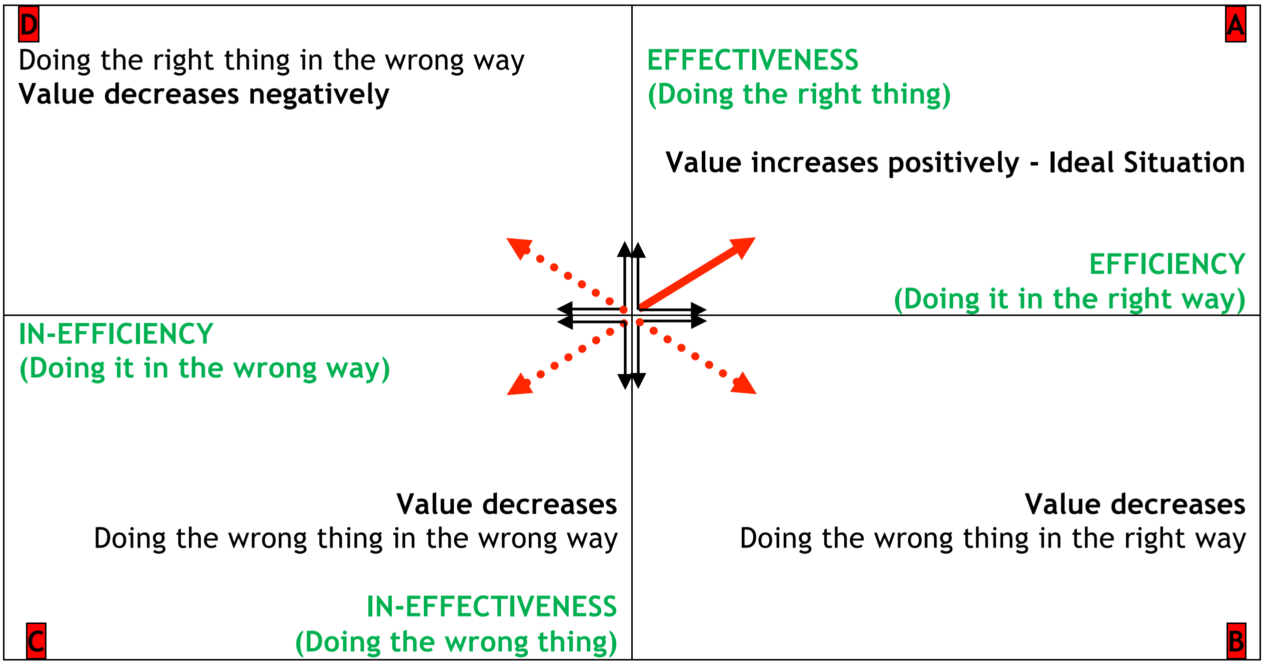

Figure 2: Efficiency and Effectiveness:-Value [14]

3. PROBLEM STATEMENT

There is indeed a need to investigate the relationship between industry and graduate industrial engineers, as emphasised by the skills expectations addressed by the government and the academic capability to meet these skills expectation. The problem statement developed read as follows: 'There is a lack of adequate communication between industry and institutions, as a result of which, the skills level and academic qualification attained by graduating industrial engineers do not meet industry expectations.'

The following question answers the aforementioned statement by asking: "Are the industrial engineering graduates able to meet the minimum demands and skills level expected by the relevant industrial engineering industry?" This led to the following set of investigative sub questions that explore the relationship between the minimum level of skills and qualification expected of a graduating industrial engineer by the relevant industrial engineering companies and businesses in South Africa by considering the following:

- What are the significant roles played by industrial engineering graduates in industry?
- What is the minimum skills level for graduate industrial engineers?
- What is the existing academic national qualification framework for industrial engineering curricula, as defined by SAQA?
- How is quality levels ensured for industrial engineering graduates in meeting industry expectations?

4. RESEARCH METHODOLOGY

The statistical inferences drawn are from three Likert type scale [2] questionnaires using a sample group of one hundred and fifty four participants from all three groups i.e. the students, lecturers and the industry, in the form of an online and manual survey in conjunction with several interview sessions[1,7]. The Three separate questionnaires similar in design and nature were developed for each subgroup [1]. A distinction per questionnaire was intentionally built in through re-structuring each survey according to the environment suitable to the sub-group in question. Each questionnaire was broken into three distinct sections covering three prescribed environments of industrial engineering. Firstly the Academic environment seeking the perception of industrial engineering in as far as knowledge understanding and creation, secondly industrial / work environment seeking the perception of industrial engineering's impact in the business organisation and lastly quality environment of industrial engineering seeking the perceived level of 'value' understood in this engineering skill.

The data sampled from the study were analysed using a Microsoft's excel application programme designed and created by Del Siegle [17]. The statistical tests derived were:

- Descriptive statistics with univariate graphs.
- Cronbach's Alpha for reliability testing.

5. RESULTS

5.1. Descriptive statistics

5.1.1. *Overall analysis of student responses*

The following is a summary of the overall analysis of student responses based on a significant percentage response related to discussions made the literature review and the investigative sub-questions highlighted in the study, see figure 3:

- **Role of industrial engineering in industry:** Ninety percent of students understand and are passionate of industrial engineering and its role in industry as asked in statement 1 of the study. However there is a significant seventy seven percent and above uncertainty as to its origin, awareness and future role in industry as asked in statement 1 and 6 respectively.
- **Significance of industrial engineering in industry:** Eighty eight percent of students agreed that industrial engineering plays a significant role in industry as answered in statement 4 of the study.
- **Minimum skills level of a qualified graduate industrial engineer:** Eighty eight percent of students agreed that a minimum requirement for industrial engineering in industry is a bachelor's degree.
- **Knowledge of the existing SAQA qualification framework for industrial engineering:** Seventy six percent of students were aware, knowledgeable and understood the workings and interpretations of the national qualification framework.

5.1.2. *Effective mechanism for students:*

A significant percentage of students agreed that they receive adequate teaching material and effective teaching styles including support from tutors and industry interactions that enhance the quality of the skills taught. Discussion groups, family and departmental interventions help enhance and counter challenges students may be facing in understanding the industrial engineering programme. Thirty three percent of students in Statement 51 agreed that interactions with the Engineering Council of South Africa in their institution help develop and keep industrial engineering current. In contrast, however students answering Statement 50 stated that there is a lack of presence from within their institutions of the quality assurance bodies such as the Engineering Council of South Africa and Southern African Institute of Industrial Engineers.

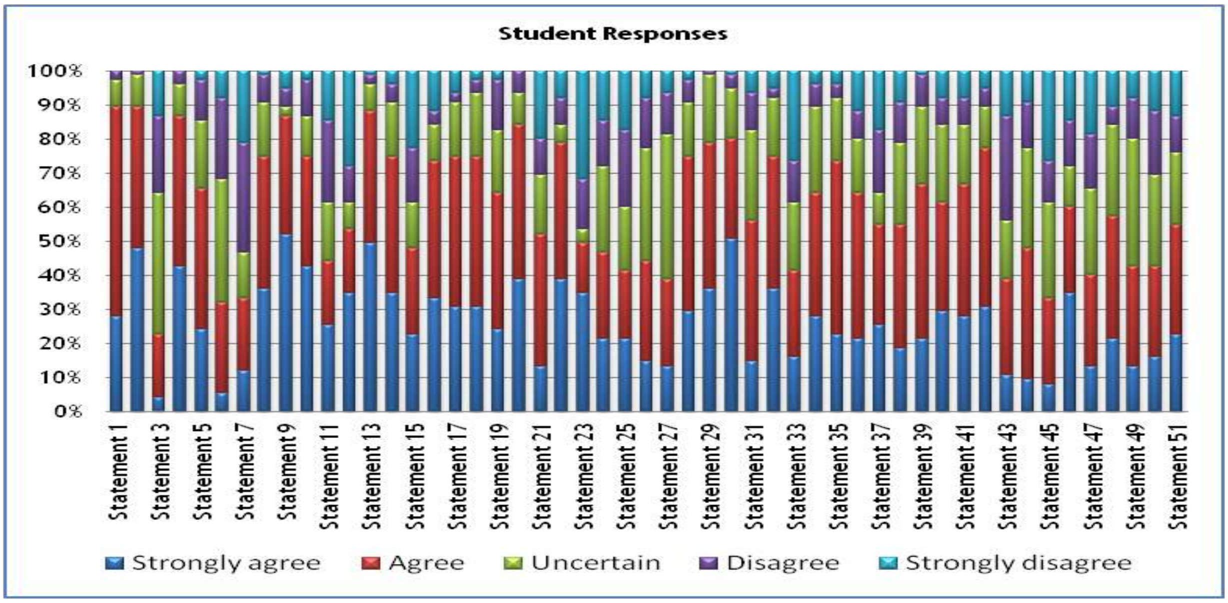

Figure 3: Stacked bar of student responses

5.1.3. *Overall analysis of institution (lecturers) responses*

The summary of the overall analysis of institution (lecturers) responses based on a significant percentage response related to discussions made within the ambit of the literature review and the investigative sub-questions highlighted in the introduction of the study, see figure 4:

- **Role of industrial engineering in industry:** Above seventy five percent of lecturers have a mastery understanding of industrial engineering and believe that it is knowledge and information based skill, which industry can capitalise on.
- **Significance of industrial engineering in industry:** Ninety two percent of lecturers agreed that industrial engineering plays a significant role in industry. Its responsibility in industry and history background is of great importance in influencing the South African economy. It is encouraging to note that a negligible number disagreed with the above feedback depicting a strong sense of industrial engineering as a pertinent component in economic growth and sustainability.
- **Minimum skills level of a qualified graduate industrial engineer:** Eighty-three percent of lecturers agreed that a minimum requirement for industrial engineering in industry is a bachelor's degree and above.
- **Knowledge of the existing SAQA qualification framework for industrial engineering:** One hundred percent of lecturers were aware, knowledgeable and understood the workings and interpretations of the national qualification framework, and what is expected for industry. Very encouraging is the fact that eighty four percent of the lectures were in total agreement as to the nature of student and industry expectations and the importance to meet this need.

5.1.4. *Effective mechanism for lecturers:*

A significant sixty seven percent of lecturers agreed that they receive adequate teaching material from their institutions and poses effective teaching styles including support from institution and industry interactions that enhance the quality of the skills taught. It is important to take note that thirty-three percent of lecturers felt that they are inadequately supported in their personal capacity to teach industrial engineering. Statement 21 highlights this personal inadequacy, which begs for further investigation. This may possibly be due to the sixty-six percent in disagreement as to the following Statement 22, which states; 'my current remuneration level is adequate given the work I do' i.e. for lecturing services rendered. Lecturers significantly support discussion groups, family and departmental interventions. Thirty three percent and twenty five percent of lecturers in Statement 51 and 52 respectively, agree that interactions with the quality assurance bodies such as the Engineering Council of South Africa and Southern African Institute of Industrial Engineers with their institutions help develop and keep industrial engineering current. Statement 40 although positively answered, highlights an important fact that sixteen percent of lectures do not believe that students have adequate access to industrial engineering information within their institutions' libraries. This small percentage may be due to inadequate or inaccessible South African industrial engineering literature students are able to utilise.

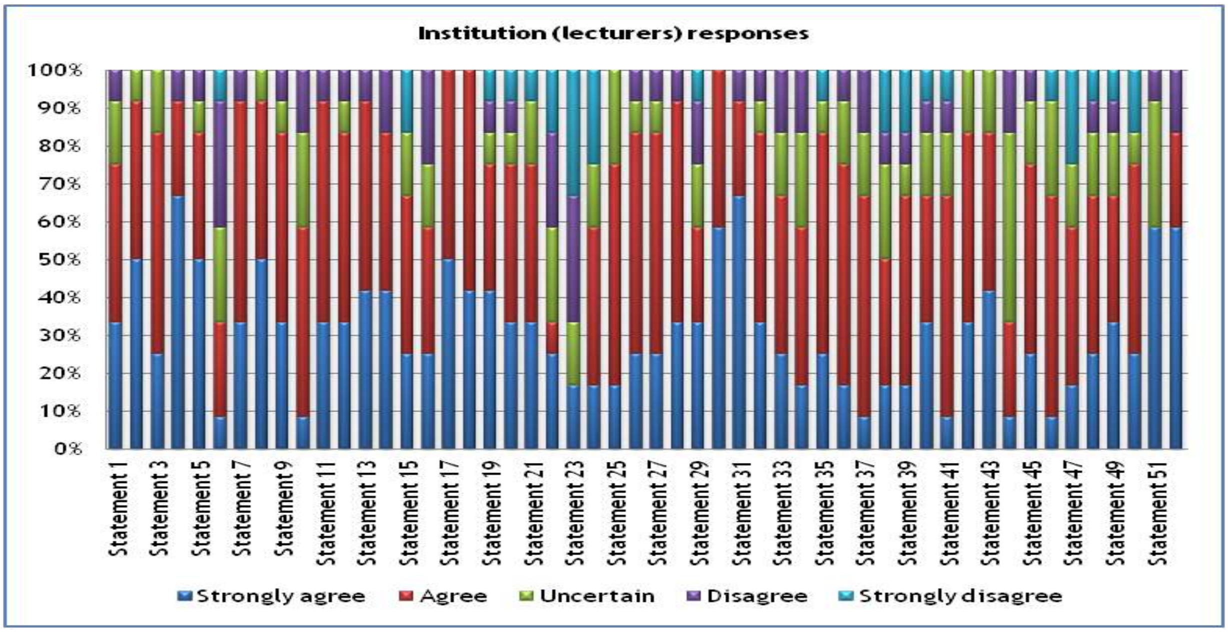

Figure 4: Stacked bar of institution (lecturers) responses

5.1.5. *Overall analysis of industry (SAIIE and ECSA) responses*

The following is a summary of the overall analysis of industry (SAIIE and ECSA) responses based on a significant percentage response related to discussions made in the literature review and the investigative sub-questions highlighted in the study, see figure 5:

- **Role of industrial engineering in industry:** Eighty-eight percent of industry have a mastery understanding of industrial engineering and believe that it is knowledge and information based skill, which industry can capitalise on.
- **Significance of industrial engineering in industry:** Ninety-one percent of industry agreed that industrial engineering plays a significant role in industry and its responsibility in industry is of great importance in influencing the South African

economy. Of significance, however, is the forty six percent of industry who are either uncertain or do not know the significant role the history industrial engineering has played in the South African economy while only fifty three percent of lecturers are in agreement as far as being knowledgeable of the fact. The actuality that seventy-seven percent of industry disagreed as to the adequate awareness of industrial engineering in industry regionally may attest to the lack of knowledge of the history of industrial engineering in industry. It is encouraging to note that fifty-five percent of industry believed that institutions are contributing to skilling productive industrial engineers. However thirty five percent are either uncertain or disagree with the fact.

- **Minimum skills level of a qualified graduate industrial engineer:** Eighty-two percent of industry agreed that a minimum requirement for industrial engineering in industry is a bachelor's degree and above. Industry is encouraging further development and research as shown by the ninety four percent of individual industrial engineers either involved in or pursuing industrial engineering related projects and activities, showing a positive growth and advancement of industrial engineering knowledge and innovation in industry
- **Knowledge of the existing SAQA qualification framework for industrial engineering:** Above eighty percent of industry were aware, knowledgeable and understood the workings and interpretations of the national qualification framework, and what is expected of industry. Seventy-eight percent of the industry agreed as to the nature of student and industry expectations and the importance to meet this need.

5.1.6. *Effective mechanism for industry (SAIIE and ECSA):*

Only forty-nine percent of lecturers agreed that institutions of higher learning receive adequate teaching material and poses effective teaching styles including support from institution and industry interactions that enhance the quality of the industrial engineering skills taught. It is important to take note that twenty-nine percent of industry and institutions of higher learning feel that there is adequate support for them in research and development of industrial engineering. The other seventy percent are in opposition and feel that more should be done to developed industrial engineering research and development within industry and institutions of higher learning. Statement 21 however, has an eighty-nine percent agreement that industry is personally encouraged to develop industrial engineering as opposed to the lecturers' views on this statement. Statement 24 shows eighty-six percent agreed that there is potential for further growth in studies on industrial engineering. Statement 48 shows that there is a seventy percent industry agreement that the teaching environment creates a positive attitude within industrial engineering. Under Statement 51, industry generally agree by forty three percent that institutions of higher learning actively and positively participate with quality assurance bodies such as Engineering Council of South Africa and Southern African Institute of Industrial Engineers in monitoring and controlling the quality of industrial engineering education. Fifty six percent of industry disagrees. In Statement 52, industry generally agrees that interactions with the quality assurance bodies such as the Engineering Council of South Africa and Southern African Institute of Industrial Engineers and students of higher learning institutions is present to help develop and keep industrial engineering current. Forty seven percent of industry either disagrees or is uncertain. This may be due to Statement 50, inadequate communication between industry and institutions of higher learning.

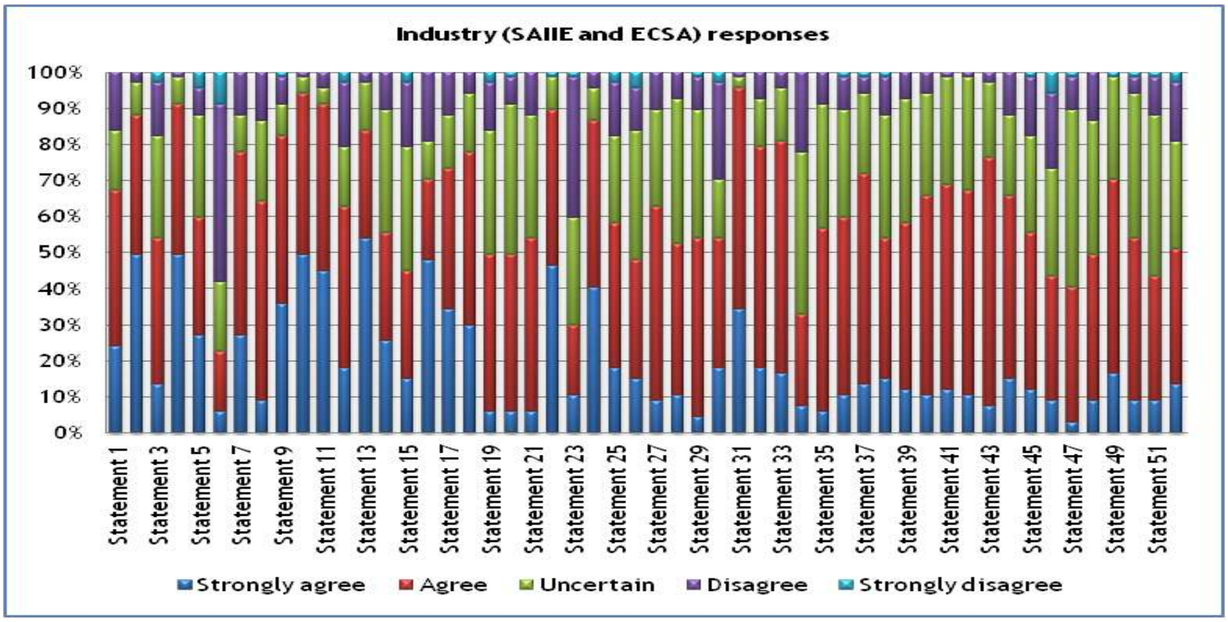

Figure 5: Stacked bar of industry (SAIIE and ECSA) responses

5.1.7. *Effective mechanism to enhance quality industrial engineers*

The interrelationship between the three quadrants, as shown in figure 2, highlight the institutions influence on the student's level of skills knowledge acquisition in industrial engineering and further demonstrates the interdependence between the students and industry in relations to the ability of the student in meeting the expectations industry places on their work ability. Lastly, a two-way relationship is described between the institution and the industry in building and developing materials relevant for teaching skills needed by industry to students [33].

There exists a relationship between the following aforementioned three groups, i.e. industrial engineering students, industrial engineering institutions of higher learning and industrial engineering work industries. The effectiveness and efficiency model measured the gap existing between the three groups, narrowing down to two groups. The measure of effectiveness and efficiency depicted the level of value that students need to attain employability and value in industry. The inferences developed categorise the three sample groups into two of the four quadrants of the effectiveness and efficiency model. From the analysis, it is evident that industry and academia are in accord as far as being effective in industrial engineering approach and being able to efficiently deliver this skill to the students. The students' 'fit' within figure 6, falls within the effectiveness and inefficient quadrant 'D' as shown:

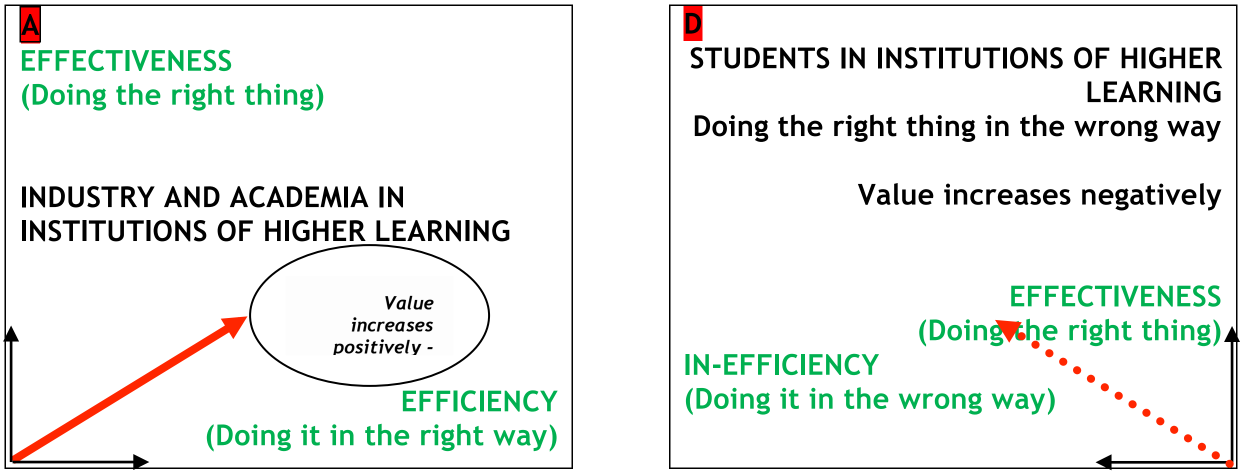

Figure 6: Efficiency and Effectiveness:-Value [14]

It is thus evident from figure 6, that students have the necessary resources attained through their academic programmes and the adequate interaction with industry to be effective at applying the attained knowledge and skill in industry. However, how efficient and capable the students are at utilizing this skill in achieving this value in industry is a significant issue requiring further research.

5.2. Reliability Testing

A reliability measurement was conducted separately on every level of statements within the student, institution (lecturers) and industry survey based on the response given in the scale. The following lists the Cronbach's alpha coefficients determined for each sampled questionnaire. Tavakol and Dennick [34] iterated that Cronbach's alpha coefficients of 0.70 to 0.95 may be considered acceptable and that at times lower values in certain cases may be accepted. Based on the tabulated information, the student, institution and industry survey shows a raw variable Cronbach's alpha coefficient of 0.979, 0.974 and 0.989, which indicates that the questionnaires were considered reliable and consistent.

Table 1: Cronbach's alpha coefficients for each sampled questionnaire

Sample Questionnaire	Cronbach's alpha coefficient
Student Survey	0.979
Institution (Lecturer) Survey	0.974
Industry Survey	0.989

6. CONCLUSION AND RECOMMENDATIONS

6.1. Recommendations

The inferences from the information gleaned from the three surveys administered to the students, institutions, and industry bodies are as follows:

- Students have the right mindset on how effective industrial engineering is in adding value in industry but are still limited in identifying with the efficiency in application of the skill in as far as 'best fit' is concerned. Efficiency in this case means the application of skills taught at universities of higher education.

- Lecturers are adopting the right approach to teaching, motivating and developing the industrial engineering skill. Furthermore, lecturers are demonstrating various avenues of dynamically delivering the learning material by involving various facets of teaching from practice to innovative theory.
- Industry fairs well in its approach to developing skilled industrial engineering students in an effort to spearhead industrial engineering as the forefront of South Africa's' economic growth and sustainability. This is evident through its involvement in the growth of practice and knowledge of industrial engineering. The manner in which this approach emerges is considerably efficient, through the curriculum development advisory bodies, industry visits, and quality assurance audits managed by the various quality assurance bodies as gleaned from the survey.

As such, the following may be addressed towards a solution to the inefficiency faced by the students:

- **Embedding of Total Quality Management principles into the learning process at universities:** According to Ho and Wearn [6], the discussion of TQM as a management philosophy and company practice, under the literature review section which aim to harness the human and material resources of an organisation, in the most effective way to achieve the objectives of the organisation; refers to the principles and tools surrounding total quality management as one way of managing institutions that provide industrial engineering as a learning programme. The opportunity is seen to develop valuable graduates, by emphasising on the human quality aspect as a resource that can be managed effectively towards efficiency.
- **A practical, hands-on approach** plays a major role as was highlighted by the industry survey in its expectations of academia in providing students with the much-needed practical exposure to be able to decide on the most feasible approach to performing tasks in industry. It is increasingly becoming difficult to cut a clear distinct line around the discipline that is industrial engineering. Due to various generic skills that have mushroomed over time that incorporate and apply a number of industrial engineering practices and skills, such as continuous improvement being a part of management practices and newly created professions such as change managers among others. This has placed the industrial engineering skill as becoming a grey discipline, creating more confusion within industrial engineering student learners. The need to clarify the role of industrial engineering within industry and through the inclusion of case study teaching methodologies in academia that focus on specific application of industrial engineering skills to specific problem areas should be considered a priority.
- **Developing and improving the students motivation by instilling a deeper sense camaraderie** through development of industrial engineering societies within the institutions and building the students knowledge of industrial engineering back ground as highlighted by the students survey, where students lacked the necessary direction and focus point at the onset of their industrial engineering learning course.

6.2. Conclusion

The skills shortage remains a topical issue for South Africa. The study has at some level; clearly demonstrated the need for further development of innovative academic approaches that will develop better-equipped graduates. The study suggests the following:

- Attaining value in students; through the introduction of industrial engineering societies in institutions of higher learning. This will ultimately fuel interest and develop industrial engineering.
- Support of lecturing staff and institutions of higher learning through research, knowledge development and enterprising projects pertinent to current industry needs
- Building on the current communication that exists between the industry and institutions of higher learning through advisory boards among other forums by enriching the current one way feedback (industry to academia), to a two way communication i.e. involving lectures in industry decision making process of company strategies.
- Influencing institutions of higher learning to stimulate young minds towards application-based thinking approaches and enterprise-based methodologies. This will cultivate a productive business environment that will benefit all supply chain stakeholders and in so doing uplift the economy.

In order to remain competitive, industrial engineering needs to position itself where overall value is the essence of performance; achieved through effective and efficient problem solving approaches. In so doing industrial engineering will be better placed, understood, and accepted by society.

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DISTRIBUTED MANUFACTURING SYSTEMS AND THE INTERNET OF THINGS: A CASE STUDY

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ABSTRACT

In order to stay competitive in today's global market, manufacturing companies need to be flexible. To ensure flexible production, shorten processing times, and reduce time-to-market, companies are utilizing the distributed manufacturing system paradigm, wherein geographically distributed, local resources are used for product development and production. In this context, the Internet of Things (IoT) has emerged as a concept which uses existing communication technologies, such as local wireless networks and the Internet to ensure visibility of anything from anywhere and at any time. In the paper, a case study of applying the IoT to the manufacturing domain is discussed. A distributed agent-based system for virtual monitoring and control of 3-axis CNC milling machine tools is designed and developed. The machines' 3D models and process states are shown through a web interface in real-time. The potential and challenges of implementing this system and the basic building blocks for decentralized value creation are discussed.

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1 INTRODUCTION

Manufacturing of products and goods is probably the most important economic activity in the world. It is the backbone of modern industrialized society and a cornerstone of the world's economy [1]. Manufacturing concepts and systems have always been influenced by new developments, especially the ones from computer, information, and communication sciences. Computers have been an integral part of Computer Integrated Manufacturing (CIM) concept and CNC technology, and have changed product design and manufacturing through development of Computer Aided X (CAx) methods. Having a strong manufacturing base is important to any society or community, because it stimulates all the other sectors of the economy [2].

A world where physical objects are seamlessly integrated into the information network in order to become active participants in integrated systems is the core objective of the *Internet of Things* (IoT) movement. As illustrated in figure 1, with time more physical objects will be equipped with sensors and be able to communicate. These ubiquitous connections will result in an information network that promises to create new business models, improve business processes, and reduce costs and risks. Services are available to interact with these 'smart objects' over the Internet, query and change their state and any information associated with them, taking into account security and privacy issues. Even in the last two decades, the Internet has provided ubiquitous information exchange and communication possibilities and in turn enabled a truly global production of goods and services. Furthermore, the business side was affected as well – several new business models have emerged, using the Internet as an integral part of value creation.

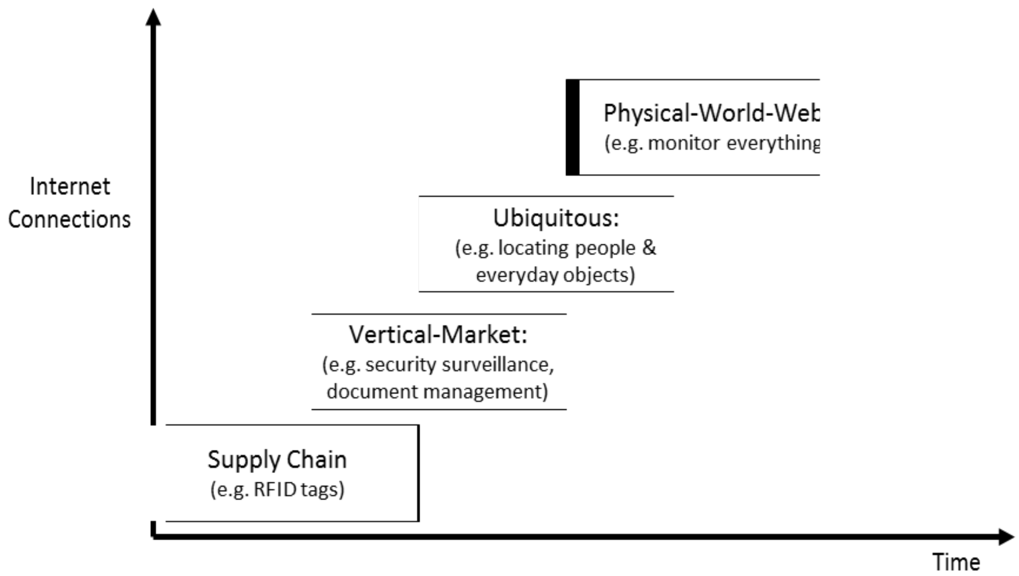

Figure 1: The Internet of Things (IoT) technology roadmap (Adapted from [3])

Promising approaches to the search for a new manufacturing paradigm include networked, adaptive, and ubiquitous manufacturing systems (UMS). UMS is an emerging manufacturing paradigm, stemming from the concept of ubiquitous computing [3]. In turn, these developments are enabling manufacturing companies to be more flexible and use this flexibility as a competitive advantage. Although ambient intelligence and autonomous control are not part of the original concept of the IoT, equipping manufacturing technologies with minuscule sensors, actuators or transceivers could be transformative to current production systems. The ability to interact could be used to remotely monitor and control manufacturing processes based on immediate or present needs, thereby eliminating factors like running out of inventory and generating unwanted waste. Production systems will thus be more prepared to balance supply and demand fluctuations [3].

Ubiquitous availability of information is enabling seamless operation of distributed manufacturing systems. Together with the services of high speed postal providers, geographical distances are becoming less and less meaningful. Products are being ordered through the Internet, manufactured all around the globe, and delivered rapidly within days. Bug Labs for example, helps organizations innovate in the rapidly-growing IoT market. It's unique, cloud-based platform abstracts the raw functionalities (e.g. sensors, actuators, transceivers) of any hardware device and exposes them as web services. Bug's Blocks are snap-together modules, including a powerful Linux-based CPU, sensors, actuators and transceivers, which allow rapid prototyping, cost-effective deployment and field upgradability in a wide variety of use cases. Therefore, companies who understand and properly manage the arising complexity are translating these opportunities into business success.

IoT is widely considered as *the* future technological development of the century. It is a concept which foresees that everything will be connected to the Internet including everyday objects. Innovative growing applications include waste management, urban planning, continuous care and emergency response, intelligent shopping, smart product management, and home automation. This will drastically change the way humans interact with their environment. The underlying principle is that machines should be left to do what machines do best, such as collecting data, automating tedious tasks and analysis, while humans should be left to do what they do best: creative thinking and synthesis.

The use of IoT in manufacturing is envisioned as connecting every element of a manufacturing system to the Internet, including machine tools, work pieces, manufacturing environments, and humans. This will enable new ways of managing manufacturing complexity, by providing relevant, context sensitive information to the right people at the right time, enabling them to improve their decision making.

In this paper, a concept of *internetization* - making things appear online - of elements of manufacturing systems is presented. The paper attempts to answer how to do that in a sensible way, and gives an outlook of how this can influence the manufacturing of today and tomorrow in different regions of the world.

The concept is discussed within the context of Ubiquitous Manufacturing Systems (UMS), an emerging paradigm, based on the principles of ubiquitous computing, wherein IoT is seen as the concept, underlying the Information and Communication (ICT) infrastructure for UMS.

A case study, illustrating the core components of the concept is developed. A CNC machine tool is mapped from real world to the digital and virtual ones.

2 THE INTERNET OF THINGS

The term Internet of Things encompasses a vision that everything will be connected to the Internet at some point in the future. However, the precise definition of the term is still not agreed upon. Ashton's original definition from 1999 [4] emphasizes the gap between the physical and the digital, and envisions the IoT as a bridge between the two:

> *Today computers—and, therefore, the Internet—are almost wholly dependent on human beings for information. Nearly all of the roughly 50 petabytes (a petabyte is 1,024 terabytes) of data available on the Internet were first captured and created by human beings—by typing, pressing a record button, taking a digital picture or scanning a bar code. Conventional diagrams of the Internet ... leave out the most numerous and important routers of all - people. The problem is, people have limited time, attention and accuracy - all of which means they are not very good at capturing data about things in the real world. And that's a big deal. We're physical, and so is our environment ... You can't eat bits, burn them to stay warm or put them in your gas tank. Ideas and information are important, but things matter much more. Yet today's*

information technology is so dependent on data originated by people that our computers know more about ideas than things. If we had computers that knew everything there was to know about things – using data they gathered without any help from us – we would be able to track and count everything, and greatly reduce waste, loss and cost. We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best. The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so.

The definition explicitly outlines the potential benefits, relevant for the manufacturing environment: reducing waste, loss, and cost. The rationale is that decision making can be improved by providing precise and relevant information in real time. Other definitions, such as the one from Cisco Internet Business Solutions Group [5] simply define the IoT as:

IoT is the point in time when more "things or objects" were connected to the Internet than people.

Although this definition is very straightforward, it specifies that existing Information and Communication technologies (ICT) – the existing Internet – are the basis for the IoT. The whole idea is to literally have everything imaginable connected to a network as a computer that uses standard protocols (such as TCP/IP) to communicate. More accurately, a computer can be attached to any physical thing, acting as a sort of an agent – representing it in the digital world as illustrated in figure 2. In this view, digitalisation of the thing means simply creating its digital representation. This representation can then be involved in different kinds of computations, from data aggregation to simulation, which do not have a physical basis, and we therefore consider them virtual. The physical world can be connected to an organisation's execution system or enterprise resource planning (ERP) systems for multiple plant connectivity from the physical devices to enterprise level. Manufacturing organisations use these connected devices to get a virtual representation that can support strategic level decision making by detecting unusual patterns and initiating the appropriate measures.

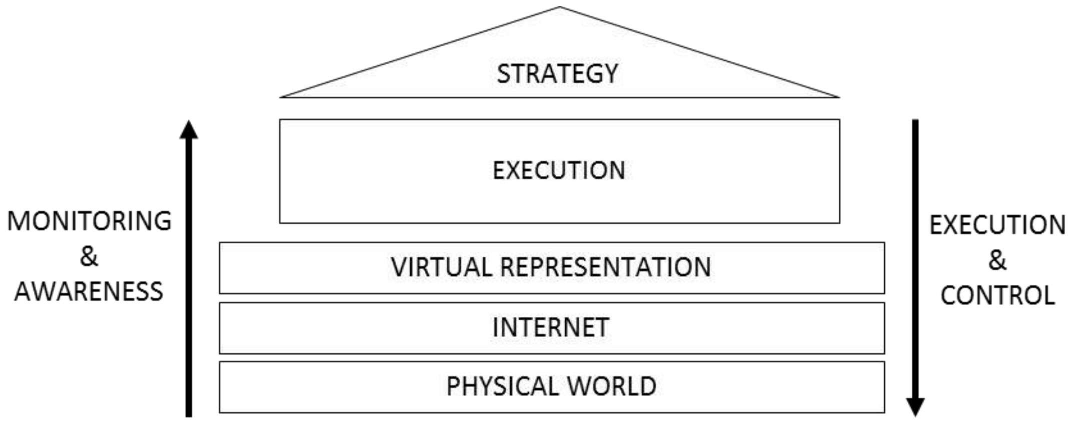

Figure 2: Connecting the physical world for consistent execution of strategy

Connecting a range of devices and systems together, by putting sensors in the physical world to monitor and control processes, can assist organisations with preventive maintenance. Still, it is not only about connecting devices, but about modelling and understanding changes of all the things to create a competitive advantage. Numerous technologies can be put in place at organisations to monitor and control these changes, of which Ethernet, wireless and cellular networks play a significant role. Using wireless networks to collect data and determinism to control decisions enables intelligent, anticipatory tracking of challenges.

From the above, it can be concluded that the IoT is a concept, and that it is based on existing ICT technologies, such as agent-based systems, web technologies, IPv6, computing technologies (grid, cloud), radio-frequency identification (RFID), near field communication, only applied on a much bigger scale. Vendors are integrating RFID technology into existing sensor products, to log data economically and efficiently, which are wirelessly transmitted to a higher level (ERP) system when activated by a programmable logic controller. All of this forms part of the Industry 4.0 industrial revolution of seeking ways to help industry achieve greater flexibility and robustness while dealing with greater complexity.

Since the technologies already exist, the challenge is mainly of conceptual and practical nature, the question being: How can we use the existing technologies to make elements of manufacturing systems appear on the Internet, and furthermore, what can we do with that afterwards.

3 INTERNETIZATION OF MANUFACTURING – THE CONCEPT

In recent years, researchers have been searching intently for new manufacturing concepts that would replace the obsolete principles of scientific management postulated by F. W. Taylor a century ago and would create new fundamentals for the next generation manufacturing systems. Rising complexity of products, production systems and organisational structures [6] on one side and turbulent market fluctuations are setting new expectations to the manufacturing sector. In order to face these challenges a shift of the existent manufacturing paradigm is needed. Several innovative concepts emerged like the Fractual factory [7], Bionic manufacturing systems [8] and Holonic Manufacturing systems [9]. Other promising approaches to the search for a new manufacturing paradigm include networked, adaptive, and ubiquitous manufacturing systems (UMS). Peklenik [10] studies the concept of Distributed Manufacturing Systems (DMS) in terms of a Complex Adaptive Manufacturing System (CAMS), which is structured as a network of many agents acting in parallel, in series or both ways.

These new manufacturing structures are accompanied by a number of questions regarding their design, development, operations, and other life cycle phases, which have to be addressed and investigated in the framework of current research and development.

The UMS concept stems from the concept of ubiquitous computing, which is based on the observation that the number of computers (computing capable devices) per person is rapidly growing. In UMS, manufacturing organisations are connected into a global network, and reconfiguration takes place within the network. A definition of ubiquity in the manufacturing sense is provided by Weber, 1928 [11]:

> *Ubiquity naturally does not mean that a commodity is present or producible at every mathematical point of the country or region. It means that the commodity is so extensively available within the region that, wherever a place of consumption is located, there are ... opportunities for producing it in the vicinity. Ubiquity is therefore not a mathematical, but a practical and approximate, term.*

This definition (albeit put forth in 1928) still encompasses the essence of the concept. Two notions are of utmost importance. Firstly, “extensive availability” implies a redundancy of resources. Having the “opportunity for producing a commodity in the vicinity” assumes that there are resources waiting to be utilised. Secondly, “availability within the region” and “vicinity” imply the presence of the geographical element of distance.

Since the definition had been put forth, advancements in the area of ICT have rendered geographical distance virtually non-existent in the informational sense. Furthermore, logistics services companies have greatly reduced the time and cost of physical transport and, in turn, contributed to the depreciation of the impact of geographical distance. This is why UMS are viewed as an extension of the Global Manufacturing concept, which aims to transcend national borders to leverage capabilities and resources worldwide.

Moreover, UMS build on the grounds of the Virtual Manufacturing concept [12]. This second influence stems from the fact that virtuality is a requirement for ubiquity. If ubiquity is understood as “omnipresence”, then virtuality, “not physically existing as such but made (by software) to appear to do so” [13] is a mechanism that enables it.

Virtuality is also identified as an enabling factor for the creation of virtual organisations within business networks. The term “Virtual Breeding Environment” (VBE) is used to describe a long-term organisation that presents an adequate environment for the establishment of cooperation agreements, common infrastructures, common ontologies, and mutual trust [14].

A core part of a VBE is its ICT infrastructure, which facilitates the creation, operation, and eventual disintegration of the virtual organisations it contains. As these are distributed in nature, it is most appropriate that the infrastructure be distributed as well.

We propose that the IoT concept is used to facilitate the infrastructure. In other words, every object or thing should be represented on the Internet and be able to interact with others. Agent-based software technologies have turned up a promising approach for the development of such systems.

Agents are a branch of distributed artificial intelligence. Each individual agent in a Multi-Agent System (MAS) works autonomously in order to achieve its own goals. A MAS thus represents a loosely coupled network. However, one of the key capabilities of agents is that they can cooperate through communication and thus solve problems that are beyond their individual capabilities [15].

Applications of MAS in manufacturing are numerous [15, 16]; however, the focus in this paper is on their support role in the interoperability of networked systems, where coordination, collaboration, and cooperation all play an important part. Accordingly, agents are seen by the paper as an underlying principle for the creation of the IoT and as an enabling technology, rather than in their problem solving sense which is more common in the area of artificial intelligence.

Some of the properties of MAS make them especially suitable to form the basis of an ICT infrastructure. MAS are distributed in nature, scalable, robust, and fault-tolerant. Nevertheless, other desired properties such as reconfigurability and flexibility are application specific and have to be implemented by the software creator as the logic and/or the architecture of the MAS.

The infrastructure consists of three layers, a physical, a digital, and a virtual one. The Elementary Work System (EWS) [17] is taken as the primary concept in system structuring. The EWS concept originates in the cybernetic approach towards the modelling of manufacturing systems. EWS is defined as the smallest structure capable of carrying out a process. The concept’s greatest power is that any manufacturing system can be described as a set of EWS.

The universal structure of the EWS is adopted as the basis for the definition of UMS elements. In accordance with the concept, these elements are processes, inputs, outputs, process implementation devices (i.e. machine tools), human subjects, and environments. If a manufacturing process is to be carried out, all of these elements have to be involved. For example, even in completely automated line production, human subjects have to set references and are involved in line supervision.

In general, elements can be tangible or intangible and must be connected when a process is to be performed. Therefore, they have to exist on the same layer of the information infrastructure. A three-layer approach presented in figure 3 is proposed.

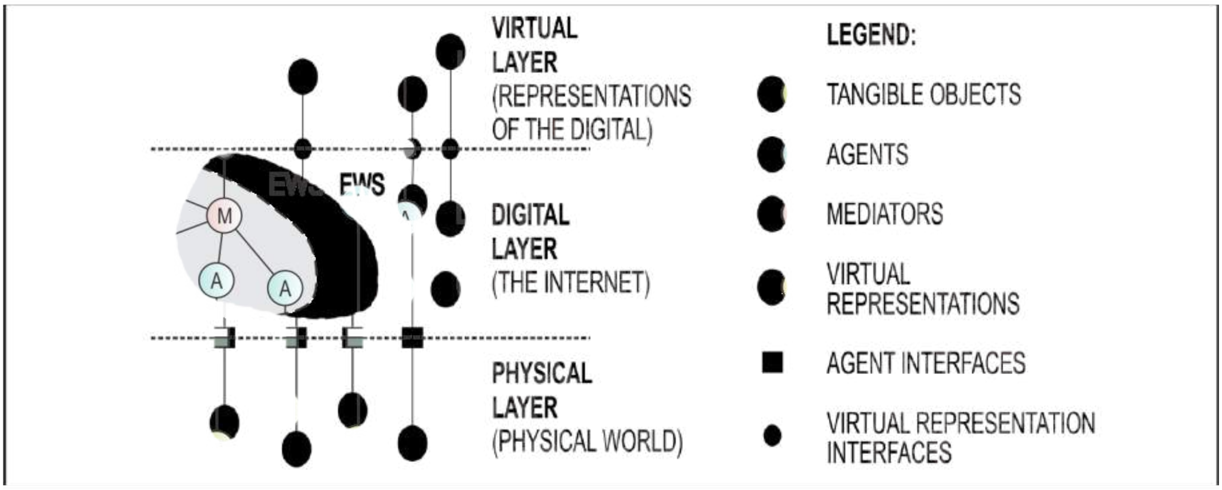

Figure 3: ICT infrastructure conceptual layers.

The physical layer contains tangible objects such as blanks, products, machine tools, and human subjects. These objects are represented on the Internet by software agents on the digital layer. Agents and elements communicate through agent interfaces, which are implemented in software. Additionally, agents of intangible elements such as NC programs or process plans exist on the digital layer.

Agents can themselves be represented on the virtual layer, allowing them to participate in a virtual world. The virtual layer can provide the means for subjects not present in the network to communicate with the agents of the digital layer (i.e. through social networks). In addition, the virtual layer can be used to connect multiple networks with incompatible digital layers due to different rule sets, ontological definitions, or communication protocols. Agents manage their virtual representation through virtual representation interfaces.

Communication within the network can take place between elements or their representatives on the same conceptual level, or between an element and its representatives via an interface. Such structure offers parallel communication, integration of different networks, and more options for potential users to participate in the network. The network hence becomes open and flexible.

The agents of the digital layer do not form a hierarchy. No agent has authority over others. Therefore, in order to manage work within a network, mediator agents (or mediators) are introduced. Mediators create organisational connections between elements and can be seen as the basis of the digital infrastructure.

Mediators facilitate a market mechanism of supply and demand following the business-to-manufacturing-network concept [18]. The market can function as a sort of a self-regulating system. The mediators act autonomously but have to comply with the rules set by the network.

In summary, to facilitate the IoT in manufacturing, elements of manufacturing systems need to be represented on the internet. We propose that this is done through software agents, representing the elements in the digital world. On top of that, the agents are responsible for virtual representations of the elements, interacting in different virtual environments.

4 CASE STUDY

The proposed ICT infrastructure is implemented in a case study of an experimental network at the University of Ljubljana also intended for the potential implementation in a global manufacturing network that is built upon a UMS test-bed [12, 19].

The test-bed was developed to support research in the fields of new manufacturing structures design and control, teleservices, dynamic reconfigurability, and semiotic-based information systems [20]. In this case study, the test-bed is used for the proposed ICT infrastructure concept validation as shown in figure 4.

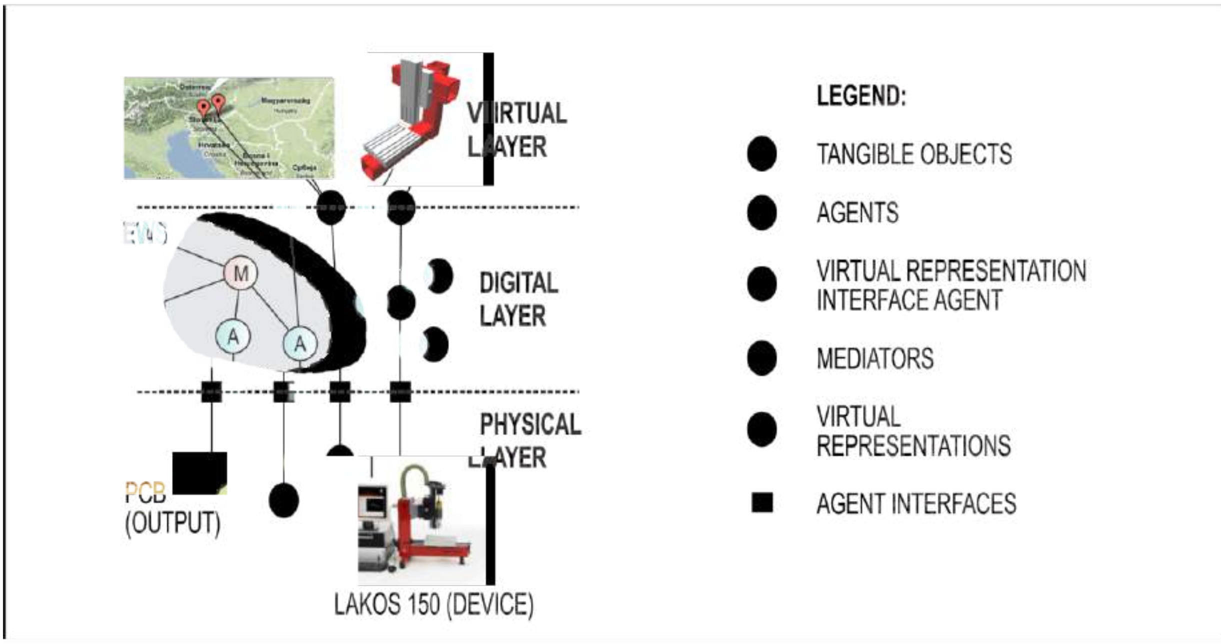

Figure 4: EAC installation at the University of Ljubljana.

The test-bed is composed of several Experimental Autonomous Cells (EAC) interconnected in a manufacturing network. Each EAC is composed of two desktop CNC engraving machines LAKOS 150 and the supporting infrastructure such as controller computers and web cameras. The CNC machines are capable of performing 2D or 3D engraving, milling, and drilling operations on small work pieces made of light materials. Their controller is based on open architecture principles and open source, and allows for the machine to be integrated with the experimental test-bed.

An important part of the cell is the human subject that operates it. There are many potential operators for a single machine. Because of the educational purpose of the machine, the number can vary significantly.

Virtual representations of outputs are generated by part designers and collected in a parts library. After part design is completed, a process engineer prepares a process procedure, which is also virtually represented and stored in the library. In the case of EAC cells, the environment is the research laboratory.

EAC are viewed as geographically connected units, but their components are not necessarily connected in the logical sense. This is because, in accordance with the proposed model, the basic elements are not cells but rather their components.

Each component is represented on the digital layer by an agent, and the components together form a MAS. Agents are developed using the Jade software library [21] which supports the FIPA standard [22]. Interoperability of the MAS is thus provided. This also allows for an easy inclusion of new elements and contributes to the robustness and fault-tolerance through mechanisms such as agent life-cycle management and agent container replication.

From the MAS standpoint, the system is organised as follows: The whole network corresponds to the agent platform. The agent containers that make up the platform are situated each on its own computational device. Finally, each EAC component is represented by one agent.

In the case study, several virtual layers are developed. Firstly, a Google Maps ® user interface is developed, on which agents' geographical location is presented. The primary objective of this virtual layer is to enable human subjects to monitor the system through an intuitive interface. Secondly, a 3D representation interface is developed, showing the 3D models of the machine tools in real time along with information about the process which they are performing. The virtual layers are implemented through virtual profile interfaces, which are themselves agents. The architecture of the system is shown in figure 5.

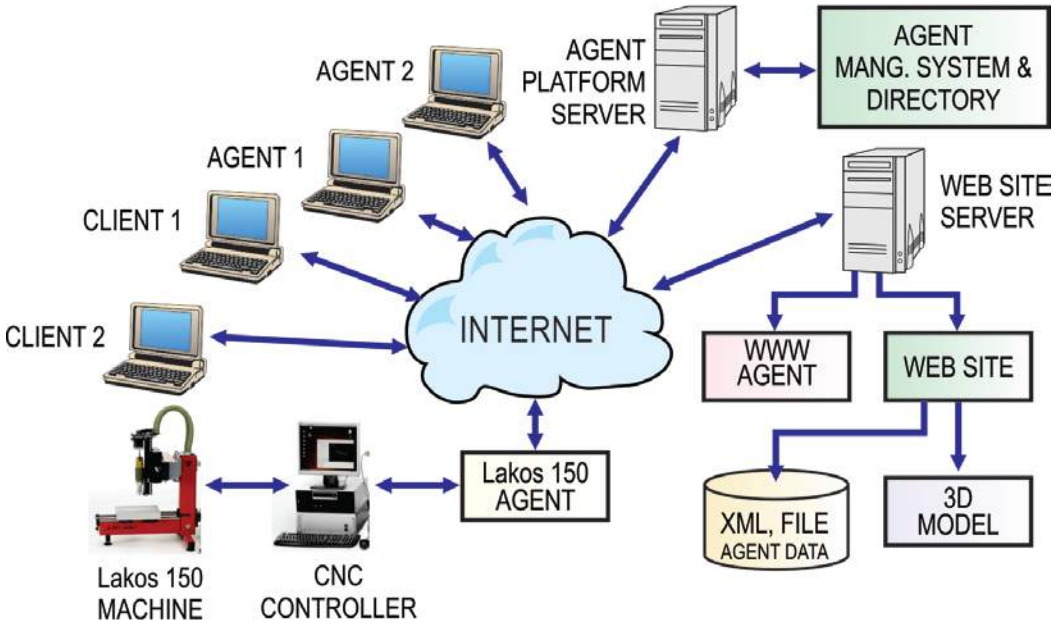

Figure 5: The architecture of the case system.

The user interfaces of the virtual representations – the Google Maps ® and the 3D model interface – are shown in figure 6. Monitoring and controlling distributed process technologies are possible with this virtual representation.

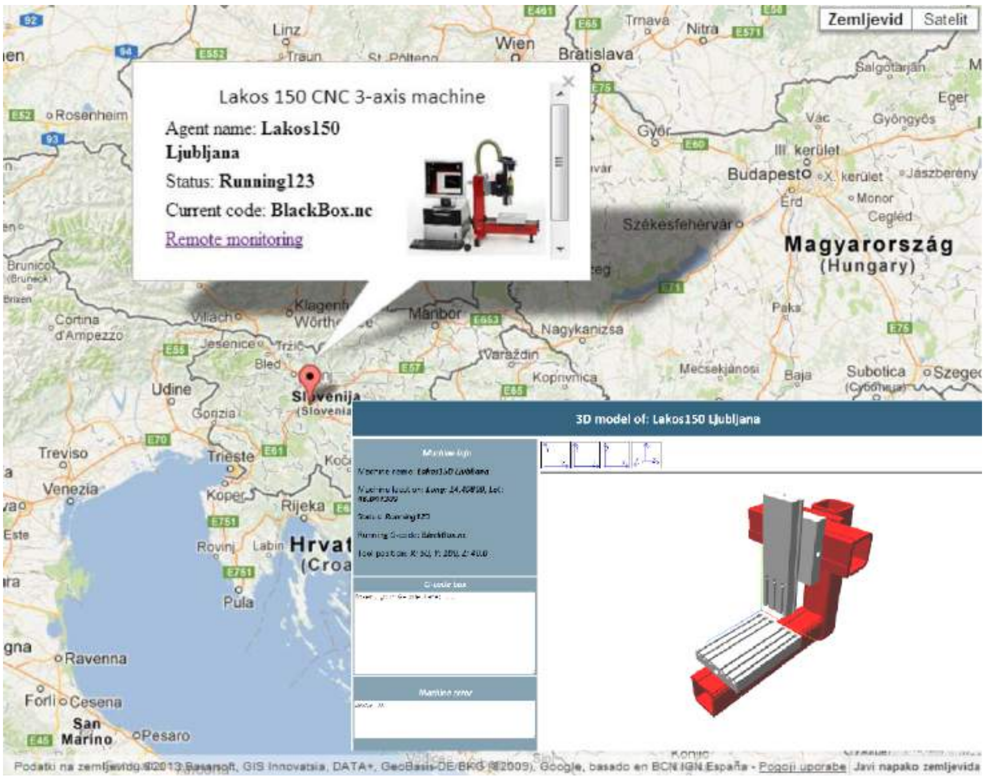

Figure 6: The virtual representation of the machine tool, showing its geographical location of a Google Map ®, and its 3D representation – synchronised with the physical system in real time.

5 CONCLUSION

The paper discusses the Internet of Things, its role in manufacturing and new possibilities which it will bring for distributed manufacturing systems – i.e. manufacturing systems utilizing local resources for product development and production. The use of IoT in manufacturing is envisioned as connecting every element of a manufacturing system to the Internet in order to provide context sensitive information to the right people at the right time, enabling them to improve their decision making. We suggest that in order to facilitate the IoT in manufacturing, the Information and Communication Technology infrastructure must also be distributed and propose an agent-based model.

A three-layer architecture is proposed: a physical layer where tangible object exist, a digital one where software agents representing tangible and intangible objects are organised to do work, and a virtual one that serves primarily as an interface with external stakeholders such as network users and other networks.

The case study presents an implementation of the concept. A network of experimental autonomous cells serves as a test-bed for the implementation. The virtual layers of the case study give external users an insight into the state of the network. A 3D virtual representation of the Lakos 150 machine tool allows for remote monitoring and control in real time.

Future work will focus on a broader implementation of the base ICT infrastructure within the network and on further development of the concept, particularly the mechanisms that enable work to be done.

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INVESTIGATING THE IMPACT OF POOR UTILISATION OF QUALITY MANAGEMENT SYSTEM IN A SOUTH AFRICAN FOUNDRY

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ABSTRACT

Background: In 2007 alone, twenty six foundries were closed down when the castings industries directory was released. A high scrap rate due to a lack of quality management is one of the root causes of low productivity and low profits, resulting in closures.

Method: This research paper focusses on the impact of defects on productivity and monetary losses due to poor utilisation of the quality management system in sand casting. Data was gathered on defects and productivity and the company's quality control records were used for monetary losses due to scrap. The study was conducted over a period of one year at a South African foundry. The standard multiple regression analysis method was used to assess the ability of five defects (cross jointed, bad mould, shrinkage, core fault, and gas porosity) to predict monetary and productivity losses.

Results: Cross jointed and bad mould defects had a correlation coefficient of 0.727 and 0.716 respectively which indicated a strong positive correlation. The overall variance explained by the model was 61%, $F = 16.263$, $p<.005$. Thus the prevalence of these two types of defects can significantly predict monetary losses, while core fault predicted productivity.

Conclusion: Foundry should concentrate on eliminating cross jointed and bad mould defects to avoid a high scrap rate, and core fault to improve productivity.

1 INTRODUCTION

The South African foundry industry is faced with a high number of foundry closures. In 2007 alone, twenty six foundries were closed down [1]. The factors leading to these closures were identified by literature review as inability of South African foundry companies to compete with countries like China, India and Brazil [2]. It is said that lack of skilled personnel, high scrap rate, lack of quality management system, and technology transfer all contribute to South African foundries not being able to compete with these emerging countries. These factors are root causes of low profits and low productivity, resulting in closures.

The foundry industry forms part of the manufacturing sector, and the manufacturing sector contributes about 15% to the South African total gross domestic product [3]. In a survey done by the South African Institute of Foundrymen (SAIF), it was discovered that the local foundry industry has been earmarked as one of the manufacturing sectors with a significant potential for growth, in both the domestic and export markets [4]. According to SAIF, South Africa casts some 500 000 tons of metal a year, generating a turnover of R10,3-billion a year, and contributes 0.32% to the country's total GDP [4]. The industry has about 230 companies, employing over 15 000 workers with 80% of them being previously-disadvantaged people [4].

Sand casting is the most popular casting process with low cost, high efficiency and reuse cycles. Of the total tonnage of castings produced each year, the greatest percentage is produced by sand casting, and it produces the highest scrap rate [5]. The aim of this research paper is to examine the types of defects that have a high negative effect on productivity, and also identify the defects that contribute to high monetary loss in a South African foundry company, specifically when using sand casting.

This research study undertakes a case study conducted at a South African foundry company. The study looks at the processes followed in sand casting process and the utilisation of the quality management system in this foundry company.

2 THEORETICAL FRAMEWORK

2.1 Foundry overview

A foundry is a factory that produces metal castings from either ferrous or non-ferrous metals including copper, brass, bronze, aluminium, zinc, lead, nickel, and all their various alloys [6]. A metal casting is a shape obtained by pouring liquid metal into a mould or cavity and allowing it to solidify and thus to take the form of the mould. Different types of casting processes are used by individual foundry companies, depending on the quantities they produce and the size of castings they produce. The most commonly used casting processes in South Africa include: sand casting, die casting, investment casting, and spin casting [2].

2.1.1 Sand casting

Sand casting is a metal casting process characterised by using sand as the mould material. A suitable bonding agent (usually clay or chemical binder) is mixed with the refractory sand. In order to produce a casting, a pattern is required [6]. A pattern for metal casting is a form used to make a cavity in sand. It is a replica of the product to be cast, used to prepare the sand cavity into which molten material will be poured during the casting process [6]. A wooden pattern is cheaper to design and most companies make use of it. In a construction of a wooden pattern, accurate layout is important, and this requires skilled personnel with excellent drawing skills. Poor design of patterns or inadequate pattern equipment results in a number of defects which include [7]:

- broken or cracked castings
- crushes

- cuts or washes
- particles of foreign material
- gas defects
- metal expansion

After the pattern has been designed, it is sent to the moulding section. Moulding is the operation necessary to prepare a mould for receiving the metal. It consists of ramming sand around the pattern placed in a support, or a flask, removing the pattern, setting cores in place, and creating the gating/feeding system to direct the metal into the mould cavity created by the pattern, either by cutting it into the mould by hand or by including it on the pattern [8]. Metal melting is done concurrent with the moulding process. Metal melting is carried out in a heat furnace, and there are different types of furnaces used to melt metal and these depend on a type of alloy being produced. The most commonly used furnaces are gas, electric, and cupola.

For melting aluminium, gas furnace is used and an electric furnace is used for melting copper. The right heating temperature of a furnace is very important to ensure good quality castings are produced. Usually, a standard temperature is stipulated in the quality manual when the quality system is implemented. The molten metal is poured into the mould at a right temperature and is given time to solidify. This process is followed by fettling which is the removal of gates and risers from the casting, and the removal of adhering sand scale, parting fins, and other foreign material that is not supposed to be in the casting, to get it ready for other processes or delivery. Inspection follows, to check for defects in the casting as well as to ensure that the casting has dimensions specified on the drawing and/or specifications [8]. Below is a figure showing a typical sand casting production plant.

Figure 1: Sand casting plant. Source: South African foundry, 2011.

2.2 Casting defects

Metal casting is the vital process in metal casting foundry companies, and it is in this process that much attention should be focused in terms of quality management. Quality control implies both prevention and cure of casting defects and wasted production effort. There are a number of casting defects that are found in castings and some of their causes are known, which makes it possible to prevent them if proper quality control procedures are followed adequately. Casting defects are those characteristics that create deficiency or imperfection to quality specifications imposed by design and service requirements [7]. Defects can be classified into two categories, first being ones based on nature of defect, second based on contributing factors. Table 1 shows some common casting defects.

Table 1: Common casting defects [7].

Defect	Description	Causes
Cross Jointed	These appear as veins or fins that cross on top of each other.	Pattern design Pattern equipment Gating and risering
Bad mould	Improper venting in green sand mould. Sufficient venting must be done to permit back-pressure in the mould.	Moulding sand Mould practice
Gas porosity	These are smooth bubbles that appear on a casting and they result from entrapped gases. This occurs because most liquid materials can hold a large amount of dissolved gas, but the solid form of the same material cannot, so the gas forms bubbles within the material as it cools.	Melting practice Pouring temperature Moulding sand
Shrinkage	Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies.	Cooling temperature Gating and risering Pouring practice
Core fault	Uncured cores, including oil, resin and hot box cores, provide an excess of gas which would normally be removed during the baking.	Core practice Moulding sand Pattern equipment
Broken or cracked castings	This refers to castings which have been broken or cracked by mechanical action or rough handling.	Pattern design Pattern equipment Flask equipment and rigging Gating and risering Moulding sand

In the next section, we look at quality and the quality management system which if applied adequately; can eliminate these defects.

2.3 Quality overview

According to Juran [9], quality means those features of a product which meet customer needs, that is, freedom from deficiencies. Quality does not pertain to a single aspect of a product, but a number of different dimensions. These dimensions of quality include performance, special features, conformance, reliability, durability, and service after sale [10].

Deming [9] taught that by adopting appropriate principles of management, organisations can increase quality and simultaneously reduce costs by reducing waste, rework, staff attrition and litigation while increasing customer loyalty. This is the problem facing foundry companies, as they do not set targets.

The statistical tools are useful in manufacturing industries, especially foundry. The casting benchmarking report released by the Network Foundry Technology Network in conjunction with CAST in November 2009 [2] revealed that foundry companies do not collect data, which is an indication that they do not make use of statistical tools. The tools are listed in the quality management manual that is provided during implementation of the quality system, but companies either do not have resources or skilled personnel to use these tools or they do not see the value.

2.4 Quality management system

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 [11]. According the book written by Tricker [11], 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, including amongst others, the South African Bureau of Standards (SABS). But according to the report released in 2009 by Who Owns Whom [12], in terms of regulations, the foundry industry lacks common standards which enforce conformance to internationally recognised quality assurance standards such as ISO 9000:2000.

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 [11]. 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 [11].

3 RESEARCH METHODOLOGY

The case study method was chosen to conduct this research because it captures the real life events in a natural setting as explained by Yin [13]. The data collection methods used in this study are: direct observation, documents, and records.

3.1 Site selection

The study was conducted at a South African foundry. The company was chosen because it is a small company and has a quality system in place, ISO 9001:2008. It makes a good case study because it has the quality system in place and yet it still faces a high scrap rate.

The company makes castings for electrical components using die casting and sand casting processes. The metal used is Aluminium 6, copper and steel. Aluminium 6 (LM6) has high resistance to corrosion under both ordinary atmospheric and marine conditions, and has excellent castability [6]. Its ductibility enables castings to be rectified easily or even modified in shape, for example, simple components may be cast straight and later bent to the required shape. The type of sand used for sand casting is green sand.

3.2 Data collection

The study was conducted over a period of one year starting with direct observations in the patternmaking department. This was done to understand the procedure followed when designing a pattern since this is the first process for sand casting. The concentration was on the quality control of drawings issued, design specifications, and design equipment.

The next section that was observed was the sand casting, which includes mould making process and metal melting. Machining procedure involves processes like cutting, milling, and grinding, and was the last section observed. These observations assisted in understanding the whole process from patternmaking to shipping of a casting.

Defects and productivity data was collected, while monetary losses due to scrap data was taken from the company's quality control records. The regression analysis was then performed to predict monetary loss and productivity. The next section presents the results of the data gathered.

3.3 Data analysis

Five defects (independent variables) were identified as recurring defects, contributing to a high scrap rate. These defects are: bad mould, gas porosity, core fault, shrinkage, and cross jointed. The two dependent variables used are monetary losses due to scrap and productivity, entered separately in the model. All independent variables are entered into the equation simultaneously. Each independent variable is evaluated in terms of its power to predict the dependent variable. Therefore the results will present two regression results with the first one presenting five independent variables and monetary losses, and the second with five independent variables and productivity.

The model is also used to check the multicollinearity amongst the variables. Multicollinearity refers to the relationship between independent variables [14]. It exists when independent variables are correlated (r = 0.9 and above).

The Pearson's correlation coefficient (*r*) is defined by:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2] * [n\sum y^2 - (\sum y)^2]}} \qquad (1)$$

Where r = the correlation coefficient

x= the values of the independent variable

y= the values of the dependent variable

n= the number of paired data points

4 RESULTS

4.1 Monetary loss and defects

In this section, data figures and regression analysis results are presented. The standard regression analysis method with all the variables and cases entered into the equation is used.

4.1.1 Descriptive statistics

Table 2 presents the mean values and standard deviation for each variable. The average for monetary loss for fifty days (N) is 2325.97. The table also shows that the defect with a highest average is cross jointed. This means that more cross jointed defects occurred during this fifty day period.

Table 2: Means and standard deviation (Monetary loss)

	Mean	Standard deviation	Sample size (N)
Monetary loss in Rands	2325.97	3288.50	50
Cross jointed	5.36	21.256	50
Gas porosity	4.86	14.580	50
Shrinkage	5.06	10.790	50
Core fault	4.48	12.445	50
Bad mould	4.12	12.758	50
Total scrap (Kg)	23.88	47.601	50

4.1.2 Correlation between variables

Table 3 presents correlation results. The correlation table shows the strength of a linear association between independent variables and a dependent variable. In the second row of the table, we look at the correlation between monetary loss and defects. Cross jointed and bad mould have a correlation coefficient of 0.727 and 0.716 respectively which means a strong positive correlation. Core fault has 0.545 which means a moderate positive correlation. Shrinkage has a weak positive correlation with r=0.338. Gas porosity shows no correlation as r=0.009. This means that the defect which has a strong relationship with monetary loss is cross jointed followed by bad mould. The correlation between the independent variables is shown from row two and column four. Cross jointed and bad mould have a correlation coefficient of 0.883, which is a strong positive and is considered to be too high. The other independent variables have a weak correlation, which is below 0.5. The second row shows that a 1-tailed sig was used. This explains whether each variable is significantly contributing to the equation for predicting monetary loss from the whole set of predictors. Thus, bad mould and gas porosity are significantly contributing to the equation.

Table 3: Correlations

		Monetary loss	Cross jointed	Gas porosity	Shrinkage	Core fault	Bad mould
Pearson Correlation	Monetary loss (Rand)	1.00	0.727	0.009	0.338	0.545	0.716
	Cross jointed	0.727	1.000	0.032	0.267	0.374	0.883
	Gas porosity	0.009	0.32	1.000	0.468	-0.079	-0.017
	Shrinkage	0.338	0.267	0.468	1.000	0.056	0.230
	Core fault	0.545	0.374	-0.079	0.056	1.000	0.496
	Bad mould	0.716	0.883	-0.017	0.230	0.496	1.000
		Monetary loss	**Cross jointed**	**Gas porosity**	**Shrinkage**	**Core fault**	**Bad mould**
Sig. (1-tailed)	Monetary loss		0.000	0.476	0.008	0.000	0.000
	Cross	0.000		0.412	0.031	0.004	0.000

	jointed						
	Gas porosity	0.476	.0412		0.000	0.293	0.454
	Shrinkage	0.008	0.31	0.000		0.349	0.054
	Core fault	0.000	0.004	0.293	0.349		0.000
	Bad mould	0.000	0.000	0.454	0.054	0.000	
N	Monetary loss	50	50	50	50	50	50

4.1.3 Prediction of variance by the model

Table 4 gives the model summary. The table presents the **R** (0.806) and Adjusted R square (0.609). Thus, this model is predicting 61% of the variance in monetary loss, which indicates a good model. According to Cohen [14], this is a large effect. In the coefficients table 5, Beta value of the core fault is the highest with 0.603. This means that this variable makes the strongest unique contribution to explaining the dependent variable, when the variance explained by all other variables in the model is controlled. Table 5 also presents Tolerance and VIF (Variance inflation factor) which is the indicator of the variability of the specified independent variable which is not explained by other independent variables in the model. In the table, this value is above 0.1, which indicates that the multiple correlation with other variables is low, and it is suggesting that there is no multicollinearity. VIF, which is an inverse of the Tolerance value, is below 10, which is highly acceptable, indicating no violation of the multicollinearity assumption.

Table 4: Model Summary

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the estimate**
1	0.806	0.649	0.609	2056.32661

Table 5: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	1236.707	342.061		3.615	.001					
	Cross jointed	73.456	30.084	.475	2.442	.019	.727	.345	.218	.211	4.739
	Gas Porosity	-17.807	23.087	-.079	-.771	.445	.009	-.116	-.069	.762	1.313
	Shrinkage	63.599	32.168	.209	1.977	.054	.338	.286	.177	.716	1.396
	Core fault	79.582	27.608	.301	2.883	.006	.545	.399	.257	.731	1.368
	Bad mould	25.182	53.246	.098	.473	.639	.716	.071	.042	.187	5.347

4.1.4 Significance of the results

As can be seen from the ANOVA (Analysis of Variance) Table 6, F = 16.263 and is significant (p<.005), and therefore the model with all the variables entered significantly predicts monetary loss.

Also, the Normal Probability Plot of the Regression Standardised Residual in Figure 2; the points lie in a reasonably straight diagonal line suggesting no major deviation from normality.

Table 6: ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	343845623.759	5	68769124.752	16.263	0.000
Residual	186053081.452	44	4228479.124		
Total	529898705.211	49			

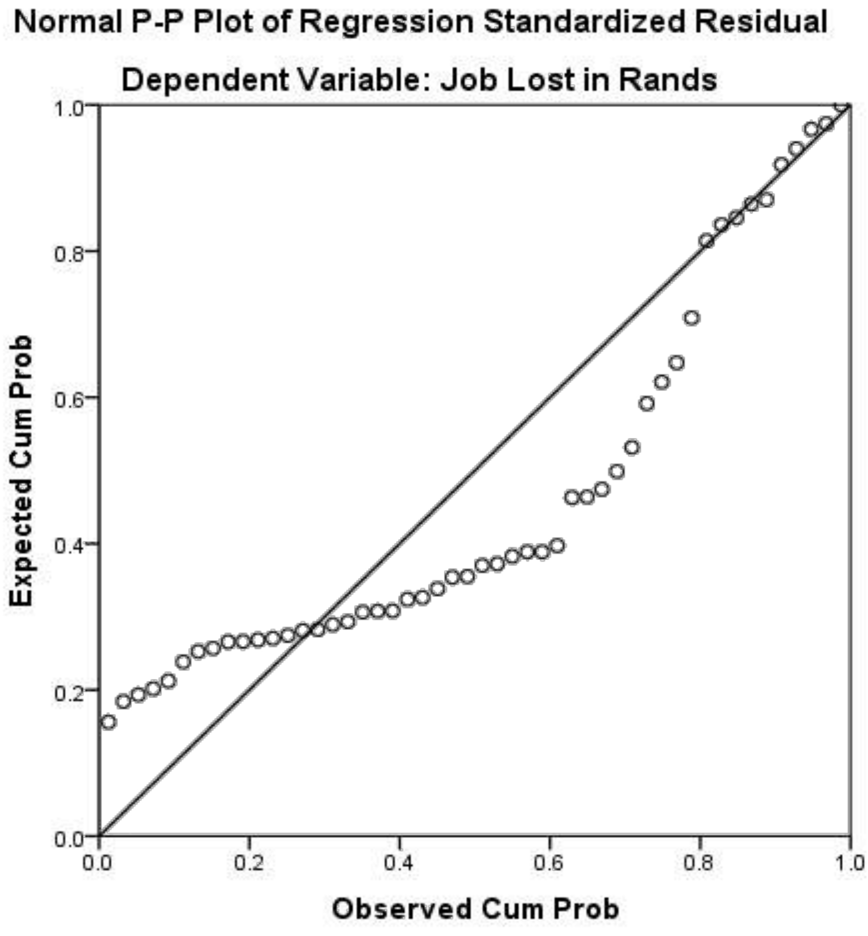

Figure 2: Cumulative probability plot.

4.2 Productivity and defects

In this section, the regression analysis results for productivity and defects are presented. Three models were used, that is, stepwise, forward, and backward regression; and all predicted significant results. Mallows' Cp value was calculated for all models to determine the best model, and for the model with the intercept and core fault as predictors, p=2, the Cp value = 4.222. For the other model where the predictors are the intercept, gas porosity and core fault, p=3, the Cp value = 2.509. The model with a Cp value that is less or equal to p; is the best model and therefore the backward regression model was selected to present the results. The independent variables were recorded as no defects or defects occurrence, which is different from the calculation of monetary loss vs defects. This was done due to the fact that productivity is calculated as a ratio.

4.2.1 Descriptive statistics

Table 7 presents the averages and standard deviation. The frequency of occurrence for cross jointed defect is 15, which accounts for 30% of the sample taken. Gas porosity occurred 50%, shrinkage 38%, core fault 30%, and bad mould 20%. This shows that the defect that occurred the most is gas porosity.

Table 7: Means and standard deviation

	Mean	**Std. Deviation**	**N**
Productivity (%)	88.56	13.547	50
Cross jointed	0.30	0.463	50
Gas Porosity	0.50	0.505	50
Shrinkage	0.38	0.490	50
Core fault	0.30	0.463	50
Bad mould	0.20	0.404	50

4.2.2 Correlation between variables

Table 8 presents the relationship between variables. Although gas porosity shows to be the highest, its correlation to productivity is weakly positive. The correlation is also not significant with Sig. = 0.176 which is >0.05. The variable making a significant unique contribution to the prediction of productivity is the core fault with a Sig. value of 0.006.

Table 8: Correlation

		Productivity (%)	Cross jointed	Gas porosity	Shrinkage	Core fault	Bad mould
Pearson Correlation	Productivity (%)	1.000	0.161	0.134	-0.097	0.353	0.028
	Cross jointed	0.161	1.000	-0.131	0.027	0.238	0.327
	Gas porosity	0.134	-0.131	1.000	-0.371	-0.306	-0.300
	Shrinkage	-0.097	0.027	-0.371	1.000	0.117	0.227
	Core fault	0.353	0.238	-0.306	0.117	1.000	0.546
	Bad mould	0.028	0.327	-0.300	0.227	0.546	1.000
Sig. (1-tailed)	Productivity (%)		0.131	0.176	0.251	0.006	0.425
	Cross jointed	0.131		0.182	0.426	0.048	0.010
	Gas porosity	0.176	0.182		0.004	0.015	0.017
	Shrinkage	0.251	0.426	0.004		0.209	0.057
	Core fault	.006	.048	.015	.209		.000
	Bad mould	.425	.010	.017	.057	.000	
N	Productivity (%)	50	50	50	50	50	50

4.2.3 Prediction of variance by the model

Table 9 presents the model summary. The adjusted R squared value is 0.233. This indicates that 23% of the variance in productivity is explained by the model.

Table 9: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Backward	0.652	0.426	0.233	12.517

4.2.4 Significance of results

The combination of all the defects significantly predicts productivity as Sig. value in ANOVA Table 10 shows Sig.= 0.007, F = 5.498, with all five variables significantly contributing to the prediction.

Table 10: ANOVA

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Backward	Regression	1705.008	2	852.504	5.498	0.007
	Residual	7287.312	47	155.049		
	Total	8992.320	49			

5 CONCLUSION

The quality management system implemented provides the company with tools and techniques to use for data collection and analysis. The data analysis is to help to point areas that require improvements. The study suggests that the company does not utilise these tools, resulting in high scrap rate. This is evident as the company is unable to point which defects lead to high monetary losses and low productivity. The results in this study suggest that the foundry should concentrate on eliminating cross jointed and bad mould defects to avoid a high scrap rate that leads to high monetary losses. It also shows that the elimination of core fault defect may improve productivity.

The study looks at a problem that is facing many foundry companies, and as mentioned before, most South African foundries fall under small companies. The SMME sector generally creates more employment than large companies, thus supporting small companies will directly impact on job creation and preservation.

The previous studies [10] mention that foundries do not collect data, and this was evident when this research was conducted. It then suggests that foundries cannot measure their performance as there are no set goals. It is important for any company to be able to measure its output in order to improve. In the literature review it was mentioned that foundries lack skilled personnel in specific areas. These areas were identified to be namely quality, metallurgy and industrial engineering.

Due to time limitations, the study could not measure the impact when the quality management system is utilised, but recommendations were made available to the company. Future studies can look at the implementation of lean manufacturing in foundry companies for improvements.

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ROOT CAUSE ANALYSIS FOR REDUCTION OF WASTE ON BOTTLE FILLING AND CROWNING OPERATIONS

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ABSTRACT

The global market place has become increasingly competitive and volatile, thus resulting in the need for the players in the beverage industry to continuously improve their processes, especially on bottle filling and crowning operations. Waste reduction becomes an increasingly dominant force in the modern manufacturing world. The paper aims to apply Pareto analysis to identify the key area which results in waste at a case study company. The process is first mapped to outline the key inputs, outputs and all the possible wastes. Historical and current data for the filling and crowning operations is gathered so that the facts about the problem are accurately described. Ishikawa diagrams are then used to present the key problems and recommended solutions are implemented. SPSS software is used for statistical analysis to compare the before- and-after scenarios with the view to verify and validate the improvements made.

1 INTRODUCTION

In an increasingly competitive market place amongst the beverage industries, bottle filling industries in particular, show a clear and distinct need to improve their operations [1]. A typical bottle filling production line generally includes arranging the bottle, cleaning the bottles, filling, crowning, labelling, detection of the foreign bodies, and packing as shown in Fig 1. Waste during these operations has become problematic since it increases the production costs. With this in mind it became imperative to conduct a study on 1 such line to establish the root causes of waste during the bottle filling and packaging operations and thereafter put in place the right cost-effective measures to eliminate these losses.

Losses are defined as loss of product from the stated liquid tank agreed volume and the volume of product exiting the filler less all rejects. The only way to control liquid product loss is to identify the main problem areas in order to effectively work towards minimising the losses. Liquid tank to filler loss is product lost prior to the filler valve monitor (FVM) on the actual filler machine. These losses include incorrect declared and agreed volumes of the liquid tank. In the event of the valve system failing, the liquid is pushed away from the liquid tank through the flush system.

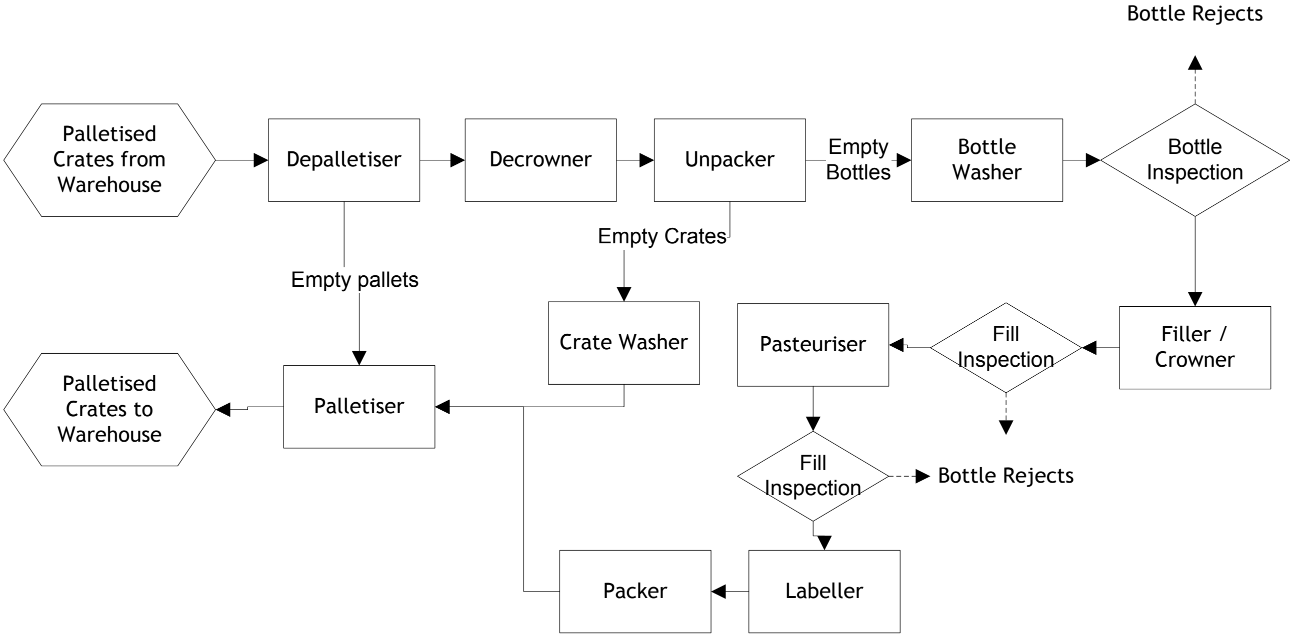

Figure 1: Flow diagram for bottle packaging operations

The aim of the paper is to identify and address the root causes of waste that arise during the bottling process of a case study company. Possible intervention measures are there after suggested as part of the study.

2 LITERATURE REVIEW

Enormous strides have been made in the last twenty years in the size, speed, quality of performance and complexity of bottle filling equipment. One of the key requirements of a filling machine is that the containers must be filled as quickly as possible with a commercially accurate quantity of product. The quality of the product must be maintained during the filling operation and there must be no mutually inflicted damage between the container and the filling mechanism [2]. When filling a bottle, the concern is to avoid the introduction of certain elements such as dissolved oxygen in some processes, which could invariably affect the accurate fill level of the product [3].

In general, filling machines are designed around a carousel of valves, allowing many bottles to be filled in a continuous system. The valves are based on mechanical and pressure actuation; pressure to open, mechanical springs to close. The filling level is determined by an open-ended pressure balance tube that projects into the bottle from the valve. As liquid enters the bottle, the pressure is balanced until the end of the tube is covered, which releases the valve to close by spring return [4].

Ridgway (1999) investigated the use of ultrasound monitoring and controller design methodologies as a means of on-line measurement of fluid levels in a bottling process. The bottling process was modelled using MATLAB and SIMULINK packages and controller designs were implemented to improve the response characteristics of the process [5].

When it comes to online detection of moving beer bottle, Zhang (2008) used a fusion algorithm based on segmentation of optical flow field and Susan's operator under the condition of camera being fixed [6]. Yepeng (2007) asserts that the defect on bottle mouth is one of the most important defects of beer bottle and developed a set of defects-inspected system based on digital image process technology to eliminate unqualified bottles [7].
Hypothesis testing is a method used by researchers to determine how likely it is that observed differences between different sample estimates are entirely due to sampling error rather than underlying population differences. An important factor in hypothesis testing is to determine whether or not the difference between two observed means is due to stochastic variation and whether or not the difference is large enough to allow the conclusion that the two samples come from populations with different means [8].
Generally, real life problems are characterised by unknown values for the population variances. Under such circumstances, the independent t-test can be used to compare the means between two unrelated groups on the same continuous, dependent variable.

Significance tests can be grouped into parametric and non-parametric when analyzing data for hypothesis testing. Parametric tests are generally considered more powerful because their data are typically derived from interval and ratio measurements when the distribution is known, except for some parameters. Non-parametric tests are also used with nominal and ordinal data. Parametric tests place different emphasis on the importance of assumptions while nonparametric tests have fewer and less stringent assumptions. They do not specify normally distributed populations or homogeneity of variance [9]. Conclusions can then be drawn from the data that is subject to random variation, observational errors or sampling variation through statistical inference [10].

3 METHODOLOGY

3.1 Defining the problem

At this case study company it was revealed that product losses through wastage on the filling operations adversely impact the company with losses amounting to hundreds of thousands of rands per year being incurred.

Product losses arising during the filling processes have its own broad scope because within it there are different contributors to it and areas which can be focused on.

There are losses that could occur between the product tank and the filler/crowner discharge operation due to incorrect measurement in the being taken at either side. Further losses could be made up through: overfills, no crowns, distorted crowns, under fills, brand change, bottle defects, start-up, shut down and incorrect jetting. Figure 2 depicts typical product losses incurred per shift.

This paper focuses on an in depth study on the losses at the filler operation due to the fact that this was the operation highlighted as being the contributing factor within the overall process. The loss is measured as a ratio of loss incurred at the respective area against the withdrawn volume of product.

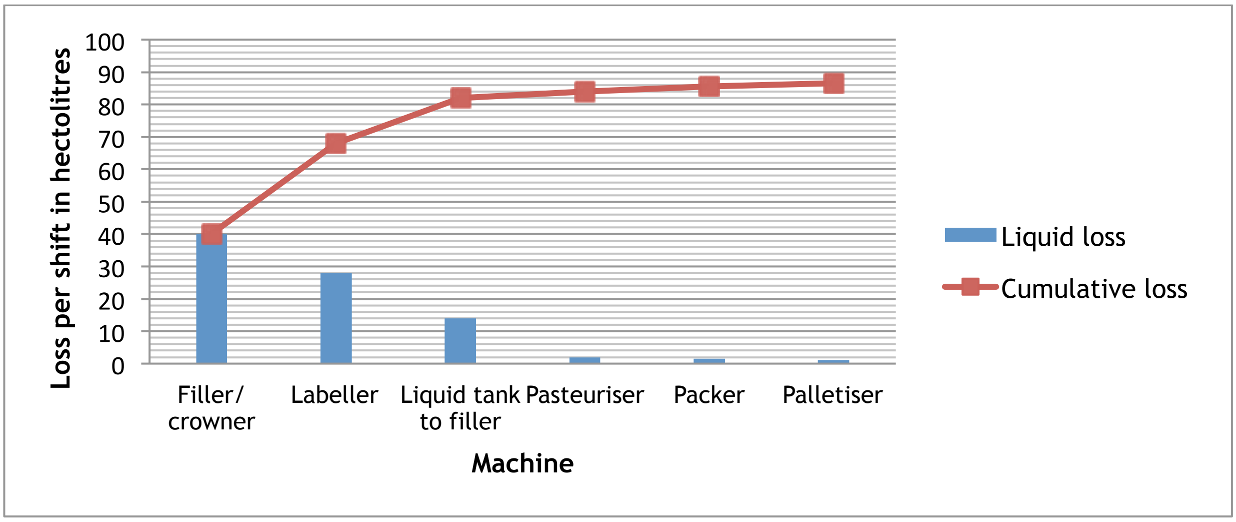

Figure 2: Pareto analysis for liquid loss from the bottle packaging line

3.2 Process mapping

Process mapping is a powerful way of visualising the relationships between a sequence of actions required to execute a task, outlining the inputs to the process, the outputs and all the possible wastes. In the diagram below, the filling process is visualised, clearly outlining both the filling and crowning which are both performed by the filler. Although the illustration shows as if the overfills and underfills leave before crowning, in reality, these are only detected after passing through the fill inspection device which is placed after the filler/crowner.

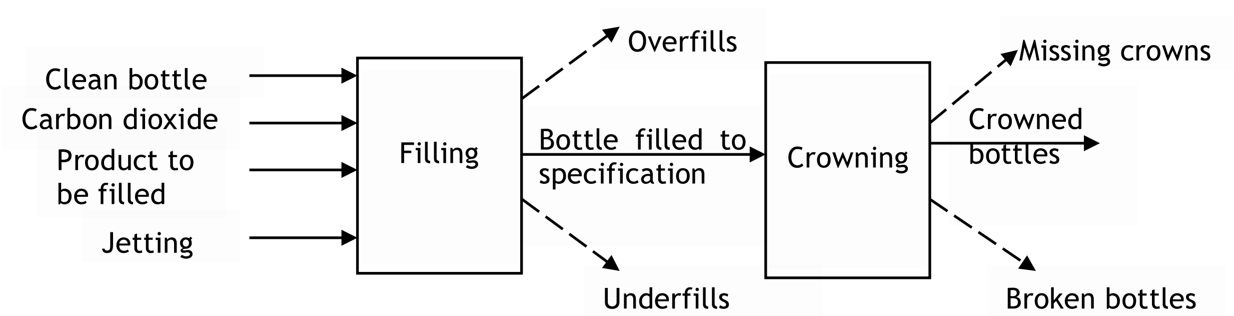

Fig 3: Mapping of filling and crowning operations

3.3 Gathering historical data

The aim is to gather all the facts so that the problem is accurately described. We also wanted to identify where in the filling process the most product is lost, whether it is the actual filling or the crowning process that is contributing to the losses.

For the selected production line, data is collected manually using the appropriate form and fed into computer. Key parameters to be entered into the system include the bottle count, underfills and missing crowns for the shift. It must be noted that total product loss will not be calculated without the labeller counts having being inserted as well. "Good bottle" counts are obtained from the filler valve monitor and entered into data warehouse. There are two fill inspection points, one is after the filler and another is just before the labeller. The system computes the liquid loss using the simple formulae shown below.

$$Total\ liquid\ loss = Volume\ withdrawn - Volume\ produced \quad (1)$$

$$Liquid\ loss\ after\ filler = Volume\ produced - Filler\ good\ production \quad (2)$$

$$Labeller\ liquid\ loss = Filler\ good\ production - Labeller\ production \quad (3)$$

$$Liquid\ loss\ after\ labeller = Labeller\ \ production - Labeller\ \ good\ production \qquad (4)$$

Figure 4 shows the extent by which the product loss deviates from the KPI target of 0.9 from early April to mid August.

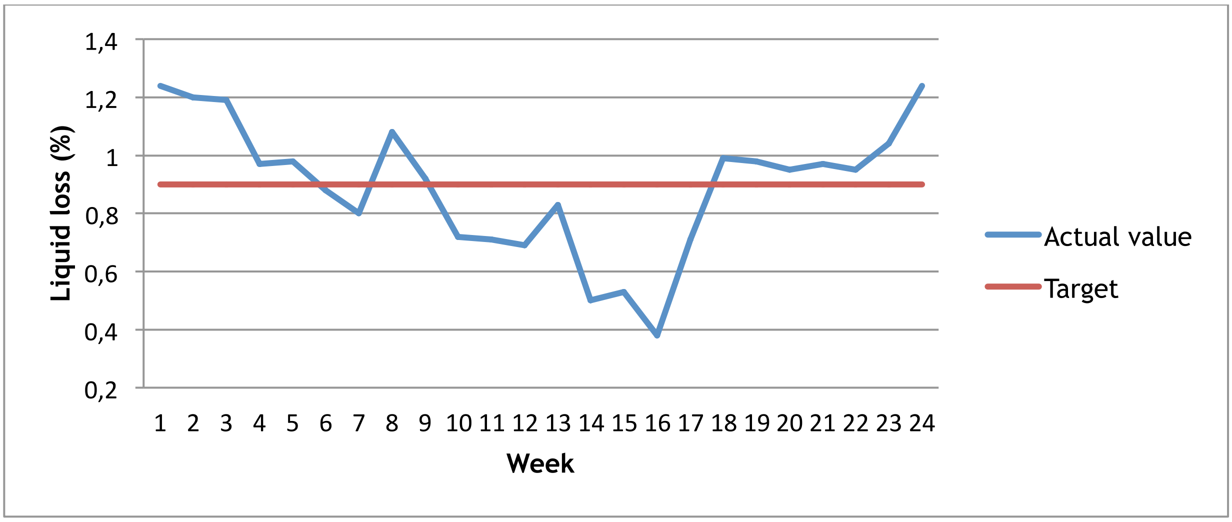

Figure 4: Deviation of product loss from target

It is clear from the graph that corrective measures were imperative since the product loss was negatively deviating from the target for the period from week 9 to about end of week 17.

Figure 5 shows the percent loss of product as a function of total volume produced per month. There is no significant difference between the underfills and the missing crowns but the underfills are still higher than the missing crowns. We also investigated the shifts to see if there were any significant differences in the waste ratio per shift and noted that there is no significant difference between the three shifts.

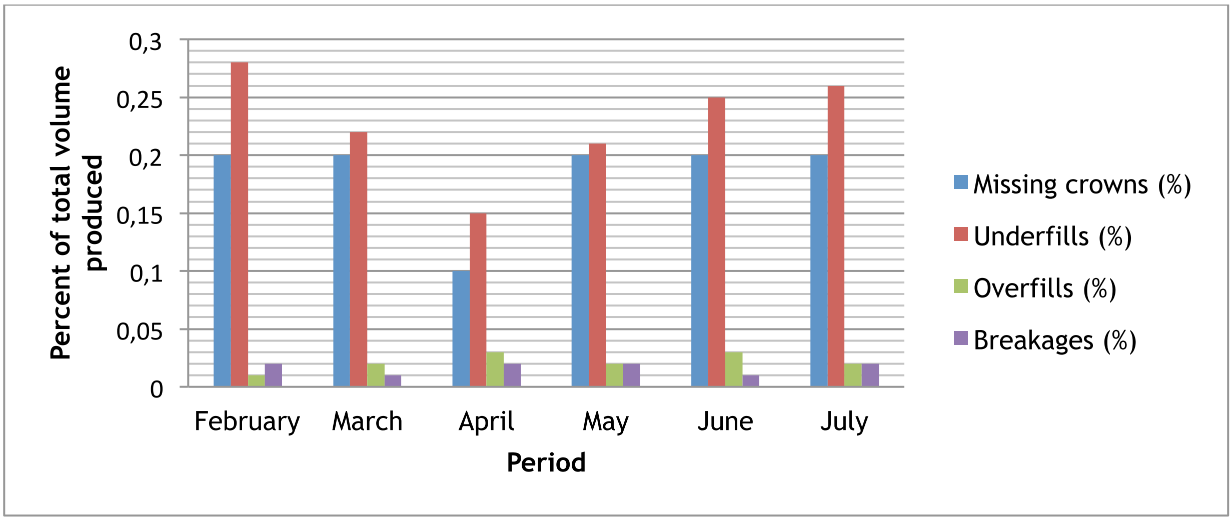

Figure 5: Data on waste from filling and crowning operations

3.4 Problem solving using basic tools

The recommended problem solving tools include the Cause-effect (Ishikawa), Scatter diagrams, Failure mode effect and criticality analysis (FMECA). The Scatter diagram captures all possible causes of a problem and shows how these causes are interrelated [11]. For this project, we decided to use the cause-effect (fishbone) to identify the root causes for beer loss.

According to Bilsel (2012), Ishikawa or Cause and Effect diagrams are popular tools to investigate and identify numerous different causes of a problem and used as a guideline to allocate resources and make necessary investments to fix the problem [12]. This is a casual diagram that shows the causes of a specific event. The causes are grouped in categories to identify the sources of variation. Figure 6 illustrates an Ishikawa diagram for bottle filling and crowning operations.

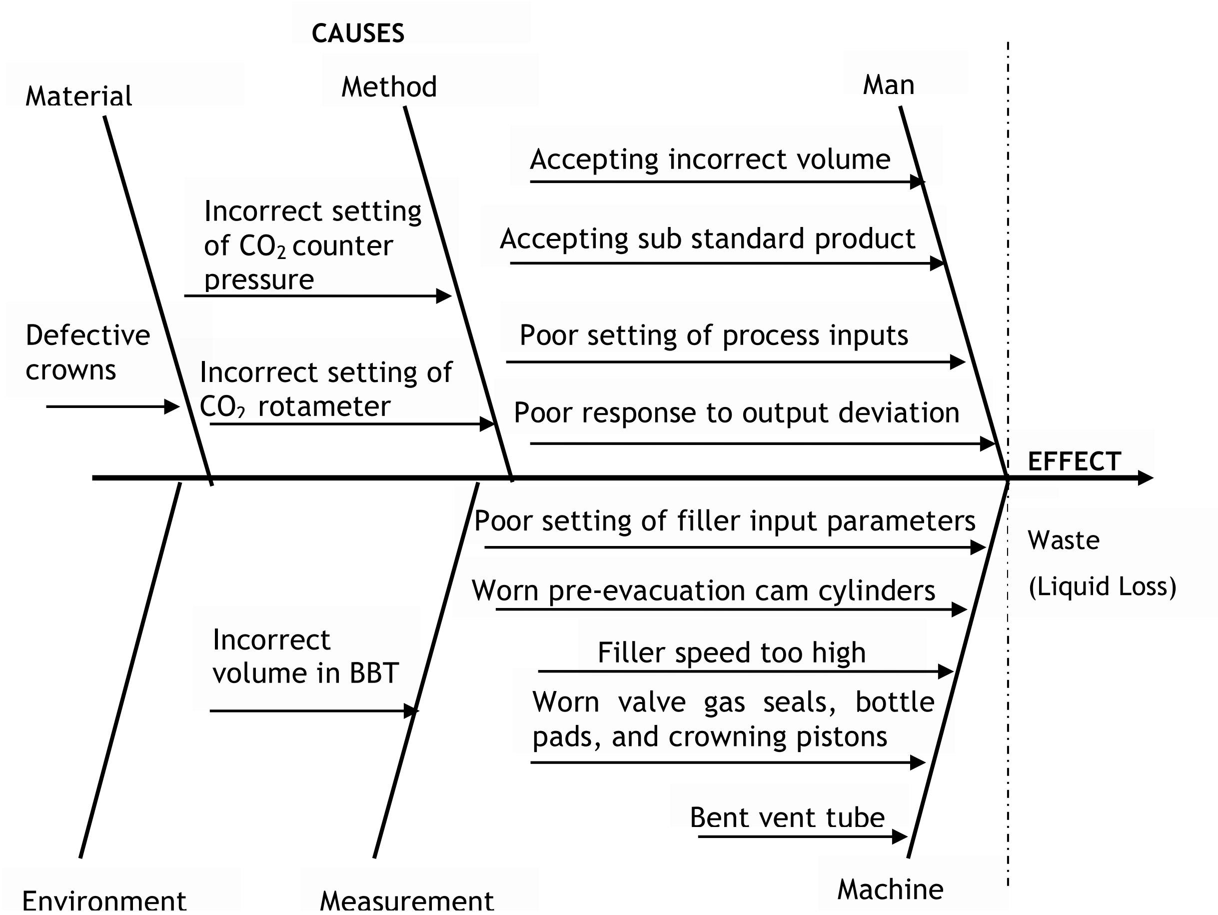

Fig 6: Ishikawa diagram for bottle filling and crowning

Fillers experience problems through gushing of product out of filling valves. Over filling also contributes towards product losses. This is, however, minimal. Poor filling control caused by filling problems can cause liquid to gush during the snift process. Poor bottle handling at the filler to crowner transfer will cause the liquid to be agitated, resulting in the product gushing out of the bottles. Poor or incorrect jetting will cause excessive liquid loss from the bottle resulting in underfilling of a bottle. Damaged filling valve components will also result in under filling and/or overfilling. Then there are rejects caused by incorrect crowning and missing crowns. Uncrowned bottles will be rejected at the filler discharge.

The environmental conditions such as time, temperature, and culture in which the process operates, in this case are not applicable since no noticeable effect was realised.

3.5 Verification of standard operation

Each of the causes were then followed up to check if the standards were taken into consideration during the filling process and also to identify if procedures are being followed. Table 1 shows a summary of the actually operating procedures when compared to the standard operating procedures.

Table 1: Comparison of observations and standard operations

Description	Verification notes	Standard Operation	Observations
Operator accepting incorrect volume from filtration	Operator to check for correct volume before confirming the volume of product from tank	Operator to check correct volume on computer monitor before confirming product from tank.	Operators checking tanks before confirming
Operator accepting sub-standard quality product from filtration.	Operator to check all quality parameters before confirming liquid from tank.	Check quality parameters before confirming product from tank.	Liquid from tank checked against specifications before confirmation.
Operator failing to respond quickly to deviations.	Process input/output monitoring sheets have triggers to guide operators monitor the process and take corrective action where necessary.	<40 underfills/hour 15 missing crowns/hr.	Quick fix routines applied in case of deviations.
Filler speed too high.	Filler speed verified via valve monitor systems display page.	Filler speed 750bpm with the recovery speed of 795bpm.	Filler running at recovery speed.
Defective crowns.	Suspect crowns to be checked or isolated and a new batch should be withdrawn.	Defective crowns should be quarantined, samples kept for the lab and on-line rejection completed.	Procedure is always complied with.
Incorrect volume in product tank.	Pull trends from active factory report for suspect low volume in product tank.	Follow procedure in case of suspect volumes.	Operators verifying volumes by pulling trend.
Inputs not set correctly.	Input settings are all marked to avoid mistakes.	Set inputs according to work instructions and monitor	All inputs set correctly.
Worn pre-evacuation cam cylinders releasing CO_2 and causing bowl to flood.	Weekly maintenance schedule issued.	Check weekly.	Weekly schedule done.
Worn valve gas seals causing excessive underfills	Physically check gas seals for wear	Gas seals replaced during annual shut down	Seal worn
Wear and tear	physically check bottle pads, key and key way for wear	Monthly schedule in place	Worn bottle pads, worn crowning pistons, worn key way on the hub

3.6 Identification and implementation the proposed solutions

These solutions included entrenching foundational practices for reacting promptly to deviation by taking corrective actions since this would effectively reduce the underfills and missing crowns. We also identified that valve overhaul and replacement of gas valve seals would result in better control of CO_2 during filing process. Replacement of crowning pistons would alleviate the problem of having worn pistons from falling and damaging machine. It was also critical to replace crowner bearings so as to reduce of skewing of crowns.

We used Deming's PDCA cycle to implement the possible solutions. It was critical to ensure that the spares for the filler/crowner were always available. The crowner was overhauled and all worn components were replaced. We also detected and corrected root causes of underfills and missing crowns at source. It was then imperative to check the bottles for improved sealability during start up as well as for improved filling. Lastly, we conducted a 200 bottle volume check and sealability of the crowns. The maintenance schedules were revised to ensure preventive maintenance on valve gas seals and crowner components performed by the engineering planner for the line. The operators were then trained on foundational practices.

3.7 Verification of improvements

After the loops are closed, the targets and actual values were then tracked to check for improvement. The target for waste reduction was 0.9% of withdrawn volume for the packaging hall. Figure 7 shows the extent by which the product loss deviates from the KPI target of 0.9 from mid August to end of February the following year.

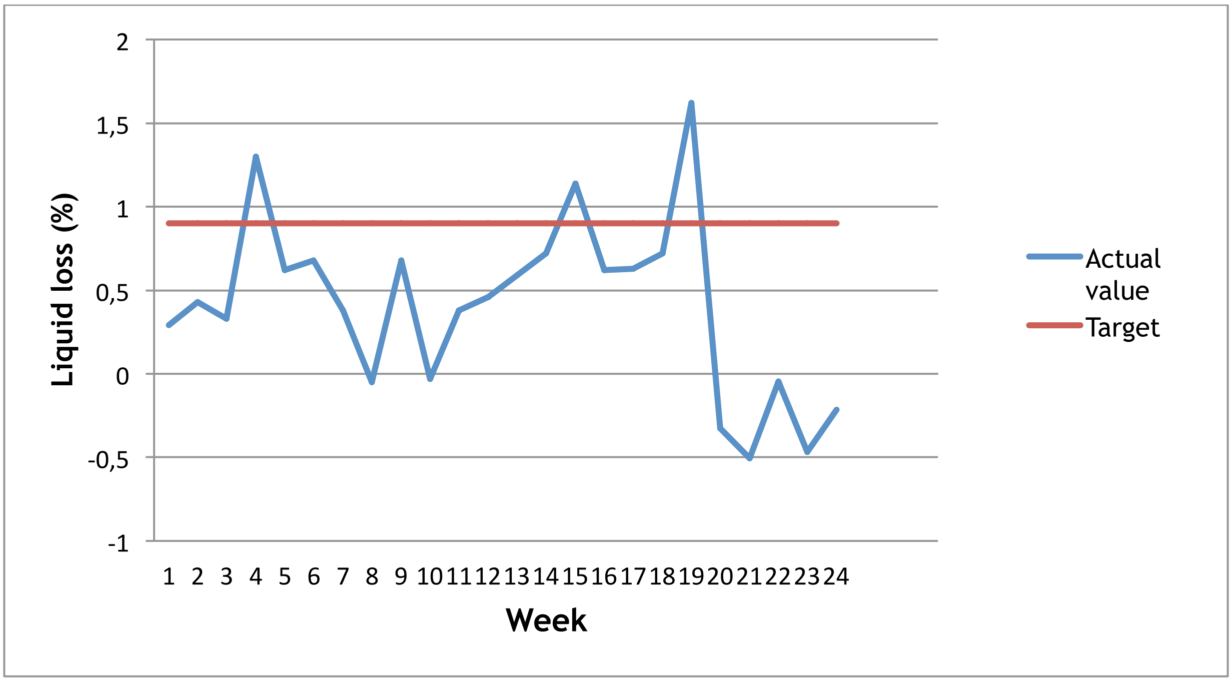

Figure 7: Deviation of liquid loss from target

Comparing Figure 7 with Figure 4 shows a marked improvement in plant performance. There is a significant difference in the product loss figures after the changes have been effected.

3.8 Statistical validation

We used the data collected for deviation of percent liquid loss from a target of 0.9 to conduct some statistical analysis using SPSS Statistics 17.0 software. Table 2 shows data on extent to which the product losses were deviating from the target 0.9 percent. It was crucial to verify and validate whether the changes made were responsible for the positive results shown in Figure 7 or whether it was due to chance.

Table 2: Data on percentage of liquid losses

Before				After			
2.14	1.7	1.73	1.88	1.19	1.28	1.49	2.52
2.1	1.98	1.4	1.85	1.33	0.85	1.62	0.58
2.09	1.82	1.43	1.87	1.23	1.58	2.04	0.39
1.87	1.62	1.28	1.85	2.2	0.87	1.52	0.85
1.88	1.61	1.61	1.94	1.52	1.28	1.53	0.43
1.78	1.59	1.89	2.14	1.58	1.36	1.62	0.69

We assessed normality of our data through the Kolmogorov-Smirnov and the Shapiro-Wilk Test. Shapiro-Wilk Test is more appropriate for small sample sizes (< 50 samples), but can also handle sample sizes as large as 2000. At 95 % confidence interval, if the sigma value of the Shapiro-Wilk Test is below 0.05, the data significantly deviate from a normal distribution.

Table 3: Test of normality

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Before	0.138	24	0.200*	0.954	24	0.336
After	0.157	24	0.128	0.959	24	0.428

The results from Table 3 show that the sigma value of both the Kolmogorov-Smirnov and Shapiro-Wilk Test is greater the 0.05, thus we reject the null hypothesis and accept the alternative hypothesis, which implies that the data is normal.

Alternatively, we used the descriptive statistics to check whether the samples resembled normal distribution. Using α = 0.05, both samples passed the normality assumption for kurtosis and skewness since the standard error (z-score) values were not falling between -1.96 and +1.96 as shown by the descriptive statics in Table 4.

That means we could then perform a parametric statistical test. We then performed an Independent samples T-test (also called a between-subjects t-test). The aim of a T-test was to check if there will be a significant difference or improvements. We state the null hypothesis as population means for the two samples as equal. An arbitrary level of significance (α) to reject the null hypothesis was selected at p = 0.05, implying that we would reject the null hypothesis when the p-value is less than or equal to 0.05, implying that the two means are significantly different. On the contrary, when the p-value is greater than 0.05, we cannot reject the null hypothesis.

Table 4: Descriptive statics of liquid loss data

Scenario	Parameter	Statistic	Std. Error
Before	Mean	1.7938	0.04708
	Variance	0.053	
	Std. Deviation	0.23067	
	Skewness	-0.468	0.472
	Kurtosis	-0.176	0.918
After	Mean	1.3146	0.10831
	Variance	0.282	
	Std. Deviation	0.53063	
	Skewness	0.172	0.472
	Kurtosis	0.095	0.918

Table 5 shows the results for the independent samples T -test for the prior situation before the improvements were effected as well as after process modification.

Table 5: Independent samples test for the before-and-after scenarios

	t-test for Equality of Means				
	t	df	Sig. (2-tailed)	Mean	Std. Error
Equal variances assumed	4.05	46	0.000	0.479	0.1181
Equal variances not assumed	4.05	31.39	0.000	0.479	0.1181

Since sigma (2-tailed) is 0.000 which is less than 0.05, assuming unequal variances, thus we reject the null hypothesis and conclude that there has been a significant difference or improvement from the previous scenario to the later situation.

4 CONCLUSION

The packaging process of the product has faced many challenges which could be alleviated through focused process improvement. Pareto analysis can be used as tool to identify key areas in the process that could benefit from a focus improvement initiative, thereby benefiting the overall company. The analysis of the filling and crowning process through Ishikawa diagrams revealed the critical process inputs and parameters which influenced excessive waste. Recommended solutions were identified and implemented to reduce the negative influence of these critical process inputs. It is crucial to always ensure that the workers comply with the standard operating procedures in order for waste to be reduced. After effecting any changes, statistical analysis can be used as a tool for verification of whether there were improvements made or if the results were due to chance.

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THE RECOMMENDATION AND VALIDATION OF AN APPROPRIATE PHYSICAL ASSET MANAGEMENT POLICY FOR PRASA'S METRORAIL DIVISION

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ABSTRACT

The problematic state of public transport by rail in South Africa is common knowledge. Improved management of the physical assets of Metrorail is required. Through the development of a generic policy statement, the existing Physical Asset Management (PAM) strategies and techniques can be improved. This study tested the generic policy statement by deriving a roadmap from the statement. The roadmap was successfully applied to the wheelset maintenance procedures of Metrorail through highlighting problem areas and identifying financially sound alternatives.

[1]The author was enrolled for a MScEng (Engineering Management) degree at the Department of Industrial Engineering, Stellenbosch University

1. INTRODUCTION

The reversal of the irrefutably poor state of public transport in South Africa, specifically rail transport, has gained traction. The past two decades have seen the deterioration of the physical assets of South Africa's passenger rail industry, which has been brought on by a lack of significant investment into the physical assets since the mid-1980s and the Physical Asset Management (PAM) systems [**1**] [**2**]. Local media has covered the Rolling Stock Recapitalisation Program, but change is also occurring to the PAM systems.

In working with the Passenger Rail Agency of South Africa (PRASA) and its subsidiary Metrorail, it was discovered that their PAM strategies have not kept pace with global and local standards [**3**]. A variety of PAM strategies exist with varied areas of application. The choice of PAM strategies depends of the strategic intent of the organisation to which the strategy will be applied. The strategic intend of the organisation manifests itself through its particular PAM policy [**4**]. A PAM policy provides guidance and a framework, which allows the selection and development of specific PAM strategies that conform to the strategic intent of an organisation and align with other existing policies [**5**].

Upon an initial investigation it was revealed that neither Metrorail nor PRASA, have a PAM policy that guides and acts as a framework for the development of the PAM strategies that they employ [**3**]. In light of this a generic policy statement, called Requirement-based Asset Management (ReBAM), was developed. The aim of this article is to discuss the effectiveness of a generic PAM policy statement in a passenger rail environment.

The assessment of the suitability of a generic policy statement will allow similar types of organisations, with different PAM needs, to confidently develop and evaluate their own specific PAM policies by the use of ReBAM.

In this article relevant literature regarding the development of PAM (Physical Asset Management) policies will be discussed, along with specific literature regarding PAM strategies and relevant contextual information regarding Metrorail. Following this, the generic policy statement is explained, with the development of a policy statement-based roadmap and the application of elements of the roadmap to wheelset maintenance. The results of this application are then discussed and conclusions drawn up.

2 LITERATURE

2.1 The development of PAM policies

The Physical Asset Management (PAM) policy of any company is a written statement that articulates and explains the target or direction and the framework that that company intends to adhere to, specifically for the management of its physical assets [**5**] [**6**] [**4**].

There are several key requirements for the development of a PAM policy: A detailed understanding of the specific industry or organisation, for which the policy is to be developed, is required. Secondly, suitable knowledge and experience of the field and PAM and its strategies and concepts needs to have been gained. Lastly, in order to ensure relevance, a procedure for reviewing and renewing the policy and strategies needs to be put in place [**6**] [**7**]. Section 2.2 and 2.3 discuss the relevant PAM strategies and the specific organisation respectively.

2.2 Relevant PAM strategies and concepts

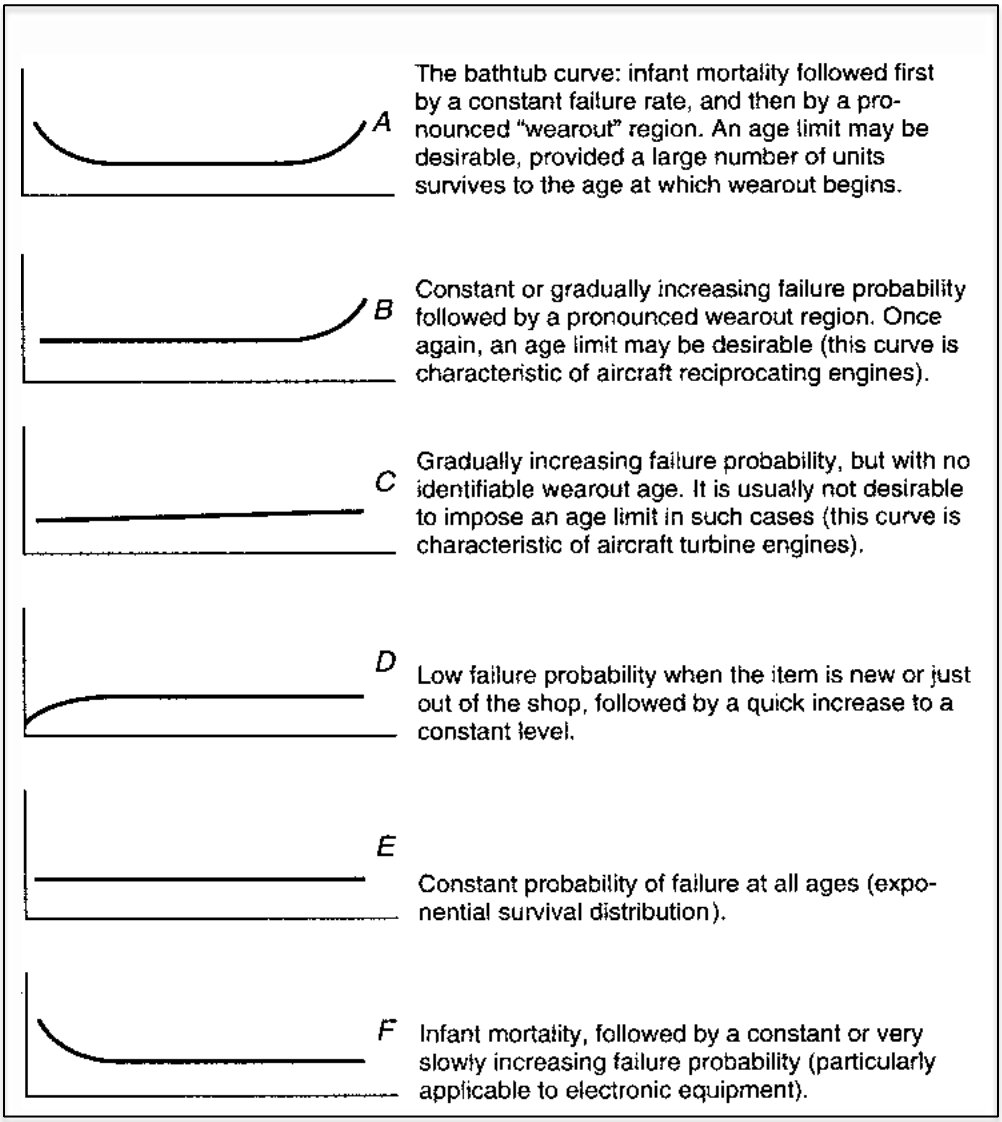

Figure 1 The six common failure mode/age-reliability profiles [8]

The largest part of PAM is maintenance, if the is known how the asset fails than it can be maintained. An understanding of how and when an asset incurs a failure allows for improved management of that asset [**8**]. The type of maintenance selected for an asset should be influenced by the failure mode of that asset. The failure profiles are generally grouped into six profiles as shown in figure 1.

Table 1 lists and briefly describes five different maintenance strategies, two methodologies and two standards that were investigated for this study. They can be grouped as being Corrective Maintenance/Breakdown Maintenance (CM/BM) or a subset of Preventative Maintenance (PM). PM can be split into four categories based on when and how maintenance tasks occur. They are Time Directed Maintenance (TDM), Predictive Maintenance (PdM), Run-to-failure (RTF) and Design-out Maintenance (DOM). All other forms of PM consist of a combination of two or more of these categories.

Table 1 is a summary of the relevant Maintenance strategies(5), methodologies (2) and standards (2) that were investigated

Acronym	Acronym Description
CM/BM	Corrective Maintenance/Breakdown Maintenance: fixing any un-anticipated fault/failure or breakdown [9] [8].
PM	Preventative Maintenance: all action taken to prevent or detect failures; includes TDM, PdM, RTF, DOM.
TDM	Time Directed Maintenance: replacing or reconditioning a component/system after a specific time period, based on the Original Equipment Manufacturer (OEM) or historic failure data [8].
PdM/CBM/CD	Predictive Maintenance: maintenance on components based on a concrete inspection that assesses the condition of the assets and can predict its failure [8].
DOM	Design-Out Maintenance: the action whereby the asset/asset components are redesigned and replaced, specifically to remove a fault [10] [8].
RTF	Run to Failure (operation until failure or breakdown): a maintenance technique applied to assets/asset components where any other strategy is neither viable nor feasible and the health, safety and environmental impact is unacceptable [8].
TPM	Total Productive Maintenance: focuses on the operator & maintainer relationship specifically in a production environment, with special emphasis on how to do the maintenance [9].
RCM	Reliability Centred Maintenance: a maintenance strategy that focuses on retaining system functionality. It determines the most suitable maintenance concept and inspection frequency, specifically focusing on the largest contributors to failure [8].
Lean Maintenance	An evolution and improvement of TPM, based on Lean Manufacturing principles [11].
PAS 55	Publicly Available Specification number 55 from the British Standards for optimised management of physical assets and infrastructure. It provides definitions and requirement specifications for joined-up, whole-life asset management [5] [6].
IRIS	The International Railway Standards Institute: its sole purpose is to develop standards for the Railway Industry from the supplier to the operator. It is fully compliant with the International Standards Organisation (ISO) specifications and by applying for IRIS certification ISO is included automatically [12].

2.2.1 Reliability Centred Maintenance

RCM was developed for the airline industry but has steadily been applied to all types of physical assets. RCM is defined by the following four features:

- To preserve functions.
- To identify failure modes that could defeat the functions.
- To prioritize function need (via failure modes).
- To select applicable and effective PM tasks for the high priority failure modes.

To achieve these four features, a nine-step (7+2) plan was developed [**8**]. This process is as important as the four features of RCM. These nine steps are listed below.

Step 1: System selection and information collection.

Step 2: System boundary definition.

Step 3: System description and functional block diagram.

Step 4: System functions and functional failures — Preserve functions.

Step 5: Failure mode and effects analysis (FMEA) — Identify failure modes that can defeat the functions.

Step 6: Logic (decision) tree analysis (LTA) — Prioritize function requirement via the failure modes.

Step 7: Task selection — Select only effective and efficient PM tasks.

These seven steps form the basis of the RCM process and contain all four features of RCM. The following two steps are specifically included for continued success of RCM implementation [**8**].

Step 8: Task packaging — carrying the recommended RCM tasks to the shop floor

Step 9: Living RCM program — comprising the actions necessary to sustain the beneficial results of Steps 1–8

2.2.2 Total Productive Maintenance

Similar to RCM, TPM is an expansion and add-on to a basic PM system. It is a strategy that focuses on involving operators in basic aspects of maintenance. It emphasises the need for operators to take ownership of - and responsibility for - the equipment that they operate [**9**].

TPM is a strategy that aims to combine conventional PM practices with the total involvement of the employee. It has five specific aims:

- To establish a company structure that will maximise production system effectiveness
- To setup a practical shop floor system that aims to prevent any loses
- To involve all departments including the support services divisions
- To involve every single employee from senior management
- To achieve zero loses through small group activities

To achieve this, TPM is based on five pillars or core principles that were developed by Seiici Nakajima [15]. In order to implement these pillars, a three-phase plan was developed based on three cycles. Together, they form the nine-step TPM improvement plan. The combination of which pillar forms part of which cycle is shown in table below. OEE in item 1 refers to Overall Equipment Effectiveness.

Table 2 The relationship between the 5 pillars of TPM and the 3-cycle TPM plan adapted from [9]

	Measurement cycle	Condition cycle	Problem prevention cycle
1. Continuous Improvement in OEE	✔	-	✔
2. Maintainer asset care	✔	✔	-
3. Operator asset care	✔	✔	✔
4. Continuous skill improvement	✔	✔	✔
5. Early Equipment Management	✔	-	✔

2.3 Relevant background information of Metrorail

Metrorail was originally part of the larger rail organisation called SATS (South African Transport Service), which became Transnet in 1990 [**13**]. In 1997 it was spun off to the South African Rail Commuter Corporation (SARCC), which is now known as PRASA (Passenger Rail Agency of South Africa) [**14**]. During the split from Transnet most of the large rail engineering services were separated from Metrorail and remained with Transnet [**15**].

According to the CEO of PRASA [**16**], when the SARCC became PRASA and ownership and operation of Metrorail was completely transferred to PRASA, PRASA found itself in a financially difficult situation. This was exasperated by the 25% and 32% increases in electricity costs in 2008 and 2009 [**15**]. In order to remain in operation, a cost containment exercise was implemented in July 2009, with various facets and numerous intended outcomes. One of the unanticipated results was that for 9 months payments for wheel maintenance were not made to Transnet and thus, no wheelset maintenance was done. There are three levels of wheel-set maintenance and Metrorail relies on Transnet for all of them.

After an investigation it was found that at present (2011), there exists no concrete, overarching PAM or maintenance policy within Metrorail or PRASA. Maintenance is being done based on the requirements of the Railway Safety Regulator (RSR) or according to the SARCC-Metrorail Main agreement from 1998, which does not contain a policy [**17**].

This manifests itself in two primary forms of maintenance, namely time directed maintenance (TDM) or run to failure (RTF), according to the senior engineers from Metrorail. However it is unclear what percentage of these RTF’s are actually unplanned failures that are then resolved versus failures that are purposefully allowed to occur. Currently there is movement within Metrorail Engineering Services department to move from primarily TDM to Condition Based Maintenance/PdM. No program has been developed as yet.

3 METHODOLOGY

3.1 Explanation of Requirement-based Assets Management

In order to develop a specific PAM policy, a generic policy statement was developed based on the knowledge gained from extensive literature study and an investigation into PAM and different best practice strategies [5]. The following is the recommended policy statement:

Implement a suitable, sustainable and living national PAM policy based on the requirements of the asset component, the system and the organisation. This policy will also be known as Requirement-based Asset Management (ReBAM)

Each of the terms of the policy is briefly discussed below.

Implement: To carry out or do. The PAM system that is developed based on this policy needs to be put into action [**18**].

Suitable: This is one of the most important words in this policy. It means that any PAM system or strategy derived from this policy needs to be realistic enough to be achievable, yet challenging, so as to create a goal to strive for. It also needs to take the current situation of the organisation into consideration. It needs to align with the high-level requirements of the company, and all stakeholders [**19**] [**18**].

Sustainable: The PAM system needs to be sustainable from an environmental viewpoint. It also needs to be sustainable in the business sense. The derived system needs to aid the growth and improvement of the company that it is applied in, in such a way that it does not jeopardize the current or future operations. In short, the PAM system needs to be affordable and have a positive ROI. A sustainable PAM system is also both effective and efficient [**18**].

Living: This term has been included to highlight the need for improvement, specifically in the ever-evolving field of PAM. Thus, any system that is derived from the policy needs to be adaptable. It must evolve with the needs of the company. [**8**].

National: In large organisations with multiple branches the organisational structure and Regulatory Requirements do not make it feasible to have different strategies in different regions. However, the application of each strategy will lead to differing requirements in different regions. [**18**].

Program: Is a system or combination of methods and strategies that are applied in an organisation. Different failure modes require different preventative maintenance techniques. Thus all strategies that are considered need to form part of an organised, structured system, for manageability, effectiveness and efficiency [**9**] [**18**].

Requirements: The requirements for any asset component or system depend on the different failure modes of each component or system and the expected performance thereof. Although standardisation has its advantages, specific failure modes can only be addressed by using a specific set of concepts.

The second facet that is covered in by the term requirements are the regulations, as per national laws that are applied through the Regulator.

An organisational policy, such as a PAM policy, is created based on two key elements, as was explained in the literature study. The first is the investigation of the specific field to which the policy should apply; the second is the accumulation of understanding and insight into the specific organisation that it will be implemented in. It is therefore very difficult to evaluate any generic policy. In order to do so, the policy needs to be applied within an organisational context, then evaluated in that context, in order to draw conclusions about the generic policy statement. Section 3.3 will discuss the policy within Metrorail’s context in order to establish its validity and suitability [**6**] [**4**].

3.2 ReBAM-based roadmap

Before looking into the roadmap specifically, some general observations are required. These high-level derivatives of ReBAM are discussed in the following two paragraphs followed by the roadmap.

The first and most important observation is that there is no one strategy or procedure that is sufficient to satisfy all the requirements of a PAM system. As was discussed in the literature, every PM strategy is made up of four elements: TDM, PdM, FF, RTF and possibly DOM as a fifth. No current best practice strategy is based only on one of these. The two predominant current strategies (TPM and RCM) both include all elements mentioned. Thus the first conclusion that can be drawn is that any strategy that is implemented needs to be a hybrid strategy.

Secondly, within any proposed strategy, consideration needs to be given to taking the organisational AS-IS situation into account. Based on the current state of maintenance at Metrorail, RCM and TPM should form the basis of any PAM improvement program.

3.2.1 Basic Roadmap outline

This roadmap's development is based on ReBAM and the current state of PAM at Metrorail. A two-phase approach is suggested.

Phase 1 entails applying RCM to the Rolling Stock and Infrastructure departments of Metrorail, but subdivided within each geographical region. In parallel with this, the implementation of a TPM or TPM equivalent program at the workshops and for the infrastructure work teams, as well as operations. The initial implementation should be followed closely by an organisation wide rollout. Once TPM is firmly in place, Lean Maintenance should be applied to integrate and consolidate the RCM and TPM programs.

Phase 2 involves implementation and accreditation of either PAS 55 or IRIS or both, depending on the prerequisites of the standards and the suitability of each to the organisational and PAM situation at Metrorail at that time.

3.2.2 Why RCM and TPM?

Both RCM and TPM adopt an attitude of hybridisation towards PM strategies and procedures. Both incorporate structured implementation plans that tackle PAM in the context of the entire organisation, not only the operations and maintenance departments in isolation. RCM and TPM both also allow for further development of the PAM system [**11**].

Both RCM and TPM are firmly rooted in statistical foundations and, according to Smith [**8**], common sense. This element of common sense makes them easier to understand and easier to implement in an organisation where a PAM policy has not existed and the PAM strategies are stagnant [**9**] [**8**].

3.3 Application of ReBAM to wheelset maintenance

In order to validate the roadmap, and by implication the generic policy, an RCM analysis was performed at the Metrorail Rolling Stock Department in the Western Cape.

Step 1 of the analysis includes the selection of the system that is to be analysed. This selection is achieved by means of a Pareto analysis. Before performing a completely new Pareto analysis, the author investigated the possible existence of similar current activities. This investigation revealed that the Rolling Stock Planning Department does a similar analysis, where operational faults and failures are documented. This analysis is known within Metrorail as the Top 7 [**20**].

From an investigation into the Top 7 analysis it was discovered that one of the biggest challenges that face PAM operations of the Western Cape Metrorail region is not the in service faults that constitute the Top 7, but rather wheel-related maintenance. The impact of the wheel set shortage on cancelled and shortened trains compared to the impact of the Top 7 faults is illustrated Figure 2.

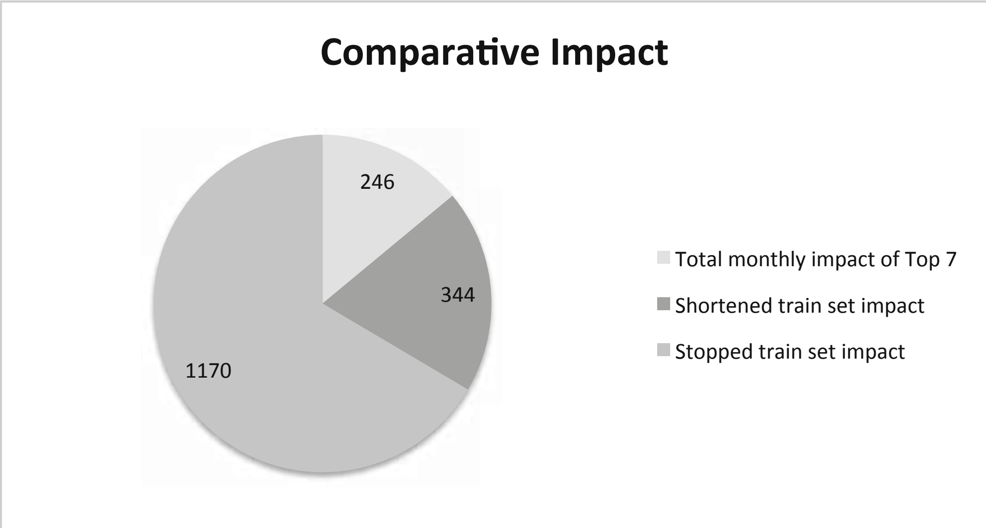

Figure 2 Comparative impact of unavailable train sets compared to the combined total of the Top 7

The findings from the investigation into the Top 7 resulted in wheelsets being selected as the system for the RCM analysis and in so doing completed the first step of the analysis. Steps 2-7 were then completed and led to the following findings.

- The current strategy of buying unused wheels from across the country is only a short term solution.
- There are currently no bearing related PM tasks being performed
- The wheelset shortage and backlog is primarily due to insufficient supply from Transnet

A secondary aspect of RCM is the items of interest (IOI). An IOI is any idea, thought or solution that has been developed as a result of the RCM analysis, but does not necessarily form part of deciding what the best strategy is [**8**]. The current backlog of reprofiling work and the lack of viable alternative supplier options are having a greater impact on the system functionality than the current PAM procedures of the wheel sets. The pursuit of retaining and maximising system functionality forms one of the core aspects of RCM, thus an investigation into an alternative to Metrorail-Transnet relationship was warranted.

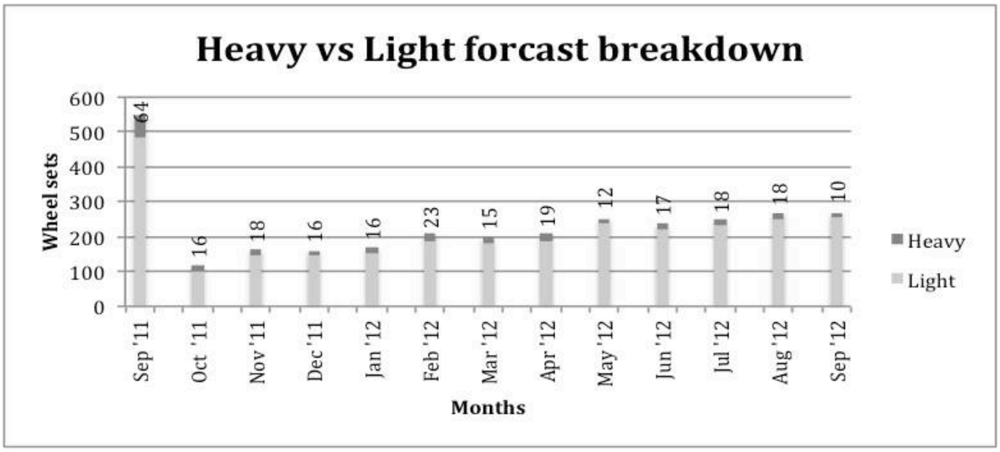

Figure 3 The forecast demand of light- and heavy wheelset reconditioning

The investigation into an alternative supplier to Transnet revealed that there is currently no viable alternative supplier for long-term wheel maintenance [21]. Thus, the viability of setting up a wheel workshop within Metrorail needs to be investigated. There are three alternatives that Metrorail could pursue. The first is to acquire a full wheel set workshop to perform all the required tasks. The second is to acquire both the under-coach system and wheel set workshop. The final option is to acquire only the under-coach system. However an under-coach system is limited to perform the light reconditioning. Thus Metrorail would rely further on Transnet for the medium and heavy work. A full workshop installation requires large amounts of capital, highly skilled and trained employees, and significant construction time. However, the greatest factor in considering any alternative is demand. Figure 3 shows the forecast demand, which has been split between light reconditioning and heavy reconditioning.

From Figure 3 it is evident that less than 10% of the wheel sets require heavy reconditioning, with a monthly average of 17 wheel sets. The primary and most expensive piece of equipment required for a wheel set workshop is a lathe. The capacity of the Hegenscheidt-MFD 165-CNC machine that is installed at Transnet is 36 wheel sets per 8-hour shift [22]. Converting this to a monthly production capability results in a monthly capacity of 756 wheel sets per month with one 8-hour shift per day and 21 working days per month. The estimated cost, as per Hegenscheidt-MFD, of equipment for a wheel set workshop is R 30 million, compared to the under-coach option, with an installation cost of R15,74 million [22]. The R15 million difference for the capability to recondition an extra 10% of wheel sets is not viable. Due to these findings, only under-coach options are considered further.

The conclusion of the application of the Pareto principle shows the same recommendation.

4 RESULTS AND DISCUSSION

4.1 Financial investigation of the ‘insource’ alternatives

Until recently, the under-coach maintenance systems were limited to under-floor lathe systems. The recent alternative to this system is a track based mobile lathe. The coach is lifted and suspended, whereupon the mobile lathe moves along the track under the coach and reprofiles the wheel set [23].

For the purpose of investigating the viability of either type of under-coach systems the two competing products produced by Hegenscheidt-MFD are investigated. Based on the requirements and specifications of Metrorail Rolling Stock, the following two products were deemed suitable and therefore investigated. The under-floor machine is a U2000-400, which is the same machine that is used at Transnet’s Saldanha workshop, the second is the

MOBITRUN®2. The system acquisition price was quoted in Euros and converted to Rands at an exchange rate of 1:12. The production capacity figures are taken for one 8-hour shift per day, with 21 working days per month and 12 months per year. The U2000-400 requires a shunting vehicle to move the coach or train set and the MOBITURN®2 requires a row of lifting jacks [**24**].

Table 3 A breakdown of the capital required to acquire each system

	U2000-400	MOBITURN®2
Production capacity/year	3096	2748
Purchase cost	R11 640 000	R13 920 000
Installation costs	R1 500 000	R0
Shunting unit/ lifting jacks	R2 600 000	R22 220 478
Total	R15 740 000	R36 140 478

In order to calculate the Return On Investment (ROI), the operating costs need to be known. There is currently no MOBITURN®2 system in operation in South Africa. The operating costs of the U2000-400 could not be made available for this investigation. According to Hegenscheidt-MFD the operating costs for both the U2000-400 and the MOBITURN®2 are very similar. In order to proceed with the ROI analysis, the operating costs of both machines were taken to be the cost that Transnet charges Metrorail for each wheel set that is reprofiled by their U2000-400 at Saldanha. The cost per wheel set is R 2 604 per wheel set. The ROI is calculated by using the potential cost saving of both of the potential machines compared to the continued use of Transnet in Salt River as the income.

The following assumptions are made with regard to the ROI analysis.

- The comparative cost used for TRE Salt River is the average cheapest light repair cost according to the ratio between motor coach and plain trailer light repairs as per the forecast.
- The forecast for the number of wheel sets requiring a light repair is currently 90% of the total. For this comparison it will be taken as 80% of the total, to be conservative.
- The current practice (at Transnet Salt River) is to replace the bearings with each repair on any wheel set. With any under-coach wheel reprofiling, the bearings are not replaced. The maximum number of times that a tyred wheel can be reprofiled is 5. Thus the longest frequency is 1:5 where the wheel set requires a new tyre in every fifth year and thus will also receive new bearings.
- The lifting jack price is supplied by Yale Engineering Products, with the cost calculated for the installation of an entire row of jacks to service a 14-coach train set.
- Depreciation is 20% per annum and is used as such on the total investment, including all peripherals. However the useful life of these products, normally exceeds 20 years. Thus the annualised ROI is calculated over 5, 10, 15 and 20 years with only the 20 year calculation table displayed here.
- The calculations do not include the tax benefit of depreciation.

Table 4 ROI comparison of the U 2000-400 and the MOBITURN®2 over the first 20 years

Average Annual ROI over first 20 years	U2000-400	MOBITURN®2
Operating cost/wheel set	R2 604,00	R2 604,00
TRE (Salt River) avg. cost	R5 509,89	R5 509,89
Saving/wheel set	R2 905,89	R2 905,89
Annual light demand (number of wheel sets)	1710	1710
Annual light demand with 1 in 2 bearing replacement	855	855
Annual light demand with 1 in 3 bearing replacement	1140	1140
Annual light demand with 1 in 4 bearing replacement	1282,5	1282,5
Annual light demand with 1 in 5 bearing replacement	1368	1368
Annual cost saving (1 in 2)	R2 484 531,97	R2 484 531,97
Annual cost saving (1 in 3)	R3 312 709,30	R3 312 709,30
Annual cost saving (1 in 4)	R3 726 797,96	R3 726 797,96
Annual cost saving (1 in 5)	R3 975 251,16	R3 975 251,16
Depreciation (5%)	R787 000	R1 807 024
Investment cost	R15 740 000	R36 140 478
ROI (1 in 2)	10,78%	1,87%
ROI (1 in 3)	16,05%	4,17%
ROI (1 in 4)	18,68%	5,31%
ROI (1 in 5)	20,26%	6,00%

From the table 4, it is apparent that the frequency with which the bearings need to be changed has a significant impact on the RIO. It is also apparent that both the U2000-400 and the MOBITURN®2 have significant spare capacity. The current forecast only takes the Metrorail demand into consideration. The Shoshaloza Meyl requirements would also have an impact and improve the ROI.

5 CONCLUSION

The need for PAM strategies and plans to be guided and bound by a framework, in order to align with the requirements of an organisation and its employees, physical assets and customers, has been highlighted throughout this discussion. To achieve this alignment and guidance, organisations need a PAM policy that facilitates the selection and development of PAM strategies and plans.

From literature it became evident that there can be no entire generic PAM policy that can be directly adopted by different organisations. A PAM policy needs to be specific for the situation and context of an organisation. Therefore, to address this need, a generic PAM policy statement was developed called ReBAM, or Requirement-based Asset Management, with the specific focus on facilitating the alignment of the PAM policy, with the needs, both present and future, of an organisation.

In order to discover the applicability of ReBAM, a proposed strategic roadmap was developed. The roadmap consists of two phases. The purpose of the first would be to lay the foundations of a "world-class" PAM system by getting the fundamental principles of PAM right. Phase 2 would then build on this foundation by looking at future best practices such as IRIS and PAS 55. Phase two was only developed as a concept, as it would be shaped by phase 1 and its outcomes.

Phase 1 was validated through application at PRASA's Metrorail, specifically in wheelset maintenance in the Western Cape. The initial RCM analysis required a Pareto style analysis and resulted in the discovery of the Top 7. The investigation into the Top 7 brought forth the full application of RCM into the case of wheel set maintenance. The results and findings of the RCM analysis demonstrate the applicability of the policy-derived roadmap and by direct implication the benefit of ReBAM.

The development of the generic policy and the successful application of its derivatives have contributed to the field of asset management by providing a basis for the development of a PAM policy for an organisation. Due to its generic nature, the policy statement is not limited to any specific industry and can be applied to any organisation with PAM needs.

The diverse portfolio that PRASA manages highlights the significance of its plans to use ReBAM and further shows the breadth of the applicability of ReBAM.

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LEAN IN SERVICE INDUSTRY

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ABSTRACT

Lean Manufacturing (also referred to as Lean) has traditionally been associated with manufacturing industries; lately many service industries have adopted the methodology with the aim of improving their processes and customer satisfaction. This study seeks to explore whether implementing Lean manufacturing principles in the service sector is feasible or viable and whether those organisations that have implemented these principles have gained from utilising the methodology. The qualitative approach was utilised to assess service organisations that have implemented lean manufacturing principles and the study revealed that although the methodology was designed for manufacturing industries, service industries could implement Lean principles as well, thereby gaining organisational competitiveness and increasing customer satisfaction.

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1 INTRODUCTION

Lean manufacturing was made popular after the book "*The machine that change the world*" by Womack and Jones was published. They explains how Toyota developed a production system that improves efficiency and increases their competitiveness using the Lean manufacturing principle Womack and Ross [1]. Liker [2] claims in his book that many organisations adopt Lean manufacturing principles to improve productivity. Womack and Ross [1] reviewed the history of the development of Lean manufacturing, primarily at Toyota, but did not explicitly indicate how to achieve the methodology Moore[3], Standards and Davis [4] . Other studies were completed recently by Standards and Davis[4], Liker [2], Womack and Jones [5]. Key points of emphasis emerging from the book by Standards and Davis[4] appear to be reducing process variability, reducing cycle time and above all eliminating waste in the manufacturing process and supply chain. Liker[2] focuses on management's responsibility on Lean, making decisions based on long term philosophy even at the expense of short term financial goals. He also outlines that production levelling, standards, employee involvement and problem solving are the main aspects of Lean methodology. Womack and Jones [5] concur with Liker[2], and Standards and Davis[4] regarding placing the emphasis on Lean thinking throughout the organisation.

Toyota Production System (TPS) provide the basis of what is known as Lean thinking by Womack [5]. The development of this approach to manufacturing began after World War II, and was pioneered by Taiichi Ohno and his associates while they were employed by the Toyota motor company Womack[5]. Forced by shortages in both capital and resources, Eiji Toyota instructed his workers to eliminate all waste Piercy and Rich[6] . Waste was defined as anything other than the minimum amount of equipment, materials, parts, space and time which are absolutely essential to add value to the product Paper and Spedding [7] . The foundation of the Lean vision is similarly focused on the individual product and its value stream and to eliminate all waste in all areas and functions within the system.

The successes of Lean manufacturing principles were never questioned because Toyota had taken control of the market shares in automobile production as a result of these crafted principles. Studies by Standards and Davis[4], and Womack and Jones[5] reveal other organisations who have implemented Lean manufacturing successfully and gained a competitive advantage.

2 DISCUSSION

2.1 Lean Manufacturing Tools

Lean is the identification and elimination of process waste in order to maximise customer value Farrington et al.[8] . Allen and Laure [9] , and Bon and Rahman [10] outline seven forms of waste which must be identified and eliminated:

- Over production – producing products which customers do not require at that moment
- Defects – failure to conform to specifications or to customers' needs
- Unnecessary inventory – too much stock which is not required for production or by the customer
- Inappropriate or over processing – unnecessary activities or features that do not benefit the customer
- Excessive transportation – unnecessary movement of material
- Waiting – failure to deliver products when needed downstream, employee idling or waiting for stock.
- Unnecessary motion - unnecessary movement by employees.

A framework of Lean manufacturing as outlined by Liker [2], Moore [3] Standards and Davis[4] and Womack and Jones[5] are:

2.1.1 Value stream mapping

Value stream mapping provides a graphical flow of the process and supports the related value stream analysis tool. It also provides the scope for the project by defining the current and future states of the system. Moreover, it includes time diagrams and identifies process steps that add value as well as those that are non value adding. And, finally, it facilitates a communication flow from customer to supplier and a resource flow from supplier to customer Allen and Laure[9]. Both Allen and Laure [9], and Paper and Spedding[7] concur that a value stream map is essential for the identification of waste in the process; therefore, this Lean tool is extremely significant in yielding speedy results in the system.

2.1.2 Visual Management:

Visual management is essential for quick referencing work standards and creating a visual environment that supports safety and guides process activities. It includes 5s (sort, shine, store, standardise and sustain) activities for maintaining a clean and uncluttered work area Taghizadegan[11].

2.1.3 Error proofing:

Error proofing, a technique to reduce the likelihood of a damaging mistake, is a concept outlined by Womack and Ross[1] and identified as a Lean tool used by Toyota to ensure product quality within the process.

2.1.4 Quick changeover methods:

Quick changeover methods facilitate the reduction of lost time during product changes. This principle resulted from the concept of Single Minute Exchange of Die (SMED). This was considered to be impossible at the time, but Moore [3] assert that by having quick setup times, the need for batches is eliminated and less material is retained in the work in process cycle.

2.1.5 Standardised operation:

Standardised operations assist in organising and documenting the process so as to permit workers to effectively use material and machinery, resulting in a flexible work force which is cross functional within the organisation Moore[3]

2.1.6 One piece flow:

One piece flow production is designed to reduce the size of batches or eliminate batch processing in order to convey output to the customers more rapidly while total productive maintenance ensures that factory and equipment are available so that production and service are not interrupted by equipment breakdowns Levitt[12].

2.2 Lean in service Industry

Lean production in the service industry was advocated by Levitt[12] and Levitt[13] in their articles 'Production line approach to service' and 'The industrialisation of service' respectively. Since then there have being many attempts at implementing Lean in the service industry. Bowen and Youngdahl [14] state that Lean in service only started gaining momentum in the late 80s as a result of McDonald's utilisation of the Lean production flow concept in order to meet their customer's expectations and Taco Bell's being recommended as an example of a Lean production line in the service industry by Psychogios et al.[15]. Piercy and Rich[6] outlined Lean as a concept comprising a set of principles, practices , tools and techniques which, when implemented by following a systematic approach, would improve resource utilisation, quality and delivery with respect to products and services.

In the early 1990s, Lean was successfully implemented in service industries such as banking sectors and public sectors, and even hospitals and airlines were adopting this methodology to improve efficiency within their organisations George[16].

It is a fact that some aspects of Lean manufacturing do not apply to all service industries; however, studies by Bowen and Youngdahl[14], Psychogios et al.[15], Allyway and Corbett[17], and Maleyeff[18] outline core Lean principles which apply to any industry, including service industries as: value - customer focus; identifying the value stream; establishing flow or continuous flow; implementing a pull system; and striving for perfection. Organisations can then transfer these principles to fit their environment and ensure compliance to other service standards. Maleyeff[18] further avers that many of the Lean manufacturing tools are recommended to service environments with the understanding that service industries vary in their mandate and that organisations have to apply tools that are suitable to their organisations, as they see fit. Some of the Lean principle tools which apply to service industries are the 5s methodology, 7 wastes of Lean and value stream mapping according to Piercy and Rich[6]. Allyway and Corbett[17], however, argue that there are more specific tools which apply to service as well as to manufacturing, such as: load balancing, complexity analysis, throughput analysis, touch time analysis, line balancing and functional analysis. Other tools such as Visual aid management and Just in time are also considered to be applicable for service environments, according to Liker[2]. It is therefore important for service industries to understand all these tools and to utilise them as they are required, just as is the case for manufacturing industries.

George[16], and Allyway and Corbett[17] report on companies such as McDonalds and Taco Bell who have implemented Lean principles and tools effectively and have gained a competitive edge and increased their productivity. The question is, can call service sectors implement Lean effectively to such a level that will increase their competitiveness and profitability? Applications of Lean in service industries is gaining momentum as there are currently more than 90 academic papers on Lean in service applications in the industry. However, some of these studies are contradicting since some argue that Lean cannot be applied effectively in service industries. Therefore, the focus of this study falls on assessing the implementation of Lean manufacturing principles and tools in service industries in order to establish whether they can be applied to service industries effectively and whether their implementation will result in increased competitiveness, just as it did in the manufacturing industries.

3 METHODOLOGY

A qualitative approach was used in an attempt to explore Lean implementation in service industries Leedy and Ormrod [19]. Many scholars have studied Lean implementation in service industries to date. Available literature was reviewed in order to investigate industries where Lean had been implemented successfully throughout the world. This analysis is considered to be limited in scope as we believe that there might have been other organisations that have implemented Lean practises but did not publish their results and therefore the researchers did not have access to those results. Nevertheless, an analysis of service industries that had implemented Lean principles was carried out and secondary data from literature was used to draw conclusions.

4 RESULTS

The results of the review on the application of the Lean principle in the service industry are presented in Table 1.

4.1 Lean in the Hospital Sector

Burgess and Radnor[20] in their study on evaluating Lean in healthcare, claim that Lean implementation at the English National Health Service has been successful and continues to be popular in English hospital trusts and also continues to spread. Burgess and Radnor [20] outline that Lean in healthcare has been studied by many scholars; since 2001 about 90 publications have been published on Lean in healthcare services. It is thus evident that Lean is being successfully implemented in health sectors. Burgess and Radnor [20] maintain that this success is due to the fact the Lean focuses on customer satisfaction and employee involvement which suits the culture of most healthcare services Aronsson at al.[21].

4.2 Lean in the Public Sector

Arlbjorn at al. [22] concur that Lean can be implemented effectively in the public sector just like in any other service industry even though this environment is more complex; its customers are more diverse and customer demands are often defined by different stakeholders such as experts, politicians and users. Therefore, despite Lean implementations being successful in public sectors organisational development and cost efficiency must remain the main focus. Pedersen and Huniche[23] assert that the success of Lean in the public sector is determined by the following factors:

- *Goals and values;*
- *Complexity and importance;*
- *Balance of power; and*
- *Resource and capabilities.*

It is therefore important to ensure that these factors are considered in order to guarantee the successful implementation of Lean in the public sector. For an effective implementation, Radnor proposes the use of the house of Lean concept and also emphasises that the purpose of these Lean tools must be employed for assessment, monitoring and improvement.

Table 1: Review of Lean in the Service industry

Sectors	Author	Results
Hospitals	Allway and Corbett[17], Burgess and Radnor[20], Aronsson et al.[21]	Successful implementation in Hospitals particularly in the USA
Public sector	Arlbjorn et al.[22], Pedersen and Huniche[23],Radnor[24], Drew and Bhatia[25]	Successful implementation after strategic direction from Top management
Food	Bowen and Youngdahl[14],Kundu et al.[26], Kundu and Manohar[27]	Problem during initial implementation; however, improved after review of some Lean tools
Airline industry	Bowen and Youngdahl[14], Parast and Fini [28], Rhoades[29],Tiernan[30]	Successful implementation with good rewards
Financial sectors	Allyway and Corbett [17], Ahlstrom [31]	Successful implementation in many insurance companies
Education	Comm and Mathaisel[32]	Successful implementation with challenges on implementation strategy.

4.3 Lean in the Food Sector

Lean can be applied effectively in service sectors focusing on food. Although this industry uses its own standards, Lean principles can still apply. McDonalds and Taco Bell are said to be amongst the first service industries to utilise Lean manufacturing principles Bowen and Youngdahl[14] . Bowen and Youngdahl [14] argue that these organisations have implemented the production line concept in their food service industry with the aim of improving customer satisfaction and efficiency.

4.4 Lean in the Financial Sector

Financial sectors have also implemented Lean successfully, particularly in call centres. Studies by Ahlstrom[31] indicate how financial sectors have implemented Lean principles and tools purely in call centres. Financial sectors such as banks, and insurance and revenue services can utilise Lean principles effectively and gain substantial benefits; the major benefits being improved efficiency, deduction of costs and improved customer satisfaction Ahlstrom[31]. The concepts can be applied to any industry with a call centre, thus, industries such as telecommunications can utilise these principles at their call centres and reap the rewards. Lean can also be applied to improve organisational processes internally in financial sectors. Maleyeff[18] avers that Lean tools and principles can be utilised to improve internal systems within the organisation, thereby increasing the organisation's efficiency and profitability.

4.5 Lean in the Airline Industry

Quality service in the airline industry is an important driver for success and profitability. Parast and Fini[28] maintain that the profitability of the airline industry is determined by labour productivity; therefore, there is a need to ensure that productivity is always at the desired level if the airline industry is to be profitable. Lean principles and tools can be used to improve productivity, thereby also improving profitability Parast and Fini [28]. Airline service quality has been a focus for many years now, with airlines focusing on customers as their main objective for improving profitability. Airlines such as Southwest airline have implemented Lean effectively and are subsequently reaping the financial benefits Comma and Mathaisel[32].

4.6 Lean in the Higher Education Institution

A study conducted by Comm and Mathaisel [32] on Lean and assessing the best Lean sustainability within higher education forms the foundation of Lean in higher education institutions. Institutions that are forced to implement cost reductions or containment were initiated in the USA in order to improve the sustainability and effectiveness of higher education institutions Comm and Mathaisel[32]. Effective implementation of lean principles in higher education depends on the following aspects, according to Comm and Mathaisel[32]:

- *Educate employees on Lean concepts;*
- *Apply Womack Lean principles;*
- *Define appropriate metrics for success; and*
- *Continue developing outsourcing, collaboration and technology initiates.*

Comm and Mathaisels[32] state that if higher education institutions can define values, map processes, eliminate waste and reduce flow by applying Lean principles, then the institution will define its niche and be able to provide a product second to none to meet the demands of its students. Administrative and academic processes could be developed to deliver efficient and cost-effective services to students, thereby increasing value. Processes could be streamlined and waste could be minimised by tapping into the resources at their disposal, particularly those from specialised niche professors. Lean in higher education can be implemented effectively, particularly if the focus falls on the principles and tools, and the application of these tools focus on problem solving and improving customer satisfaction Comm and Mathaisel [32].

5 CONCLUSION

Lean manufacturing principles and tools were found to be applicable in the service industry. Although in some service environments some Lean tools had to be adjusted Ahlstrom [31], applying these tools results in the organisation improving its efficiency and effectiveness. The application of Lean in the service industry has been studied by many scholars and the following scholars concur that Lean applications in this industry is realisable, regardless of the nature of the service rendered, customer satisfaction or financial return Piercy[6], Bowen and Youngdahl[14], Allyway and Corbett[14], Burgess and Radnor[20], Aronsson et al[21], Arlbjorn [22], Radnor[24] Kundu and Manohar[27], Ahlstrom[31], Piercy and Rich[33]

The results indicated that different service industries have attempted to implement Lean in their organisations. Although this analysis is limited in terms of the number of organisations and quantification of financial returns, it shows that various service industries such as hospitals, Finance and higher education have utilised the principles and tools to increase their competitiveness.

It is evident that Lean in higher education has not made the same inroads as other sectors; the reason being that higher education institutions are not knowledgeable about Lean concepts although they utilise similar tools to maintain efficiency and effectiveness but these are not termed Lean initiatives. They also have complex customer and stakeholder relationships which makes the implementation of Lean more complex. With this in mind, the next research area should focus on how Lean tools can be adjusted to suit all service environments, particularly in higher education institutions.

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A LINEAR PROGRAMMING MODEL FOR BLENDING

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ABSTRACT

Quality factors are extremely important in the malting barley industry. The potential value of blending depends largely on the variability of quality attributes and operations. It stands to reason that higher variability in quality attributes would result in greater blending opportunities and, depending on premiums and discounts, higher net revenues for grain handlers. Similarly, end-users of grain can employ blending to reduce acquisition costs. By buying lower quality grain at a discount and blending it with higher quality grain, they may be able to meet quality specifications at a lower cost than by purchasing grain that meets specifications. Blending is widely recognized as a linear programming model and with most models having a maximum of five constraints. The paper shows how linear programming can be used to solve a problem that has fifteen constraints. Each set of constraints is from a single batch of malt grain to give us two proportions, which will be used for the control of blending equipment. Outcome of experiments indicated that blended mixture had an average standard deviation of 0.254 against deviation of 0.919 for the batch with the lower quality.

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1 INTRODUCTION

The potential value of blending depends largely on the variability of quality attributes. Wheat used for milling has several quality attributes of importance with one of these being protein. Low-protein wheat is normally priced at a discount relative to high-protein wheat hence elevators enhance their margins through careful blending operations. It stands to reason that higher variability in quality attributes would result in greater blending opportunities depending on premiums and discounts, higher net revenues for grain handler. One difficulty in modelling and quantifying the economics of grain blending is representing the distributions of quality attributes. For any given commodity there may be several attributes that are important to potential purchasers and end-users. Because these attributes vary across shipments and growing seasons they are best described by a joint probability or frequency distribution. In this paper, linear programming is used to solve a malt blending problem with fifteen constraints. The paper is organized in the following manner. Section 2 contains a review of the related literature. Section 3 formulates the problem as an optimization model. Section 4 shows computational results using the data from a real-life case study. Finally concluding remarks are given in section 5.

2 RELATED RESEARCH

Blending is concerned with mixing different materials called the constituents of the mixture (these may be chemicals, fuels, solids, colours, foods, etc.) so that the mixture conforms to specifications on several properties or characteristics, Hayta et al [1]. Blending diverse batches of grain allows grain merchandisers to make extra profits, while also delivering grain within contract specifications, Gibson [2]. The goal of the grain handler when blending is to increase the value of poorer quality batches by mixing small quantities into higher quality batches while remaining within the grade specifications set by the purchaser.

The United States system encourages the blending of grain to a minimum standard by blending poor grain into higher quality grain. Gibson [2] points out that restrictions placed on the blending of grain qualities include recombination or addition of dockage or foreign material, blending of different kinds of grain unless such blending results in grain are being designated as mixed grain or addition of water for purposes other than milling, malting, or similar processing operations. Sivaraman [3] affirms also to the above restriction. It is acceptable to blend grain of the same kind together to adjust quality and recombine or add broken corn and broken kernels to whole grain of the same kind provided no dockage or foreign material including dust is added to the broken corn or broken kernels.

2.1 Distribution of protein: blends vs. mixtures (Linear Programming)

Protein distribution in grain is critical because it determines the final quality of the product produced. In malting, the nitrogen compounds that form the protein determine the brand for the beer that will be produced. When two lots of grain are blended together, the mean value of protein (and most other quality attributes) is a weighted average. If the two lots are each normally distributed, the blend as a linear combination of normal variables will also be normal Sivaraman [3]. Unblended mixtures occur when different lots of grain are loaded into the same storage container or vessel in sequence rather than simultaneously. Within an individual elevator bin, for example, there may be multiple truckloads of wheat with different levels of protein—their physical positions reflecting order of arrival with most recent grain at the top of the bin. In this situation, the distribution of protein can be described as a mixture of (normal) distributions, Greene [5].

According to Johnson [4], the distinction between blends and mixtures is illustrated in Figure 1 with two lots of wheat being represented. Figure 1 shows the Protein distribution function (pdf) against the protein percentage for the mixtures. Protein in the first lot is distributed Z1 ~ N(14.5, 0.3), and protein in the second lot is distributed Z2 ~ N(15.5, 0.3). With (arbitrary) blending proportions of 20/80, the mean protein for the blend is given by equation (1) were *p* is the blend proportion and μ is the protein distribution function.

$$\mu_1 p_2 + \mu_2 p_1 \qquad (1)$$

$$14.5(0.2) + 15.5(0.8) = 15.3$$

Standard deviation $$\sigma = \frac{(0.2^2 0.3^2 + 0.8^2 0.3^2)}{2} = 0.247$$

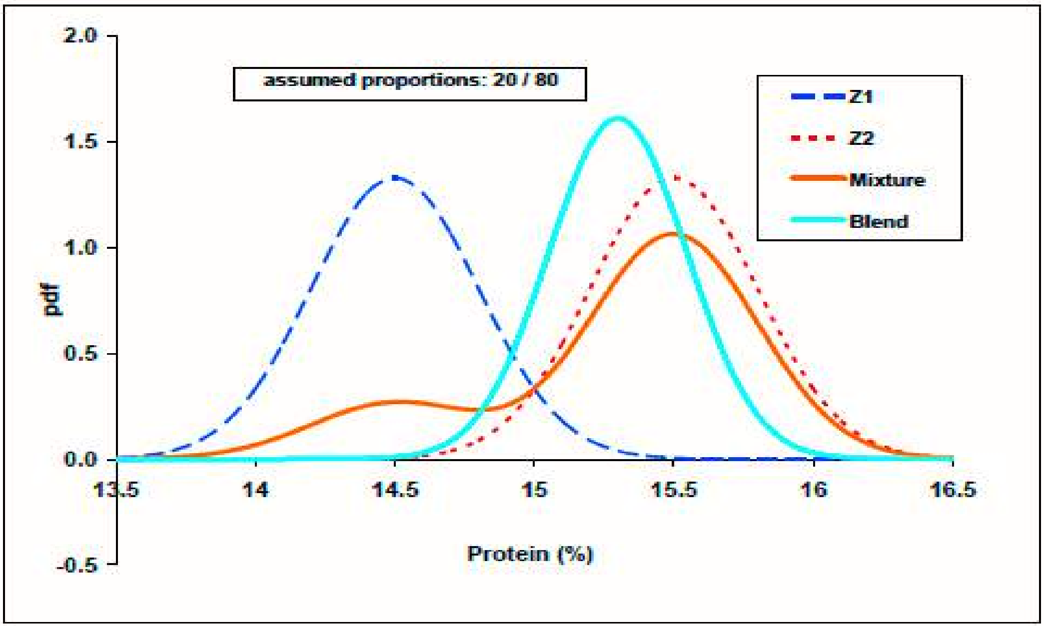

Figure 1 : Protein distribution in blended and unblended mixture (Source Johnson [2])

In this example, the blend has lower variance than the individual lots. The mixed distribution using the same proportions, has a much larger standard deviation $\sigma = 0.5$. Although the mean is identical to that of the blend, the variance of protein in the mixture is calculated as the mean of conditional variances plus the variance of conditional means.

2.2 Blending Linear Programming Formulations

To model a blending problem as an LP the linear blending assumption must hold for each property or characteristic. This implies that the value for a characteristic of a blend is the weighted average of the values of the constituents, the weights being the proportions of the constituents.

Eric et al [10] in his analysis suggests a representation method based on Gaussian quadrature. This approach maintains the blending opportunities available by preserving moments of the distribution. His focus is demonstrating the importance of preserving variability in attribute quality. His model involves preserving quality attributes of barley, which is the raw material for malt. The focus of this paper is on blending the product.

Bilge et al [8] discusses a mixed-integer linear programming model for bulk grain blending and shipping. Constraints on the system include blending and demand requirements availability of original and blended products. The difference with our approach is utilization of the specific parameters that constitute the chemical and physical properties of the malt. Maitri [9] presents a blending and cost optimization problem which he presented as a multi-objective mixed integer model with two objectives: (1) Minimize the number of storage bins used to blend grain for a given shipment, (2) Minimize the total cost for blending and shipping grain. The total cost includes the discount given to customer when contract specifications are not met, the cost of transporting grain between different locations and the blending cost.

The decision variables in a blending problem are usually either the quantities or the proportions of the constituents in the blend. If a specified quantity of the blend needs to be made then it is convenient to take the decision variables to be the quantities of the various constituents blended. In this case one must include the constraint that the sum of the quantities of the constituents is equal to the quantity of the blend desired, Murty [7].

In the cases where there is no restriction on the amount of blend made but aim to find an optimum composition for the mixture, it is convenient to take the decision variables to be the proportions of the various constituents in the blend. In this case, one must include the constraint that the sum of all these proportions is one, Lee [6].

Johnson [4] demonstrates how sorting and blending activities affect the variability of grain quality attributes. He developed a firm-level optimization model that incorporates quality uncertainty and analysed the effects of this uncertainty on blending decisions. Kosntantinos [11] showed a linear programming model that maximizes blending revenues and used this to examine the impact of adding additional protein standards on blending revenues. The models however dealt with a few quality factors. The model we created examines the impact of 15 quality attribute standards as applied to the malting industry. The next section deals with the mathematical model formulation.

3 LINEAR PROGRAMMING MATHEMATICAL MODEL FORMULATION

In the reviewed literature, it was seen that there is gap in blending of grain using intrinsic grain quality properties. This prompted development of the Linear programming model that focuses on using the intrinsic quality properties in achieving the optimum quality. Table 1 displays the notations used in formulating the mathematical model.

3.1 Model development steps

Malt has to confirm to the specifications listed in Table 2 from which Malt undergoes analysis after the malting process and conformance is tallied against the set limits. Table 1 displays the notation used in formulating the mathematical model.

Table 1: Notation

Notation	Remark
i	i= 1 or 2
P_i	Proportion of grain *i* in the blend *i* = 1 to 2
M_{si}	Malt Score
Constraints	
M_{mi}	Malt Moisture
F_{GEi}	Fine Grind Extract (FGE) %
C_{EBCi}	Malt Colour in pale malt (Col. E.B.C).
C_{FGEi}	Conv. FGE-Time (min)
T_{NDryi}	Total Nitrogen Dry %)
F_{ANi}	Free Amino Nitrogen (FAN) mg/l
D_{pi}	Diastatic Power
F_{ri}	Friability
F_{li}	Flintiness
P_{UGi}	Partially under modified grains (PUGs)
P_{UGWi}	Wholly under modified grains PUGWUGs
$M_{breakagei}$	Malt Breakage
K_i	Kolbach Index (KI)
T_{NDryi}	Total Nitrogen Dry %

Table 2 : Malt Specification constraints

Specification	Range
Moisture	≤ 5.0
FGE (dry)	≥ 79.0
FGE-CGE diff.	≤ 2
Col. E.B.C.	3.5-4.5
Conv. FGE-Time (min)	5-10
Total Nitrogen Dry %	1.65-1.95
K.I.	40-46
D.P.	≥300
FAN	150-220
Homogeneity	>90
Friability	>78
Flintiness[WUG] %	≤ 2
PUG	≤ 5
PUG + WUGs	<5
Malt Breakage	≤ 1.5

3.1.1 Determine vector of decision variable

A solution to an optimization problem is a set of values for all its decision variables that respects the constraints of the problem.

Taking the two instances for the blending of grain from two silos with:-

P_i = Proportion of grain *i* in the blend *i* = 1 to 2

$0 \leq P_i \leq 1$ (2)

With $P_i = 1$ when there is no blending

During blending of the two batches

$P_1 + P_2 = 1$ (3)

Thus *P*= $(P_1, P_2)^T$vector of decision variables.

3.1.2 Determine objective function

For each parameter for malt specification in Table 2a, weighting is attached to the value to determine extent of deviation from range and these averaged to determine the Malt score (M_{si}) for each batch equation (4). Malt score equation shown in equation (4) is a standard found in the company malting manuals with x denoting average number of batches produced per month. For the malting company under case study, 20 batches of malt are produced per month on average; *Points* denote weighting lost per specification out of range.

$$M_{si} = \frac{10\left(1200-\left(\sum_{i=0}^{15} Points * X\right)\right)}{1200} \quad (4)$$

Since malt score incorporates the 15 parameters with $M_{si} \leq 10$, 10 being the highest value when points lost amount to zero the blended output should have a value greater than the Malt score for the batch with the lower malt score. Thus the objective function is:-

Maximize: $M_{s1}P_1 + M_{s2}P_2$ (5)

3.1.3 Determine the constraints

Constraints express conditions that must be true in any solution of the problem. A constraint is an expression involving decision variables (P_1, P_2)

Subject to:

$$3.5 \leq M_{m1}P_1 + M_{m2}P_2 \leq 5.0 \quad (6)$$

$$F_{GE1}P_1 + F_{GE2}P_2 \geq 79 \quad (7)$$

$$F_{GCE1}P_1 + F_{GCE2}P_2 \leq 2 \quad (8)$$

$$3.5 \leq C_{EBC1}P_1 + C_{EBC2}P_2 \leq 4.5 \quad (9)$$

$$5 \leq C_{FGE1}P_1 + C_{FGE2}P_2 \leq 10 \quad (10)$$

$$1.65 \leq T_{NDry1}P_1 + T_{ND2}P_2 \leq 1.95 \quad (11)$$

$$40 \leq K_{i1}P_1 + K_{i2}P_2 \leq 46 \quad (12)$$

$$150 \leq F_{AN1}P_1 + F_{AN2}P_2 \leq 220 \quad (13)$$

$$H_{p1}P_1 + H_{p2}P_2 \geq 90 \quad (14)$$

$$D_{p1}P_1 + D_{p2}P_2 \geq 300 \quad (15)$$

$$F_{r1}P_1 + F_{r2}P_2 \geq 78 \quad (16)$$

$$F_{li}P_1 + F_{l2}P_2 \leq 2 \quad (17)$$

$$P_{UG1}P_1 + P_{UG2}P_2 \leq 5 \quad (18)$$

$$\mathrm{P}_{\mathrm{UGW1}}\mathrm{P}_1 + \mathrm{P}_{\mathrm{UGW2}}\mathrm{P}_2 < 5 \quad (19)$$

$$M_{breakage1}P_1 + M_{breakage2}P_2 < 1.5 \quad (20)$$

$$P_1 + P_2 = 1 \quad (21)$$

$$0 \leq P_1 \leq 1 \quad (22)$$

$$0 \leq P_2 \leq 1 \quad (23)$$

Constraints from equation (6) to (20) denote those bounded by quality attributes. Constraint equation (21) gives a boundary so that the two blended proportions will equal unit so that in the control of the actual blending process, the blending equipment will be calibrated in such a scenario that the sum of discharge from each silo will equal unit. Constraints (22) and (23) ensure that when no blending is being done as discussed in the section of discussions and extensions, the proportion of each batch is equal to one.

It should be noted that when solving the above inequalities of the form in equation (24), this equates to two inequalities of the form $x \leq sP_1 + sP_2$, $sP_1 + sP_2 \leq y$. Thus for solving the linear programming model, the number of constraints increases by one for each constraint of the form discussed. This applies to constraints (6), (9), (10), (11), (12) and (13).

$$x \leq sP_1 + sP_2 \leq y \quad (24)$$

4 DATA AND EMPIRICAL ANALYSIS

We now report on results of the optimization model as applied to (i) data on malt specifications compiled from a Malt Analysis Sheet from a malting company and (ii) actual malt blend analysis results of actual quality data measured at a Malting Laboratory. These data sets are sufficiently indicative of realistic distribution of quality characteristics in malt, and were used to summarize statistical characteristics amenable to mathematical analysis. Results on proportions to blend were solved using Microsoft Excel Solver.

Validation was carried out by carrying out experiments using the model to determine the proportions and then manually mixing by weighing the proportions relative to a weight then analysed the blend and tallied it against the results from the mathematical model.

4.1 Experimental analysis

To Validate the Mathematical Model with the objective function:

Maximize $M_{s1}P_1 + M_{s2}P_2$

4.1.1 Experiment 1: Batches used Batch 1 and Batch 2

For the first experiment, results are displayed in Table 3. Mathematical model column shows results solved using the software Excel Solver while Experiment 1 column are the actual results from analysis of the physically blended batches. Figures in italics and bold indicate parameters which are out of rated limits.

Table 3 : Experiment 1(Batch 1 / Batch 2)

		Batch 1	Batch2	Mathematical Model (Excel Solver)	Experiment 1
		0.44	*0.56*	Blend(0.44-Batch 1,0.56-Batch 2)	Blend Model
Malt Moisture	3.5-5.0	5	4.5	4.72	***5.232***
FG Extract (dry)	≥79	80.9	80.9	80.9	83.09568
FGE-CGE diff.	≤2	1.5	1.5	1.5	1.540711
Col. E.B.C.	3.5 - 4.5	***3***	4	3.56	3.492278
Conv. FGE -Min(Time)	5-10	5-10	5-10	5-10	5-10
K.I.	40 - 46	44.6	44.8	44.712	45.89265
F.A.N.	150 - 220	172	178	175.36	179.1333
D.P.	≥300	316	301	307.6	318.4136
Friability %	≥78	79.5	86.4	83.364	84.69802
Flintiness[WUG] %	≤ 2	0.6	0.2	0.376	***1.24***
PUG	≤5	3.6	1.2	2.256	2.711651
PUG + WUGs	<5	4.2	1.4	2.632	3.163593
Homogeneity %	≥ 90	N/A	91.5	90.91	93.37736
Malt Score		9	10		
Blend Malt Score				9.36	9.1

Malt moisture increased because of high affinity of malt for water. Flintiness value increased to 1.24 because of malt moisture.

4.1.2 Experiment 2: Batches used Batch 3 and Batch 1

The second Experiment 2, results are displayed in Table 4. Mathematical model column shows results solved using the software Excel Solver while Experiment 2 column are the actual results from analysis of the physically blended batches. Figures in italics and bold indicate parameters which are out of rated limits.

Table 4: Experiment 2(Batch 3/ Batch 1)

		Batch 3	Batch 1	Mathematical Model	Experiment 2
		0.24584	*0.709153*	Blend(0.25-Batch 3,0.71-Batch 1)	Blend Model 0.27- Batch 3 ,0.73- Batch 1
Malt Moisture	3.5-5.0	4.9	4.6	4.47	***5.1***
FG Extract (dry)	≥ 79	80.8	81.3	77.52	79.6
FGE-CGE diff.	≤2	1.9	1.4	1.46	1.5
Col. E.B.C.	3.5 - 4.5	3.5	3.5	3.34	3.4
Conv. FGE Min.(Time)	5-10	5-10	5-10	5-10	5-10
K.I.	40 - 46	40.4	42.4	40.00	41.1
F.A.N.	150 - 220	189	176	171.27	175.9
D.P.	≥ 300	***274***	311	***287.91***	***295.7***
Friability %	≥78	78.8	79.2	***75.54***	***77.6***
Flintiness'[WUG] %	≤ 2	***2.4***	0.8	1.16	1.2
PUG	≤5	***6.4***	3.2	3.84	3.9
PUG + WUGs	<5	***8.8***	4	5.00	5.1
Homogeneity %	≥ 90	-	-	-	-
Malt Score		8.7	10		
Blend Malt Score				9.23	9.06

For experiment 2, ratios were increased from 0.25-0.27 and 0.71-0.73 so that $P_1 + P_2 = 1$

Malt moisture increased because malt absorbs moisture over time. Friability affected by malt moisture level

We calculated the standard deviation of the malt scores for the two experiments as illustrated in Table 5 and Table 6. The percentage increase in conformance was calculated using the proportion equation (24) below were σ is the standard deviation.

Percentage increase in conformance

$$\left(\frac{\sigma_2}{\sigma_1+\sigma_2}-\frac{\sigma_1}{\sigma_1+\sigma_2}\right)*100 \qquad (25)$$

Table 5: Analysis of Experiment 1

Standard deviation of blend from Batch 1	0.07071
Standard deviation of blend (σ_1) from highest malt score	0.63639
Standard deviation of Batch 1 (σ_2) from highest malt score	0.70710
% increase in conformance	5.26

Table 6: Analysis of Experiment 2

Standard deviation of blend from Batch 3	0.25456
Standard deviation of blend (σ_1) from highest malt score	0.66468
Standard deviation of Batch 3 (σ_2) from highest malt score	0.91924
% increase in conformance	16.07

In both experiments, we recorded an increase of conformance of the blend

5 DISCUSSIONS AND EXTENSIONS

A linear programming model that maximizes blending advantage has examined the impact of adding specific quality attribute standards on the blending problem. The results indicate that the grain quality value for the batch of lower quality increases when a grade is blended with one with higher quality attributes. In experiments, it was also noted that blending is efficient and effective if done during a period in which the grain has not started undergoing modification from exposure to the environment. This can be seen by the fact that in both experiments the malt score from the experiments was lower than that for the mathematical model. This is attributed to change in chemical properties because of the exposure of malt to the environment.

It has also been seen that in solving LP problems with a number of constraints, optimum solution do not always tally to unit for the proportions because the scale for the individual constraints is distributed over a large interval. Thus in actual setups when a scenario like that is met, adjustments should be made to the solution to account from the difference from unit as illustrated in experiment 2.

Much of this paper has been devoted to the quality attributes of blending. Segregation is another aspect of grain handling that poses difficult analytical problems when uncertainty is introduced. When grain is transferred from processing, it must be allocated to one of several storage bins and deliveries are to be homogeneous in quality terms noting also that allocation to bins changes the malting technician blending opportunities.

5.1 Application of Malt production in a blending area

We suggest possible application of the LP model in Figure 2. Data is collected from malt analysis. This is loaded in Microsoft Excel, which is linked to a Human machine Interface created using Visual Basics.net. This is then linked to a PLC using Object Process Control (OPC Client/Server).

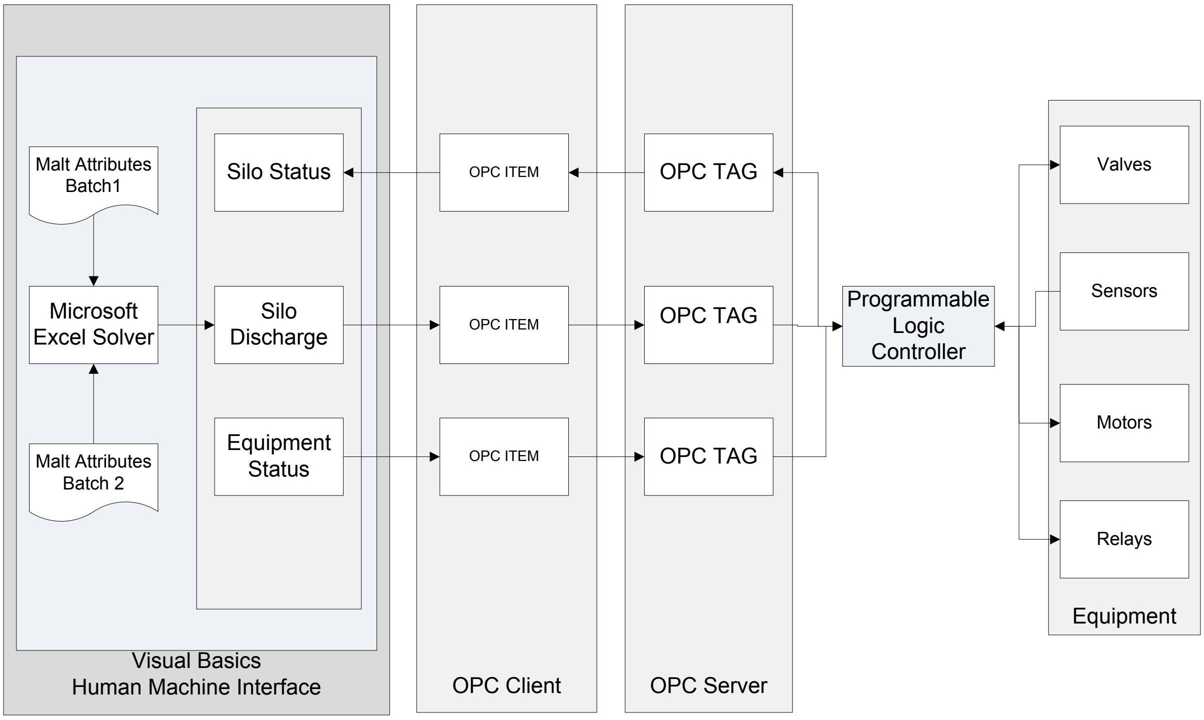

Figure 2 : Application of Linear programming in the control of a blending system

6 CONCLUSION

In this paper, we have offered a general formulation to model grain blending and we emphasized the use of grain quality attributes in determining the optimum quality. Results from the experiments have shown that it is feasible to blend based upon the intrinsic properties of grain as to other constraints from the reviewed authors.

The model based on results presented, shows that it is possible to predict targeted final malt quality properties without the need of analyzing the blended mixture. The model can also be extended (i) to model grain blending decisions based on more than 15 quality attributes because the flexibility of the model allows one to make any alteration quite easily, and (ii) to incorporate uncertainties in measurement of quality attributes. Both of which are avenues inviting further inquiry since the quality attributes used as constraints are determined by both physical and chemical analysis.

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AN ASSESSMENT OF THE MATURITY OF TELERADIOLOGY SERVICES WITHIN THE WESTERN CAPE PUBLIC HEALTHCARE SYSTEM

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ABSTRACT

Telemedicine can be defined as the exchange of health care information and the delivery of clinical health care at a distance, by means of information and communication technology (ICT). Driven by technological advancements, telemedicine adoption rates increased significantly over the past few years. In an effort to benefit from these advancements, the South African National Department of Health (NDoH) is encouraging the delivery of healthcare in the public health sector through telemedicine.

Many studies suggest a range of reasons for the generally low success rate of telemedicine services. A Telemedicine Service Maturity Model (TMSMM) was developed by the Health Systems Engineering Group of Stellenbosch University to encapsulate these reasons in a systematic way and to enable the description, evaluation and optimization of an existing telemedicine services.

According to the Government of the Western Cape their Department of Health is the most advanced and reputable in the country, with emphasis on constantly improving quality of health care provided to its citizens. Telemedicine services which are successful at this level could be considered as a template/guideline on how to implement successful telemedicine services in the remaining 6 provinces.

The purpose of this paper is to describe the process of evaluating existing telemedicine services (teleradiology in particular) implemented in the Public Health sector of the Western Cape by means of the Telemedicine Maturity Model.

1 INTRODUCTION

One of the major challenges South Africa is facing in the 21st century is providing quality primary health care (PHC) to all citizens of South Africa. The current health care system is under increasing pressure, due to the rapidly growing population, the fact that a large portions of the population live in rural areas and the increasing lack of resources. Eighty percent of the population depends on the government for healthcare. The government is not equipped to support these numbers [1].

1.1 Western Cape Health Care System

According to the Western Cape Government, the Province of the Western Cape health care system has the best reputation in the country. The way forward for the Western Cape Department of Health is to place emphasis on the improvement of information management systems and the optimisation of the primary health care sector with the help of advanced information and communication technology (ICT)[2].

Health Care in South Africa operates on a referral system and the procedure is as follows: Patients visit a Community Health Centre (tier 1) and if the medical condition requires it, they are referred to a higher tier hospital in this case a Primary Health Clinic (tier 2) and from there if need be to a Specialist Hospital (tier 3). A common issues encountered is that medical staff at the rural, lower tier facilities have a limited capacity and medical knowledge to diagnose certain medical cases and thus require expert advice, thus the patient needs to travel long distances to be seen by qualified Medical Officers (MO). In the majority of referred cases patients could have been treated at the local clinic instead of being transferred.

Telemedicine is a potential solution to improve the current health care system in South Africa, which the National Department of Health (NDoH) recognised in its formulation of the 1998 Telemedicine Strategy.[3]

> *"The mission of the telemedicine strategy is to facilitate the provision of high-quality and cost-effective health care to all the citizens of South Africa."*[3]

Telemedicine is considered the exchange of health care information and the delivery of clinical health care at a distance, by means information and communication technology (ICT)[4].

> *"Telemedicine is not new … It is unlikely that there is any medical practitioner in South Africa who has not practised telemedicine, albeit unwittingly."*[5]

Per definition a telephone call between a doctor and a patient or the exchange of SMS-messages between clinician and specialist, constitutes a telemedicine service.

1.2 MRC Telemedicine Workstation

The issue of unnecessary referral, deteriorating quality of health care and the declining resources sparked the development of the so-called Telemedicine Workstation. The Telemedicine Workstation is the brainchild of the Medical Research Council and the Stellenbosch University.

The Telemedicine Workstation includes a touch screen panel, a camera and a 3G internet connection. The aim of the workstation is to enable medical staff at District Hospitals to consult with specialists and transfer medical information to and from their respective higher tier hospitals. Thus eliminating unnecessary referrals to higher tier hospitals, and improving the quality of health care. Besides connecting clinicians and specialist the workstation is to raise awareness, train clinicians in the use of telemedicine as a medical tool and identify the type of scenarios in which a store and forward services would be useful.[6]

The Telemedicine Workstation was rolled out to 90 District Hospital in South Africa, of which 7 were implemented in the Western Cape Public Health sector[6]. Since the publication of the Telemedicine Strategy in 1998 and the newly released National eHealth Strategy (2012) the department of Health has supported the development of a number of telemedicine services, with the aim to improve the Patient's experience, quality of care and the strive for operational efficiency[3][7].

Although the intention of these projects was to strengthen the South African primary health care system, the opposite was accomplished due to unsustainability and unsuccessful implementation of the systems[8]. Due to the failure of many of such telemedicine projects the level of confidence in telemedicine has decreased, although it is recognised that the service is an effective means to overcome the challenges in the rural health setting of South Africa.

1.3 Teleradiology

Of all the telemedicine services available, teleradiology is the most common and successful implementation of telemedicine in South Africa. Teleradiology is the transfer of radiological information via electronic pathways from one geographical location to another for the purpose of interpretation and consultation [9].

The majority of South African private health groups and a few networks in the public sector have fully functional teleradiology systems based on the picture archiving and communication systems (PACSs). A digital radiology image is uploaded to an internal server along with relevant medical patient data, this data can then be accessed by clinicians, radiologists and specialist irrespective of their location.

There are more simplistic, less complex, non-official teleradiology services, which involve the use of mobile phones, and e-mail to transmit radiological data between clinicians and specialists.

Ever since the introduction of telemedicine there have been calls for a more generalised and systematic approach to telemedicine. The National Health strategy recognises the potential telemedicine has towards the re-engineering of the PHC system and the importance of monitoring and evaluating the performance of these services, to ensure sustainability and continuous improvement[7]. A Telemedicine Services Maturity Model (TMSMM) was developed by the Health Systems Engineering Group of Stellenbosch University to enable the description and evaluation of an existing telemedicine service, together with a systematic service maturation path [10].

1.4 Purpose and Scope

The purpose of this paper is to describe the process of evaluating existing telemedicine services (teleradiology in particular) implemented in the Public Health sector of the Western Cape by means of the Telemedicine Maturity Model. The parameters of the paper were set to include teleradiology services within the Western Cape Public Health sector, firstly due to the established nature of teleradiology services and secondly the highly rated Western Cape health care system.

2 METHODOLOGY

The methodology involved four phases as shown in Figure 1. The respective research methods that were used during each of these phases are shown in brackets.

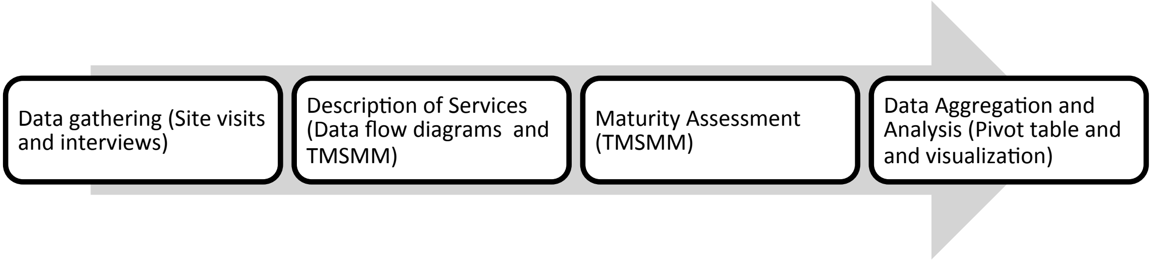

Figure 1: Methodology

2.1 Site Visits

The sites selected were not at random but are hospitals which received the MRC Telemedicine Workstation the previous years. The reason these hospitals were chosen is simply because at least one telemedicine service was known to have been implemented at the sites, thus ensuring that a minimum of one telemedicine service could be evaluated at the selected hospital.

The study was approved by the Health Research Ethics Committee at Stellenbosch University assuring that the study will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research. Further clearance had to be received from the Western Cape Department of Health to conduct this research within the public health care facilities of the Western Cape. Healthcare facilities in Caledon, Ceres, Hermanus, Robertson, Swellendam and Worcester were visited for purposes of this study.

At the beginning of each interview the interview participant was informed regarding the purpose of the study and asked to sign an informed consent form acknowledging that the information was obtained in an ethically correct manner.

During the interview the participant was asked to answer a series of questions regarding their exposure to telemedicine services (see below).

- What is your experience with respect to telemedicine?
- Which Telemedicine services are you involved with, either as a participant or as a developer?
- What is your role within the service?
- Are any standard frameworks or guidelines being used to help with the implementation, operationalization and optimization of the telemedicine service?

This series of questions enables the identification and general description of existing telemedicine services being performed at the hospital.

2.2 Description of Telemedicine Services

With the information gathered during the interview a data flow diagram was generated, with the participant, for each identified telemedicine service. The purpose of the data flow diagram (DFD) is to visualise the data flow of the telemedicine service and identify the individual processes involved. For example Figure 2 depicts a data flow diagram for teleradiology service using a mobile phone to capture and transmit the medical data. With all the processes comprising the telemedicine process identified and noted on the DFD, the mapping and maturity evaluation of the service can commence.

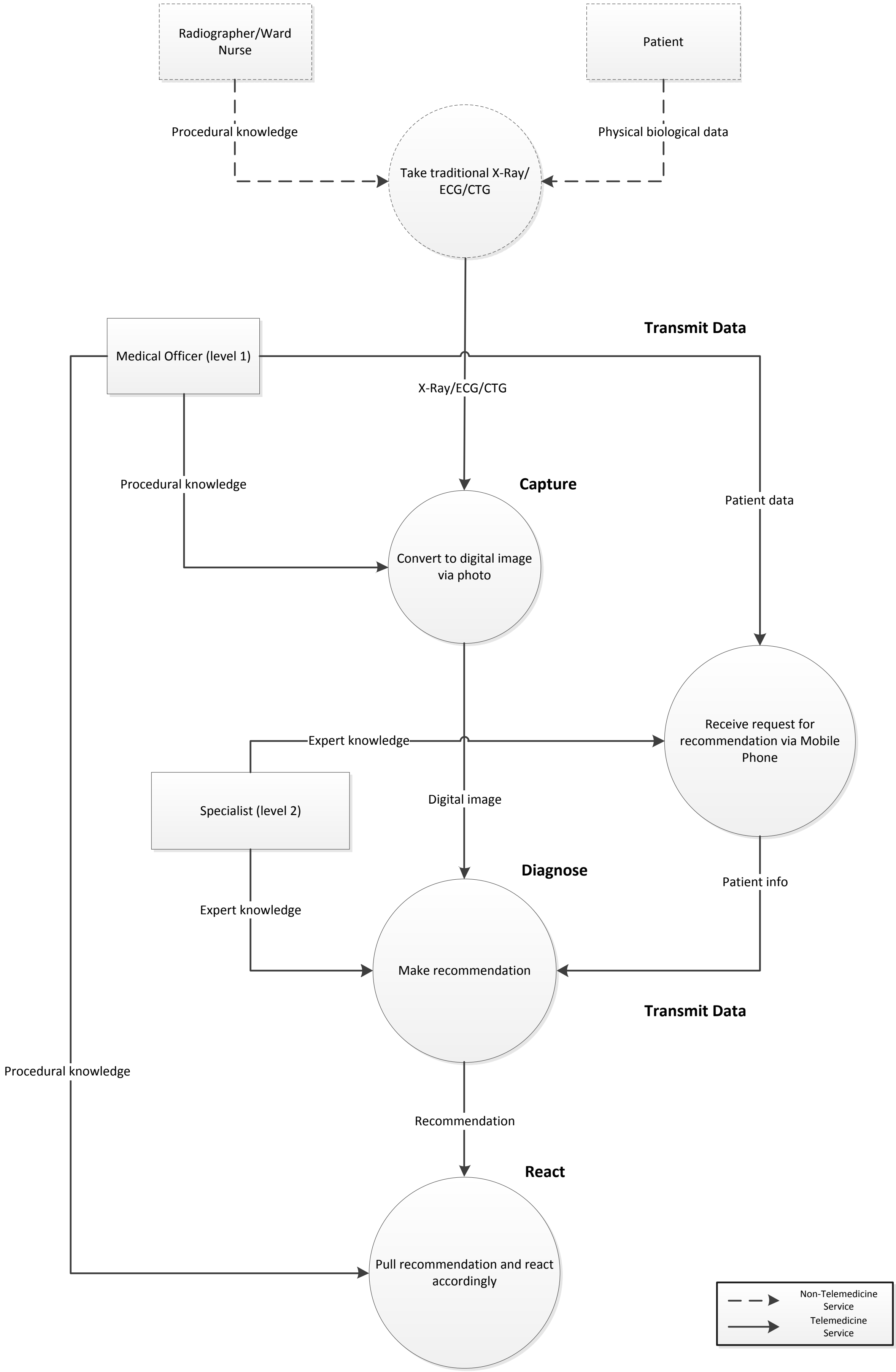

Figure 2: Mobile Phone TeleradiologyDFD

2.3 Maturity Assessment

The assessment of the Western Cape Public Health Care teleradiology services was conducted with the help of the telemedicine services maturity model developed by the University Stellenbosch Health Systems Engineering Group.

The TMSMM Figure 3 is designed along three dimensions. These dimensions are defined as, the domain-, telemedicine service- and maturity scale dimensions. The intercept of each pair of these dimensions form a matrix, each with a specific significance and function.

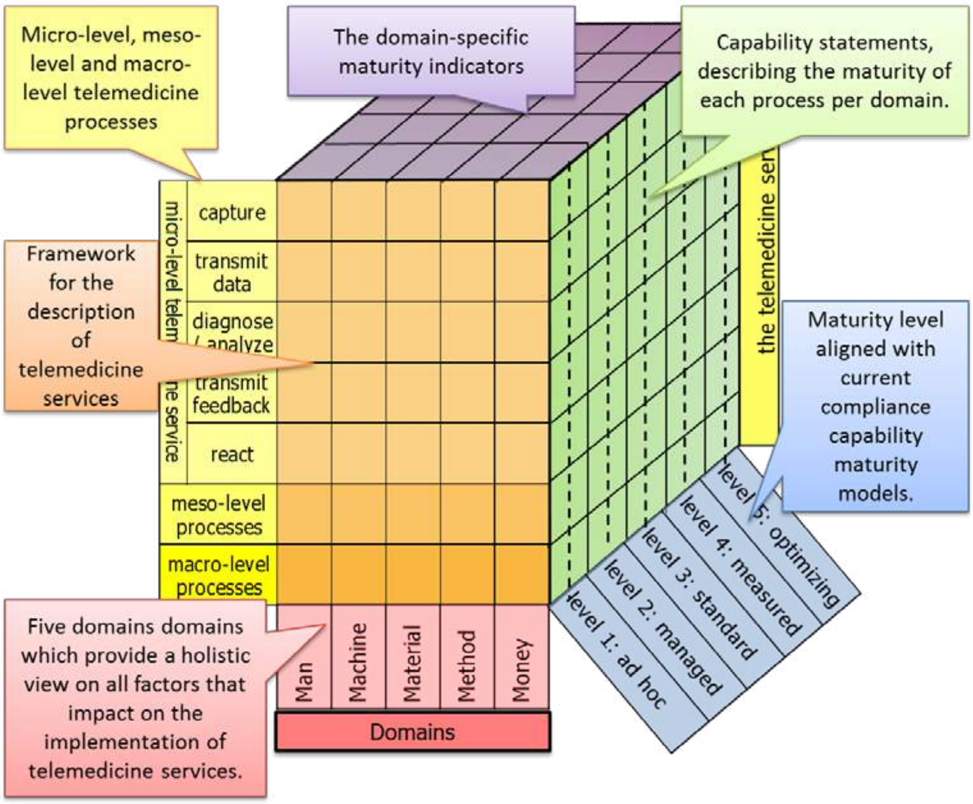

Figure 3: 3D representation of theTMSMM

2.4 TMSMM Mapping

The previously identified telemedicine service is then captured using the TMSMM visualization tool. The above mentioned mobile phone teleradiology service was used as an example for the mapping process.

The idea behind the TMSMM tool is to capture telemedicine services as simply as possible and rate each aspect of the service. The DFD (Figure 1Figure 2) of the service clearly indicates that the first process is a capture process. After selecting the Capture option in the Micro-level Type tab, the service process is entered according to the five domains explained in Section 2.2. The Medical Officer [Man] uses his personal mobile phone (digital image) [Machine] to create x-ray (digital image) [Material] according to his/her own discretion [Method] at the cost of Department of Health (employing institution) [Money], see Figure 4.

			Man		Machine		Material		Method		Money
#	Descritpion	Micro-level Type	User		Devices and Applications		Electronic Health Record		Work Protocol		Operational Cost
1	Make a digital image copy of the paper based x-ray	Capture	Medical Officer (level 1)	use(s)	personal mobile phone (digital camera)	to create	x-ray (digital image)	according to	own discresion	at the cost of	DoH (employing institution)

Figure 4: Capture Process (Mobile Phone Teleradiology)

This process is replicated for each of the remaining processes until all the identified processes are mapped on the TMSMM. Each of the (orange) blocks is then rated according to domain specific capability statements, ranging from Ad Hoc (light green) to Optimising (dark green) see Figure 5.

			Man		Machine		Material		Method		Money
#	Descritpion	Micro-level Type	User		Devices and Applications		Electronic Health Record		Work Protocol		Operational Cost
1	Make a digital image copy of the paper based x-ray	Capture	Medical Officer (level 1)	use(s)	personal mobile phone (digital camera)	to create	x-ray (digital image)	according to	own discresion	at the cost of	DoH (employing institution)

Figure 5: Rated Capture Process (Mobile Phone Teleradiology)

Similarly as for the micro-level the meso-level and marco-level of the telemedicine service are mapped and rated.

The final result of the mapping process is the entire telemedicine service in one picture, including the micro-, meso- and marco-level services rated across the five domains (Man, Machine, Material, Method and Money), also referred to as the Maturity Dashboard (see Figure 6). The domain fields in Figure 4 are coloured orange, indicate an instance of the telemedicine service which has been assigned the lowest possible maturity rating (not available). A telemedicine service is only considered fully functional if all the processes of the service, firstly exist and secondly achieve a minimum Ad Hoc maturity rating.

Telemedicine Maturity Model: Swellendam (LVD) ... radiolo

Refresh | Show Criteria | Save Data | Restore Data | Reset

Number of Processes: 5

#	Descritpion	Micro-level Type	Man		Machine		Material		Method		Money
			User		Devices and Applications		Electronic Health Record		Work Protocol		Operational Cost
1	Make a digital image copy of the paper based x-ray	Capture	Medical Officer (level 1)	use(s)	personal mobile phone (digital camera)	to create	x-ray (digital image)	according to	own discresion	at the cost of	DoH (employing institution)
2	Send patient data (Verbal Communication) via service provider	Transmit Data	Medical Officer (level 1)	use(s)	personal mobile phone(synchronous voice)	to send/ pull	patient medical data (recorded in patient file)	according to	mobile phone service protocol	at the cost of	Medical Officer (Level 1)
3	Send digital photo via service provider	Transmit Data	Medical Officer (level 1)	use(s)	personal mobile phone (MMS/IM)	to diagnose	x-ray (digital image)	according to	mobile phone service protocol	at the cost of	Medical Officer (Level 1)
4	Make recommendation based on patient data transferred	Diagnose	Specialist (level 2)	use(s)	personal mobile phone	to send/ pull	radiological case	according to	traditional medical protocol	at the cost of	DoH (employing institution)
5	Send recommendation via service provider	Transmit Data	Specialist (level 2)	use(s)	personal mobile phone (synchronous voice)	to send/ pull	treatment recommendation/diagnosis	according to	mobile phone service protocol	at the cost of	Specialist (level 2)
			User Community		Infrastructure		Electronic Health Record Management		Change Management		Financial sustainability
		Meso-level	End-user community Analyst community		Physical Infrastructure		EHR mgmt across the service eco-system		Policies with in service context		Business model
		Macro-level	Society for which the service is developed		National, regional ICT infrastructure		National EHR mgmt		National policies and strategies		National Business Case

Figure 6: Mobile Phone Teleradiology Maturity Dashboard

2.5 Data Aggregation and Analysis

The information obtained during the data gathering processes described in the previous sections was collected and stored in a data warehouse, with all the information linked to the respective telemedicine services.The data was then nominalised to generate one coherent data set. The data was then organised and aggregated using pivot tables and visualisations for the purpose of analysis.

The remainder of the article is devoted to a discussion of these analyses.

3 WESTERN CAPE TELERADIOLOGY EVALUATION RESULTS

All the telemedicine services identified and evaluated via the evaluation process as explained in Section 2, were assessed with the same framework, namely the TMSMM. This allowed for quantitative aggregation of results. The discussion follows the structure of the TMSMM.

3.1 Telemedicine Devices

The machine domain represents all the devices and applications which aroused to perform telemedicine services. Figure 7 represents a pie chart of all the devices used to perform telemedicine (teleradiology specifically).

The majority (5/8) of teleradiological services utilises a normal Desktop Workstation, operating on Windows to perform a telemedicine services such as teleradiology. Due to the general store-and-forward nature of teleradiology, for example the use of email to send radiological information between two clinicians.

An unexpected result on the other hand was the low percentage of Telemedicine Workstation utilised (1/8), especially taking into account that the Telemedicine Workstation was specifically designed to perform telemedicine specific tasks. The reasons for this low usage are explained at a later stage in the paper.

The number of mobile phones (3/8) used to perform telemedicine services is impressively high considering that no official mobile phone teleradiology services have been implemented in the Public Health Care district of the Western Cape. A reason for the high percentage of mobile phone use can be attributed to the practical and mobile nature of the device.

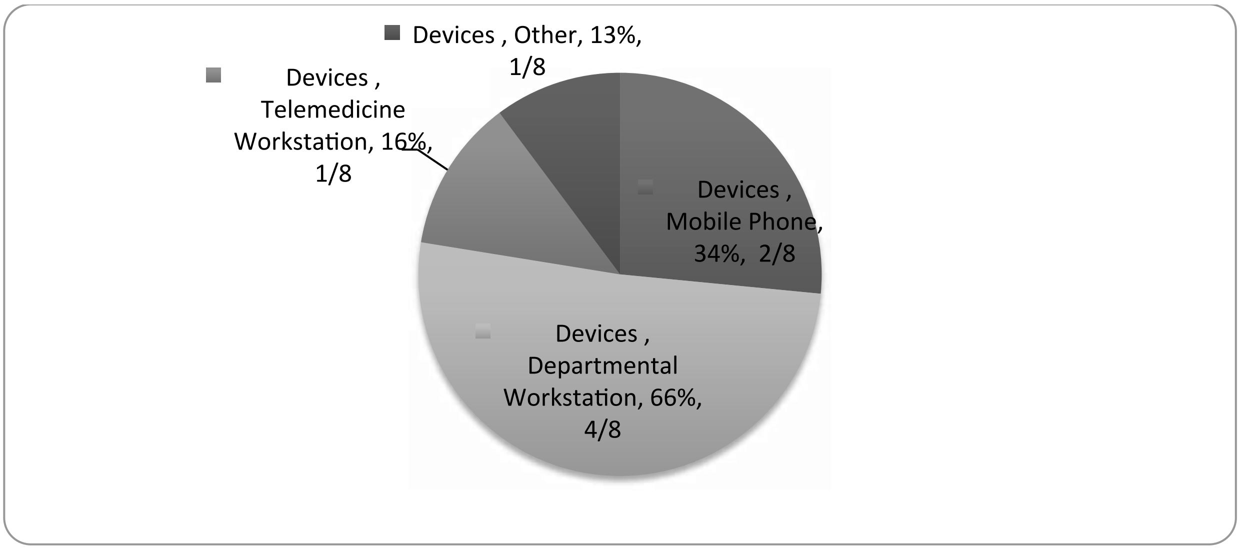

Figure 7: Teleradiology Devices used (fractions)

Although the mobile phone is often used as a telemedicine device it receives a considerably low maturity rating in comparison to the Telemedicine Workstation, see Figure 8. The average maturity of the mobile phone (2.19), within the context of telemedicine, is below that of the combined device maturity (2.83).

There are a number of explanations as to why the maturity of mobile phones is that much lower. The mobile phone is not designed solely as a telemedicine device; it is rather a convenience application which was born out of the need to have a portable means of communication between clinicians and specialists. The Telemedicine Workstation, departmental workstation and x-ray/ultrasound devices are all official telemedicine devices or partial telemedicine. All these services are governed by a general framework/protocol and are fully incorporated in the operational costs of the institution.

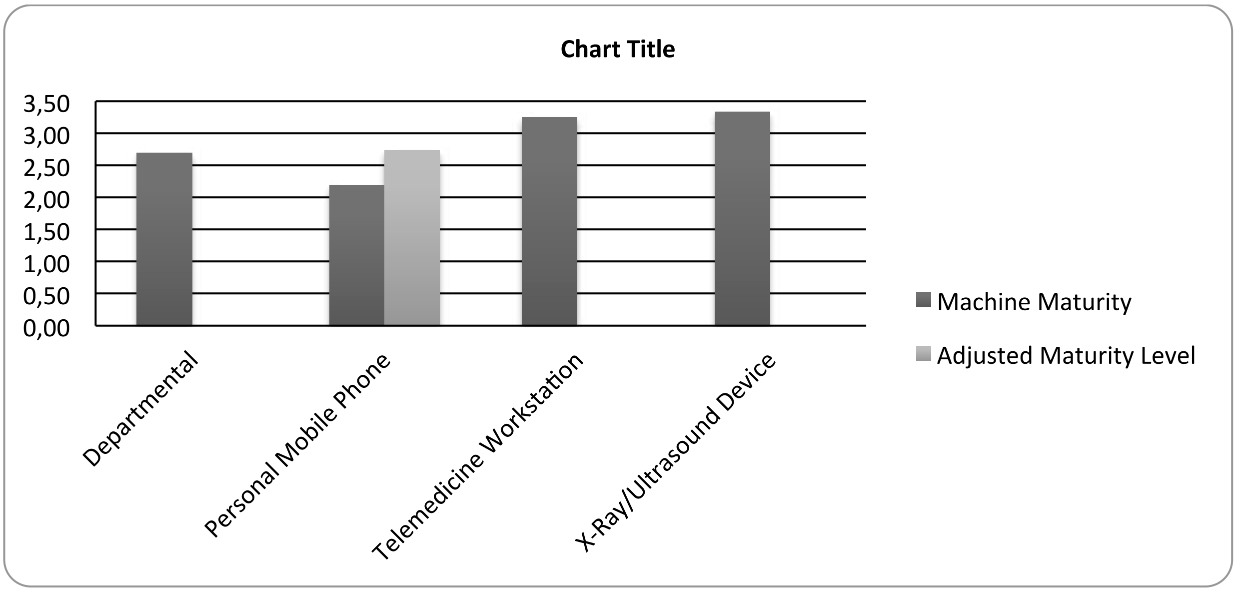

Figure 8: Comparison of Maturity Level for Different Telemedicine Enabling Devices

For the purpose of comparison the maturity of the mobile phone was weighted as an official telemedicine device in order to relate to the other official services on the same scale. The result is an increase in maturity by 25 percent (see Figure 8), considering the jump in maturity the use of mobile phones to perform telemedicine services could well be considered as an official telemedicine service.

In contrast with the mobile phone, the Telemedicine Workstation scores a high maturity, which does not mean that it is the better more mature telemedicine service implemented. Many more factors influence the effectiveness of a telemedicine service and the fact that the Telemedicine Workstation is only used to perform such services in 1 out of 8 cases is a clear indication of that. The Telemedicine Workstation is installed in a fixed location and thus not as readily accessible as a mobile phone and on the other hand has the same properties as a normal workstation, making it redundant.

3.2 Telemedicine Material (Electronic Health Record)

This section will analyse the material aspect involving the use of mobile phones for teleradioology purposes. As discussed in Section 3.1 the mobile phone has proven to be a very resourceful telemedicine tool, although this is the case as far as the device is considered the same is not true for the material capturing and transmission processes (see Figure 9).

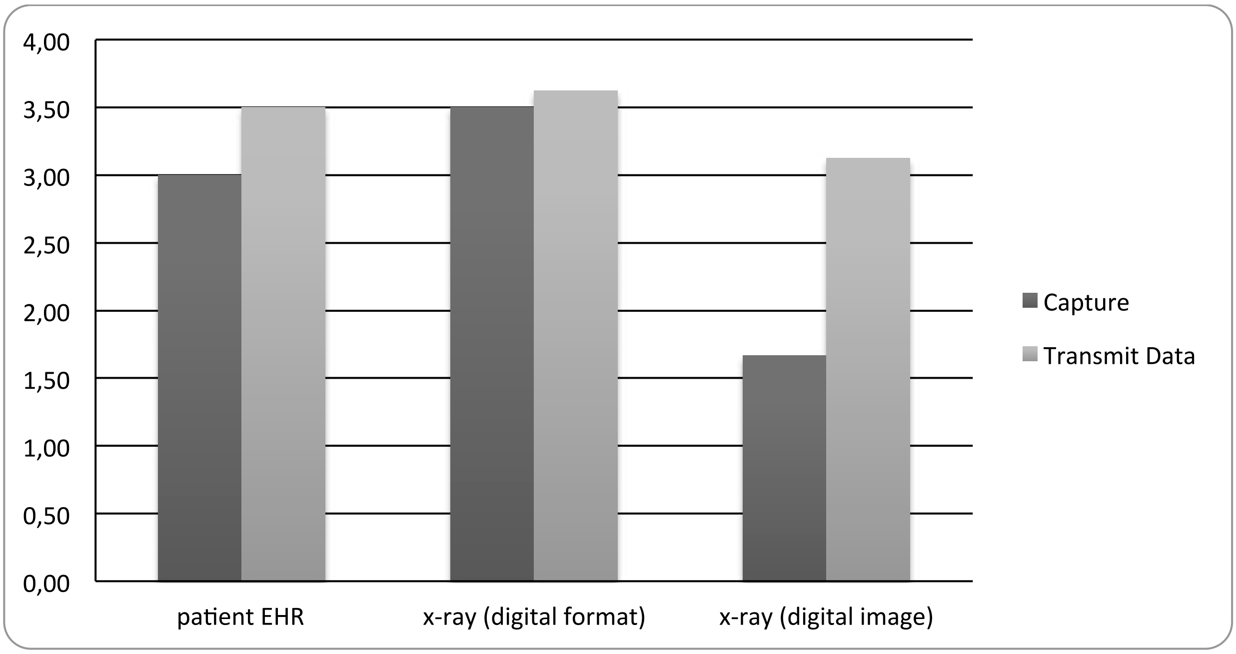

Figure 9: Average material maturity (captured and transmit data services)

Utilising a mobile phone for teleradiology purposes involves the process of capturing a digital image of the radiological examination (x-ray film), the quality and consistency of a digital image is not guaranteed or defined by any clinical effectiveness standards therefore it scores a low maturity (1.67). The transmission of the data reaches a maturity of 3.13, due to the fact that mobile data transmission protocols are well managed and measured.

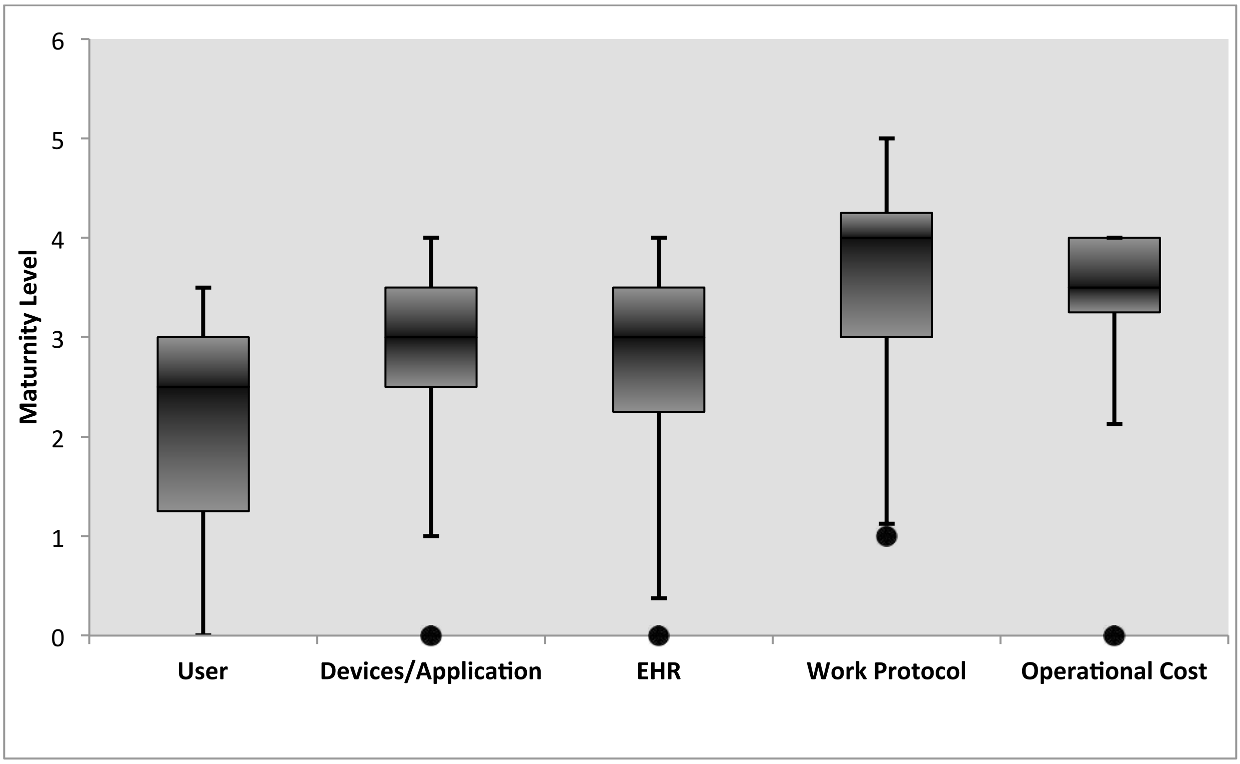

Figure 10: Micro Level Maturity Distribution

The relative high maturity for work protocol (see Figure 10) is possibly an indication of the fact that technology is adapting to existing protocols and not the other way around, namely that new methods are developed due to the enabling technology available.

4 CONCLUSION

The purpose of this paper was to describe the process of evaluating existing telemedicine services (teleradiology in particular) implemented in the Public Health sector of the Western Cape by means of the Telemedicine Maturity Model. The TMSMM served as means to describe these processs and assess the maturity in a consistent way that allow for cross-service comparison.

In the course of the study 5 District Health Care facilities in the Western Cape were visited. During these visits a total of 8 teleradiology services were mapped with the help of the TMSMM, resulting in the data acquisition of 51 micro-service-level. It was shown in this paper that interesting conclusions can be drawn from an aggregated view of this data.

Future work will involve the expansion of this study by including other telemedicine services, such as teledermatology, telepathology and services from other health care facilities. This will allow for more representative conclusions as well as determining the correlation between the different aspects that constitutes telemedicine service maturity.

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TO COAT OR NOT TO COAT WHEN CUTTING IT COOL WITH TITANIUM ALLOYS

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ABSTRACT

The popularity of titanium alloys is on the increase, predominantly in aerospace, but also in biomedical applications, chemical processing and upmarket sporting goods. This in turn increases the demand for titanium, which inevitably increases the production rate. The manufacturing rate increases as the production rate of titanium alloy parts increases. For manufacturing to keep pace with these high demands for titanium parts, the cutting and milling speeds need to increase, which causes the machining temperature to increase dramatically. The thermal conductivity of titanium alloys is exceptionally low when compared to that of high carbon steels. Cooling is therefore crucial for productive titanium alloy machining.

Another possibility to increase the production rates of titanium alloy parts would be to use coated tools for the machining of the alloys. Some previous studies, however, show that there is minimal or no economic benefit to coating the machining tools. This study investigates the effects of combining cooling and coated tools simultaneously for the more effective machining of titanium alloys.

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1 INTRODUCTION

The use of titanium and its alloys in modern applications is constantly increasing due to its unique characteristics, of which the most favourable is its high strength to mass ratio [1]. Titanium alloys, especially Ti-6Al-4V, have become the workhorse material in high performance components, especially in the aerospace industry [2]. High cutting temperatures during the machining of titanium alloys and the reactivity of the alloy with atmospheric air lead to rapid tool wear and even tool failure. To reduce the rate of tool wear, the cutting temperature should be minimized by performing machining operations with appropriate tools and adequate cutting parameters. These cutting parameters include cutting speed, depth of cut and feed rate [3].

An effective method for the removal of heat produced by the machining process, which shortens tool life, is by cooling strategies [4]. The most common cooling method is flood cooling, where the machined part is constantly engulfed with cooling and lubricating fluid. Another method for cooling a machined part and cutting tool is high pressure cooling. This method uses cooling and lubricating fluid under high pressure to remove heat and material chips from the point of cutting [5].

An alternative method for enhanced tool performance and enhanced tool life is coating the tools with a hard, tough material [6]. Research has been conducted to determine the most suitable coatings for titanium alloy machining. The main goal is to improve tool life, but some studies have indicated negative results, while others reported prolonged tool life [3], [6]. These contradictory findings are responsible for the scepticism of many companies when it comes to the prolonging of tool life with coatings. This perception is further amplified by the high cost of coated tools, resulting in elevated, uneconomical machining costs.

The reduction of the cost of machining titanium alloys thus calls for further research and the development of methods utilizing coated tools. It is necessary to keep the coating on the tool for as long as possible to ensure optimized tool performance. Once the coating is removed, the tool will wear in the same manner as an uncoated tool. There is insufficient information and research on the impact of various cooling methods on coated tool life. If a specific cooling and lubricating fluid is combined with optimal cutting parameters to improve tool life, coated tools could prove to be economically justifiable.

The purpose of this study is to investigate the effects on coated tool life during the machining of titanium, the influence of various cooling methods on coated tool performance, and the most suitable tool coating and cooling method for Ti-6Al-4V machining.

2 TI-6AL-4V CHARACTERISTICS

Titanium has a hexagonal close-packed (HCP) lattice structure at normal ambient temperatures. It undergoes an allotropic transformation at approximately 882°C from a HCP structure to a body-centred cubic (BCC) structure. The HCP crystal structure is known as alpha phase and BCC as beta phase and by alloying titanium one of these allotropic phases will be favoured [7], [8].

Titanium alloys can be categorized according to metallurgical characteristics into four main phase groups: alpha alloys, near-alpha alloys, alpha-beta alloys and beta alloys. Ti-6Al-4V is an alpha-beta alloy, where the aluminium is an alpha stabilizer and the vanadium a beta stabilizer. The aluminium reduces the alloy density, while vanadium increases ductility [3], [9]. The most commonly used titanium alloy, Ti-6Al-4V, accounts for more than 50% of the total titanium world usage [1].

Alpha-beta titanium alloys are the most popular alloys, which account for approximately 70% of the titanium alloy market. Ti-6Al-4V has the composition shown in Table 1. The mechanical properties of Ti-6Al-4V and high carbon steel are shown in Table 2 for the purpose of comparison. The low thermal conductivity of this alloy leads to increased machining difficulties. The machining of Ti-6Al-4V is further complicated by other material properties of the alloy. Tungsten carbide cutting tools have shown superior performance during Ti-6Al-V4 machining and will thus be the preferred tool insert substrate material.

Table 1 - Ti-6Al-4V composition [9]

Component	Content
C	<0.08%
Fe	<0.25%
N_2	<0.05%
O_2	<0.2%
Al	5.5 - 6.76%
V	3.5 - 4.5%
H_2 (for sheets)	<0.015%
H_2 (for bars)	<0.0125%
H_2 (for billets)	<0.01%
Ti	Balance

Table 2 - Properties of Ti-6Al-4V compared with High Carbon Steel [9]

Property	Ti-6Al-4V	High Carbon Steel	Ratio
Density (kg/m^3)	4420	7850	0.56
Hardness (Rockwell C)	36	15	2.4
Young's Modulus (GPa)	110	208	0.52
Tensile Yield Strength (MPa)	828	375	2.21
Ultimate Tensile Strength (Mpa)	1030	615	1.68
Compressive Strength (MPa)	960	375	2.56
Shear Modulus (GPa)	43	80	0.54
Ductility (% elongation at break)	10%	25%	0.4
Poisson's ratio	0.34	0.29	0.72
Resilience (kJ/m^3)	3.76	0.9	4.17
Rupture work (MJ/m^3)	96.3	134	0.72
Stiffness-to-weight ratio (MN-m/kg)	24.9	26.5	0.94
Strength-to-weight ratio (kN-m/kg)	187	47.8	3.91
Max working temperature (^{o}C)	400	310	1.29
Specific Heat Capacity (J/kg.K)	565	490	1.15
Thermal Conductivity (W/m.K)	7.2	50	0.14
Thermal Expansion ($10^{-6}/^o$C)	8.8	12	0.73

3 EXPERIMENT

All the experiments are conducted in the same environment under identical conditions in order to obtain comparable results. The machining equipment will therefore remain the same for each experiment. The milling machine used for the experiments is the HERMLE C40 Dynamic CNC machine, capable of high speed 5-axis machining on components of up to 1400 kg. The characteristics of the HERMLE C40 can be seen in Table 3.

Table 3 - CNC machine characteristics [10]

Design Information	Value
Machine type	HERMLE C40
Control unit	iTNC530
Number of axes	5
X-axis travel	850 mm
Y-axis travel	700 mm
Z-axis travel	500 mm
Motor power	14 kW
Spindle speed	Up to 18000 rpm
Torque	Up to 200 Nm

To machine titanium and titanium alloys successfully, low cutting speeds with small depth of cut is most appropriate. These preferred parameters increase machining time, although this is favourable for prolonged tool life. Therefore these parameters are not always used in industries where high production volumes are required. The machining parameters used for the experiments are comparable with those used by Boeing for their titanium milling operations. These machining parameters can be seen in Table 4.

Table 4 - Machining parameters used in the experiments

Cutting parameter	Value
Cutting speed	120 m/min
Feed rate	116.128 mm/min
Radial depth of cut	1 mm
Axial depth of cut	10 mm
Spindle speed	1528 rpm
Feed per tooth	0.076 mm
Material removal rate	1161.22 mm^3/min

The cutting and lubricating fluid used for the experiment is a Rocol Ultra Cut 260 coolant emulsion. The machining experiment uses two different cooling and lubricating techniques. The first is flood cooling and the second high pressure cooling at 60 bar pressure.

The cutter body used in the experiment is a Mitsubishi BAP3500. This cutter body has a through spindle coolant passage that allows for the testing of high pressure cooling. The BAP3500 has a high rake angle that allows for more efficient titanium machining. The geometry of the BAP3500 can be seen in Figure 1 and the design parameters are listed in Table 5.

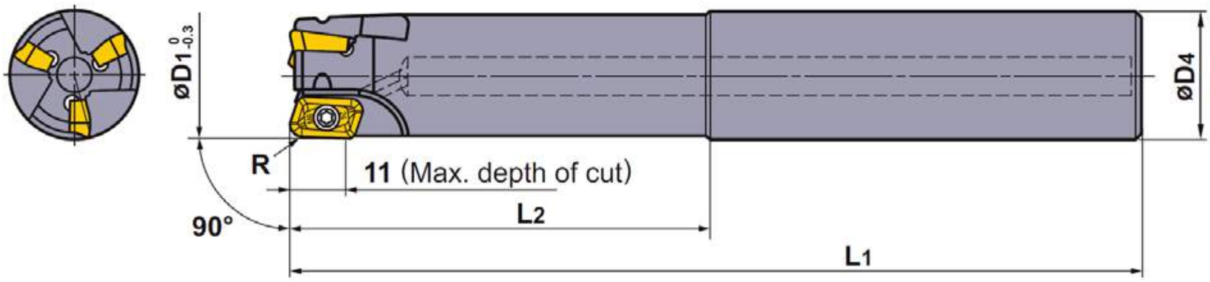

Figure 1 - BAP3500 cutter body geometry [11]

Table 5 - BAP3500 design information [11]

Design parameters	Dimension
Corner radius	0.8
Rake angle (Re)	11°
Number of teeth	3
Cutting diameter (D1)	25 mm
Tool length (L1)	120 mm
Tool length (L2)	40 mm
Max depth of cut	11 mm
Tool diameter (D2)	25 mm

The inserts used in the machining experiments are of three different types. One of the insert types is uncoated and polished high strength tungsten carbide that is used as a control, while the other two insert types are coated tungsten carbide inserts. The single-layered insert has a (Al, Ti)N Physical Vapour Deposition coating, while the multi-layered insert has a TiN-Al2O3-TiCN Chemical Vapour Deposition coating [12], [13]. The difference between PVD and CVD coatings lies in their mechanical properties, edge preparation, cost and coating thickness [14].

The inserts are Mitsubishi Rhombic 75° inserts having a clearance angle of 11° and a corner radius of 0.8 mm. The insert geometry can be seen in Figure 2, with F_1 = 1.2 mm and Re = 0.8 mm. The information on the coating composition of the three inserts is available in Table 6.

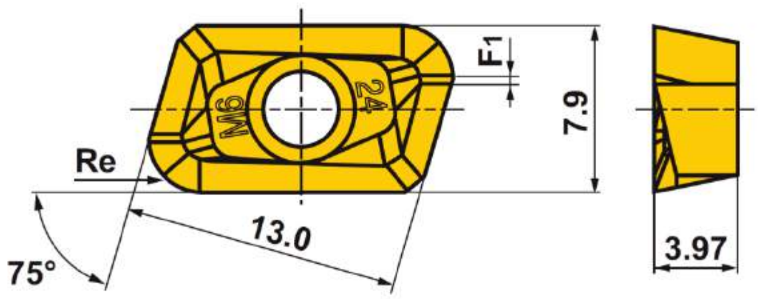

Figure 2 - Insert geometry [11]

Table 6 - Insert information and coating composition [11]

Insert	Substrate	Coating	Application	Layer geometry	Additional
VP15TF	K10	(Al, Ti)N	Physical Vapour Deposition	Single-layered	-
F7030	K30	TiN-Al_2O_3-TiCN	Chemical Vapour Deposition	Multi-layered	-
HTi10	K10	-	-	-	Polished

A micrographic image of each coated insert is shown in Figure 3.

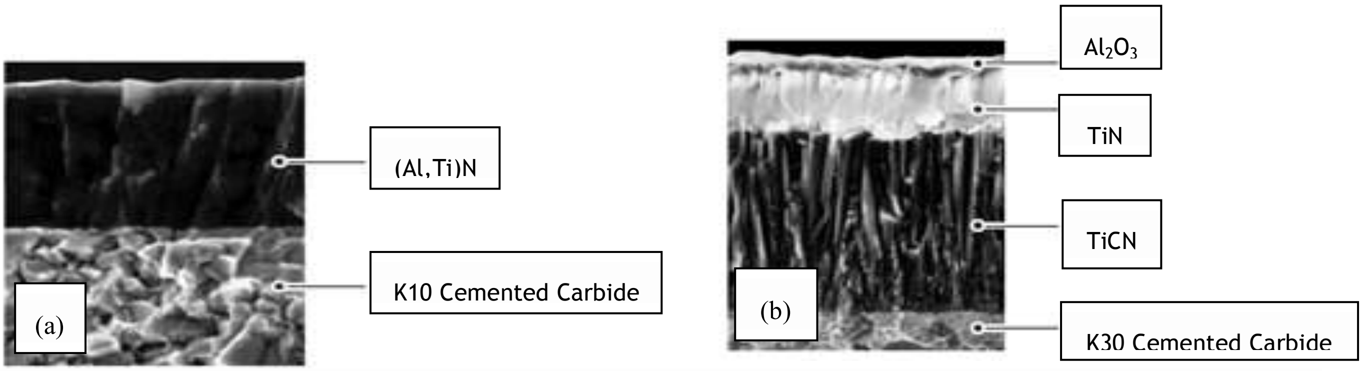

Figure 3 - Insert layering micrograph showing (a) single-layered insert and (b) multi-layered insert

The machining process used for the experiment is a shoulder milling operation performed on a 500 mm by 254 mm by 150 mm block of Ti-6Al-4V. The block is cut by a non-continuous process, as depicted in Figure 4. The BAP3500 cutter is rolled into the block, shoulder mills the block and rolls out. Only a single insert is used during the milling operations. This process takes approximately 5 minutes and 20 seconds, after which the operation is stopped to microscopically examine wear on the insert. Thereafter the process is repeated.

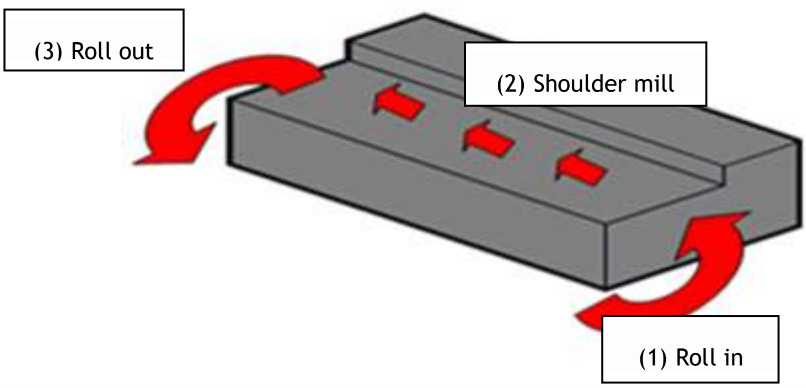

Figure 4 - Machining process used during the experiment

The microscope used for analysing the inserts is an Olympus GX51 Inverted Optical Microscope, with total magnification of 50x, 100x, 200x, 500x and 1000x. An insert holder is used to keep the insert flank and rake face perpendicular to the lens of the microscope. The experiment follows the flow chart depicted in Figure 5. A test run is done with a VP15TF single-layered insert and flood cooling to confirm machining parameters.

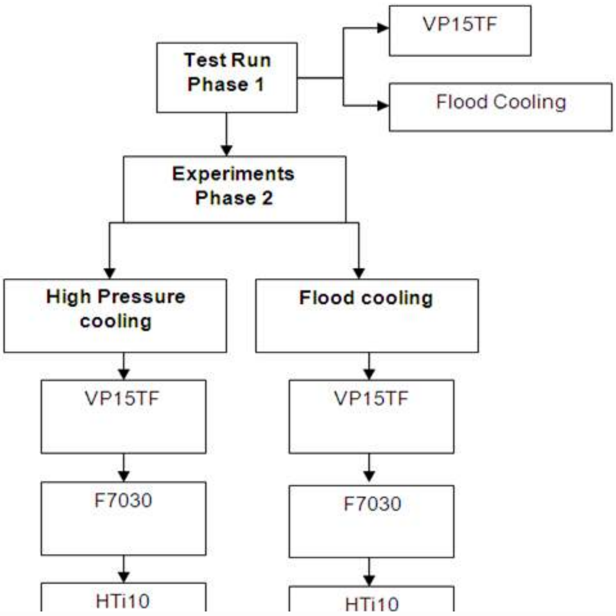

Figure 5 - Experiment execution phases

4 EXPERIMENTAL RESULTS

For the first part of the experiment, a flood cooling and lubricating method for machining Ti-6Al-4V is investigated on the three different tool inserts. Some microscope images of flank wear of each insert are shown in Figure 6 to Figure 8.

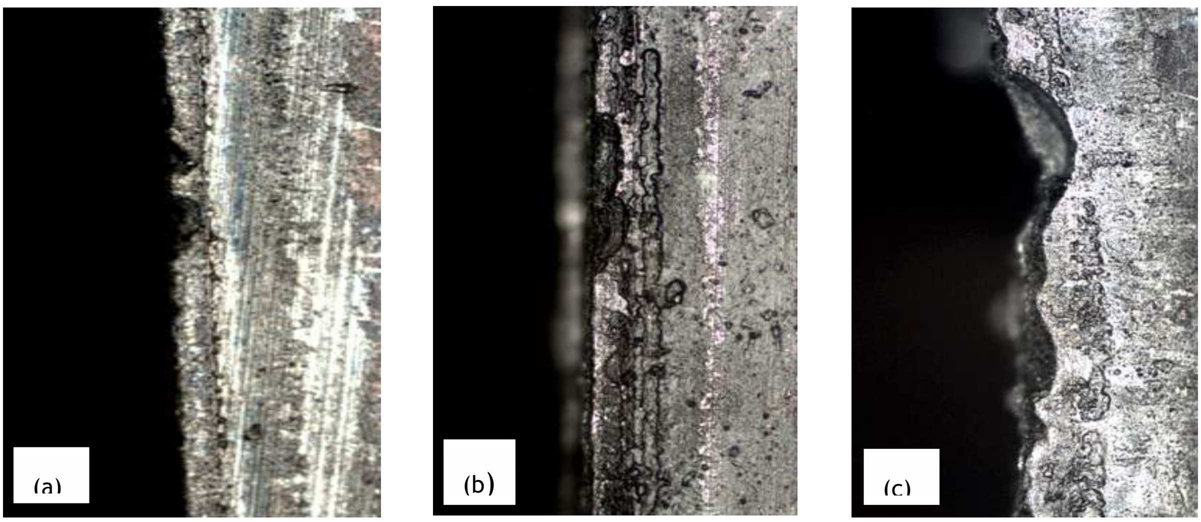

Figure 6 - Wear of the uncoated insert after (a) run 1, (b) run 3 and (c) run 6 during milling operations while using flood cooling

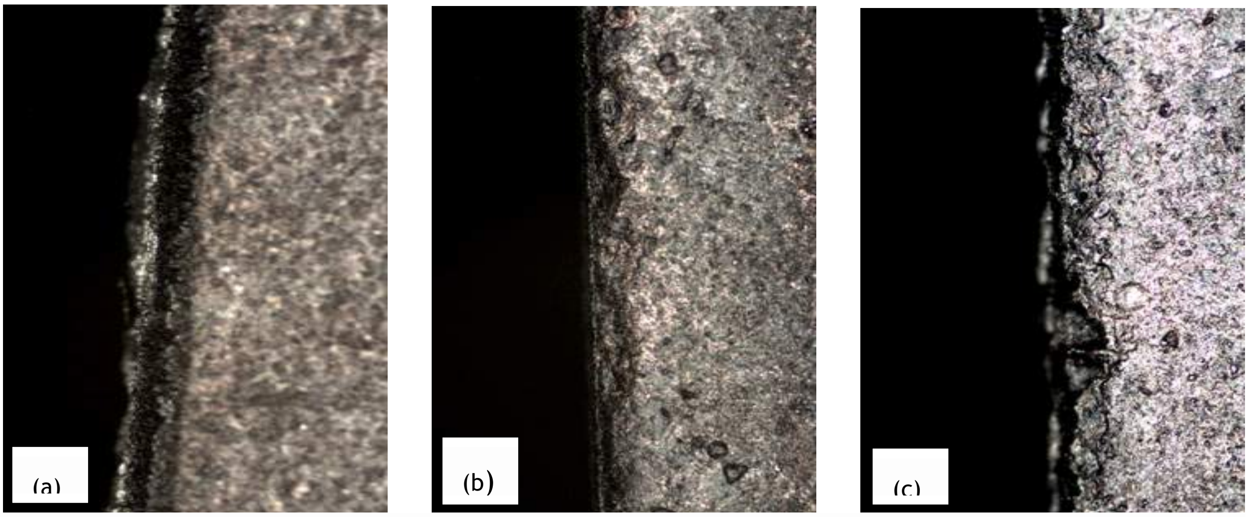

Figure 7 - Wear of the single-layered insert after (a) run 1, (b) run 3 and (c) run 6 during milling operations while using flood cooling

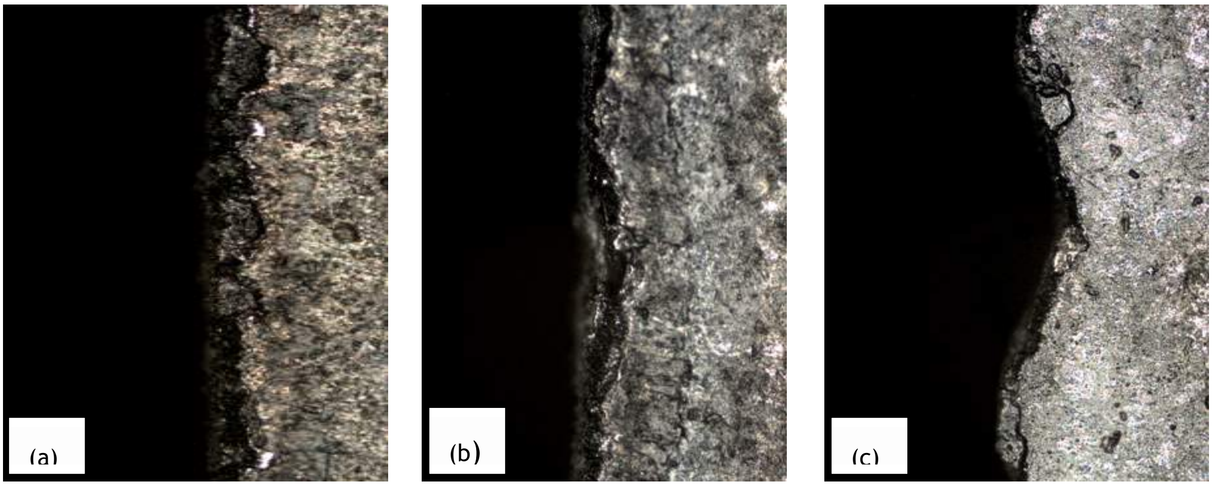

Figure 8 - Wear of the multi-layered insert after (a) run 1, (b) run 2 and (c) run 4 during milling operations while using flood cooling

From these images it can be seen that the multi-layered coated tool insert performed least favourably. Minor chipping and delamination is more noticeable on the multi-layered insert than on the single-layered insert. Damage was too severe to continue after the fourth machining run with the multi-layered coated insert and testing was terminated. The flank wear of the multi-layered insert is not uniform and small chips can be identified after the first milling operation.

The flank wear of the uncoated insert is more uniform than that of the multi-layered insert, but less uniform than that of the single-layered insert. Small chips are visible after the first machining run, while severe chipping is identified only after the fifth machining run. The single-layered insert displayed the most favourable performance. The flank wear on the single-layered insert is uniform and small chips are observed only after the sixth machining run. The measured flank wear of each insert is shown in Figure 9.

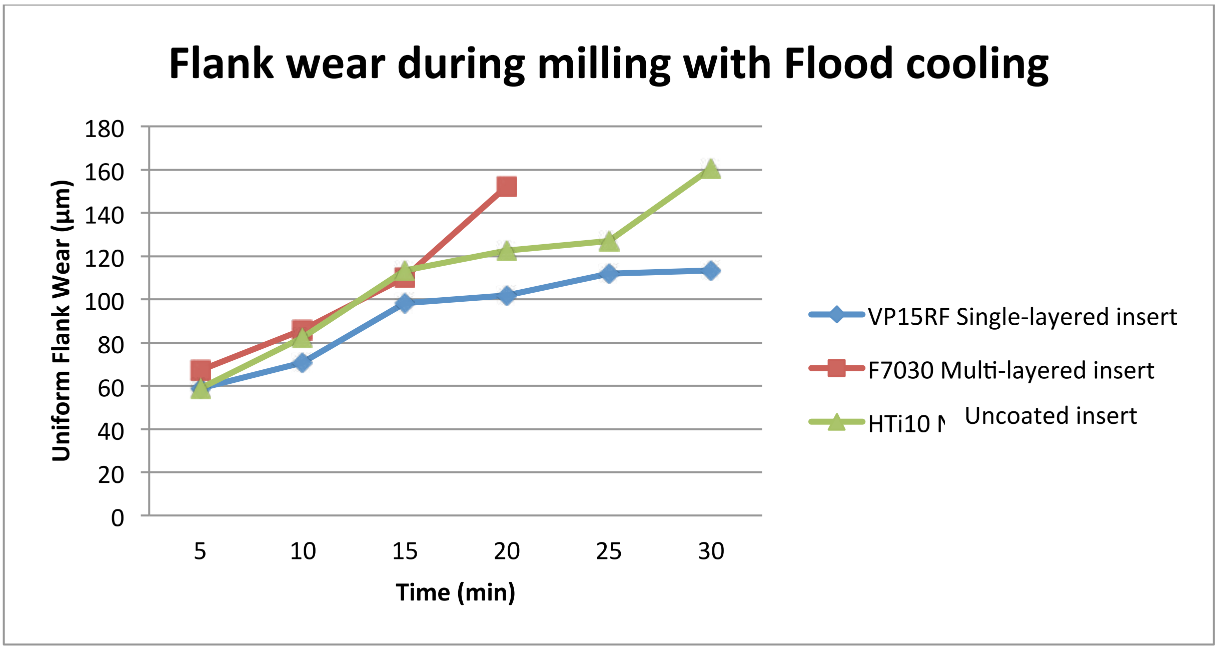

Figure 9 - Flank wear during milling with flood cooling for all three inserts

From Figure 9 it can be seen that the flank wear of the single-layered insert is less than that of the flank wear of the other two inserts. It had the least amount of flank wear during the flood cooling machining experiment. The wear rate of the multi-layered insert increased to the point where the tool could no longer be used successfully. The wear rate of the single-layered insert and uncoated insert followed similar wear patterns, with the single-coated insert having the least wear throughout the first part of the experiment. From Figure 9 it can be concluded that coatings on the inserts have an impact on the tool life, either positive or negative.

For the second part of the experiment, a high pressure cooling and lubricating method is investigated for machining Ti-6Al-4V. Some interval flank wear analysis images are shown in Figure 10 to Figure 12.

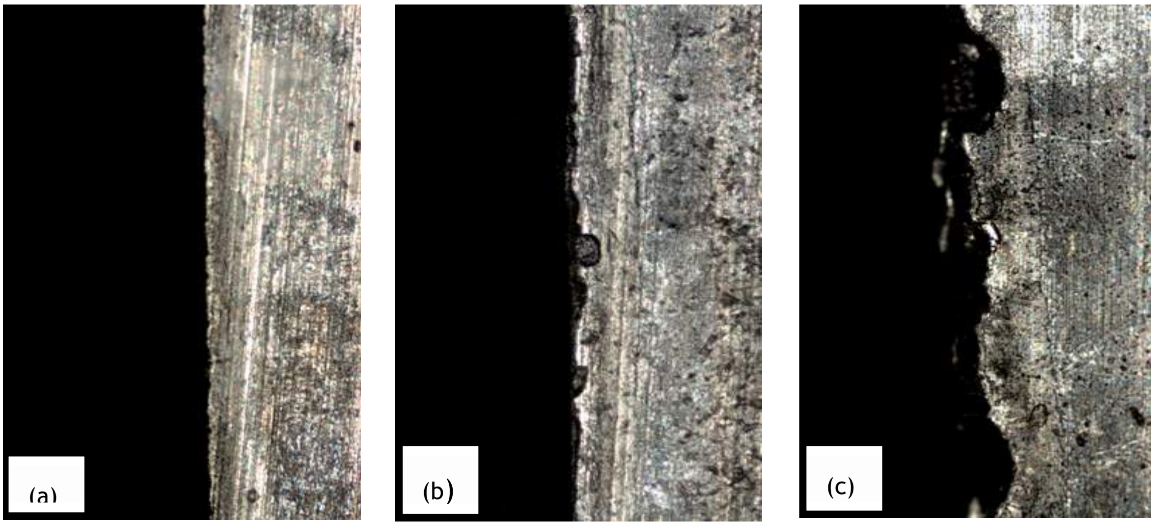

Figure 10 - Wear of the uncoated insert after (a) run 1, (b) run 3 and (c) run 6 during milling operations while using high pressure cooling

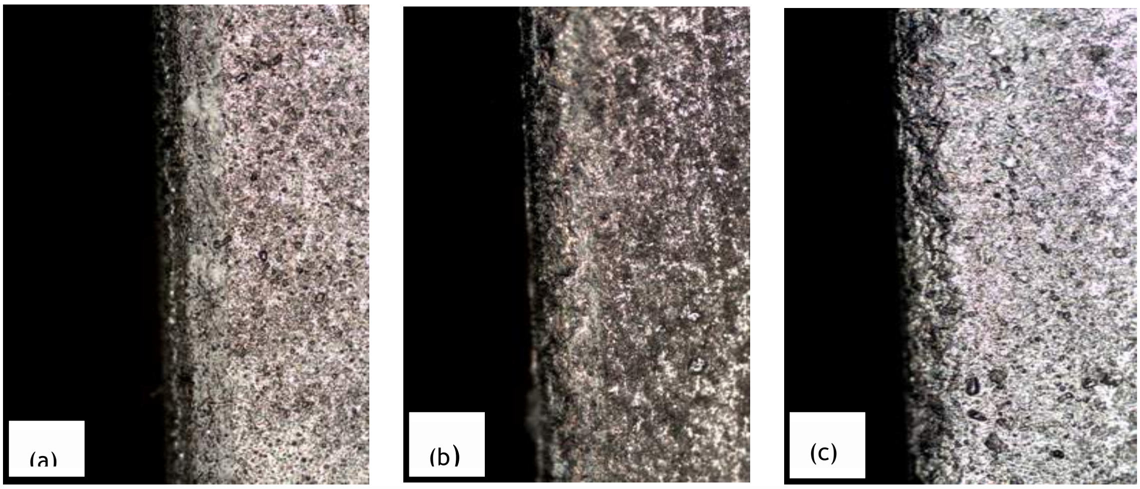

Figure 11 - Wear of the single-layered insert after (a) run 1, (b) run 3 and (c) run 6 during milling operations while using high pressure cooling

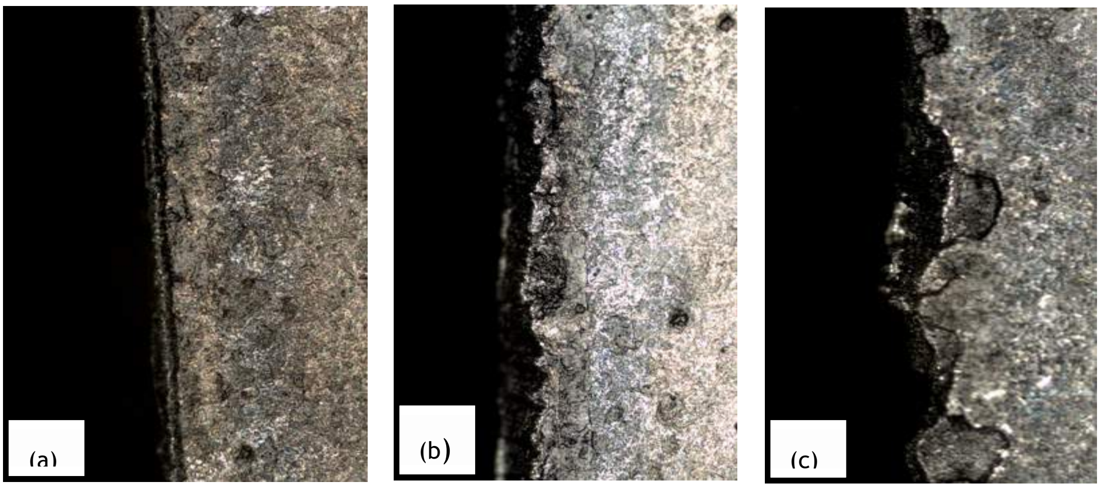

Figure 12 - Wear of the multi-layered insert after (a) run 1, (b) run 2 and (c) run 4 during milling operations while using high pressure cooling

From initial comparison with the flank wear when using flood cooling, it can be seen that the inserts had improved performance and a reduction in wear rate. The single-layered insert demonstrated superior performance when compared to multi-layered and uncoated inserts. It displays the longest tool life and greatest resistance to tool wear. From Figure 11 it can be seen that the insert showed no significant chipping and the flank wear remained uniform throughout the experiment. After the final machining operation, the insert could have been used for additional machining, if necessary.

For both single-layered and multi-layered inserts, coating delamination is less evident with high pressure cooling than with flood cooling. The multi-layered insert again performed worse than the other two inserts. Despite this, the multi-layered insert shows less chipping after the second high pressure cooled machining run than it did with the flood cooled machining run. The reduced chipping leads to a decrease in tool wear and thus an increase in tool life. Although the wear rate is less than it had been in the flood cooled experiment, chipping is too severe to continue machining after the fourth machining run.

With the high pressure cooling method, the flank wear of the multi-layered insert was more uniform than it had been in the flood cooled experiment. With a slower rate of chipping occurring than with flood cooling, multi-layered and uncoated inserts still displayed some chipping. The uncoated inserts displayed superior performance compared to the multi-layered insert. Until after the third machining run, no chipping was observed on the uncoated inserts while using the high pressure cooling method. This is a significant improvement when compared with the chipping observed after the first run when using the flood cooling method. The flank wear of the uncoated insert was also less with the use of high pressure cooling. Figure 13 shows the flank wear for each insert during use with high pressure cooling.

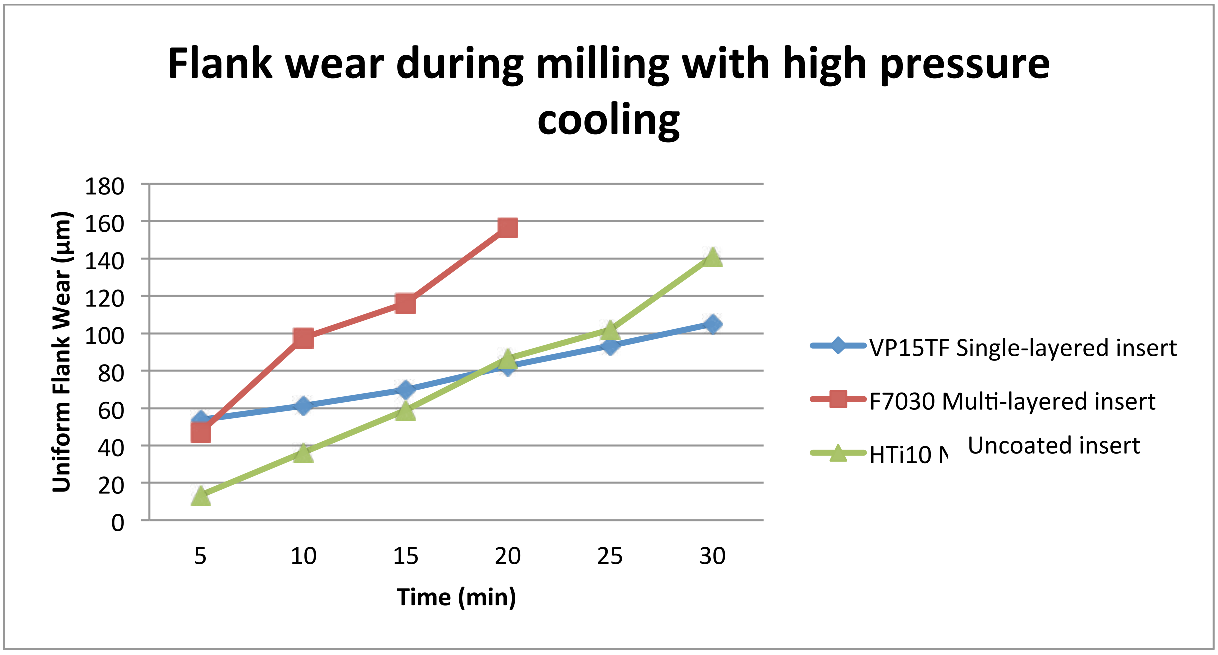

Figure 13 - Flank wear during milling with high pressure cooling for all three inserts

The results seen Figure 13 are similar to the results found in Figure 9, but at a lower wear axis offset value. As seen in Figure 13, the wear for the multi-layered insert is higher than the wear for the other two inserts. This excessive wear caused the multi-layered insert machining to be terminated after the fourth machining run. Again the single-layered insert showed the lowest wear rate and demonstrated superior performance. An interesting observation is that the wear of the uncoated insert was initially lower than that of the single-layered insert. Only because of the higher wear rate of the uncoated insert did the wear of this insert exceed that of the single-coated insert after the fourth machining run. The results in Figure 13 indicate that the single-coated insert has the most resistance to wear.

The average and maximum flank wear produced during machining for each insert is shown in Table 7. The average flank wear of the uncoated and single-layered inserts is reduced when high pressure cooling is used. The average flank wear of the multi-layered insert is slightly worse when high pressure cooling is used.

Table 7 - Average and maximum wear results for the three insert types when used with flood cooling and high pressure cooling

	Flood cooling		High Pressure cooling	
Insert	Avg. Wear (μm)	Max. Wear (μm)	Avg. Wear (μm)	Max. Wear
HTi10 uncoated	110.74	160.44	72.98	141.12
VP15TF single-layered	92.4	113.4	77.56	105
F7030 multi-layered	103.76	152.04	104.76	156.24

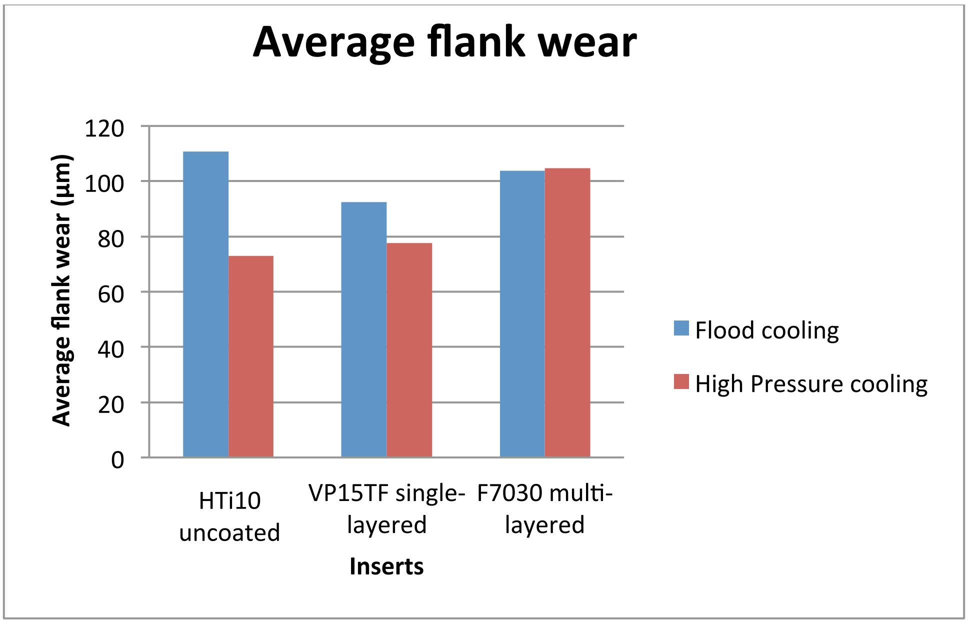

Figure 14 - Average flank wear on inserts during flood and high pressure cooling

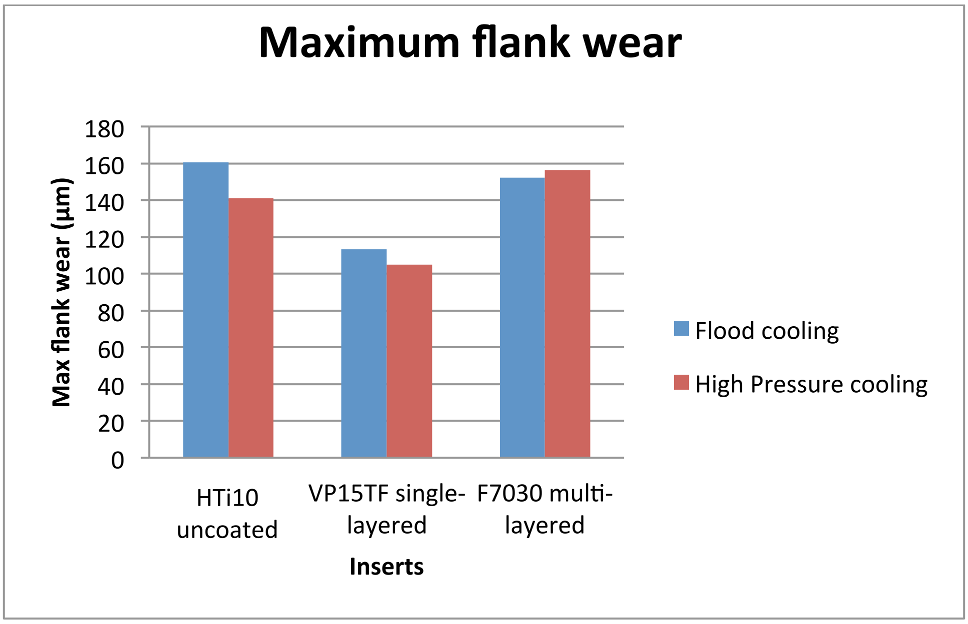

Figure 15 - Maximum flank wear on inserts during flood and high pressure cooling

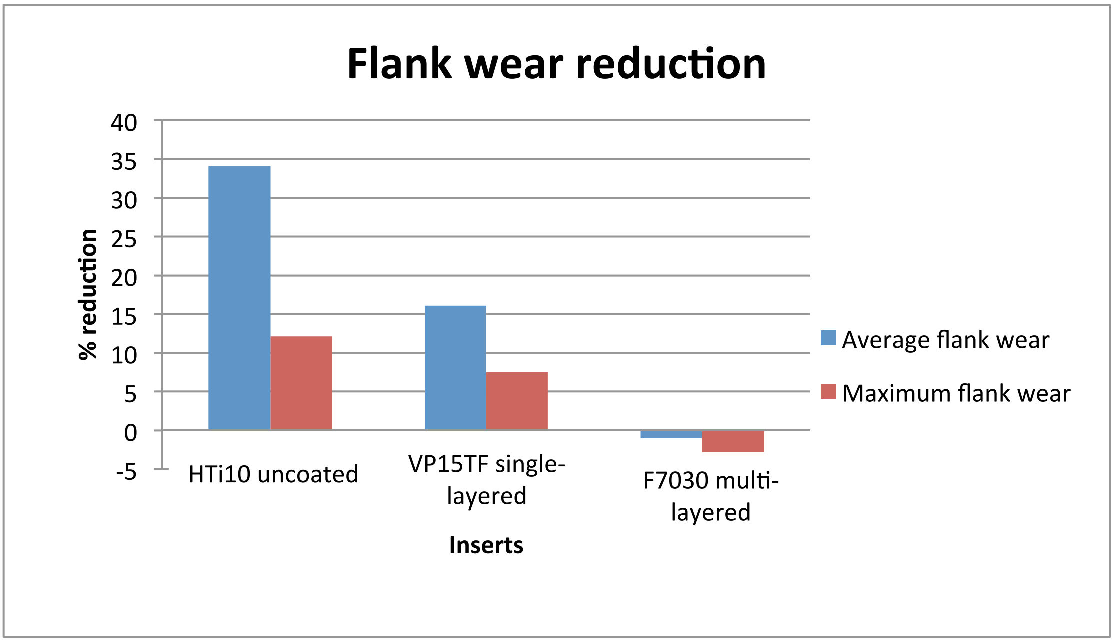

Figure 16 - Reduction in flank wear for inserts when applying high pressure cooling

Figure 14 and Figure 15 show the average and maximum flank wear of the inserts during cooling. Figure 16 shows the effect of high pressure cooling on the reduction of average and maximum flank wear for each insert.

5 DISCUSSION AND CONCLUSION

The experimental data suggests that machining with a single-layered insert and a high pressure cooling method will produce the best insert performance. This insert shows the best resistance to wear during milling with both cooling methods when compared with the uncoated and multi-layered inserts, as it has a higher resistance to wear [15]. The only part of the experiment where the single-layered insert does not have the best performance, is in the first three runs during the high pressure cooling test (Figure 13) and the average flank wear during high pressure cooling (Figure 14). The average and maximum flank wear of the single-layered insert are lower during high pressure cooling than with flood cooling (Table 7), suggesting that high pressure cooling is a more effective cooling method. The reason for this might be that high pressure cooling removes machined chips more effectively, which extends tool life [5]. There is a model for coating failure that can further be implemented to more accurately predict insert coating wear [16].

Further and future investigations can include larger sample batches to produce more accurate statistical results, which lead to better result analysis. Different substrate materials for tools can be used to determine the effects thereof on the performance of the tools, coated or uncoated, on the different machining parameters. A variety of pressures can also be investigated to determine the optimal pressure for machining with high pressure cooling techniques.

The experiment that was conducted tested three different insert types and two cooling methods. From the experimental data it is found that a single-layered (Al, Ti)N PVD coated insert with high pressure cooling of 60 bar is the optimal combination to increase tool life during Ti-6Al-4V machining.

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FUNCTIONAL PERFORMANCE AND MACHINABILITY OF TITANIUM ALLOYS FOR MEDICAL IMPLANTS: A REVIEW

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ABSTRACT

Recent findings in biocompatibility research indicate that titanium alloys that are currently used for medical implants may have biological side effects necessitating their replacement. Long term investigations into biocompatibility have identified serious adverse biological systemic effects caused by the implant materials that are in use today. Substantial work is being conducted into biocompatibility yielding improved performance in this field for alloys under development. The medical implant industry is not predominantly cost sensitive but is part of a free market business environment. Prohibitive costs of implants will prevent their acceptance in this market segment. Machinability has a large cost implication on the business feasibility of implant manufacturing. It is therefore essential that biocompatibility as well as machinability should be on acceptable levels for the alloy to be accepted in this market. This study reviews the literature for recent findings on long term biocompatibility studies of currently used titanium alloys for medical implants. The study also includes biocompatibility and physical material characteristics of the next generation titanium alloys under development for medical application. The study is concluded with a comparison of these two categories and an identification of alloys that need to be included in future machinability research.

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1 INTRODUCTION

The population ratio of aged people over 65 years of age is growing. There is an increase in the number of aged people requiring the replacement of failed hard tissue with artificial implants made of biomaterials [1]. To this date, metallic biomaterials are the most suitable material for replacing failed hard tissue [2]. Biomaterials for biomedical applications cover a wide spectrum of applications and should exhibit specific properties. The most important properties of materials used for the fabrication of implants are biocompatibility and corrosion resistance. Other important properties include mechanical behaviour, machinability and availability [3], [4], [5], [6].

The main biomaterials used include stainless steels, cobalt-based alloys as well as titanium and its alloys [2], [3] , [7]. Stainless steel was the first metallic biomaterial that was successfully used as an implant. In 1932, Vitallium, a cobalt-based alloy, was developed for medical applications. As a biomaterial, titanium is the newest metallic biomaterial in both the medical and dental fields and together with its alloys have demonstrated success in biomedical applications [7].

Titanium and its alloys satisfy the material property requirements for biomaterials for biomedical applications better than any other competing material [3]. Titanium alloys have excellent specific strength and corrosion resistance, no allergic problems and the best biocompatibility among metallic biomaterials [2].

The high strength-to-weight ratio and exceptional corrosion resistance characteristics of titanium were the main causes of the rapid growth of the titanium industry over the last 40 years. However, titanium still remains a high cost material when compared to other metals due to the complexity of the extraction process, difficulty of melting and problems during fabrication. Nevertheless, longer service lives and higher material property levels counterbalance the high production costs [8], [9], [10], [11]. In 1955, Siekmann pointed out that "*machining of titanium and its alloys would always be a problem, no matter what techniques are employed to transform this metal into chips*" [12].

Ti–6Al–4V alloy is generally classified as ‘‘difficult to machine’’ because of its thermo-mechanical properties. The main challenge when machining titanium is to overcome the short tool life which prevents manufacturers from using high cutting speeds. Titanium has low thermal conductivity and high chemical affinity towards the cobalt binders that are found in most cutting tool materials. The low thermal conductivity increases the temperature at the cutting edge of the tool. The interface between titanium chips and cutting tools is quite small, which results in high cutting zone stresses. There is a strong tendency for titanium chips to pressure-weld to cutting tools and lastly, the low modulus of elasticity of titanium alloys and its high strength at elevated temperatures impair its machinability [13], [14], [15].

The main reasons for the difficulties experienced with commercialization of recently developed Ti-alloys are the production costs and/or their machinability. Many alloys recently developed failed to compete with the commercial alloys due to their production challenges and their content of high cost rare earth metals such as niobium (Nb), tantalum (Ta), zirconium (Zr) and molybdenum (Mo) [16].

2 TITANIUM AND BIOCOMPATIBILITY

Titanium is considered to be a relatively new engineering material seeing that it was discovered much later than the other commonly used metals and its commercial application only started in the late 1940’s. Initially it was mainly used as a structural material and its usage as an implant material began in the 1960’s [17]. However, even though titanium displays superior corrosion resistance and tissue acceptance when compared with stainless steels and cobalt based alloys, its mechanical properties and tribological behaviour confines

its use as biomaterial in some cases especially when high mechanical strength is required such as with hard tissue replacements or under intensive wear use [18]. In an attempt to overcome these restrictions, commercially pure titanium was substituted by titanium alloys, particularly; the Ti-6Al-4V and Ti-6Al-4V ELI (Extra Low Interstitial) alloys [3], [19]. The alpha-beta type alloy, Ti-6Al-4V, is the most extensively utilised titanium alloy worldwide and was initially developed for aerospace applications [20], [21]. Even though this type of alloy is considered a particularly suitable material for biomedical implants, recent studies have found that vanadium may react with the tissue of the human body. According to Wang (1996), the vanadium in the Ti-6Al-4V alloy may react with the tissue of the human body and the aluminium may be related to neurological disorders and Alzheimer's disease [19]. Two new vanadium-free alpha-beta type alloys were developed in the 1980's to overcome the vanadium toxicity. The vanadium was replaced by niobium and iron which lead to Ti-6Al-7Nb and Ti-6Al-2.5Fe alpha-beta type alloys [22], [23]. Both of these alloys show mechanical and metallurgical behaviour that is comparable to Ti-6Al-4V; however a disadvantage is that they both still contain aluminium in their compositions.

Titanium alloys that are suitable for bone implants should contain no elements with potential adverse effects on the tissues of the human body, such as vanadium, copper, chromium, cobalt and nickel. Aluminium should only be used in minimally acceptable amounts [24]. Titanium alloys are currently utilized as structural biomaterials for use in implants such as artificial knee joints, hip joints and dental roots. The alloys are mainly used in implants that replace hard tissue in the human body such as bone. The alloys are required to have a long fatigue life, high fatigue strength as well as a low elastic modulus equivalent to that of cortical bone [25], [26].

Dense titanium implants have an elastic modulus of 80-130 GPa [23] which is much higher than that of natural bone (0.1 – 20 GPa) [27]. This causes stress shielding which leads to the loosening of the implant and contributes to the early failure of the implant material [28]. Extensive research has thus been carried out to develop new titanium alloys with a lower elastic modulus. Niobium (Nb), tantalum (Ta), silicon (Si), zirconium (Zr), molybdenum (Mo) and tin (Sn) are commonly used to develop new titanium alloys [19], [25], [28], [29], [30], [31].

Titanium is a transition metal with an incomplete shell in its electronic structure. This enables it to form solid solutions with most substitutional elements with a size factor of ±20%. Titanium has a high melting point of 1678°C in its elemental form [23]. It also undergoes an allotropic transformation at 882.5°C [32] where it changes from the alpha phase to beta phase which are the hexagonal close-packed (HCP) and body-centred cubic (BCC) structures respectively [8], [24], [33]. The transformation temperature is strongly influenced by the addition of certain elements. Elements that produce an increase in the temperature of transformation are aluminium (Al), oxygen (O), nitrogen (N) and carbon (C) and known as alpha stabilizers. Elements that produce a decrease in temperature of transformation are known as beta stabilizers and include molybdenum (Mo), vanadium (V), niobium (Nb), copper (Cu) and silicon (Si). Other elements have little influence on the transformation temperature and are known as neutral elements (Sn and Zr) [3], [8], [16], [24]. Titanium alloys are classified into four main groups:

- Unalloyed titanium
  These alloys present excellent corrosion resistance but have low strength properties. Increases in strength can be achieved by the addition of small amounts of oxygen (O) and iron (Fe) [8].
- Alpha and near-alpha alloys

Alpha alloys contain alpha stabilizers and present excellent creep resistance; near-alpha alloys are alpha alloys that contain limited quantities of beta stabilizers but behave more like conventional alpha alloys [8], [16]. These alloys exhibit superior corrosion resistance with their use as biomedical materials being principally limited by their low strength at ambient temperature [23]. Alpha titanium alloys have thus far not been involved in the development of biomedical applications [24].

- Alpha-beta alloys

  This group presents a mixture of “alpha” and “beta” phases at room temperature and contains additions of both alpha and beta stabilizers. This group of alloys is the largest used in the aerospace industries, and Ti-6A1-4V is its most common alloy [8]. Alpha-beta alloys exhibit higher strength due to the presence of both alpha and beta phases. Their specific properties depend upon composition, the relative proportions of the alpha/beta phases, and the alloy’s prior thermal treatment and thermo-mechanical processing conditions [23]. Alpha-beta alloys have the greatest commercial importance for biomedical application, since Ti-6Al-4V and Ti-6Al-4V ELI are widely used as loadbearing orthopaedic implants due to their relatively superior fatigue resistance and biological inactivity. These alloys however suffer from a large degree of biomechanical incompatibility, due to their relatively high elastic modulus compared to that of bone tissue [24]. Thus for example when used as a hip implant, these alloys take over a considerable part of body loading, which shields the bone from the necessary stressing required to maintain its strength, density and healthy structure. This effect, known as stress shielding, is one of the main mechanical factors leading to aseptic loosening of metallic implants [23], [34].

- Beta alloys

  This group contains significant quantities of beta stabilizers and is characterized by high hardenability but also a higher density [8]. Beta alloys (metastable or stable) are titanium alloys with high strength, good formability and high hardenability. Beta alloys also offer the unique possibility of combined low elastic modulus and superior corrosion resistance [23]. Metastable beta titanium alloys contain enough beta stabilizing elements to displace the martensite start line (Ms) at room temperature, consequently avoiding the formation of martensite alpha upon quenching [24].

Most of the biomedical titanium alloys belong to the alpha-beta or metastable beta class. The Ti–6Al–4V alloy is still the most commonly used alpha-beta titanium biomedical alloy and is normally used in an annealed condition. The metastable biomedical alloys are preferred in solution treated (ST) and, ST and aged conditions. The alpha-beta treated structures have higher strength, higher ductility and higher low cycle fatigue resistance while the beta treated structures have higher fracture toughness. In general, the strength of an alloy increases with increasing beta stabilizer content [16].

Alloy chemistry and structural components appear to have a significant influence on the elastic modulus of the alloys. Since the high modulus of alpha-beta titanium alloys results in bone resorption and implant loosening, lower modulus alloys that retain a single phase beta microstructure on rapidly cooling from high temperatures are attracting a great deal of interest [16].

Theoretical studies of Yong *et al.*, [35] have shown that niobium (Nb), zirconium (Zr), molybdenum (Mo), and tantalum (Ta) are the most suitable alloying elements that can be added to decrease the modulus of elasticity of BCC titanium without compromising the strength. It has been observed that addition of these alloying elements up to a certain weight percentage decreases the modulus, beyond which an increase in modulus is noted which is due to omega phase formation and precipitation of alpha on aging [36], [37]. It is also interesting to note that these elements belong to the category of non-toxic elements, which makes them more suitable for implant applications [38]. Based on these considerations the biomedical titanium alloys developed recently, consist mainly of titanium (Ti), niobium (Nb), tantalum (Ta) and zirconium (Zr). Alloys such as Ti-29Nb-13Ta-4.6Zr, Ti-35Nb-7Zr-5Ta and several other compositions have now been receiving considerable attention and are investigated seriously [23], [28], [39]. Metastable beta alloys developed in the recent past include Ti-Mo-6Zr-2Fe (TMZF), Ti-15Mo-5Zr-Al, Ti-15Mo-3Nb-3O, Ti-15Mo-2.8Nb-0.2Si (TIMETAL 21SRx) and Ti-13Nb-13Zr [16].

The beta titanium alloys are generally solution treated in the beta phase field and aged to decompose the metastable phases and achieve high strength. In spite of the fact that a variety of microstructures can be formed in beta alloys by appropriate heat treatment, in particular, equiaxed structures in the beta alloys are tried with great interest seeing as equiaxed structures have been found to possess the best combination of mechanical properties in the alpha-beta alloys [40]. It is important to note that thermo-mechanical processing of biomedical beta alloys has hardly received any attention and the first report on the effect of thermo-mechanical treatment on the development of equiaxed structure in Ti-13Nb-13Zr came out from the work of Geetha *et al.*(2004), [40].

Biomedical titanium alloys applied as biomaterial in hard tissue replacement should exhibit a low elastic modulus combined with enhanced strength, high fatigue resistance and good workability. The mechanical behaviour or titanium alloys are directly related to composition and thermo-mechanical processing [3]. Table 1 presents some mechanical properties of selected titanium based alloys that have been developed for medical applications [28].

Table 1: Selected titanium based alloys developed for medical applications [28].

Material	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Elongation	Elastic Modulus (GPa)
Alpha type				
Pure Ti grade 1	240	170	24	102.7
Pure Ti grade 2	345	275	20	102.7
Pure Ti grade 3	450	380	18	103.4
Pure Ti grade 4	550	485	15	104.1
Alpha-beta type				
Ti-6Al-4V	895-930	825-869	6-10	110-114
Ti-6Al-4V ELI	860-965	795-875	10-15	101-110
Ti-6Al-7Nb	900-1050	880-950	8.1-15	114
Ti-5Al-2.5Fe	1020	895	15	112
Beta type				
Ti-13Nb-13Zr	973-1037	836-908	10-16	79-84
Ti-12Mo-6Zr-2Fe	1060-1100	1000-1060	18-22	74-85
Ti-15Mo	874	544	21	78
Ti-15Mo-5Zr-3Al	852-1100	838-1060	18-25	80
Ti-15Mo-2.8Nb-0.2Si	979-999	945-987	16-18	83
Ti-35.3Nb-5.1Ta-7.1Zr	596.7	547.1	19	55
Ti-29Nb-13Ta-4.6Zr	911	864	13.2	80

The specific mechanical properties decide the type of material that will be selected for a specific application. The properties of prime importance are hardness, tensile strength, modulus of elasticity and elongation [16].

Mechanical strength of the alloys can be increased by adding alloying elements, which may lead to solid solution strengthening, or even precipitation of second phases. By using ageing processes, metastable structures obtained by rapid quenching from beta field may give rise to fine precipitates, which considerably increases the mechanical strength [3]. Titanium alloys present a high strength-to-weight ratio, which is higher than most steels. While commercially pure (CP) titanium has a yield strength between 170 (grade 1) and 485 MPa (grade 4), titanium alloys may present values higher than 1500 MPa [41].

The elastic modulus corresponds to the stiffness of a material and is associated to the way interatomic forces vary with distance between atoms in the crystal structure. A comparison between both crystal structures of titanium has led to the conclusion that the HCP crystal structure presents higher values of elastic modulus than the BCC structure. Hence, addition of beta-stabiliser elements allows beta phase stabilisation and hence, low elastic modulus alloys. While CP titanium displays elastic modulus values close to 105 GPa, Ti-6Al-4V type alpha-beta alloy presents values between 101 and 110 GPa, and beta type titanium alloys may present values as low as 55 GPa [28]. When compared with common alloys used as biomaterials, such as 316 L stainless steel (190 GPa) and Co-Cr alloys (210-253 GPa), low elastic modulus titanium alloys display a more compatible elastic behaviour to that of human bone [42]. In general, as the elastic modulus decreases, so does the mechanical strength and vice versa.

The elastic modulus of 316L stainless steel and Co–Cr–Mo alloy are much greater than that of cortical bone. The elastic modulus of the alpha-beta type titanium alloy, Ti–6Al–4V (the most widely used titanium alloy for biomedical applications), is much lower than those of stainless steel and Co based alloys. However, its elastic modulus is still much greater than that of cortical bone. The elastic modulus of beta type titanium alloys are known to be smaller than those of alpha or alpha-beta type titanium alloys [1]. Beta type titanium alloys show excellent cold workability and high strength and the elastic modulus of beta type titanium alloys are recognized to be much smaller than that of the alpha-beta type titanium alloy, Ti-6Al–4V ELI. The elastic modulus increases with the precipitation of alpha phase or beta phase by aging treatment in beta type titanium alloys [2]. Therefore the elastic modulus tends to increase with increasing strength by aging treatment in beta type titanium alloys. The elastic modulus can also be controlled by aging treatment in beta type titanium alloys. The strength of beta type titanium alloys can be increased with keeping the elastic modulus low by cold working after solution treatment because high ratio cold working is possible in beta type titanium alloys.

3 MACHINABILITY OF TITANIUM AND ITS ALLOYS

Titanium alloys are among the most widely used and promising materials for medical implants. The selection of a titanium alloy for implantation is determined by a combination of the most desirable characteristics including immunity to corrosion, biocompatibility, shear strength, density and osseointegration [43].

Generally, there are three main aspects of machinability namely: tool life, surface finish, and power required to cut [44]. Part accuracy and the chip form or chip breakability are also used to assess machinability. The best criterion for rating machinability under normal conditions is the machining cost per part and under special conditions where machine capacity is limited and production output is of major concern, the proper machinability criterion is the number of parts per unit time [44]. Research by Kahles *et al.* (1985) show that power requirements of cutting titanium alloys are lower than those required to cut steels and Nickel and Cobalt-based alloys. Their result is similar to the findings of Motonishi *et al.* (1987), who state that no definite relation between cutting force, hardness and tensile strength of the titanium materials exists. They conclude that it cannot be said that the magnitude of cutting force causes difficulty in cutting [45].

With regard to tool life however, the machinability of titanium and its alloys is poor. The tool wear is inherently high and the cutting speed must be kept low, which gives rise to high machining cost per part [44]. Table 2 presents some machining time ratios for various types of titanium alloys compared to AISI 4340 steel at 300 BHN (Brinell hardness number).

Table 2: Machining time ratios for various types of titanium alloys compared to AISI steel at 300 BHN [44].

Titanium alloy	Turning (Carbide Tool)	Face milling (Carbide Tool)	Drilling (HSS Tool)
Commercially pure 175 BHN	0.7:1	1.4:1	0.7:1
Alpha Ti-8Al-1Mo-1V 300 BHN	1.4:1	2.5:1	1:1
Alpha-beta Ti-6Al-4V 365 BHN	2.5:1	3.3:1	1.7:1
Beta Ti-13V-11Cr-3Al 400 BHN	5:1	10:1	10:1

Wang *et al.* (2007) also reported that it takes over three times as long to manufacture parts from titanium as to manufacture them from aluminium alloys [27]. It can be seen from table 2 that the hardness has a big impact on the machinability. This phenomenon is also reported in Trucks (1987), who claims that the machining characteristics of titanium alloys change significantly at hardness levels of 38 Rockwell (C scale). From the table it can be seen that the alloy type also has an impact on the machinability. When ranked in a descending order in terms of machinability, the materials are commercially pure titanium, alpha alloys, alpha-beta alloys, and beta alloys.

There are various types of cutting tool materials currently on the market for use in machining, including carbide, high-speed steel, cast cobalt alloy, ceramic-based alumina, diamond and others [15]. Due to all aforementioned issues, the choice of cutting tool material has been limited to carbide tools [13], [44]. The use of straight tungsten carbide cutting tools is superior in almost all machining processes of titanium alloys and it is the preferred material for machining titanium and its alloys [46]. Carbide-based cutting tools have been the most extensively used tool in the machining industry since they were introduced in Germany in the 1920s to fulfill the high-wear-resistance requirement of the mould industry [15]. Carbide-based cutting tools are produced from the mixture of a carbide compound and a soft, ductile metal binder. This mixture is compressed before being sintered, making the resulting material hard and highly resistant and resilient to heat.

Cutting tools composed of tungsten carbide (WC) with a cobalt (Co) binder were the first to be fabricated in the industry [15]. In order to ensure good tool life, cutting speeds for Ti-6Al–4V are often limited to 60 m/min [13], [47]. There are several ways to improve the machinability of titanium. These include the use of standard coolants or lubricants [13], cryogenic cooling [48], [49] and the use of alternate cutting tool materials [50] such as coated carbide cutting tools.

It is reported by Ezugwu and Wang (1997) that progress in the machining of titanium alloys has not kept pace with advances in the machining of other materials [13]. This is due to their high temperature strength, very low thermal conductivity, relatively low modulus of elasticity and high chemical reactivity. Therefore, success in the machining of titanium alloys depends largely on the overcoming of the principal problems associated with the inherent properties of these materials [13].

3.1 Specific Machining problems

It is frequently reported that one or more factors are those most responsible for the poor machinability of titanium and its alloys. However, many characteristics operate together to cause this metal to be classified as a difficult to machine material. The reasons for the poor machinability of titanium and its alloys include the following:

1. The high strength is maintained to elevated temperatures generated in machining and this opposes the plastic deformation needed to form a chip [8].
2. Titanium produces a relatively thin chip resulting in an unusually small contact area with the tool. It is one-third that of the contact area of a steel at the same feed rate and depth of cut [8], [12], [51]. This causes high pressure and hence high contact stresses on the tool, in spite of cutting forces that are reported to be similar to steel [8]. Hence the power consumption in machining is approximately the same. The combination of a small contact area and the low thermal conductivity results in high cutting temperatures. The cutting speed of the titanium should be low to avoid an excessively short tool life. The high unit pressure resulting from the thin chip, high surface friction and high heat generated could give rise to pressure welding and galling [44].
3. It has a high coefficient of friction between the chip and the tool face; however this is in line with that obtained in machining many steels [51].
4. There is strong chemical reactivity of titanium at the cutting temperature (> 500°C) with almost all tool materials available [8], [44]. High affinity of titanium and its alloys for the interstitial oxygen and nitrogen gives rise to the pick-up of interstitials of the heated outer surface layer of the work piece during machining, which contributes partially to the hardening of titanium and its alloys in addition to the strain hardening [44]. The active properties of titanium alloys control tool wear rate, especially crater wear [45].
5. The adiabatic or catastrophic thermoplastic shear process by which titanium chips are formed. The low volumetric specific heat of titanium together with a relatively small contact area and the presence of a thin flow zone (8 μm compared to 50 μm when cutting steel) cause high tool-tip temperatures of up to 1100°C [8].
6. Even though the built-up edge have been said not to occur, its presence have been confirmed at low cutting speeds, and this could lead to a poor surface finish in some operations [32].
7. Low modulus of elasticity which can cause chatter, deflection and rubbing problems [8], [44]. The forces perpendicular to the work piece may increase three to four times as a result of a build-up of titanium on the wearland of the tool (the cutting forces will generally increase 25 to 50% as the tool dulls when cutting a steel) [51]. Because of this high thrust force and the low elastic modulus of titanium, the deflection of the work piece can be a serious problem. When subjected to cutting pressure, titanium deflects nearly twice as much as carbon steel due to its low young's modulus values. The greater spring-back behind the cutting edge results in premature flank wear, vibrations and higher cutting temperatures [13]. In effect, there is a bouncing action as the cutting edge enters the cut. The appearance of chatter may also be partly ascribed to the high dynamic cutting forces in the machining of titanium. This can be up to 30% of the value of the static forces due to the adiabatic or catastrophic thermoplastic shear process by which titanium chips are formed [32].
8. Care should be taken considering titanium's tendency to ignite during machining because of the high temperatures involved [8], [44].

9. There is a high rate of work hardening although it work-hardens to a lesser extent than steel [8].
10. The poor thermal properties of the materials [8], [44]. This problem may be more pronounced in drilling operation using conventional twist drills because cutting speed diminishes towards the centre resulting in considerable cutting forces and excessive heat [44].

All these factors above, whether they are operating separately or in combination cause rapid wear, chipping or even catastrophic failure of the tools and hence add to the difficulty in machining titanium and its alloys for medical application.

4 FUTURE MACHINABILITY RESEARCH

Bone is a living anisotropic and viscoelastic material and it remodels in response to the mechanical demands placed upon it according to Wolff's law [52]. Of utmost importance in the consideration of implants, is device stiffness, which can be defined as the product of the moment of inertia and the modulus of elasticity. A low stiffness as close to that of the natural bone as possible provides a good load transfer whereby the stimulation of new bone formation is achieved [24]. While stress shielding (high stiffness) results in bone resorption [2], a low stiffness under static and/or dynamic loading will provide an elastic elongation of the cells in the vicinity of the implant which will stimulate the deposition of calcium, which is the basis of bone formation. In the region of physiological stress and strain, respectively, bone formation and resorption are balanced. A decrease in the stress in this region causes resorption, which decreases the cross section of the bone, whereby stress and bone formation are increased until equilibrium is again achieved [24].

Cyclic loading is applied to orthopaedic implants during body motion which results in alternating plastic deformation of microscopically small zones of stress concentration produced by notches or microstructural inhomogeneities. The interdependency between factors such as implant shape, material, processing and type of cyclic loading, makes the determination of the fatigue resistance of a component an intricate, but critical, task [23]. The response of the material to the repeated cyclic loads or strains is determined by the fatigue strength of the material and this property determines the long-term success of the implant subjected to cyclic loading. If an implant fractures due to inadequate strength or mismatch in mechanical property between the bone and implant, then this is referred to as biomechanical incompatibility. Thus a material with excellent combination of high strength and low modulus closer to bone has to be used for implantation to avoid loosening of implants and higher service period to avoid revision surgery [16].

As mentioned previously, titanium alloys for biomedical applications should exhibit a modulus of elasticity as close as possible to cortical bone, enhanced strength, good fatigue resistance and good corrosion resistance. Figure 1 shows a comparison of the average modulus of elasticity between alpha type, alpha-beta type and beta-type titanium alloys developed for medical applications. From the figure it can be seen that the beta type alloys show the lowest modulus of elasticity when compared to the alpha and alpha-beta type alloys. Therefore, in future machinability studies of titanium alloys for biomedical applications the following beta type alloys need to be included in the research.

- Ti-13Nb-13Zr
- Ti-12Mo-6Zr-2Fe
- Ti-15Mo
- Ti-15Mo-5Zr-3Al
- Ti-15Mo-2.8Nb-0.2Si
- Ti-35.3Nb-5.1Ta-7.1Zr
- Ti-29Nb-13Ta-4.6Zr

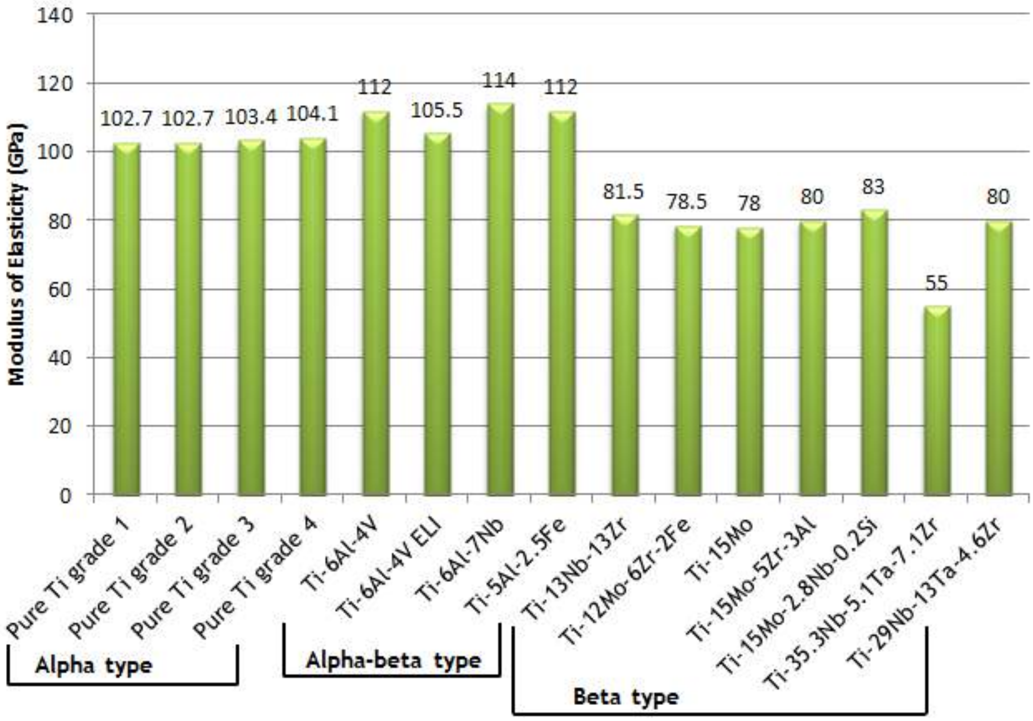

Figure 1: Comparison of the elastic modulus of various alpha, alpha-beta and beta type titanium alloys

The aim of these studies should focus on machining methods to reduce the cost of manufacturing these titanium alloys, ensuring their acceptance in the market segment of biomedical materials for orthopaedic implants.

5 CONCLUSION

- The beta type titanium alloys are the most suitable alloys for medical implants.
- Titanium alloys for medical implants should have a modulus of elasticity as close as possible to cortical bone to prevent stress shielding, enhanced strength, good fatigue resistance as well as good corrosion resistance.
- Titanium alloys that are suitable for bone implants should contain no elements with potential adverse effects on the tissues of the human body, such as vanadium, copper, chromium, cobalt and nickel. Aluminium should only be used in minimally acceptable amounts
- Titanium and its alloys are generally classified as a difficult to machine material and this leads to high costs of manufacturing biocompatible titanium alloys for biomedical applications.
- Future machinability studies should attempt to reduce the manufacturing costs of beta type titanium alloy biomedical implants.

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OPTIMIZING INVENTORY ORDERING POLICIES WITH RANDOM LEAD TIMES

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ABSTRACT

One area of focus by inventory managers is the ability to cope with random fluctuations in lead times. These random lead times may be caused by many factors such as run-time or operation time, set-up time, waiting time, customers' demands, machine down-times, handling time and lot size inspection time which may all be random. The present paper concentrates on the impacts of maintenance operations and fluctuation in demand volume on the random lead times that in turn affect the optimal inventory level. The paper proposes stochastic models for periodic (R,S) and continuous (r,q) inventory levels that depend on total Lead Time. Results reveal that increase in machine breakdown time brings about a reduction in depletion rate and increase in demand increases the depletion rate. An increase in depletion rate is revealed by the fact that time evolution of the inventory level lies above that of a deterministic system. Thus the optimal inventory level can only be determined by following the plot derived from the model.

***Keywords*: random demand, random maintenance operation, random Lead Time, inventory level**

1 INTRODUCTION

Lead Time is defined as the time that elapses between the placement of an order and the receipt of the order. It is usually defined for a stock-pile-up inventory or stock-shipment inventory. In most deterministic and stochastic inventory models encountered in the literature, the optimal policy is determined with the assumption that **Lead Time** is independent parameter [1]. However, **Lead Time** is composed of many controllable components such as run time, set-up time, waiting time, moving time and lot size inspection time [1]. **Lead Time** may influence customer service and impact inventory costs. These effects of **Lead Time** are well known but are too general to be used in practical ways. In fact, under practical situation, **Lead Time** should be reduced. Consequently, it is important to know how and to what extent each of the many components of the manufacturing lead time influence the level of inventory in order to select the most cost effective inventory model [2].

There is a growing literature on modelling the effects of changing **Lead Times** on inventory control models. Many studies that deal with **Lead Time** reduction in inventory review models have been performed in the past years [3,4]. Lin [5]. Examined the effects of the reduction of the **Lead Time** associated with the controllable backorder rate in the periodic review inventory. Later, many methods for reducing **Lead Time** and their impact on the safety stock and the expected total cost of a continuous (r, q) inventory review models were studied [6]. The focus by Glock [6] was on a single vendor- single buyer integrated inventory model with stochastic demand and variable lot size-dependent **Lead Time**. It was assumed that lead time consist of production, set-up and transportation times. As a consequence, it was found that **Lead Time** may be reduced by increasing producing rate or by reducing the lot size [6]. In many practical ways, by reducing the **Lead Time**, it is possible to lower the safety stock, reduce the stock-out level and improve the customer service level. It should be noted that the work of Glock [6] was dealing with random demand (or specifically variable lot size). Furthermore, the work did not include the impact of maintenance operations that may take place. It should, further, be noted that the variable lot size as proposed by Glock [6] can be deterministic and not stochastic as considered in the present paper. Thus, this present paper seeks to improve on previous results by considering random downtimes (or maintenance) and random demands (or stochastic lot size). It should be emphasized that the inventory level at any time depends on the actual inventory policy in place.

In classical periodic (R,S) and continuous (r,q) inventory review models with deterministic demand and **Lead Time**, the problem of shortage is easy to address. It is possible to predict what the inventory level would be when an order arrives. This is not easy when the demand and **Lead Time** are random. For instance, there are situations where the replenishment may take even longer. This situation happens if there are disruptions at the producer level. That is why it is necessary to carry some additional stock to avoid stock-out costs that may occur, especially when the **Lead Time** is also random. This stock, known as safety stock, is defined as the expected value of the net inventory at the time an order arrives. In reality, when the fluctuations in demand are high, a reasonable amount of safety stocks are required to avoid stock-out, and as result, holding costs are increased. This issue indicates that controlling the **Lead Time** should be the principal concern in backordered environment because it directly affects the safety stock level. Unfortunately, for classical periodic (R,S) and continuous (r,q) inventory review models, the lead time and safety stock are rarely designed to be fully utilized under different and uncertain conditions such as poor operation maintenance performance and demand fluctuation. A sound mathematical approach to **Lead Time** will therefore help to determine the appropriate inventory level.

2 METHOD

The relationship between inventory level, flow rate and time that may be used for inventory system is represented as follows [7].

$$I = I_0 \pm \frac{Q}{MLT} * t \qquad (1)$$

Where I_0 is the initial inventory, Q is the demand, MLT is the manufacturing Lead Time or inventory replenishment time, t is the time and Q/MLT is the flow rate. The "±" is used to represent whether stocks are piled up (+) or shipped out to customers (-).

The ability of manufacturing firm to keep the optimal product inventory level is hugely dependent on demand. In general, it is assumed that the *MLT* model comprises at least demand size (or lot size), the waiting time, processing time, inspection time, moving time and queuing time, which are all stochastic in nature. The general mathematical formulation of the manufacturing Lead Time can be written as follows [7].

$$MLT(t) = n_0\left(T_{su} + QT_c + T_{no}\right) \qquad (2)$$

Where MLT = total lead time for an order, Q = Batch quantity of all product or demand or lot size, n_0= Number of "machines" along the line, T_{SU}=up time or waiting time to prepare for the batch quantity Q, T_C = Operation cycle time and

T_{no} =Non operation time (source of delay mainly due to transportation time, waiting time, queuing time, etc.). From the general model, the *MLT* or delivery cycle time that is dependent on the type of maintenance program implemented is therefore determined.

2.1 MLT with reactive maintenance time

Reactive maintenance is the type of maintenance in which equipment is maintained when they break down or which occurs within production cycle. This mode of maintenance is still being preferred and employed by some African manufacturing companies since it requires less staff and does not incur capital cost until something breaks. In this case, the *MLT* may be represented by the following formula:

$$MLT(t) = n_0\left(T_{SU} + Q(T_{operation} + F_{Corrective} * T_{Corrective}) + T_{no}\right) \qquad (3)$$

2.2 MLT with preventive maintenance time

Preventive maintenance program is the type of operation in which actions are performed according to a specific schedule so as to detect, prelude or minimize the degradation of equipment, or extend their life trough controlling their degradation to an acceptable level. Since preventive operation is performed while equipment is at rest, the manufacturing Lead Time is given as:

$$MLT(t) = n_0\left\{T_{SU} + Q(T_{operation}) + F_{preventive} * T_{Preventive} + T_{no}\right\} \qquad (4)$$

2.3 MLT with predictive maintenance time

Predictive maintenance is the type of operation in which measurements that detect the beginning of equipment degradation are taken so that they can be eliminated or controlled in either reactive or preventive maintenance. In predictive maintenance, the MLT is, thus, given as follow:

$$MLT(t) = n_0\{T_{SU} + Q(T_{operation} + F_{corrective} * T_{corerective}) + F_{Preventive} * T_{Preventive} + T_{no}\} \quad (5)$$

For all the three types of maintenance operations mentioned above, the probability of breakdown or downtime is represented by F_i and the average downtime is represented by T_i where *i*' stand for the type of maintenance operation. The time increment of *MLT* may then be obtained and results made stochastic by addition of periodic and continuous fluctuation [8-12] terms given as.

$$d(MLT(t)) = T_C * \frac{\partial Q}{\partial t} dt + Fluctuation \quad (6)$$

Equation (1) and (6) are solved simultaneously while taking into consideration the constraints given by expression (3),(4) and (5)

3 RESULT AND DISCUSSION: Illustrative examples

An illustrative simulation-optimization for the three different maintenance programs is dealt with. The parameters to be dealt with are obtained from empirical data. The expected demand may evolve linearly. Due to the continuous and periodic fluctuations, the demand quantity can be represented as follow as $q = a + \int_0^T (b + f_C + f_P)dt$ where $f_C = c*t$, $f_P = p\sin(d*t)$, *a*=20= initial demand, *b*=0.025= rate of change of demand, *c*=0.00007, *d*=1, *p*=4. The machine parameters are given as n_0=3, T_{su}=1.5min, T_{no}=0.5min, $T_{operation}$=1.5min, $F_{Corrective}$=0.0008, $F_{Predictive}$=0.000008, $F_{Preventive}$=0.009, $T_{Dcorrective}$=2min, $T_{Dpredictive}$=1.5min, $T_{Dpreventive}$=0.5min and *T*=6000min. It should be noted that f_c and f_p are fluctuation terms respectively. The results are presented in the plots below.

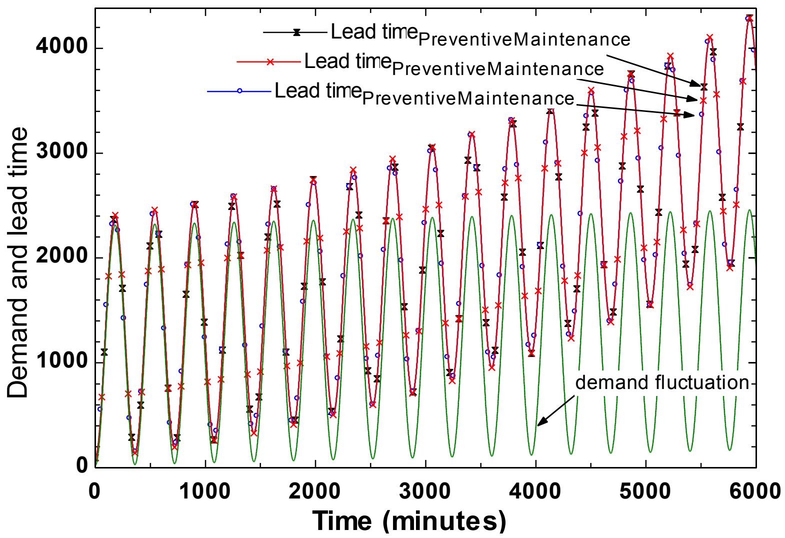

Figure1: The impact of maintenance program time and demand on the MLT an

It should be observed that the demand volume fluctuates in the same way as mamufacturing lead time, although MLT increases more rapidly than demand. This radid increase is because the MLT is the time that it takes from the receipt of demand-order until when the demand is completely devilvered to the satisfied customer. The deviation between the MLT and demand increases as time progresses is shown in figure 1 and figure 2. The higher increase (or deviation) of the MLT may be due to the fact that equipments may break down during the demand-lead time, and it takes random amount of time maintaining them. The time spent maintaining these equipments should then increase the MLT and may therefore affect the delivery of products to customers. In fact the long run behaviour shows that demand evolves linearly while the MTL evolves in a parabolic manner which is not one-to-one relationship as many be predicted by expression (2).

The effects of MLT and demand level on the inventory level are found in figure 2. It should be recalled or mentioned here that the inventory trend or inventory level depends on whether inventories are piled up or shipped out. From shipment operation angle, it is observed that a linear increase in demand results in a parabolic decrease in the inventory level. It is obvious that an increase in demand should bring about a decrease in Inventory level for shipment operations, but the interesting revelation is that this decrease in inventory level is not linear as that of demand. The long run behaviour of the shipment operation indicates a point whereby there is rapid increase in inventory level as demand increases before another decay with further demand increase. This abrupt increase is a subject of further investigations. For inventory pile-up, it is seen that as demand increases linearly, the inventory level decreases in a parabolic manner, but this time with the axis of symmetry being the time axis. The abrupt drop in demand is also observed under this scenario.

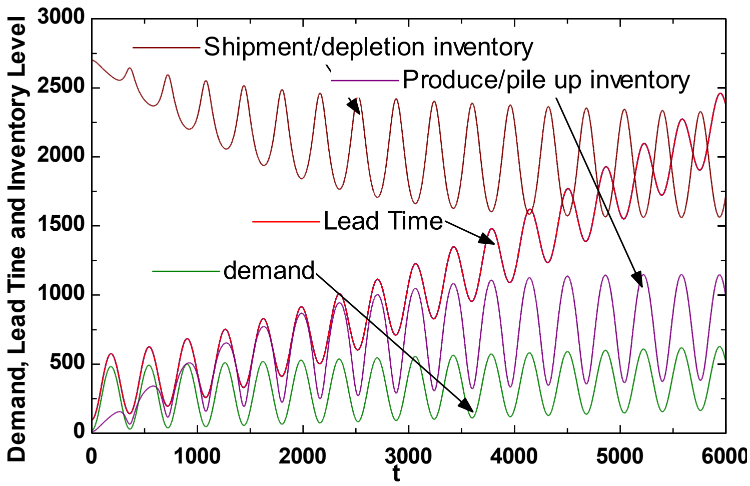

Figure 2 **The impact of time on manufacturing Lead Time, inventory level from consuming and producing companies**

One can then see that the relationships between demand level, maintenance time and inventory level are not one-to-one. Thus, the use of the models proposed here might be beneficiary.

4 CONCLUSIONS AND RECOMMENDATION

This paper shows how simulation model and simulation optimization can be used to investigate the effects of maintenance program time and varying demand volume on the inventory level which in turn affects the manufacturing system performance.

It was also found that as time goes by, maintenance operation affects the MLT and then the inventory level depending on whether the analysis is made on stock pile-up or stock shipmet angle.

It is also observed although demand may vary linearly, the variations in MLT and inventory levels turned out to be parabolic, which does not trivially follow up from the one-one-relationship as give by expression (2).

Thus, the use of the models proposed here might be beneficiary as they indicate deviations that are inherent from the probable maintenance operations.

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THE IMPLEMENTATION OF SIX SIGMA PROCESS IMPROVEMENT IN A SMALL FLEXIBLE ENTERPRISE WITH LIMITED RESOURCES

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ABSTRACT

A small manufacturer in Cape Town with 60 employees successfully supplies low volume, specialized socks to its South African customers through fast delivery and high quality. Although the quality delivered to the customer is mostly very good, due to extensive visual inspection before the customer shipment, the processes within the company can be improved.

The Six Sigma process improvement methodology is often used in large corporations to improve complex processes, whereby trained experts titled as Six Sigma belts support the implementation. It is yet unknown if this system can be effectively implemented in a small, responsive enterprise with a low average level of education and extensive resource constraints.

The real-world implementation of the Six Sigma Methodology will show the strengths and weaknesses of the method within a SME and an environment as described. Depending on the process identified and the time needed for improvement, metrics will be measured to validate the effects of the Six Sigma implementation. In addition to this the feedback of Industry experts will be used to confirm the legitimacy of the results.

1 INTRODUCTION TO SIX SIGMA

The practical implementation according to [1] and [2] and the analysis of the results gained thereby, will form the focal point of the abstract.

In this chapter a short description of the Six Sigma Methodology will serve as the introduction.

1.1 Origin

Six Sigma was formed by Motorola in the early 1980's with the intention of improving product reliability tenfold over a five year period. By 1988, the methodology had proved so successful that the company was awarded the Malcom Baldridge National Quality Award. Following this tribute, Motorola (Bob Galvin) decided to share Six Sigma with other companies in the world and it was rapidly adopted by other large manufacturers; most famously General Electric CEO Jack Welsh [3][4].

1.2 Definition

The content of Six Sigma varies within the different schools worldwide, as does the definition. A few examples in the literature are quoted in the following:

> '*The Six Methodology is a structured tool with techniques of quality management. It is an effectiveness approach that uses mathematic techniques to understand, measure, and reduce process variation. The core function is process improvement by striving for perfection*' [5].

Originally the statistical definition included that a process could shift 1,5 sigma without detection. Therefore, a 1.5 sigma drift margin was built into the standard definition. If a Six Sigma process shifts 1.5 sigma units from the process mean to left or right, the process would be 99.97% defect free, having 3.4 defects per million opportunities (See Figure 1) [6].

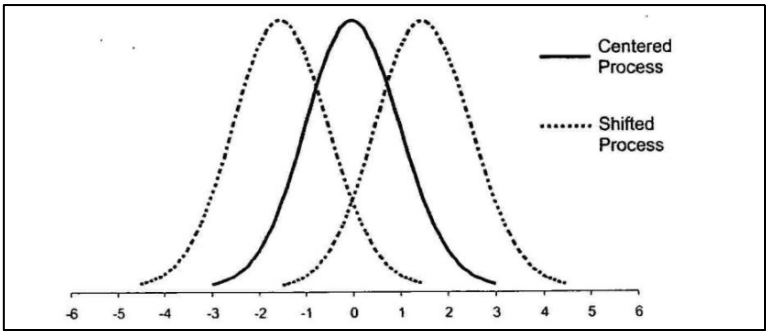

Figure 1 - Process shift of 1.5 Sigma units

1.3 Goal

The goal of Six Sigma is to minimize the number of defects that will cost more to correct in the long term than it would to prevent them from the start. Defects are not only limited to measurable errors, but are defined as anything that stops the process from running at a high quality from the perspective of the customer. These factors are regarded to be critical to quality (CTQ). A large amount of CTQ defects will lead to lost customers and reduced profitability [7][8].

1.4 Metrics

Six Sigma primarily uses three metrics to measure the effectiveness of a given process. These are:

Defects per million opportunities (DPMO's): Number of CTQ factors that are defective per million opportunities. When measuring, this value is extrapolated by sampling and it is not necessary that one million measurements be completed.

Error free yield (EFY): EFY is the percentage of a process that is free of defects.

Sigma Level (σ): σ is the Greek lowercase symbol for Sigma. The higher the sigma value, the lower the number of defects. This relation is described in Figure 2.

Provided one of these metrics is known, the others can be determined.

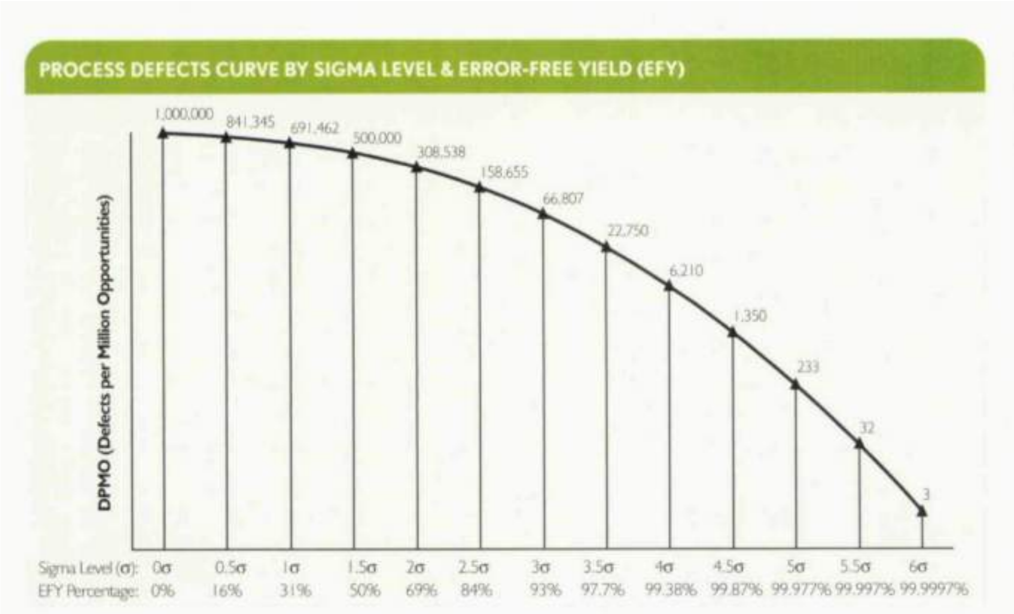

Figure 2 - Sigma Level & Error-Free Yield

1.5 Six Sigma Process

The steps of the DMAIC roadmap can be generally described as follows:

*'**Define** a project's purpose and scope, especially the output's CTQ factors;*

***Measure** by creating a performance baseline against which data evidencing errors can he compared, both leading to a more precise refining of the problem statement;*

***Analyse** root causes quantified by actual data;*

***Improve** performance by implementing procedures to eliminate the root causes of errors;*

***Control** the process by evaluating performance both before and after attempting improvement; initiating a monitoring system to reduce future errors; and documenting results, recommendations and lessons learned'* [7]

Within these phases the tools as described by [2] as well as those described by [1], will be used where possible at Sockit Manufacturing and described in detail.

2 PRELIMINARY EXPLORING

Before the practical implementation of the Six Sigma approach could be started, a basic understanding of the processes at Sockit had to be acquired. This was critical as the Six Sigma Methodology would be implemented without prior work experience in quality management or the textile industry and ideally the 'belt' implementing the methodology should be an employee with experience in the given company.[9]

To partially aquire this experience and trust the of the employees two weeks were spent creating a software supporting the label creation in the factory and linear programming was used to understand where the profit is made at Sockit better. A value stream map and an organogram shown in Figure 3 were created too.

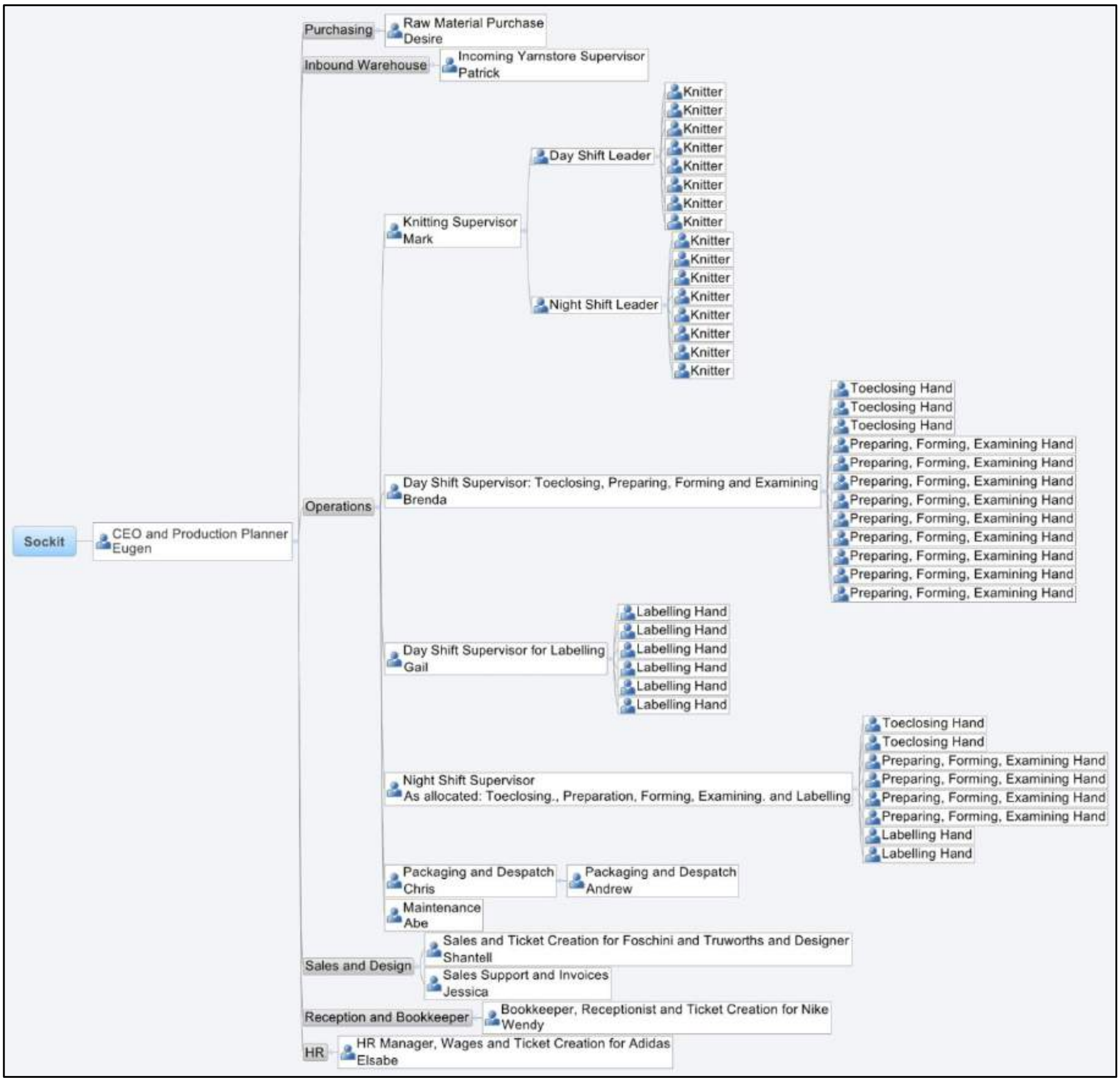

Figure 3 - Organogram

3 DEFINE

A better understanding of Sockit Manufacturing as a company had been acquired. The aforementioned also assisted in building a relationship with the employees and their trust. Therefore the implementation of the Six Sigma Methodology could now begin by starting with the first Phase of the DMAIC process: Define.

3.1 Project Charter

The Project Charter is the first tool of the Define phase according to [1][2].

It was finalised at Sockit Manufacturing as shown below (Table 1**Error! Reference source not found.**) after all the steps of the Define Phase were completed. Prior to this point no clear overview of the failure modes was known and the specific process problems to be solved were unclear.

At Sockit Manufacturing the project team consisted of all the key personnel per department. The CEO was selected as the champion and the author would fill the role of the belt.

Table 1- Project Charter

Project Charter			
Project Description	Optimisation of the Sock Production Process		
Project Nr.	Six Sigma Analysis		
Company	Sockit Manufacturing		
Department	Knitting Department		
Awarding Authority/ Champion	Stellenbosch University / Eugen Dohm		
Process Owner	Mark		
Start	10.09.2012	**End**	12.11.2012
Business Situation			
Product / Process	Knitting Process		
Problem Description	The Uptime in the knitting department is too low		
Situation the company is in.	Sockit is less responsive and efficient due to too low uptime.		
Problem and Project Goal			
The Problem Definition at the Project Kick-Off	Accurate data is not available yet. It is visible that the Knitting machines are often standing still for half a day due to unplanned maintenance. They are also standing for shorter intervalls		
Project Goal	Decrease the downtime which still has to be measured in order to be more specific.		
Project Benefits			
Direct Cost Saving	Missed deliveries, high inventory, direct maintenance cost (parts, labour etc.), additional		
Indirect Cost Saving	Yarn storarge cost, logistics, administration		
Direct Additional Revenue	increased sales		
Indirect Additional Revenue	-		
Advantages that do not influence the Revenue	Problem definition for future process improvements documented in the Define Phase.		
Advantage for the External Customer	Faster delivery		
Project Focus and Framework			
Project Focus	Knitting Process		
Internal Metrics	Load, Unload, Rework, Inspection, planned process maintenance, unplanned process		
Excluded from Project	Downtime on the toeclosing and forming machines is not relevant for this project.		
Roles and Milestones			
Project Manager	Markus Papsch	**Working Time in %**	100%
Team Members	Mark	**Working Time in %**	10%
	Abe	**Working Time in %**	10%
	Shiftleaders	**Working Time in %**	10%
		Working Time in %	
Support Required	Which resources are needed? E.g. Hardware, Software, Material, Equipment, Support of Experts	Knitting machine data read outs, Konrad von Leipzig and Eugen Dohm	
Milestones	Completion Date Define	28.09.12	
	Completion Date Measure	17.10.12	
	Completion Date Analyze	24.10.12	
	Completion Date Improve	31.10.12	
	Completion Date Control	Open	
Comments			
Awarding Authority		Projectmanager	

3.2 Stakeholder Analysis Matrix

The Stakeholder Analysis Matrix (Table 2)[2] indicates the importance and attitude of the stakeholders towards the Six Sigma Project. Herein the current attitude of the stakeholders and the required attitude for the project to be successful are indicated. The usual discrepancy at this point leads to the Strategy to Influence the Stakeholders (Table 3)[2].

Table 2 - Stakeholder Analysis Matrix

Stakeholder Analysis									
Processdescription									
	Which groups or persons are relevant?	*Is the stakeholder internal or external?*	*How relevant/what weighting/which Influence does the stakeholder have towards the project?*	*How can the stakeholder be judged concering their attitude/behaviour(O) and where should they stand in future (X)?*					*Are there possibly additional comments?*
Nr.	**Stakeholder**	**Classification**	**Importance**	**Attitude towards the project**					**Comment**
		internal / external	relatively unimportant (1) - of great importance (6)	*opposing strongly --*	*partially opposing -*	*Neutral 0*	*partially supportive +*	*supporting strongly ++*	
1	CEO Eugen	internal	6					O/X	Is not aware of a lot of the problems and wants to find out more
2	Knitting Department Lead Mark	internal	6				O	X	
3	Maintenance Abe	internal	6				O	X	
4	Shiftleader Raphael	internal	5		O			X	
5	Shiftleader ...	internal	5		O			X	
6	Shiftleader ...	internal	5		O			X	
7	Shiftleader ...	internal	5		O			X	
8	Raw Material purchasing Desire	internal	4		O			X	
9	Yarnstore Responsible Patrick	internal	4		O			X	

current state	O
Soll-Zustand	X
beides	O/X

In the strategy to influence the stakeholders, the effects of the Six Sigma Methodology that will influence the stakeholders positively are mentioned (Table 3). These simple points proved to be very effective as soon as they were consciously used to influence the stakeholders. The support gained from the stakeholders became stronger, and in addition to this influenced them to motivate their colleges to support the project too.

Table 3 - Strategy to Influence Stakeholders

Strategy to Influence Stakeholders							
Process Description							
	Which groups or persons are relevant?	*Is the stakeholder internal or external?*	*How relevant/what weighting/which Influence does the stakeholder have towards the project?*	*What attitudes exist in detail*	*Where is the starting point for influencing?*	*Who should influence the stakeholder?*	*How shall the stakeholder be influenced?*
Nr.	**Stakeholder**	**Classification**	**Importance**	**Expectation / Worries**	**Leverage**	**Strategy to Influence**	
1	Knitting Department Lead Mark	internal	6	more work	less frustration	Markus	easier control over department by measuring
2	Maintenance Abe	internal	6	more work, competence is measured	importance of maintenance	Mark	more time for maintenance made available in future if lack thereof is proven
3	Shiftleader Raphael	internal	5	more work, competence is measured	smoother work flow	Mark	explain possible improvements by measuring and analysing
4	Shiftleader ...	internal	5	more work, competence is measured	smoother work flow	Mark	explain possible improvements by measuring and analysing
5	Shiftleader ...	internal	5	more work, competence is measured	smoother work flow	Mark	explain possible improvements by measuring and analysing
6	Shiftleader ...	internal	5	more work, competence is measured	smoother work flow	Mark	explain possible improvements by measuring and analysing

3.3 SIPOC Map

The SIPOC-Map (Supplier, Input, Process, Output, Customers) (Table 4) is an identification- and communication tool. The identification of the departments involved in the processes, and the definition of the supplier-customer relationships over the process-inputs and – outputs is achieved.

The SIPOC would serve as a communication tool in the Define Step [1] and ensure a uniform understanding of the process.

Table 4 - SIPOC Map

SIPOC									
Sock Manufacturing									
Who are the Suppliers?		*How do the Suppliers contribute to my Process?*		*Overview of Process Steps*		*Which Product or which Service does the Process deliver.*		*Who are the Customers?*	
Suppliers		**Input**		**Process** *(High Level)*		**Output**		**Customers**	
	Polydye, Spintex, Elasticos,	1	Good yarn	Starting Point:			Good quality yarn	1	Knitting, Toeclosing
1	BG International, TRM	2	Bad yarn	Order		1	Rejected yarn	2	Supplier
	Not:Meagre, Martilon, Millcher	3	Wax				Wax	3	
	Upstairs Office, Yarn Store,	1	Order, Productionsheet,				Open socks, Seemless socks	1	Toeclosing
2		2	Tickets	Operation bzw. Aktivität		2	Used Yarn, Empty cones, Nor	2	Boarding
		3	Good yarn, wax	1	Receive Yarn			3	
	Yarn store, Knitting	1	Yarn	2	Knitting		Closed Socks, Cutoffs,	1	Forming
3		2	Open socks	3	Toeclosing	3	Waste from Errors	2	
		3		4	Forming			3	
	Knitting, Toeclosing	1	Seemless socks	5	Labelling		Boarded socks, water	1	Headercards, Seconds
4		2	Closed socks	6	Packing in plastic	4	Waste from errors	2	Packaging,
		3		7	Packing in boxes			3	Replenishment Nike
	N&R, Labels Incorporated	1	Header cards	8	Delivery		Labelled socks,	1	Packaging in plastic
5	International Trimmings,	2	Formed socks			5	Waste from errors	2	
	Alton Press	3	Kimbals, hooks					3	
	Preffpack	1	Plastic				Packaged Socks	1	Socks in boxes
6	Labelling	2	Labelled, not labelled socks			6		2	
		3						3	
	Yarnstore	1	Boxes				Socks in boxes	1	Nike, Adidas, Edgars,
7	Packaging in Plastic	2	Socks in plastic			7		2	Foshini, Reebok
	Customers	3	Buf tape, company name tape					3	Factory shop
	Jessy	1	Invoice				Socks in boxes	1	Eugens Van
8	Despatch	2	Packed Socks			8		2	Courier service
		3						3	
				Final Step:					
				Sockboxes at Customer					

3.4 Brainstorming

Although the use of brainstorming to determine problems within the process is not discussed in the book by '[2]' it is implemented at Sockit as defined by [1]'. This can be explained, as the practical example of [2] was implemented at an established company, with a higher average skill level and where current problem areas were clearer.

At Sockit Manufacturing there were concerns with regards to implementing the Murphy's analysis, as the staff members might be afraid to speak about issues in their department in front of their colleges. Quite a few feared losing their jobs if they mentioned any problems. For this reason the employees were interviewed on an individual basis, so their comments could be questioned directly. Hereby it would be more difficult for the person to withhold his opinion and the discussion could also be guided towards the problem source more. Additionally, worries about the consequences of the problem analysis could be discussed individually. By only interviewing one staff member at a time it also had minimal impact on operations and was in line with the target to be minimum resource intensive.

After interviews with the most experienced staff members were completed a first attempt was made to sort the answers into the problem categories [1]. At this stage it was still very difficult to prioritise and correctly allocate the problems to root causes. The issues were numerous and seemed chaotically spread over process steps in the different departments.

Therefore an attempt to use the Murphy's Analysis was made nonetheless, as it serves to structure the root causes of the failure modes and should help to identify further failure modes.

3.5 Murphy's Analysis

To summarise how a Murphy's Analysis is usually completed, it is described with the following steps [1].

1) Show SIPOC map and define the goal of the process:

2) It is brainstormed how the process can fail and each failure mode is written on an individual sticky note.
3) For each failure mode identify why the failure mode occurs.

As there was not enough time to group all the failure modes according to their exact root cause during the one and a half hour brainstorming session with the staff members, the final grouping was completed with the CEO (Figure 4). He had a good overview of the processes as he was involved in solving the operational problems on a daily basis. Whilst going through every sticky note for approximately one hour, it became clear that he was aware of most of the problems. Nonetheless, the feedback from the employees by means of the whiteboard allowed him to see where the staff was confused and in some cases where the intentions of the staff were aligned with his own, but still not executed due to lack of communication. At the same time the voice of the customer, which is defined as that of the CEO in 3.6, could be integrated into the problem definition phase very early.

Figure 4 - Failure Modes of CEO added and sorted according to affinity

3.6 Voice of the Customer

The customer at Sockit Manufacturing was defined as the CEO and not the organisations to which Sockit delivers for the following reasons:

1) The internal problems were obvious enough. Contact to the external customer was not needed for first improvements
2) The risk of creating new expectations needed to be prevented, especially as the result of the Six Sigma project at Sockit Manufacturing was uncertain.

3) The Six Sigma Methodology was implemented successfully at Roeko Kaffeegenuss GmbH [2], without direct contact to the customers outside the company.

3.7 Knitting Department VOC-2-CTQ-Matrix

In the Voice of the Customer to Critical to Quality Analysis (VOC-2-CTQ) the CTQ's show the properties of the process that influence how the customer sees the quality of the process. It was possible to define the problem categories [1]. These are defined as the key issues in accordance to [2].

The problems to be improved were narrowed down to those in the knitting department, as most of the errors occurring here influence all the downstream processes in the factory. From the twenty-five problem categories the following three (Figure 5) were selected as the Key Issues in the knitting department.

VOC-2-CTQ-Matrix								
What did the customer say?	*Who is the customer? Is he internal or external?*	*Howdid you get this information?*	*Critical to...?*	*What is the key issue?*	*What is the requirement in a measureable form?*		*In which SI-unit is the requirement measured?*	*What is the target value?*
VOC/VOB	***Customer***	***Source of information***	***Driver***	***Key issue?***	***CTQs***		***SI-unit***	***Target value?***
Errors in knitting, rejects on change over	CEO	Interview in front of Murphy's Analysis	**Quality**	Process defects too high	Rolled Throughput Yield (RTY) or First Time Right	Defects, Accuracy, Scrap, Rework Issues	%	90
The knitting machines are standing still too often.	CEO	Interview in front of Murphy's Analysis	**Business**	Knitting machine uptime too low	Value Adding Uptime		%	90
Theft, half used bobbins, unused yarn types	CEO	Interview in front of Murphy's Analysis		Process waste/loss is too high	Raw Material Losses	$\frac{\sum Inputs(kg) - \sum Outputs(kg)}{\sum Inputs(kg)}$	%	90

Figure 5 - VOC-2-CTQ Matrix

3.7.1 % Uptime of Process is too low in the Knitting Department

From the three Key Issues that were found, the problem category "% Uptime too low" was selected as the core issue for the Six Sigma Analysis at Sockit Manufacturing for the following reason:

It was unclear, why many of the machines were standing for longer periods in regular intervals. It was assumed that this was mainly due to too much unplanned maintenance, but this could not be proven.

This point will automatically be considered when looking at the downtime, as it will lead to the definition of one of the following problem categories with a high likelihood [1].

- Load, unload, setup- or change-over time is too long
- Re-work time or inspection time is too high
- Too much unplanned maintenance
- Planned maintenance takes too long
- Scheduled workforce breaks

4 MEASURE

The problem category was defined so the Measure phase could begin. The first step to solve this process problem is to complete a Measurement System Analysis. As no data was being taken at this time, a measurement system had to be set up. The best option would have been to purchase a software system from the knitting machine supplier which could automatically log the downtime on a central computer. As it was too expensive an alternative manual measuring system had to be found.

4.1 Manual Measurement of Downtime

For this purpose a downtime sheet was created.

4.1.1 Downtime Sheet

The shift leaders were asked to log the type of downtime with start- and end-time. The types of downtime were defined as follows: Loading Yarn, Unloading Yarn, Rework, Inspection of Machine, Planned Maintenance, Unplanned Maintenance, Break Downs, Scheduled Breaks, and Scheduled-Process-Downtime of any form, Change-over time and Setup time. It was important to communicate to the staff that whenever the machine stood still, it was defined as downtime.

4.2 MSA Downtime

As there was no variable data but just attribute data, a classical MSA showing the influence of the measuring device (repeatability), the variance caused by the operator (reproducibility) and the variation caused by the part adding up to the total variation, could not be shown.

4.2.1 Validation

To validate the attribute data logged by the shift leaders, a second method in parallel had to be implemented [1]. Therefore, a second sheet was created to monitor the Rate of Production on the machines. On this sheet, Time of Day, Nr of Socks and Cycle Time should be logged in regular intervals.

After a first test-run where the author measured the production speed to control the logged downtime, the following results were gained. For each drop in production, the cause was found in the downtime sheet and is noted below the graph as shown in Figure 6 for the machines 11-K.

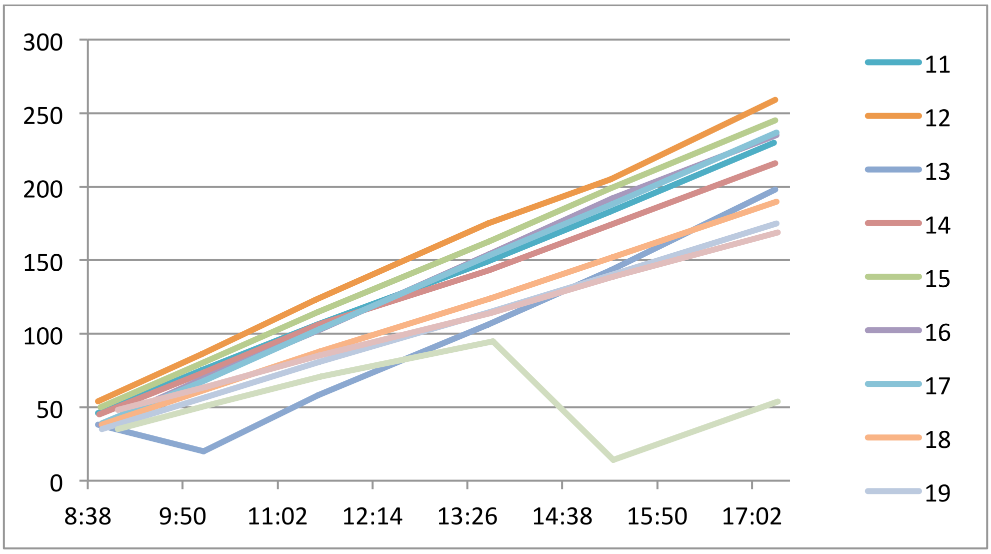

Figure 6 - Rate of Production Machine 11 - L

09:00: Machine 13 had a mechanical error that caused the pattern on the sock to be faulty. Unplanned maintenance was needed to repair the error.

14:00: A new sock type is produced on machine L

4.2.2 Validation Result

After the first measurements were completed it became visible that the different kinds of downtime had to be measured over a minimum of one week to draw valid conclusions.

During this phase it was also noticed that the operators were able to change the sock-count on the machines manually. However this did not have an influence on the validation, as the theoretically possible sock count could be compared to the amount that should be produced with the cycle time that was logged from the machines. After logging and doing the calculation, a method had been found to monitor the production performance by hand.

After discussing the diagrams the department head agreed to this method measuring.

4.2.3 Measuring by the Fixers

After a few weeks, it became apparent that the method to monitor the downtime was not being completed accurately by the fixers. They were well aware that they were measuring their own performance and that it would require effort to write down all the data. Even after repeated explanation the data was still not logged accurately. At this point, it became clear that the manual logging of data might be possible over the short-term under very tight supervision, but was not a long term solution.

4.2.4 Automatic Measurement of Downtime

As mentioned previously, the machine supplier did offer software that would enable a central computer, connected to the machines to monitor the downtime. The cost of this system was too high and would only be considered for purchase when the benefit it would have for Sockit and its 43 machines could be proven.

Therefore, the measurement data could not be validated and the problem category “Uptime of process too low” could not be further analysed for the machines with the current measuring method.

4.2.5 Advantages resulting from the Measurement Method

Although the measured data was not accurate enough for the Six Sigma Improvement Methodology, it became clear that the continued logging of downtime and production volume improved the process.

Before this time, there had been very little measurement tools in place for this process, which made the supervising function of the shift leaders more difficult. Even if the data was not valid and accurate enough for the Six Sigma analysis, it did help to show the major errors that did occur on the machines. The fixers that had to log the sock-count were informed at 3h intervals, which machines were standing still. Therefore they could take counter measures earlier.

As the production workers were now being visibly monitored, the head of the knitting department noticed a definite increase in productivity too.

Unfortunately, as this could not be measured at this time, it could not be proven.

4.3 Measuring Downtime on new machines only

Although a measuring system was not in place to measure the downtime for all the machines, a few of the latest machines on the floor were able to automatically log the last 70 failures. The type and duration of the failure could be measured. The task of writing down every value that the machine logged over the last two to three days was a big effort and would not be viable over the long term. Nonetheless one set of the latest data was enough to make the next attempt to continue with the DMAIC process on the latest machines.

4.4 Measurement System Analysis Downtime on New Machines

4.4.1 Validity

A perfect Attribute Measurement System would classify every entity of downtime correctly. Unfortunately this is not the case for the failure statistic. For example if the machine is paused or switched off manually, this is not logged, as it is not a failure. Another problem with the failure statistic is that the same error message can mean several different things. For example Broken Yarn H Sensor N. x indicates that that there is no yarn passing a specific sensor. This could be caused by low quality yarn tearing or the unavoidable situation of when the bobbin runs out of yarn.

The Ishikawa Diagram which will be discussed later would create further clarity on the number of causes for each error type logged by the knitting machine.

4.4.2 Reliability

The automatic logging system is reliable according to the machine specifications.

5 CONTINUING WITH THE AVAILABLE DATA

As the last 70 values spanned over different times on the different machines, only the data over 24 hours was used, because all machines covered this period. By repeated copying of the data from the machines into an Excel sheet, further data could have been acquired, but this was not done due to lack of time.

It was unfortunate that only the downtime on the newest machines was logged. These would most likely have the least technical problems and therefore create a distorted picture of the real situation.

Nonetheless, with the knowledge that more extensive data could be acquired in future, the Six Sigma process was continued. The current data was sufficient to draw conclusions for the newest machines and could serve as a training run for the repeated implementation of the Analyse, Improve and Control Phase on other data in future.

6 ANALYSE

6.1 Baseline Capability Study

The baseline for the downtime with the different causes logged by the knitting machine for a 24 hour period is:

Failure Type	Effect (min)
Broken yarn H sensor N.x	373
Stop elastic 2	133
End bobbin scaffolding	26
Stop heel and toe take up	25
Yarn not cut H sensor N.x	18
Dial not at zero!! Manual. Reset obliged.	12
Phase displacement encoder sinker cap posit. Motor	12
Stop Dial jacks enter 1	9
Stop yarn creel	9
Other	37.4

Table 5 - Baseline Capability: Downtime within 24h

As mentioned previously the machine does not log the times when it is switched off, which will typically be done during setup or after a break-down. Therefore this output is not complete.

6.2 Process Variables Map

The Process Variables Map is a graphical representation of the process that should be analysed. It is important to find the inputs (x's) influencing the output metrics (y's) that are important for the customer.

6.3 Pareto Chart

The Pareto Chart can be applied at any point in the project and helps to focus the attention on key areas when there are large amounts of data. With its help, the main downtime causes of the Baseline Capability (Table 5) were graphically displayed for further analysis.

6.4 Ishikawa Diagram

To identify the influencing factors for these main failures the Ishikawa Diagram was used in two separate discussions with the head of the knitting department and the maintenance technician. A diagram was created for each of the first five most common failures detected by the automatic logging system of the new machines. For example Figure 7 – Broken Yarn Sensor.

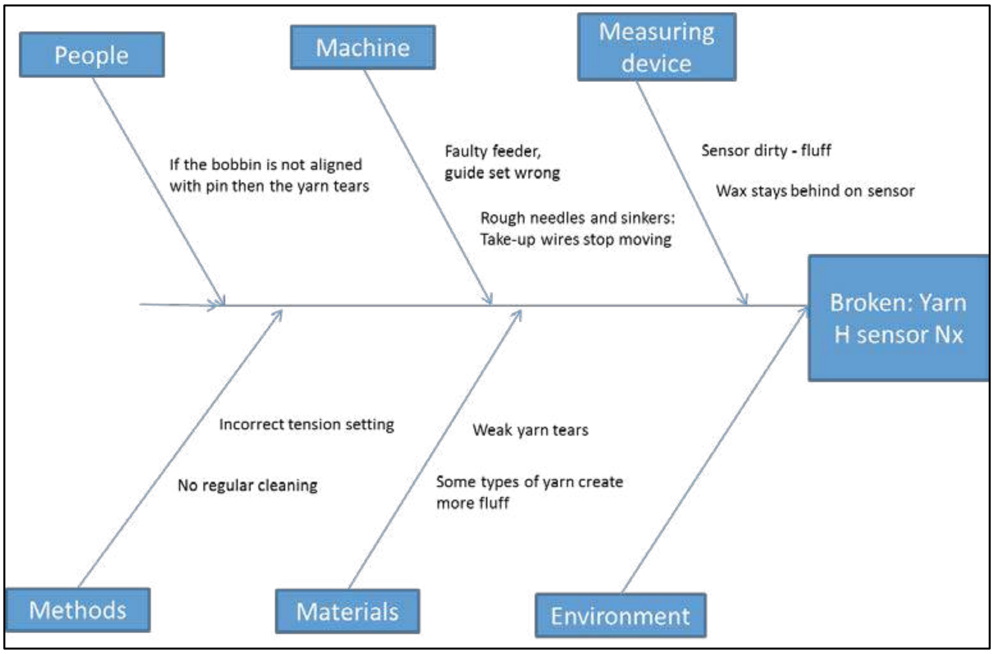

Figure 7 - Broken: Yarn H Sensor Nx

7 TEAM SUPPORT

At this point the implementation of Six Sigma with the team had to be aborted, as the time period of two months which had been dedicated to the project at the factory, had been completed.

8 CONCLUSION

8.1 Six Sigma Effects

The methodology definitely helped to identify some of the core problems experienced at Sockit Manufacturing (3.7 Knitting Department VOC-2-CTQ-Matrix).

8.1.1 Implementation in Sequence

During the implementation it was noticed, that the Six Sigma tools were intuitively understood and also helped to identify issues and gather ideas from the employees in a constructive manner. Even as an outsider to the company it was possible to gain a good overview rapidly, by implementing the steps of the methodology in the correct sequence. If these quality tools had been picked and chosen without the methodology, they would not have supported each other as effectively. Lastly there was no experience required to implement the tools at the right moment in the improvement process.

8.1.2 Dangers

Care had to be taken when documenting the opinions of the staff. In many interviews problems were brought up that would shift the blame to other departments. Many of them would also not mention the problems in their own department, as they were worried that their performance would be judged to their disadvantage. Convincing the staff that the Six Sigma Process would be good for them and the company, was essential.

8.1.3 Knitting Process

For the knitting process specifically, the manual measurement of the downtime could be performed by a green belt [10], to improve the reliability of the results. Although the Hawthorne effect would play a role here, this would not change the major causes of the downtime, which would be expected to be technical issues (**Error! Reference source not found. Error! Reference source not found.**). Additionally, the duration of the measurements could be increased to one or two weeks, improving the validity of the results even further. The belt would also be able to log the data on the laptop directly, making the data analysis more efficient.

After acquiring the results, the team members could be included in the Analyse, Improve and Control Phase. By doing so, a drastic improvement in the results would be expected, as the knowledge of the person close to the process could be utilised.

8.1.4 Innovation Management Capability Improvement

By continuing the implementation of the Six Sigma Methodology permanently, the innovation management capability of Sockit Manufacturing could be improved at a cost, which should be continuously monitored. The company would move from a level 2: *'Know they need to change, but not how or where to get resources'* to a level 3 organisation *'Know they need to change and have some abilty to generate and absorb technology'*.

8.2 Research Question

Can Six Sigma be used to improve the processes of Sockit Manufacturing with limited resources?

The following comments were made by the head of the knitting department:

- Lower downtime periods are being achieved as the fixers are more aware of the issues due to logging the production rate of each machine in three hour intervals.
- Improved concentration of the operators as their performance is measured by the new downtime sheet and the production rate sheet.
- The awareness of problems in the knitting department by the head of the knitting department has increased, due to the documentation of downtime and production rate.

For these reasons the downtime sheet and production rate sheet are still in use after the Six Sigma project was completed.

When discussing the results of the Pareto Chart with the head of the knitting department and the maintenance technician, these were confirmed to be major causes for the downtime across all the machines.

Feedback from the industry experts confirms that the Six Sigma approach helped to identify some of the core problems within the knitting department, even without having had substantial experience within the company. However, due to the time constraints, the Six Sigma Improvement project could not be completed in its entirety and the full advantage therefore not measured.

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EVALUATION OF RAPID PRODUCT DEVELOPMENT TECHNOLOGIES FOR PRODUCTION OF PROSTHESIS IN DEVELOPING COMMUNITIES

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ABSTRACT

The production of prostheses using conventional methods or advanced technologies makes it unaffordable for people living in developing communities. Since the Fablab revolution and due to the collaborative open source movement, numerous rapid product development technologies were invented. The idea of these movements is to provide widespread access to modern means for sustainable invention and to ensure distributed value creation. This research study was to evaluate suitable rapid product technologies for value creation in developing communities, primarily for the production of prostheses. Open source technologies were used to fabricate prosthetic ears. These prototypes were evaluated in terms of cost, time and material consumption. The accuracy of these more affordable open source technologies were also critically analysed, after developing the ears in a few hours. The results revealed that open source technologies can be used for distributed prosthesis production.

1 INTRODUCTION

Affordable healthcare is desperately needed in Africa. There are also an increasing number of prostheses required, most of which are not affordable to the people [1]. Additive manufacturing (AM) has been defined by the ASTM F.42 committee as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive cutting processes (e.g. milling). AM has also been referred to as rapid prototyping (RP) and layer manufacturing [2].Additive manufacturing originated as rapid prototyping in the 1980's and has many disciplines [3]. The most successful RP systems are ink jet printing (IJP), stereolithography (STL), fused deposition modelling (FDM), laminated object manufacturing (LOM) and selective laser sintering (SLS) [3]. These emerging new techniques and technologies coupled with globalisation of the product market are pushing creativity and product solutions to its limits.

Research [4, 5] suggests that the reported consequences of individuals who are missing body parts include depression, feelings of hopelessness, low self-esteem, anxiety and in severe cases suicidal ideation. Additive manufacturing has become a popular research area for manufacturing and medical sciences. Research institutes are considering biomedical applications for both AM technologies and 3D scanners [6]. There is also an increase in research projects on additive manufacturing of prostheses, and whether or not it is feasible to implement the suggested value chains [7]. Medical prostheses are devices that are located either inside or outside of the patient's body, to perform a function either aesthetically or practically [1]. Considering the research [4]that indicates both physical and psychological trauma in cases of amputations, prosthetic devices should provide some form of functionality as well as human-like appearance and feel. It is further found that improved aesthetic prostheses suggest greater psychological well-being [8].

There are several techniques that can be used to create a prosthetic ear. Advanced design methodologies are used to reduce time to market, leverage creativity and design intent. At the same time advanced manufacturing technologies are used to reduce manufacture time by lowering cost and lead time. The traditional method involves a trained sculptor fabricating the prosthesis by the formation of an impression and resulting mould [7] from which a prosthetic body part can be obtained through methods such as pouring of Room Temperature Vulcanising silicon, or using a gypsum casting as a model which the prosthetists replicates by through hand carving. Modern reverse engineering methods which utilise data (e.g. computerised tomography (CT) scan or a point cloud) obtained from a 3D-scanner and an additive manufacturing process [6] are being investigated, however have not been widely accepted [9]The traditional method of prosthesis fabrication is expensive and takes a considerable amount of time and skill to complete [7]. Additionally, the makers of health policies agree that individuals who form part of the unilateral upper extremity amputee group should be placed at the bottom of the priority list regarding treatment for amputations, particularly in areas with limited resources [8]. This provides a massive opportunity for AM technologies to be used to provide the option of lower cost prostheses to people in rural areas.

In order to be a worthwhile venture, the benefits of the new technology should outweigh those of the traditional methods. The benefits of AM technologies are that the machines can produce a product or mould, which requires only minor manual post-processing efforts, in just a few hours and this technology can run continuously with none or little supervision [10]. AM also provides for mass customisation of parts where many parts can be produced during a single build procedure within the same build platform, however, each part can be customised [11, 9]. Thus, there is a product development shift from the physical to a digital mock up. This means less waiting time for the patient and less skills required to fabricate the prosthesis. If the costs of producing prostheses are kept to a minimum, these technologies could find their way into the developing communities, where people are unable to afford the more expensive traditional prostheses.

This study focused on the production of auricular prostheses, commonly known as prosthetic ears, using open source AM and 3D-scanning technologies. The research focused on the FDM process as these technologies are available to developing communities and are more affordable [9].It was critical that the shape and detail of the prosthetic ear replicates that of the outer human ear, in order to meet both the functional and aesthetic requirements. The systems for implementing AM technologies to ensure distributed prosthetic production in developing communities are also mentioned.

2 DISTRIBUTED MANUFACTURING SYSTEMS

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, the concept of *sustainable value* has emerged to target not only ecological sustainability, but also social and economic values [12]. South Africa is facing severe poverty levels, especially in underdeveloped regions. Manufacturing is seen as the sector which could create work, but it requires innovative development concepts. In order to develop a new concept for sustainable development in developing communities, one has to consider advanced manufacturing concepts for the next generation manufacturing systems. Promising approaches to this search for a new manufacturing paradigm include networked, adaptive, and ubiquitous manufacturing systems [13].The developed concept [13] of Open Collaborative Manufacturing (OCM) incubators intend to support distributed manufacturing incubators with an open design and social selection platform as shown in figure 1. The OCM concept include infrastructure in community centres designed to support the development of visionary entrepreneurs, which are developed and orchestrated by management and offered both in the incubator and through its network of open design contacts. The OCM incubation concept can also be integrated into the country’s national innovation system as proposed by [14].

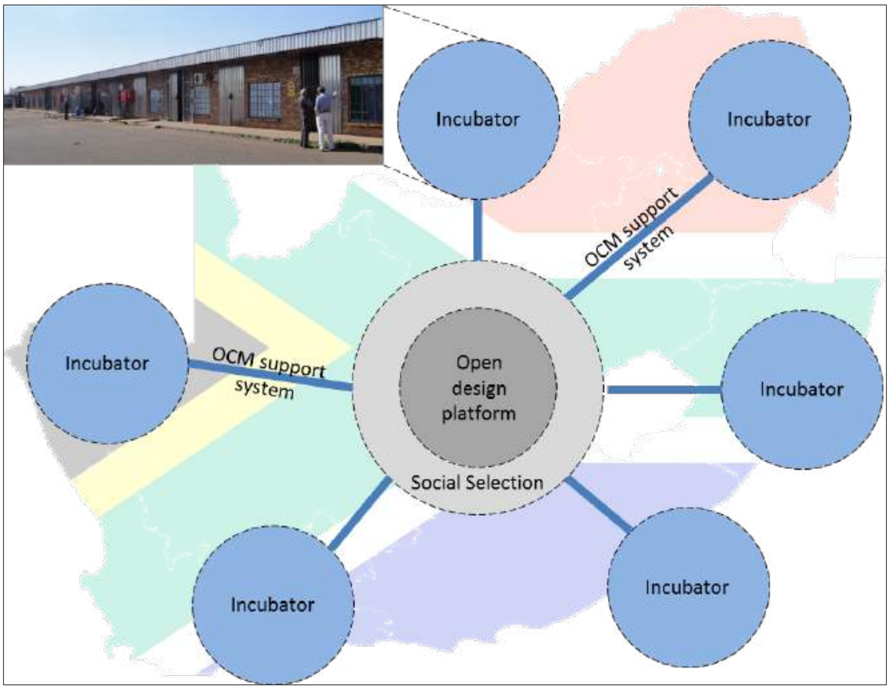

Figure 1: Building blocks for open design supported incubators (Adapted from [13])

In order to meet customer demand, production systems can rapidly develop more products or technologies, which can also lead to an increase in the number of variants of assemblies and parts [15]. In this favorable ecosystem, innovative enterprises can flourish by interacting with different innovation actors and across sectorial boundaries [16].

AM processes are not exclusively used for prototyping any longer. New opportunities and applications in appropriate manufacturing systems can open up, even though the economic impact is still modest [11]. An overview of AM technologies with their acronyms and development years are shown in Table 1 [17].The most popular AM machines are the FDM machines [9]. Fused deposition modelling uses a heating chamber to liquefy polymer, which is fed into the system as either filament or pellets. The extrusion nozzle is located on three (3) different axes namely the x-, y-, and z-axes, also commonly known as the Cartesian coordinates [18].

Table 1: The development years of additive manufacturing technologies [17]

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

In fused deposition modelling the filament is fed into the heating chamber where it is melted down and fed out the nozzle at a certain rate, depending on the relative rate of movement of the three axes [18]. The temperature of the nozzle is typically around 170 °C to 220 °C depending on the type of material that is used as a filament. The diameter of the nozzle is very important, because the resolution of the print relies on the thickness of the nozzle and the feed rate of the filament. A typical nozzle has a diameter in the vicinity of about 0.35 millimetres to 0.5 millimetres [18]. The strength of the FDM process shown in figure 2 is the range of materials it can use and the effective mechanical properties of the produced parts [9]. The main drawback of using FDM technology is its manufacturing speed. This relatively slow prototyping speed is due to the inertia of the plotting heads. This means that the maximum speeds and accelerations that can be obtained are slower than other AM systems (e.g. laser sintering) [9].

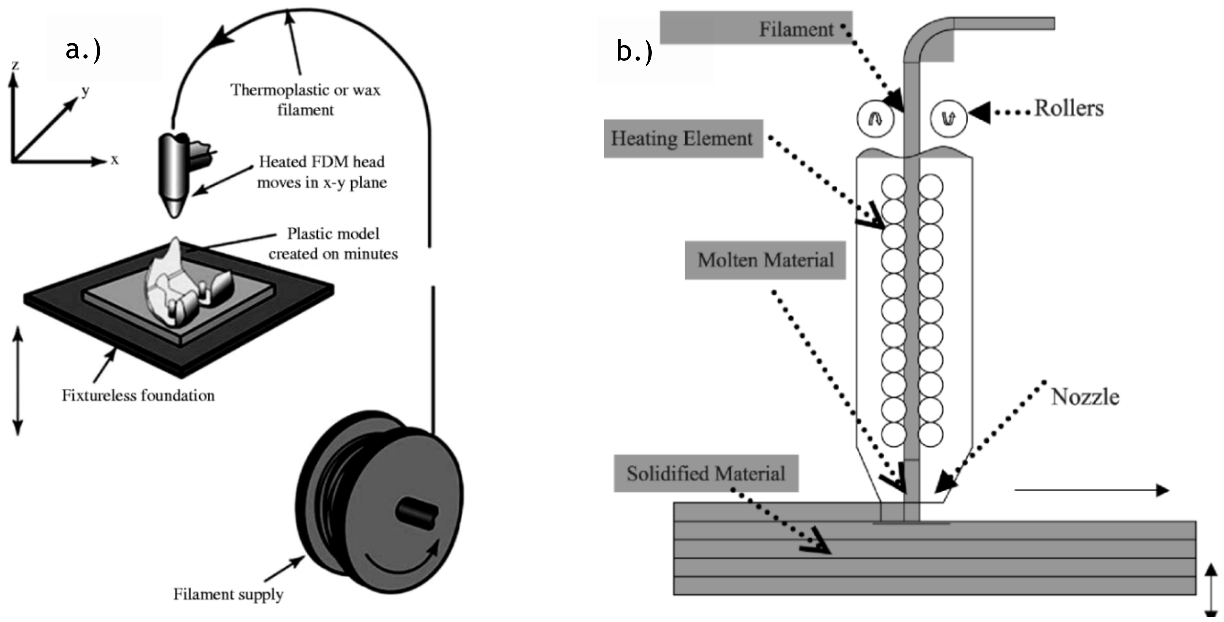

Figure 2: Schematic of the fused deposition modelling (FDM) process's (a) system and (b) principle [19]

The nature of FDM allows itself to be complimented by secondary technologies such as Room Temperature Vulcanising (RTV) silicon and investment casting [11]. This concept is valuable; particularly in the medical industry as the biocompatibility of materials is critical. The scope of biomedical materials that can be used in AM machines is currently limited, but the use of complimentary secondary technologies such as RTV, helps to overcome this challenge. After manufacturing the moulds with the available AM material, a biocompatible material (e.g. RTV agent) can be poured into the mould, to be used as the end user product [11].

As there are a lot of variables with regards to the FDM machines, setup time is required before each print. The bed of the machine needs to be levelled in order for the print to be accurate and to reduce quality issues and warping of the part.

Once the machine setup is complete the manufacturing can begin. The manufacturing time is dependent on a number of variables such as the time it takes for the heating chamber to reach its operating temperature, the size of the component, the resolution of the printer, the quality of the print, the software being used, and the amount of support material needed [9]. All of these variables are user defined and can be varied when creating the initial G-Code file on the software provided with the machine.

Post-processing of the manufactured part may be required, depending on whether a support material was used, the surface quality and the need for coatings. Post-processing includes, but is not limited to, the removal of all burrs, sharp edges, all of the support material and chemical treatment [9] (e.g. exposure of ABS parts to acetone vapour can be used to effectively reduce the effects of visible layers [20]). The finished prosthesis can then be attached to the patient using a medical grade adhesive (e.g. Pros-aide) [6], or prosthetic socks and liners.

3 EXPERIMENTAL SETUP AND DESIGN

The objective of this research study was to evaluate suitable open source rapid product technologies for value creation in developing communities, primarily for the production of prostheses. The research approach was divided into different phases as illustrated in Figure 3. The first step constituted of a thorough literature study on rapid product development technologies.

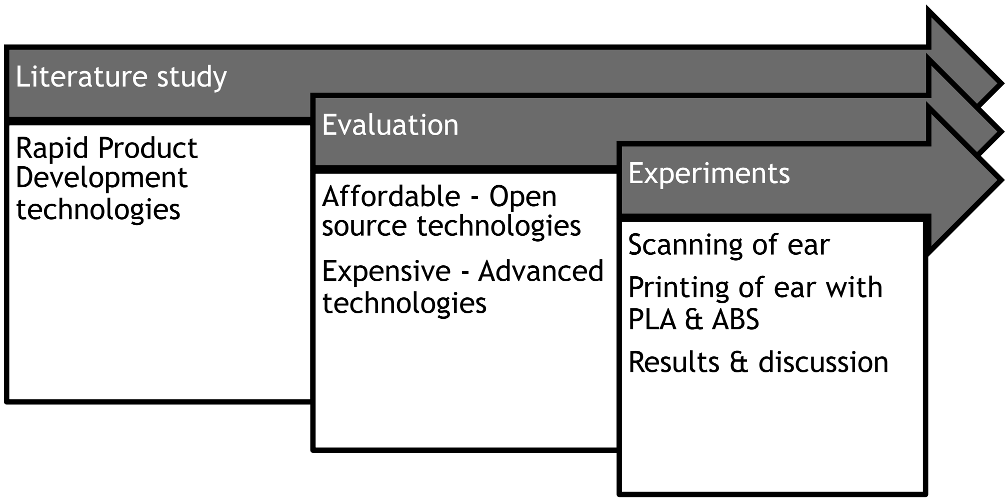

Figure 3: Experimental approach followed to evaluate rapid product development technologies and fused deposition modelling materials

Thereafter, affordable open source and expensive advanced rapid product development technologies were evaluated in terms of print volume, resolution, speed, accuracy and costs. The experiments were conducted to investigate the feasibility of utilising 3D scanning methods and AM technologies to validate a process chain, which could be adopted in developing communities to produce auricular prostheses. ABS and PLA materials were analysed toward finding a suitable material to use for low cost prosthetic ear manufacturing.

3.1 Prostheses manufacturing value chain

The prostheses production value chain [1], which is being used by several institutions and hospitals, include the use of modern 3D scanning equipment and AM machines. The value chain to be investigated is shown in the flow chart in figure 4.

In this study the prostheses were manufactured by the AM machine. Generally, the process chain involves the generation of a prosthesis mould through AM techniques, followed by the pouring of RTV silicon into the mould in order to obtain the prosthesis, however in this study an attempt was made at producing the prosthesis directly from the AM machine.

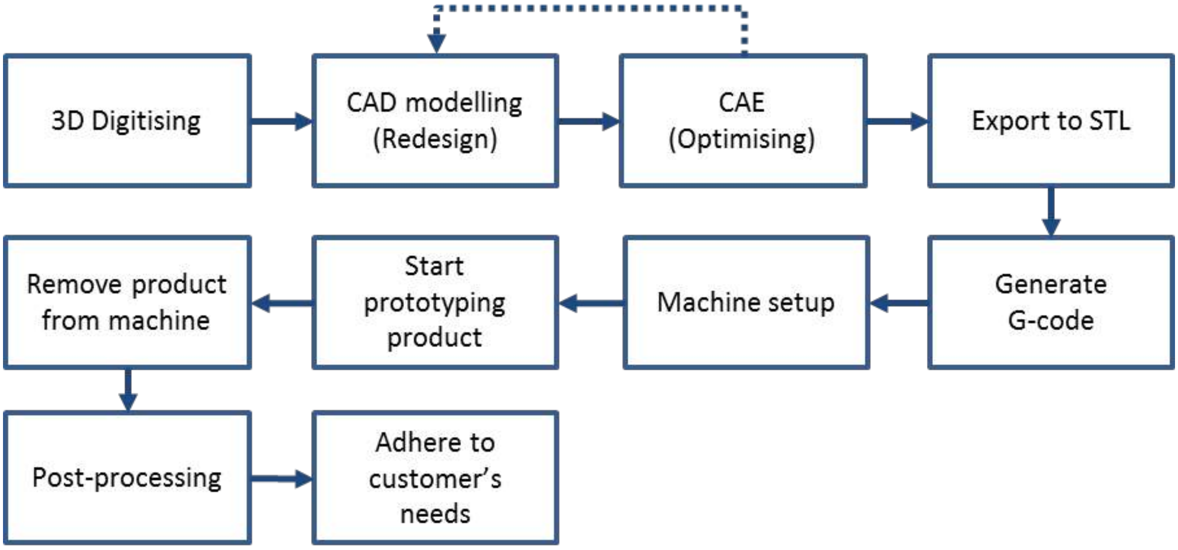

Figure 4: Prostheses manufacturing value chain using rapid product development technologies

The first step is to scan the contralateral ear (remaining ear), which will be mirrored in the scanner's software, so that a correctly orientated ear is manufactured. The scanning process can be performed in a number of ways. The remaining ear can be scanned using a CT scanner and then the data can be transferred to an Endoplan-workstation, where the data can be converted into an STL file. Due to the high costs of CT scans and that the patient has to be exposed to radiation, this process will not be investigated in this study [7].

The alternative to the CT scan is a conventional white light scanner. The scanner works by utilising a flash bulb and a camera. The bulb flashes a light onto the object and the camera catches and records the data from the light, which is then translated into a 3D image by the Artec software. Using the scanner, the patients' ear can be scanned in a couple of minutes and then mirrored and edited using the Artec software.

The second step entails exporting the scanned ear into a CAD program, such that a 3D model of the ear can be established. This can be done by making the ear a solid and creating a box over the ear by using CAD software (e.g. SolidWorks) [7]. This edited model then becomes the piece to be manufactured and it can be exported as an STL file.

Most open source machines come with software to convert the STL file into the G-Code format, which the AM machine's firmware uses to control the output of the machine. The STL file is then uploaded onto the software platform and the orientation of the model selected. After running the software, the G-Code is exported to the AM machine. A screenshot of the scanned ear from the program Axon by Bits from Bytes is shown in figure 5.

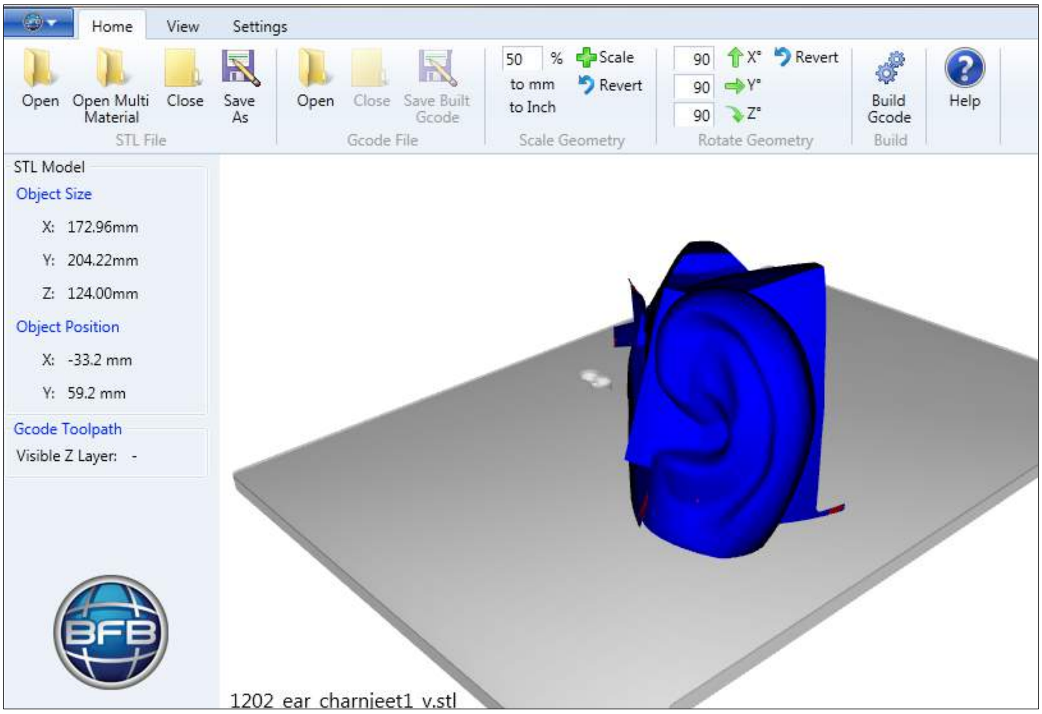

Figure 5: Screenshot of the scanned ear in the Axon build software

3.2 Fused deposition modelling technology

The RapMan 3.1 is an open source FDM machine designed and priced for students, educators, and hobbyists for do it yourself (DIY) personal fabrication. The machine comes in a kit with assembly instructions and typically takes approximately 20 hours to assemble. The specifications of the RapMan 3.1 are shown in table 2. Once assembled and calibrated, the machine can start manufacturing 3D objects in distributed areas.

Table 2: RapMan 3.1 Specifications [21]

	RAPMAN 3.1 SINGLE HEAD	RAPMAN 3.1 DOUBLE HEAD
X Axis	270 mm	190mm (7 ½ inches)
Y Axis	205 mm	205mm (8 inches)
Z Axis	210 mm	210mm (8 ¼ inches)
Z Axis Resolution	0.125 mm	0.125mm
Print Speed Extruded Volume	Maximum 15mm^3/s print & polymer dependent.	
Power Requirements	60 Watts (5 A @ 12 V)	
Approx. Weight	17 kg	
Overall Dimensions exc. extruder	650 mm (w) x 570 mm (l) x 510 mm (h)	
Overall Dimensions inc. extruder	650 mm (w) x 570 mm (l) x 820 mm (h)	
Max.extruder operating temp.	280 °C (536 °F)	

3.3 Experimental materials

The RapMan is capable of printing two different types of plastic materials namely Polylactic Acid (PLA) or Acrylonitrile Butadiene Styrene (ABS) plastics, which have different material properties as shown in Table 3.

Table 3: Material Properties of PLA and ABS [22] [23]

Properties	Units	ASTM	Common Material	
			PLA	ABS
Tensile Strength	MPa	D638-03	59	40
Elongation at Break	%	D638-05	7	50
Modulus of Elasticity	MPa	D638-04	3750	2600-3000
Izod Impact Strength	J/m	D256-06	26	34
Density	kg/mm^3		0.00105	0.00125
Cost per kilogram	Rand/kg	-	R 900	R 900
Colour		-	Various	Various

PLA is a thermoplastic polyester which is produced from renewable resources, such as corn-starch or sugarcane, and is readily biodegradable unlike the petrochemical plastics. PLA resins have been widely used for biomedical applications, because of their biodegrading properties [18, 24].

PLA has a low threshold for high temperatures and is also a tough plastic that is quite brittle and hence it cannot be sanded down or smoothened out [18]. PLA usually extrudes at about 180ºC and is required to be cooled by fans while printing. Although the biodegradable properties and origin of the material are favourable for rural areas, the mechanical properties, particularly the brittleness, make it a not ideal choice for a lifelike prosthesis.

ABS is a thermoplastic with a broad range of desired properties, when considering prostheses. ABS is very durable and slightly flexible. It can be sanded down, painted, and adheres well when using a suitable glue for prosthesis adhesion [18]. ABS has been successfully used for the application of prostheses in other studies [6], because the surface roughness can be altered with sand paper and acetone vapour.

The disadvantage of printing with ABS rather than PLA is that ABS has a higher melting point (240 ºC), which in turn means that there is more wear and tear on the printer extruder head, that more power is required in order to print the part, and the heat up time of the extruder is longer. For small production sizes, the extra cost in energy usage for producing the prostheses will be very small, however further research could be done to determine whether for large batches the higher energy requirements make ABS an unsuitable choice of material.

3.4 Hommel Etamic T8000

The surface quality of the final ear models were determined by measuring the surface roughness. This was done using the Hommel Etamic T8000, illustrated in Figure 6.This device can measure surface roughness, topography and contour. It allows for the recording, analysis, evaluation, graphical representation and archiving of values and parameters.

The Turbo roughness software which accompanies the device allows the configuring of measuring conditions and collection of individual parameters.

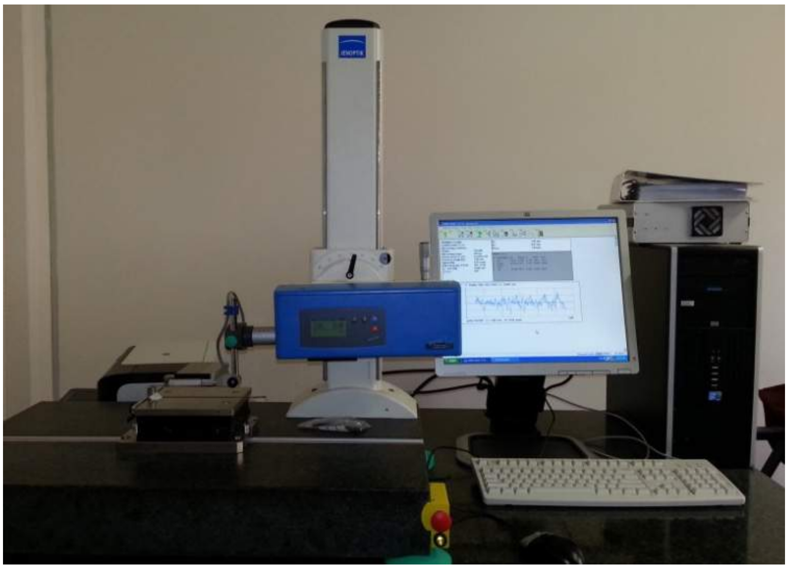

Figure 6: Hommel Etamic T8000 surface roughness machine

The specifications of this machine are shown in Table 4, indicating the intention of using this machine. This setup allows for easy evaluation of surface roughness parameters and makes a contribution to the ease and efficiency, as well as the reliability of evaluating the surface of the prosthetic ears.

Table 4: Specifications of the Hommel Etamic T8000 Machine

Measurement Range	±300 to ±600 μm
Scanning Direction	Z+ / Z- Axis
Measurement Force	±1 mN -to ±50 mN

The T8000's measurement range varies from 300 μm to 600 μm. The measurement force ranges from 1mN to 50mN.

4 EXPERIMENTAL RESULTS AND DISCUSSION

The 3D printers that are available in South Africa were analysed with respect to the manufacturer's specifications and the types of materials it can print. The costs of these printers were compared in table 5 and table 6 with the necessary specifications.

Table 5: List of affordable personal printer specifications and prices [18]

Affordable open source printers						
		Makerbot	Bits from Bytes		3D Systems	
Printers	Units	Replicator 2	RapMan	3D Touch	Cube	Cube X
Print Volume	mm	285x153x155	270x205x210	275x275x201	140x140x140	275x265x240
Resolution	mm	0.1	0.125	0.125	0.2	0.1
Print Speed	mm/hr	15	20	20	20	20
Pref. material		PLA or ABS	PLA or ABS	PLA or ABS	PLA or ABS	PLA or ABS
Accuracy	mm		0.2	0.2	0.2	0.1
Price	Rand	≈R 24 000	≈R 14 000	≈R 32 500	≈R 15 500	≈R 28 000

Selecting one of the more advanced AM machines is not feasible in developing areas due to the limited funds, particularly for non-essential prostheses such as ears. Funding for such devices would be much more difficult. The most affordable printer, being the RapMan 3.1, was selected to print some experimental ears to analyse. The quality, time, cost and waste were analysed for both ABS and PLA materials.

Table 6: List of advanced printer specifications and prices [18]

Advanced printers				
		Z Corp	3D Systems	Objet
Printers	**Units**	**Zprinter 150**	**ProJet 3500**	**Connex 260**
Print Volume	mm	236x185x127	298x185x203	260x260x200
Resolution	mm	0.1	0.16	0.016
Print Speed	mm/hr	20		
Pref.Material				Med/Rubber
Accuracy	mm		0.025	
Price	Rand	≈R 140 000	≈R 1 150 000	≈R 1 750 000

An approximate build time model and cost model can be established, which will be verified experimentally, that indicate the estimated time and cost per build. Build time (T_b) can be calculated from the time it takes the machine to heat up to the required temperature for extrusion (T_{start}), the actual deposition time (T_d) and the recoat time (T_r) as per eqn. (1), which for FDM technologies is nil.

$$T_b = T_{start} + T_d \quad (1)$$

The time taken for the deposition of the filament is given as the volume of the object divided by the speed at which the machine can deposit material. Although for the RapMan a maximum print speed of 15mm^3/s is given, typical machine speed (S_d) is approximately 120mm^3/min. The ear is a difficult shape to evaluate, and heat up times for the machine to reach operating temperatures should also be considered when using eqn. (2).

$$T_d = \frac{v_{ear}}{S_d} \quad (2)$$

The cost per part can be determined by adding the machine operating cost and the cost of material per part as per eqn. (3).

$$C_p = O + M \quad (3)$$

The operating cost is equal to the energy used by the machine (E) in watts, whilst building the part as per eqn. (4). The assumption is made that the cost in cents per unit of electricity (c/kWh) is R 0.9357 [25]:

$$O = T_b \times E \quad (4)$$

The cost of material can be determined from the material density (ρ), the part volume (v) and the cost per kg of material (C_m) as per eqn. (5).

$$M = \rho \times v \times C_m \quad (5)$$

The CAD modelling of the scanned experimental ear can be seen in figure 7. Prototypes of a scanned ear were manufactured using each material at a resolution of 0.25 mm. The estimations and derived values provided by the AM machine software for other resolutions, namely 0.125 mm and 0.5mm were also compared.

Figure 7: Screenshot of Axon 3.0 Rendering of Finished Ear Model

The resolution, time, cost, and mass for the different materials are shown in Table 7. The STL model of the ear was opened up in Axon 3.0 software. The G-Code was then obtained for a 0.5 mm, 0.25 mm, and a 0.125 mm resolution for both PLA and ABS materials.

Table 7: Build Data from Axon 3.0 Software

	ABS			PLA		
Resolution [mm]	0.5	0.25	0.125	0.5	0.25	0.125
Time [h:m]	00:51	01:42	01:33	00:42	01:32	01:41
Mass [g]	17.01	11.86	10.43	14.51	11.33	12.15
Cost [ZAR]	15.31	10.67	9.39	13.06	10.2	10.94

Figure 8: Printing process of the PLA ear model

The results for generating two prostheses at a resolution of 0.25mm for ABS and PLA materials respectively are listed in TableTable 8. In terms of manufacturing time, the PLA is a more favourable choice, due to the fact that it takes 10 minutes less to produce a PLA ear compared to an ABS ear. If this method is used for mass customization and the demand is high enough, software which is available could be purchased which generates a plan to optimise the production of many different parts in one cycle. The fact that prosthetic ears were produced which resembled real ears indicates that the process chain can in fact be reduced to eliminate the need for a mould in the case of prosthetic ears. This can save energy, time, money and materials.

Table 8: Comparing the manufacturing parameters using ABS and PLA materials

	Unit	ABS Material	PLA Material
Printing time	[h:m]	01:42	01:32
Resolution	millimetres [mm]	0.25	0.25
Mass	grams [g]	11.86	11.33
Cost of prinintg	Rands [ZAR]	10.67	10.2
Surface roughness (R_a)	µm	21.3	33.4
Material waste	grams [g]	1.18	1.24
Cost of waste	Rands [ZAR]	1.06	1.12

The resulting prostheses can be seen in figure 9. Conventional production of prosthetic parts takes days, depending on the skill and availability of the prosthetics. A 10 minute difference in manufacturing time in this context is negligible. The mass difference between the two ears is only 0.53 grams.

Figure 9: Finished prototypes of the ears with PLA (left) and ABS (right) materials

The surface roughness (R_a) of the ABS was 21.3 um and that of the PLA was 33.4 um. The smoother surface means that the prototype needs less surface finishing operations. This indicates that for the same machine resolution setting the ABS provides a better surface quality with respect to prosthetic ears. The difference in cost and material wastage for the production of a single ear was very small and thus not taken into account. The material properties of ABS for the application of prosthetic ears outweighed those of the PLA in terms of flexibility and post processing. The post processing of the model is a lot easier to perform on the ABS. This is due to the fact that conventional surface finishing methods can be used with ABS, without compromising the integrity of the part. Although the price of producing an ABS prototype is slightly higher than a PLA prototype, the mechanical properties of ABS ensured a better quality prosthesis that will last longer. The waste material for one ear for the ABS was 1.18 grams and for the PLA was 1.24 grams. The difference between these figures is 0.06 grams which is negligible, particularly with mass customization manufacturing cycles. The comparison between ABS and PLA indicated that ABS is the better material of choice when producing a prosthetic ear using FDM machines.

5 CONCLUSION

This paper investigated the feasibility of utilising open source scanning methods and AM technologies to verify a process chain which could be adopted in developing communities. The study compared available AM technologies. ABS and PLA materials were analysed to determine which is more suitable to use as the material of choice for a low cost prostheses. This study concludes that it is possible to manufacture ABS prosthetic ears using more affordable open source technologies. Further research should be done to optimise the value chain's other parameters and test the feasibility with a broader range of materials.

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THE EFFECTS OF COOLING AND CUTTING TOOL COATING ON TOOL WEAR DURING MILLING OF TI6AL4V AND 40CRMNMO7

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ABSTRACT

In response to increasing climate change, the development and production of light weight structures in the aircraft- and automotive industry, has become a priority. This has increased machined component manufacture utilising various difficult-to-cut materials such as Ti6Al4V and 40CrMnMo7. In order to satisfy achieve business goals, there is a general urgency towards the reduction of machining time and -cost in the manufacturing industry. This has however led to demanding cutting parameters and higher process temperatures of the material during the machining process. In the pursuit for improved performance, there is a need to investigate alternative methods for effectively machining these materials. An important criterion during the processing of these materials is therefore their machinability.

This article investigates the high performance machining of Ti6Al4V and 40CrMnMo7. The properties that make the use of these materials advantageous in the aerospace- and automotive industry also make them difficult to cut and create various challenges. Ti6Al4V has a low thermal conductivity that causes heat to accumulate in the cutting zone. 40CrMnMo7, on the other hand, has a high stiffness which results in greater mechanical loading on the cutting edge. This has encouraged studies into cooling strategies and -techniques to improve tool life and reduce the cost of machining of these materials.

This paper further investigates the application and effect of a coating (TiAlN) as well as various coating treatments under selected cooling conditions. A clear guideline is given for possible improvement and optimisation in milling operations, and creates a better point of departure for further studies.

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1 INTRODUCTION

Recent manufacturing technology developments in the machine tool-, aerospace- and automotive industries have increased the machining of components from difficult-to-cut materials, such as Ti6A14V, and the new generation hardened steel 40CrMnMo7.

In general, the manufacturing industry endeavours to reduce machining time and machining cost, which has brought about higher cutting speeds, -feed rates, -cutting parameters and -process temperature during the machining process. This article investigates aspects of high performance machining (HPM) of Ti6Al4V alloy and 40CrMnMo7. Titanium's relative toughness, high strength and low modulus of elasticity (when compared to many steels) present demanding challenges in order to achieve a high material removal rate (MRR). The properties that make Ti6Al4V alloy and 40CrMnMo7 favourable for use in the tooling-, aerospace- and automotive industry also make them difficult to cut. When machining Ti6Al4V alloy, a large proportion of the heat is generated and concentrated on the tool's cutting edge, which causes an increase of heat in the cutting zone. This is mainly caused due to Ti6Al4V alloy's *low thermal conductivity* [1]. Therefore, the predominant problem during machining is caused by the direct or indirect heating of the cutting zone. It can therefore be deduced that the heat generated during the machining of these difficult-to-cut materials play a major role in determining the tool life.

It follows that cutting tools now require superior hardness, wear resistance, high strength, toughness and thermal stability when machining difficult-to-cut materials. Recent trends favour coated carbide systems [2]. Therefore, the overall aim is to optimise the machining process to establish how tool coating, coating treatment, and different cooling strategies or -techniques influence the cutting tool life during HPM of difficult-to-cut materials such as Ti6Al4V alloy and hardened steel 40CrMnMo7.

2 APPLICATION OF COOLING DURING MILLING

Thermal- and mechanical loading demands create fundamental challenges when difficult-to-cut materials are machined. The heat development in the cutting tool and workpiece, as well as the deformation zones in which the mechanical and the thermal demands develop are depicted in Figure 1 [3]. Machining difficult-to-cut materials produces excessive tool wear in the secondary deformation zone. In order to reduce wear, lower cutting speeds are used resulting in extended machining times and increased manufacturing costs [4].

The interrupted cutting process of milling intensifies the mechanical- and thermal loading on the cutting tool. The mechanical demands are largely influenced by the feed rate, whereas the thermal demands are proportional to and intensified by the cutting speed. These demands simultaneously apply load on the insert which intensifies the wear of the tool and introduces varying modes of tool failure [5,6,7,8].

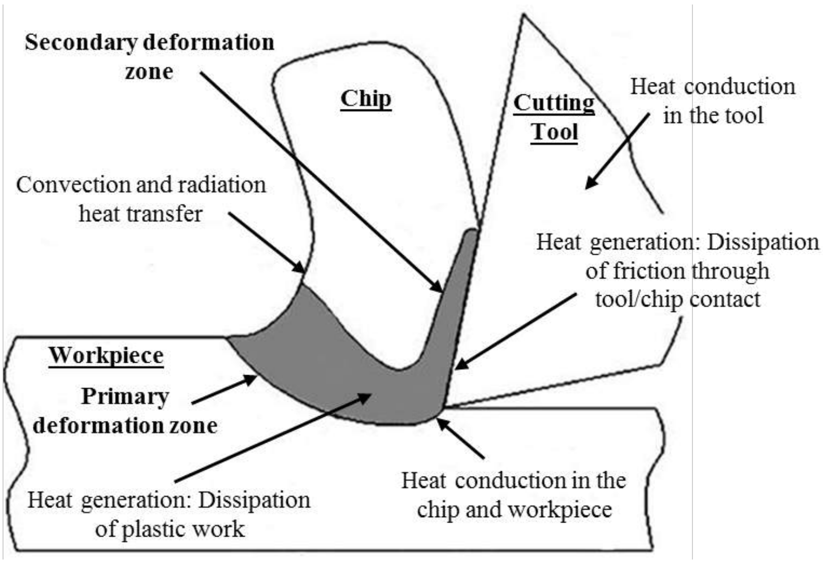


Figure 1: The distribution and flow of heat and deformation in the cutting zone [3]

The initiation of tool failure can consist of one or a combination of wear modes. These modes lead to overloading or -fatigue of the tool which can lead to catastrophic tool failure due to advanced stages of wear [5,9]. The modes of failure determine the mechanisms of wear and wear formations, which ultimately influences the cutting tool life. In the context of tool failure, the occurrences of these modes of failure are classified by temperature failure and fracture failure, which is depicted in Figure 2, below [10]. It should be noted that adhesion is an outcome of both thermal- and mechanical loading [11].

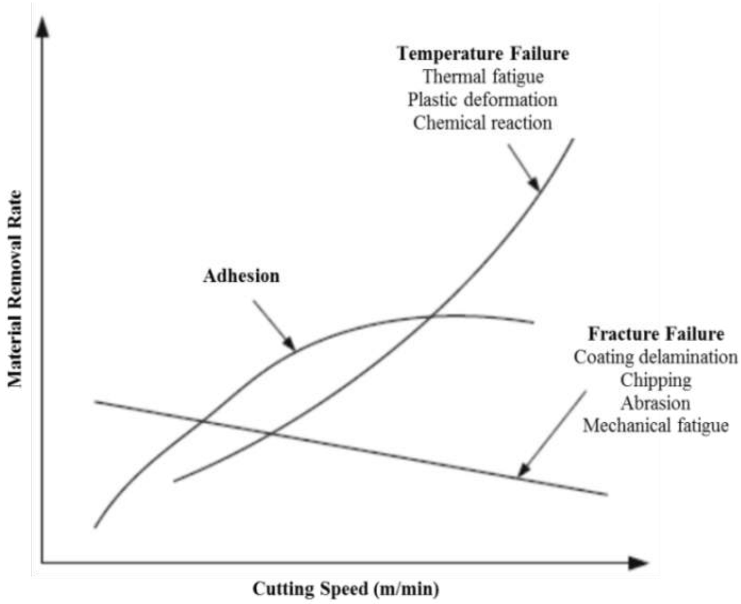


Figure 2 : Tool failure modes vs. cutting speed (adapted from [10])

2.1 Designated cooling strategies

One of the most practical and effective methods of raising productivity in the cutting process of Ti6Al4V alloy and 40CrMnMo7 is to dissipate heat as quickly as possible during cutting. This is accomplished by means of an efficient cooling strategy or –technique, as any reduction in the cutting temperature will increase the tool life [12,13,14,15,16]. The cooling strategy forms the base of the cooling method and can be defined as the most basic process of applying coolant. The technique of application can be seen as a subdivision of the cooling strategy itself and supplies a method for a more specific application method of coolant.

Recent research by various institutes and researchers has determined the following cooling strategies or -techniques:

- Flood cooling
- Forced air cooling (dry cutting)
- Minimal quantity lubrication (MQL)
- High pressure through spindle cooling (HPTSC)

2.2 Evaluation of cooling strategies

The cooling strategy or -technique should simultaneously execute high efficiency cooling and effective chip removal [17]. The selected cooling strategies where evaluated in terms of heat removal, chip removal, lubrication and economic and environmental friendliness (E & EF), as illustrated in Table 1. Each cooling strategy or –technique was graded as excellent, good, average, fare and poor.

Table 1: Selected cooling strategy evaluation criteria for machining hard-to-cut materials under HPM

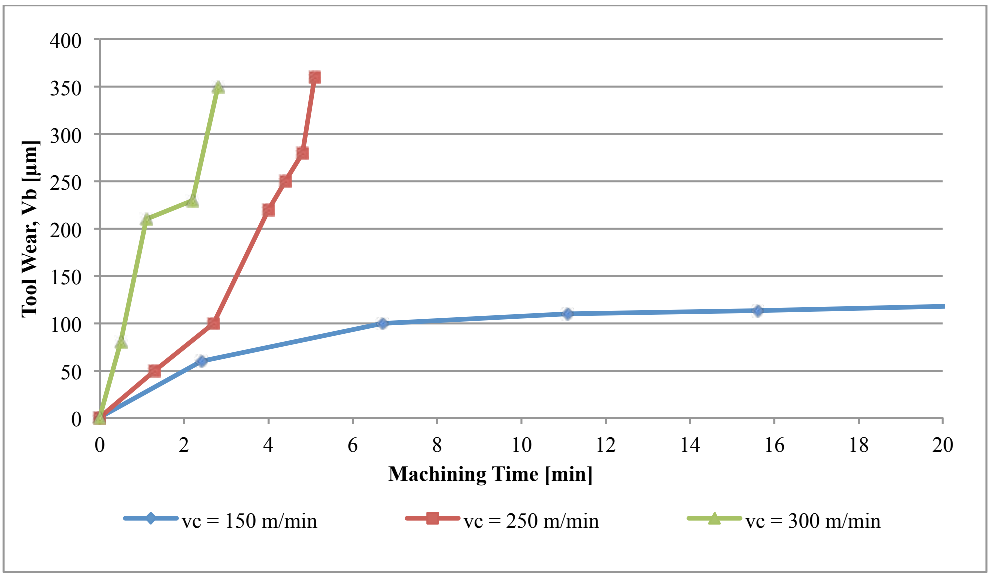
Criteria	Cooling and Lubrication Strategies			
	FC	FADC	MQL	HPTSC
Heat removal	◐	◔	◔	●
Chip removal	◔	◐	◔	●
Lubrication	◔	○	◐	◐
E& EF	◔	●	◐	◔

●Excellent; ◕ Good; ◐ Average; ◔ Fare; ○ Poor
FC: Flood cooling; FADC: Forced air cooling (dry cutting);
MQL: Minimum quantity lubrication; HPTSC: High pressure through spindle cooling

The *heat removal* indicates the potential of the cooling strategy or -technique to remove the heat generated in the cutting zone. The chips that forms on the workpiece surface retain and remove a portion of the heat generated on the cutting zone, and the remaining heat is then conducted into the cutting tool and work piece. For this reason, *chip removal* is vital for the improvement of tool life. Finally, the *economic and environmental friendliness* of the cooling strategy relates to environmental problems, fluid disposal, toxicity, filterability, misting, staining and indirect costs incurred when using coolant during the machining process.

Flood cooling is the benchmark for all experiments in this article, as it is the most widely used cooling technique in standard machining processes. Dry cutting is also investigated, as it is an economic and environmental friendly cooling strategy. MQL has a good capability to transfer heat, but during HPM of Ti-6Al-4V it has been found that this proficiency is substantially reduced for this alloy. The SECO tool does not have the ability to apply through-spindle-cooling. Therefore MQL- and HPTS cooling have been omitted from this investigation.

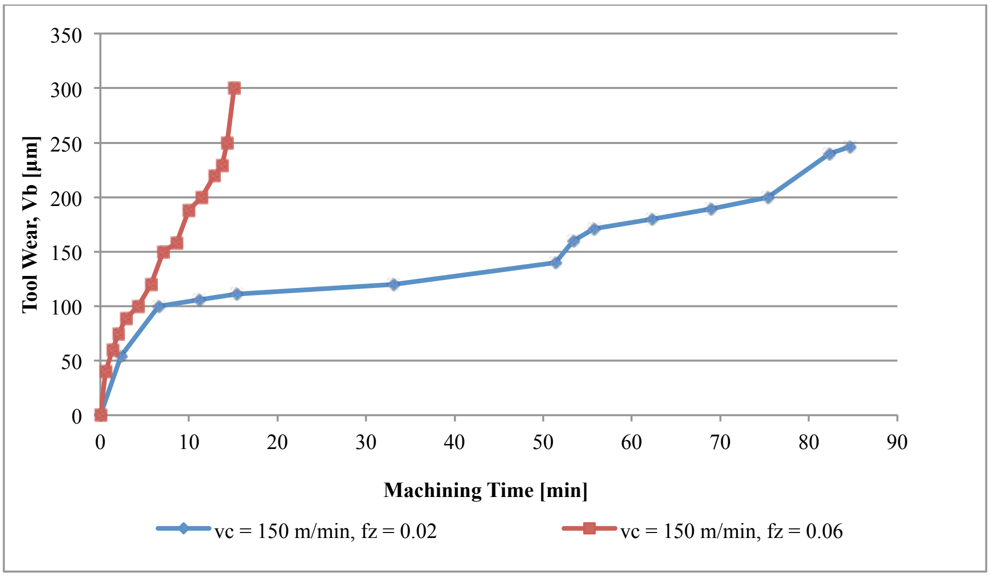
In a study done by Li Anhai *et al*, [11] dry cutting was compared during varying cutting speeds and feeds. The insert was a 25 mm diameter tungsten carbide insert coated with CVD Ti(C, N)-Al_2O_3. Remarkable tool life was recorded at cutting speeds of 150 m/min when compared to speeds of 250 m/min and 300 m/min. The progressive flank wear over machining time is shown in Figure 3. Tool life at speeds of 150 m/min that exceed 90 min before 300 µm flank face wear is reached. After a certain period of time, chipping on the cutting edge was noticed and thereafter flank wear and chipping intensified until failure occurred [11].



(a_e = 5 mm, a_p = 1 mm, f_z = 0.02 mm/z)

Figure 3: Progression of average flank wear vs. machining time with varying cutting speed for coated carbide machining Ti6Al4V under dry cutting conditions [11]

Figure 4 shows the tool wear progression of varying feed rates over machining time. In applying higher feed rates, the wear development is substantially increased [11]. Therefore it can be seen from Figure 3 and Figure 4 that an increase in speed at a constant feed rate causes a drastic decrease in tool life. However, when the cutting speed is constant and the feed rate is increased the identical consequence is realised. It is therefore evident that an optimal cutting condition exists for machining difficult-to-cut materials with coated carbides under dry cutting.



(a_e = 5 mm, a_p = 1 mm)

Figure 4: Progression of average flank wear vs. machining time with varying feed rates for coated carbide machining Ti6SAl4V under dry cutting [11]

The coating technique that was found to be most prevalent throughout the research literature was TiAlN [18]. Coated carbides show promise under dry cutting conditions. Additionally, coated carbides are cost-effective and readily available. With recent developments in coatings, coated carbides have been making advances in higher temperature capabilities, force resistance and, in some cases, lubrication. The tools used in this paper were produced by SECO using their standard preparation techniques.

3 MACHINING OF DIFFICULT-TO-CUT MATERIALS

3.1 General considerations

The results are separated into two components comprising titanium and hardened steel. The experiments conducted, observes the wear on various coating treatments of carbide inserts mounted on the SECO tool holder that have been subjected to flood cooling and forced air cooling (dry cutting) conditions. The experiment evaluated the performance of the coating and coating treatments of the insert when subjected to different cooling strategies and – techniques in terms of the machining time.

3.2 Experimental procedure

Machining was done using a SECO 220.13-12-0050-12 50 mm diameter milling tool holder fitted with a SECO SEAN1203AFTN-M14 insert. The inserts were coated with a TiAlN layer (2 µm thick) encased in a TiN layer (approximately 0.2µm thick) and each insert had a different cutting edge treatment. The various coating edge treatments used were abrasive blasting (AB), abrasive flow machining (AFM), brushing (B), honing (H), laser machining (LM) and magneto-abrasive machining (MAM). Each experiment was conducted with a single insert mounted on the tool holder. The dimensions for both the Ti6Al4V and 40CrMnMo7 plates were both 330 x 253 x 48 mm.

Table 2: Experimental parameters for milling Ti6Al4V alloy and 40CrMnMo7

Material	Cutting speed v_c (m/min)	Feed per tooth f_z (mm/z)	Axial depth of cut a_p (mm)	Radial depth of cut a_e (mm)
Ti6Al4V	150	0.375	2	0.65
40CrMnMo7	250	0.485	3	4.7

The machining experiments were carried out in the type down milling operation along the shoulder of the workpiece material. The cutting parameters were derived from CIRP-Collaborative Project and complied with international standards and are assembled in The various coating edge treatments used were abrasive blasting (AB), abrasive flow machining (AFM), brushing (B), honing (H), laser machining (LM) and magneto-abrasive machining (MAM). Each experiment was conducted with a single insert mounted on the tool holder. The dimensions for both the Ti6Al4V and 40CrMnMo7 plates were both 330 x 253 x 48 mm.

Table 2 [19]. The experiment cooling strategies or -techniques were the benchmark flood cooling, and forced air cooling (dry cutting). The flank face wear band width (V_b) gave an indication of the effect of the chip contact and cooling effect on the cutting edge. For this reason the wear scar measurement was on the flank face of the insert. The tool flank wear was examined for clear wear mechanisms that contributed to tool failure. The tool rejection criteria were as follows:

- Average flank wear V_b = 200 µm
- Maximum flank wear V_{bmax} = 350 µm
- Excessive chipping or catastrophic fracture of the cutting edge

3.3 Machining Ti6Al4V alloy

The tool life of various coating treatments under flood cooling and dry cutting are presented in Table 3. The average time taken to reach the tool wear criterion represents tool life/machining time.

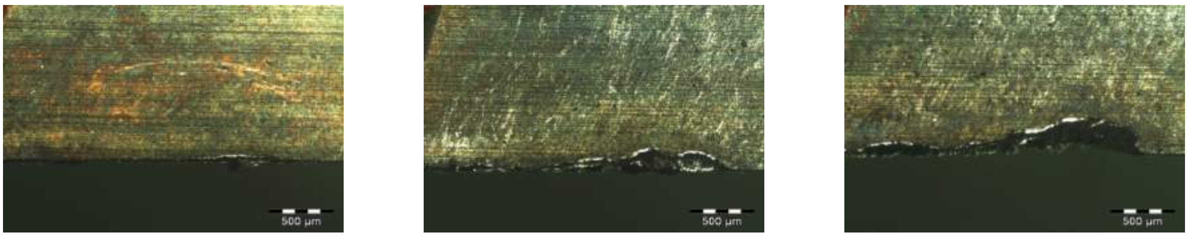
Table 3: Effect of various coating treatments on tool life during HPM Ti6Al4V

Cooling strategy	Type of coating treatment						
	U	*AB*	*AFM*	*B*	*H*	*LM*	*MAM*
	Tool life (min)						
FC	10.7	9.6	12.1	9.4	12.8	10.7	9.4
FADC	119.9	125.2	127.3	111.4	132	134.6	157.3

Cooling strategy : Flood cooling : FC; Forced air cooling (dry cutting) : FADC

Coating treatment: Untreated : U; Abrasive blasting : AB; Abrasive flow machining : AFM; Brushing : B; Honing : H; Laser machining : LM; Magneto-abrasive machining : MAM

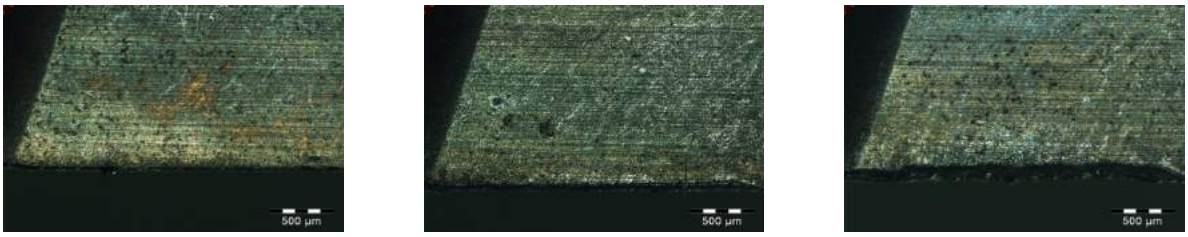
The coating treatment which obtained the longest tool life under flood cooling was the Honing coating treatment. In the initial stages of machining, tool wear was relatively high until approximately 7 min machining time have elapsed. The flank wear progressed evenly over the cutting edge during this period, as can be seen in Figure 5. Hereafter, the wear stabilised, and increased gradually until 11 min machining time had elapsed. From there on the wear accelerated up to 200 μm flank wear at a tool life of 12.8 min. The formation of notch wear became significant after the initial stages of machining and was the reason for the accelerated wear.



Wear after 4.2 min | Wear after 8.9 min | Wear after 12.8 min

Figure 5: Wear scar progression for honing coating treatment under flood cooling, machining Ti6Al4V

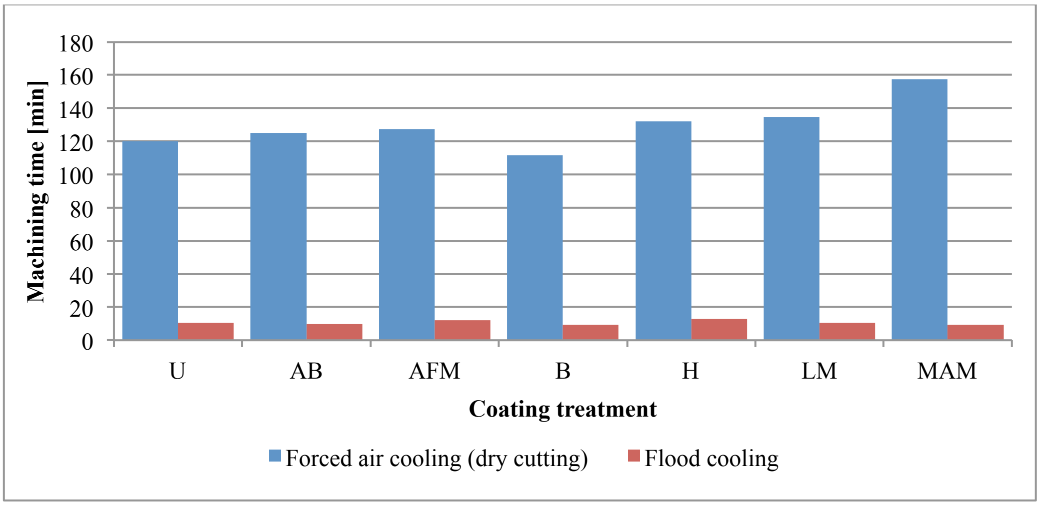
The coating treatment that performed the best under forced air cooling (dry cutting) was the MAM coating treatment. The wear development of MAM reached a constant linear wear rate in the initial stages and increased noticeably after 100 min machining time. The progression of the wear is shown in Figure 6, where the wear only starts to increase prominently after 114.6 min machining time, and accelerating until the 200 μm wear limit after 157.3 min machining time.



Wear after 12.7 min | Wear after 114.6 min | Wear after 157.3 min

Figure 6: Wear scar progression for magneto-abrasive machining coating treatment under forced air cooling (dry cutting), machiningTi6Al4V

The overall tool life/machining time for the coating treatments under flood cooling and dry cutting conditions are compared in Figure 7. This gives clear indication that dry cutting Ti6Al4V with a MAM-coating treatment yields a favourable tool life/machining time under the given experimental conditions and cooling strategies.



Untreated : U; Abrasive blasting : AB; Abrasive flow machining : AFM; Brushing : B; Honing : H; Laser machining : LM; Magneto-abrasive machining : MAM

Figure 7: Cooling strategy performance under various coating treatments, machining Ti6Al4V alloy

3.4 Machining 40CrMnMo7

The effects on tool life for various coating treatment applications when machining 40CrMnMo7 and subjecting it to flood cooling and dry cutting conditions, are given in Table 4.

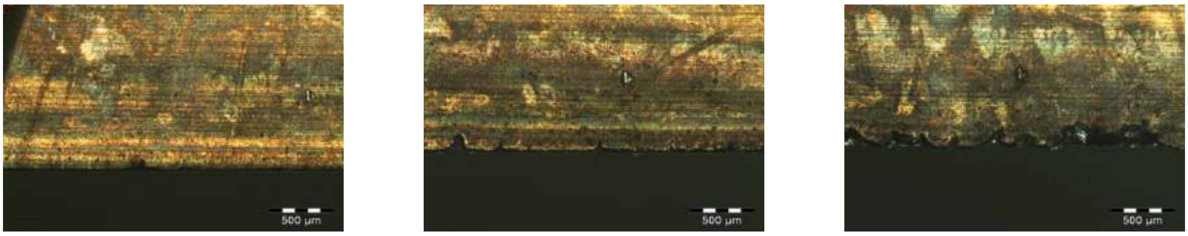
Table 4: Effect of various coating treatments on tool life during HPM 40CrMnMo7

Cooling Strategy	Type of coating treatment						
	U	***AB***	***AFM***	***B***	***H***	***LM***	***MAM***
	Tool life (min)						
FC	13.7	13.3	12.7	14.3	12.9	13.4	21.2
FADC	27.6	26.5	30.7	37.5	21.6	15.0	47.2

Cooling strategy : Flood cooling : FC; Forced air cooling (dry cutting) : FADC

Coating treatment : Untreated : U; Abrasive blasting : AB; Abrasive flow machining : AFM; Brushing : B; Honing : H; Laser machining : LM; Magneto-abrasive machining : MAM

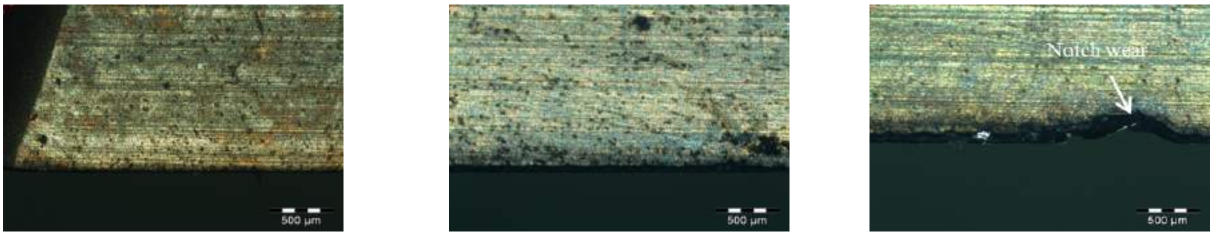
The wear progression for MAM-coating treatment under flood cooling is depicted in Figure 8. Thermal cracking was present after a machining time of 5.9 min and progressively formed along the cutting edge until failure occurred. Thermal cracking became prominent after a machining time of 14.8 min, which caused chipping and material removal from the cutting edge. The wear rate was almost linear throughout the machining under MAM-coating treatment.



Wear after 5.9 min Wear after 14.8 min Wear after 21.2 min

Figure 8: Wear scar progression for magneto-abrasive machining coating treatment under flood cooling, machining 40CrMnMo7

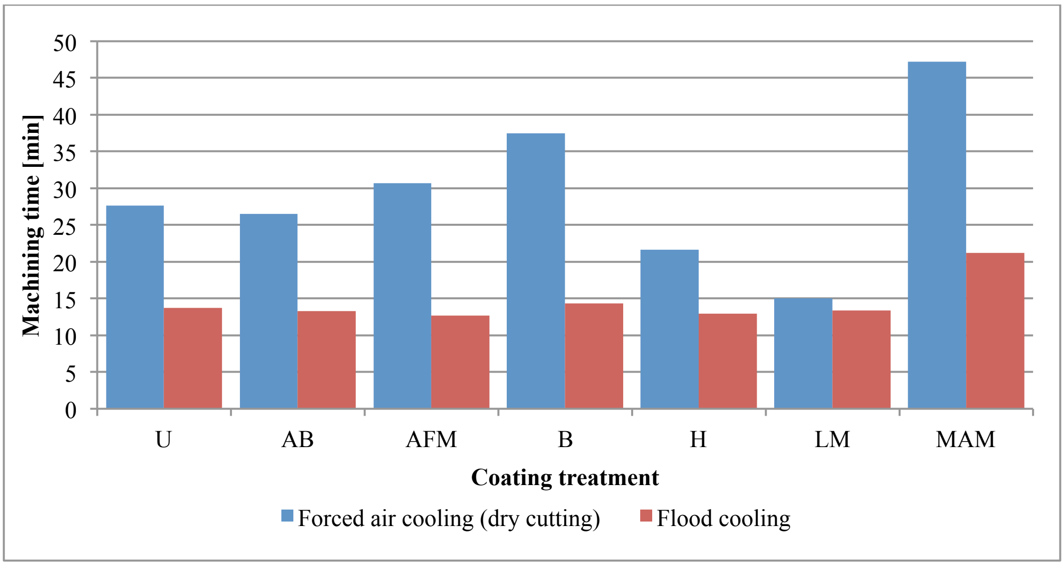
The coating treatment that demonstrated the best tool life was a MAM-coating when subjected to forced air cooling (dry cutting). The wear progression of the MAM-coating treatment is shown in Figure 9. The machining time up to the failure criterion of 200 µm wear was 47.2 min and the initial wear after 5.9 min was distributed evenly along the cutting edge, and increased incrementally from that point up until 35.4 min machining time. Thereafter notch wear became evident at the maximum depth of cut, after which the notch wear increased substantially until finally failing after 47.2 min machining time.



Wear after 5.9 min Wearafter 35.4 min Wear after 47.2 min

Figure 9: Wear scar progression for magneto-abrasive machining coating treatment under forced air cooling (dry cutting), machining 40CrMnMo7

An overview of the outcomes for flood cooling and dry cutting is presented in Figure 10. It is therefore evident that MAM-coating treatment is preferred when machining hardened steel for both flood cooling and dry cutting. It however tends to yield more a favourable tool life under dry cutting conditions.



Untreated : U; Abrasive blasting : AB; Abrasive flow machining : AFM; Brushing : B; Honing : H; Laser machining : LM; Magneto-abrasive machining : MAM

Figure 10: Cooling strategy performance under various coating treatments, machining 40CrMnMo7

4 CONCLUSION AND OUTLOOK

From the results presented in this article, the following was determined for each cooling strategy or -technique:

Flood cooling

- When machining a titanium alloy as well as hardened steel, the cutting tools simultaneously experienced adhesion and abrasive wear, also known as attrition. This promoted oxidation as a result of the creation of new surfaces during the wear process, resulting in a reduction of tool life.
- Thermal fatigue was prominent over the entire cutting edge of the tool, that caused sections to break away, and further caused aggravated delamination of the coating layers. This exposed the cemented carbide substrate to the mechanical and thermal loading, resulting in chipping of the cutting edge.

Forced air cooling (dry cutting)

- The temperature experienced in the cutting zone made the deformation and shearing of the chip easier and did not harm the tool. This can be attributed to the coating that resisted the effect of high temperature.
- There was evidence of thermal fatigue at later stages of machining time, which induced the chipping and hammering effect on the cutting edge of the insert. The reduced thermal fatigue can be attributed to the coating that shielded the substrate from the bulk of the thermal loading.

From the experiments conducted it was evident that thermal fatigue and chipping formed the predominant wear mechanisms under flood cooling. This caused thermal loading on the cutting edge of the insert and resulted in the reduction in tool life. Therefore, the temperature fluctuations increased the phenomenon of thermal fatigue and accelerated the deterioration of the cutting edge.

In conclusion, it could be determined that, under the given cutting parameters and experimental setup, the cooling technique of forced air cooling (dry cutting) has the potential to improve the tool life during the HPM of titanium and hardened steel. The movement towards more environmentally friendly machining conditions encourages the reduced use of cooling fluids and harsh chemicals. This favours the use of dry cutting machining processes that are more environmentally friendly and cost efficient. It should therefore be noted that it is important to select the correct cutting tool material, cutting tool coating, coating treatment and cutting parameters. For this study and the results thereof, the recommended coating is TiAlN with MAM coating treatment under forced air cooling (dry cutting).

Further work is suggested in the following fields:

- Investigation into an optimised flow rate of the forced air cooling (dry cutting) and its impact on tool wear and surface quality. Closer attention should be paid to the mechanisms of tool failure and the impact it has on the coating and coating treatment, as well as the effect that an increase in temperature has on the microstructure of the work piece. From the results of this study, the recommended coating of the inserts should be TiAlN with a MAM coating treatment system when machining titanium and hardened steel.
- Investigation into the impact that different cooling liquids have on the machinability of Ti6Al4V
- Further investigation on effect of different flow patterns onto the cutting interface.
- Investigate the effects of cooling the air-stream, with the possible introduction of liquid nitrogen.

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CONCEPTUAL DESIGN FRAMEWORK FOR DEVELOPING A RECONFIGURABLE VIBRATING SCREEN FOR SMALL AND MEDIUM MINING ENTERPRISES

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ABSTRACT

In many mining applications worldwide, the need to keep up with production demands is becoming a necessity. However there are some factors which play a role in preventing the current mining machinery to synchronize with the fluctuating production demands, regardless of these factors, many researches are creating new innovative designs that will deal with these factors effectively. The purpose of this paper is to present a framework that has a structured approach for developing a reconfigurable vibrating screen (RVS) that will be used by small and medium mining enterprises. The research explores the current literature and design approaches used to develop vibrating screens. The paper also provides detailed methodologies to be used for concept selection, structural analysis, component simulation and performance evaluation of the machine. The framework provides suitable guidance for designers to make appropriate decisions from the initial design stage to the commercialization of the designs. The paper also includes necessary adjustable mechanisms needed for different process or production variations. The authors conclude that the preliminary framework be applied for similar reconfigurable machinery in the small and medium mining sector.

Keywords: framework, reconfigurability, production, screening

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1 INTRODUCTION

In mining industries today, there is a need for machines that are able to respond to ever changing production demands. Competitive advantages in the new global economy will belong to enterprises which are capable of responding rapidly to the demand for customized, high-quality products [1]. Many times after a particular size of screen has been ordered and installed it becomes desirable to increase the size of the screen to handle an additional load or flow rate of materials or in the alternative, it is sometimes desirable to reduce the size of a screen for space reasons when it is determined that the screening capacity selected is too large for the flow rate of a particular application [3]. Hence this calls for the introduction of new machineries called RVS. This paper presents a work in progress for the development of a RVS. As experienced currently, most vibrating screens are designed in standard sizes for specific demands. This means that for each production variation the designers have to develop a new machine, this procedure is considered costly and takes time. The new machine design concepts are mostly copied from similar type of designs and only one or two parameters are changed. The creation of design concepts is based on the knowledge that the designers have accumulated through years of design experience [2]. It is therefore the objective of this paper to propose a conceptual framework to assist engineers or designers from the concept selection stage to the final concept evaluation stage? To address this problem, different types of design frameworks such as the design recovery framework by Jill et al. [5], the agent framework by Cao et al. [6] and modularity framework by Manzini et al. [4] are studied.

1.2 Objective

This work proposes a conceptual framework to assist engineers or designers during the planning stage of concept selection. The paper also investigates several design frameworks currently used. Utilizing all these aspects mentioned above, the proposed framework is developed to assist from the process of concept selection to the final stage of concept evaluation.

2 BACKGROUND

2.1 Related work

Concept development is the process of generating ideas based on existing concepts; these concepts are generated through the memories constructed by the designer's interaction with the environment [4]. In this paper, a brief description of most important literature on the topic of RVS development is presented.

Various design frameworks exist in the industry and academics in general, therefore understanding the methods used on these frameworks is vital in discovering what is lacking for them to be more effective. From diverse literature sources, three different types of frameworks commonly used to develop machineries and machines components were identified, namely:

- Design recovery framework
- Agent framework
- Modularity framework

Different design techniques have been developed in the past, amongst them is a process called design recovery framework. This type of framework consists of three different levels namely: functional, structural and data resolution. Jill et al. [5] conducted a study on the design recovery framework for mechanical components, from the study a multi-level road map to all functional, structural and data information to be accumulated for different levels was achieved. Design recovery framework was developed to drive collaboration across the different design domains in order to improve the design reconstruction process. Cao et al. [6] conducted a study using a well know agent-based framework for guiding conceptual design of mechanical products. From the study a hybrid hierarchical agent architecture that is responsible for creating and improving design alternatives was proposed.

The most commonly implemented framework called modularity framework Manzini *et al.* [4], is a combination of all above techniques, combining their strengths and trying to reduce their weaknesses.

2.2 Development of reconfigurable machines (RMs)

A good design of a RM is a design that makes it proficient in handling changes and simplifies the changeover procedure [7]. It is well known that scalability and modularity are very important characteristics of reconfigurable machines. According to Koren *et al.* [15] scalability is defined as the ability of a system to adjust in production capacity through reconfiguration with minimal cost, in minimal time, over a large capacity range, at given capacity increments.

A system is called modular if the type, the shape and the size of each building block are systematically designed in a manner which makes combination into new varieties possible: thus the importance of standardizing interfaces emerges [8]. A modular, structured, multi-perspective approach is essential as knowledge from many disciplines may be required to encompass all of the relevant aspects [9]. Recent studies on reconfigurable machines by Bi *et al.* [10], they studied the needs and drivers to develop the RMs and also clarified them, Further on in the study they defined the academic and practical's issues involved in the development of RMs, and identified the future direction of RMs. In the survey conducted, it was found that there are some typical obstacles that influence the development of RMs. The following obstacles were identified:

- The identification and generalization of design requirements
- The automated programming of reconfigurable machines
- The systematic methodologies for the system reconfigurations
- The standardization and modularization
- The development of a heterogeneous system consisting of different types of RMs.

The study conducted by Spicer et al. [11] has illustrated the need for scalable machines and established a basis for evaluating and describing them. In the study four metrics for evaluating scalable machines are defined namely; capacity increment size, lead-time, cost per unit of capacity and floor space per unit of capacity. It is further determined that the maximum size of scalable machines along with the number of module interfaces to be included in the base machine structure can be achieved by using a mathematical approach [11].

From the literature it is clear that the concept of scalability and modularity is defined in more details and both are considered important in achieving reconfigurability. After analyzing some obstacles mentioned in the literature for development of RMs, the proposed conceptual framework was develop to eliminate such obstacle and further on assist the development RVS.

3 CONCEPTUAL FRAMEWORK FOR DEVELOPMENT OF RVS

This type of framework aims at providing better solutions for designers of RVS. In order to address problems of costly development processes, long development time frames, the designer should incorporate virtual development, simulation, real-time testing and validation before the actual construction of machine [12]. Figure 1 below represents all methodologies that must be taken into consideration from the initial stage of the design to the commercialization of the RVS.

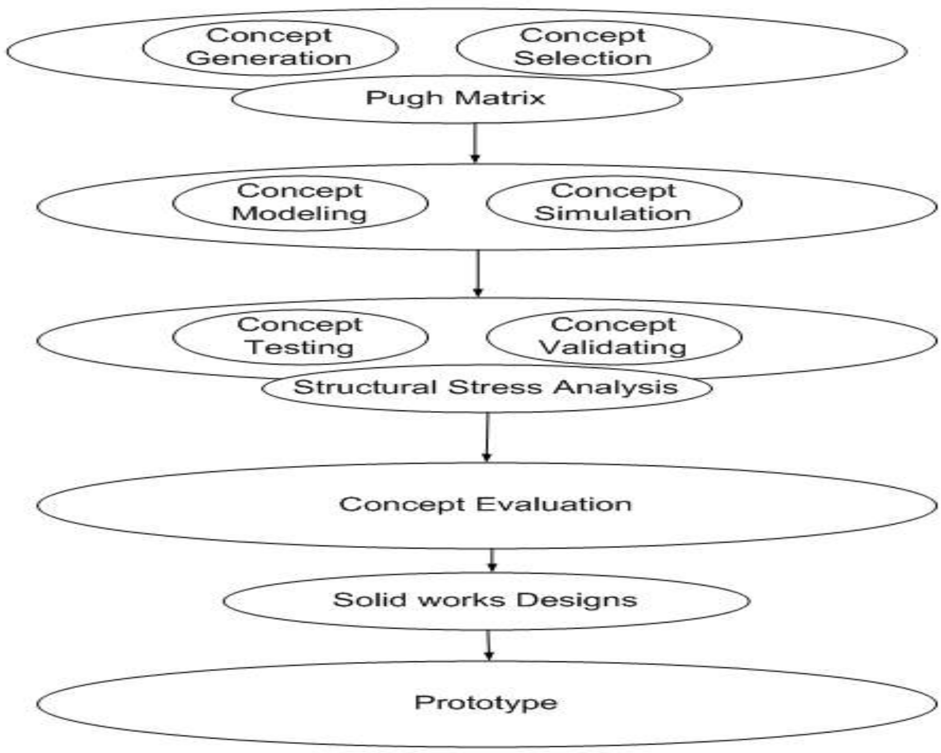

Figure 1: Conceptual framework

The proposed framework is divided into five different stages. In the first stage concept generation and concept selection are grouped together, since they both depend on each other. Further on the concept modelling and concept simulation are also grouped to complement each other, while concept testing and concept validating are also grouped. After all stages have taken place, concept evaluation is proposed as the last stage before the actual prototype could be designed.

3.1 Concept generation and Selection

In this process concepts are generated based on requirements, functionality and capabilities. A method called Pugh matrix is used for concept selection. This method is based on a concept scoring matrix, where each concept is scored according to is functions and capabilities.

3.2 Concept modelling and simulation

A design process where simulation rather than only verifying solutions that are already decided upon, support dialogues with customers, stimulates creation of new concepts and provides guidance towards more optimized designs [13]. A full embracing of simulation-driven design potentially provides the leverage companies need on today's increasingly competitive market.

3.3 Concept testing and validation

For concept testing and validating, a structural stress analysis is performed in order to ensure that the structure will fulfil its intended function in a given loads environment. It is important to anticipate all the possible failure modes and design against them. For a vibrating screen structure the most common modes of failure are as follows;

- Ultimate failure, rupture and collapse due to stress exceeding material ultimate strength.

- Detrimental yielding that undermines structural integrity or performance due to stresses exceeding material yield strength.
- Instability (buckling) under a combination of loads, deformations and part geometry such that the structure faces collapse before material strength is reached.
- Other time dependent material failure modes including stress corrosion, creep, stress rupture, and thermal fatigue.

3.4 Concept evaluation

This process is one of the most important steps taken near to the final stage of the design. Figure 2 represents a schematic diagram of a design evaluation cycle. From the proposed framework, the authors adopted a similar methodology developed by Newcomb et al [14]; this is an evaluation methodology designers can utilize during the configuration of a design. Through this method a degree to which a design can meet its functionality and service life is achieved

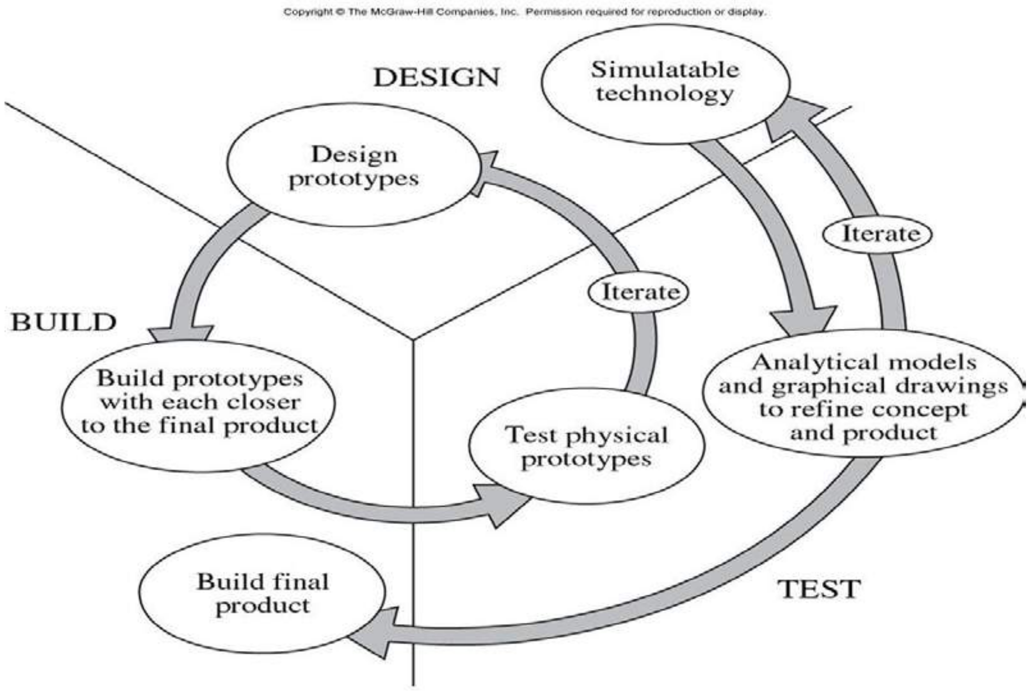

Figure 2: Design Evaluation Cycle (Source: McGraw Hill Corporation)

4 METHODOLOGY

The framework is designed with consideration of other design frameworks that are currently used. The main focus is to design a framework that is efficient and simpler to apply. Utilizing the proposed framework three concepts enabling mechanism was generated.

4.1 Design Concepts

The concepts enabling mechanisms for achieving a reconfigurable system were generated. Figure 3 below shows three vibrating screen enabling mechanisms concepts; these are new mechanisms to be used for achieving the reconfigurability of the vibrating screen structure. Among these concepts there is a gear drive mechanism, modular bolted inserts and sliding mechanism. These mechanisms are essential in meeting the requirements and constraints indicated in 4.2 and 4.3 respectively.

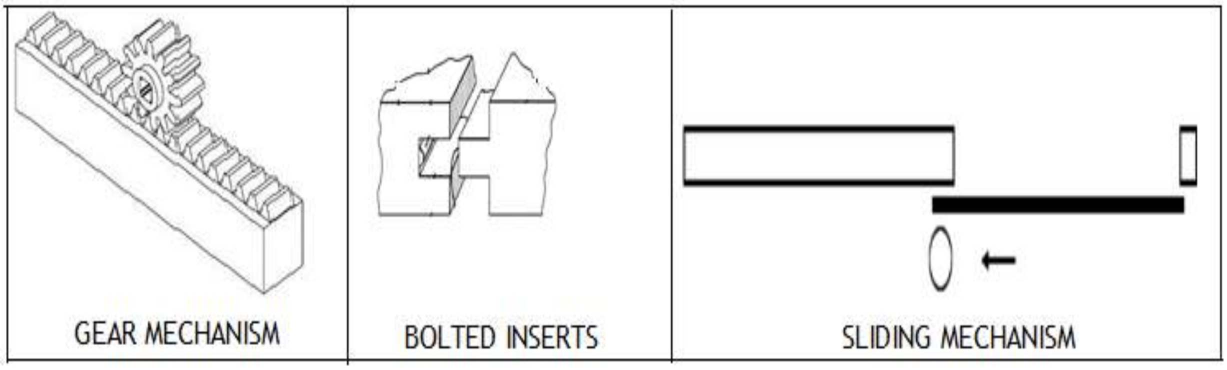

Figure 3: Three vibrating screen enabling mechanism concepts

4.2 Design Requirements and Constraints

The following requirements and constraints are needed for a vibrating screen to be reconfigurable

- The structure of the screen must be reconfigurable, which means it must be able to extend or reduce in structure depending on the production demand.
- It must consist of different mesh modules to allow easier expandability and reducibility
- The structure must be able to extend both in the X and Y direction
- The screen must be capable of processing different material depending on the mesh size.
- The structure must be able to change screening angles as it was discovered to be one of the factors affecting performance of screen

Table 1: Design Constraints (Source: Ngwangwava *et al*)

Cartesian position	**Cartesian displacement (X,Y,Z)**
Linear position (X)	**Linear displacement (X)**
Vertical position (Y)	**Vertical displacement (Y)**
Length	**Extend or Shorten**
Height	**Extend or Shorten**
Angle	**Clockwise or Anti-clockwise**
Force/Tonnage/Torque/Power	**Increase or decrease**
Size	**Increase or decrease**

5 RESULTS

5.1 Pugh Matrix

In this study a method called Pugh matrix is used for concept selection. This method is based on a concept scoring matrix, where each concept is scored according to is functions and capabilities. Unlike the other matrix, this matrix operates the similar to other but its advantage is that is using criteria of selecting a best or accepted concept based on importance. Another advantage of this matrix is that subjective innovative ideas about one concept versus the other can be achieved. This method works on the scoring sequence where the base-case gets a scoring of '5' for each set of customer requirements. New innovative concepts are scored in relation to the base-case. Base-case referring to the average score based on importance.

This method uses a rating of 1, 5 and 9:

- '1' represent a scoring that is below the base-case
- '5' represent a scoring which is equal or similar to the base-case
- '9' represent a scoring that is better that the base-case

Table 2: Concept selection matrix

Customer requirements	Gear mechanism	Bolted inserts	Sliding mechanism
Low cost	5	9	5
Adjustable structure	9	1	9
Reconfigurability	5	9	5
Easy Maintenance	9	5	5
Total	28	24	24

6 DISCUSSION

Low cost- The bolted modular inserts scored the highest score of '9' on cost as compared with the other mechanism. The modular inserts were found to be cheaper to machine as compared to the gears and sliding devices.

Adjustability-The gear mechanism and sliding mechanism concepts scored equally on adjustability, they both scored above average, while the bolted modular inserts are fixed and are unable to adjust. A score of '1' was given for modular inserts.

Reconfigurability-The gear mechanism and sliding mechanism concepts scored an equal average score of '5', while bolted modular inserts scored the highest score of '9', since is easily reconfigurable and it uses different modules of inserts to extend or reduce in capacity.

Easy maintenance- The gear mechanism scored the highest score of '9' above average on maintenance as compared with the other mechanism. This is simply because a gear consists of only fewer parts, but never the less regular maintenance should be done on gear teeth to check if they are not damaged. The rest of the concepts mechanisms scored equally at an average score of '5' for maintenance.

The result from the Pugh matrix concept selection indicated that with the total score of '28', the gear mechanism is the most appropriate for this type of configuration. Since this work is still in progress, the authors could not disclose full concept of the RVS before the provisional patent application is completed. In the future, scalable systems will change the way managers approach capacity decisions by eliminating attempts to forecast economic conditions and by allowing managers to respond to market and demand fluctuations in minimal time Spicer [11].

7 CONCLUSION

The development of reconfigurable vibrating screens is a new research direction proposed in the small and medium mining industries. As observed from the literature sources not all the design frameworks guarantee solutions across all the design steps. The proposed framework integrates all the different design elements described in section 3.

The proposed framework can be utilized on the concept stage of the design. The proposed framework is found to be more appropriate to different types of design conditions; therefore we recommend that the framework be applied to similar types of reconfigurable designs.

Reconfigurable principles are a promising tool for improving machine operations in the processing industry, but this technique is at the initial stages of its exploitation for processing applications, there are some aspects, which still need to be optimized for the system to be fully effective. The concepts of the reconfigurable vibrating screen will further be pursued to validate the proposed framework. At a later stage of this study, Authors will investigate performance results using a scaled down functional prototype model. In this regard, we consider the proposed framework to be a convenient alternative to other design frameworks.

8 ACKNOWLEDGEMENT

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AN ALTERNATIVE APPROACH TO MANUFACTURING STUDIES AND ENGINEERING INNOVATION TEACHING

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ABSTRACT

South Africa is under pressure to produce and retain engineers primarily as a result of an education system struggling to produce the quantity and quality of professionals to meet the needs of the country. At tertiary educational level, engineering faculties have to contend with students from a weakened system. In addition, training facilities at some tertiary institutions are inadequate to meet the needs of industry. Industrial Engineering education, specifically, has experienced difficulties in offering suitable laboratory facilities.

Practical training for Industrial Engineers (IEs) often falls short in encouraging practical and creative thinking processes. This paper explores an innovative approach to attempt to solve this problem.

The methodology used for this research is based on literature studies in fields of teaching and learning. It builds on the concept of the FabLabs that originated under Niel Gershenfeld, and was further developed to ensure that it matches industry and regulatory needs.

The research led to the development of a workspace, designed to allow IE students get first-hand experience of manufacturing and to foster a pragmatic approach. It features equipment to challenge and enable students to explore their own creativity and typical manufacturing limitations.

1 INTRODUCTION

South Africa is under pressure to produce and retain engineers and engineering related skills. Seggie [1] reports that during the years from 1998 to 2010, only 16% of engineering enrolments in South African universities graduated. This compares poorly with the international average of 25%. Referring to comparisons, Seggie quotes a 2005 study that showed that SA struggles with one engineer per 3000 general population, compared with Australia with 1:455 and Brazil with 1:227.

The South African government has optimistic infrastructure plans for the next ten years, says Seggie [1]. However, Seggie argues that without a sufficient engineering population, the question should be raised of who will be responsible for the design, implementation and maintenance of these ambitious improvements.

Clearly the pressure is on tertiary education to increase the supply of engineers, but according to the World Economic Forum's 2011 report [2] on global competitiveness, learners wishing to follow a career in this field face many challenges. Most alarmingly such challenges mainly include school environments where South Africa is rated 132nd in terms of the quality of primary education and where the quality of math and science education is rated 143rd, according to Schwab [2]. This, in turn, leads to additional pressure on tertiary institutions to produce high quality engineers while their feeder stock is either becoming weaker or simply not enough.

2 LITERATURE REVIEW AND BACKGROUND

The methodology used for this research is based on literature studies in fields of education and engineering training as well as current practices within selected industrial engineering departments in South Africa.

2.1 Tertiary Education of Industrial Engineers

Nel and Mulaba-Bafubiandi [3] report on the plight of the industrial engineering (IE) profession in South Africa. She refers to four threats posed to the profession:

- The diverse nature and fragmentation of the discipline as its members find their skills useful in a wide range of industries,
- Poor staffing and low staff-student ratios at universities,
- The intake and quality of first-year IE students,
- The disparity between the training and eventual practice which IE tends to move into: Training tends to be manufacturing focused, while many IEs end up in service industries.

As part of any engineering course, a certain minimum of practical and laboratory work is required by the Engineering Council of South Africa (ECSA) which currently acts as the regulatory body for all engineering studies [4]. This presents IE training with a problem.

Due to the nature of manufacturing, IE work is difficult to recreate in a laboratory facility. Adding to this, the tendency of IEs to increasingly move into service industries has served to complicate the implementation of laboratory facilities for industrial engineering students.

Based on personal observations various attempts have been made in this regard. Some attempts applied by the Department of Industrial Engineering (DIE) at the Nelson Mandela Metropolitan University (NMMU) include time-study exercises, supply chain simulation games, kanban and batch production games, set-up time reduction simulations and pneumatic circuit design to name a few. While this list is not representative of all tertiary institutions teaching the course, it serves to shed some light on the extent to which IE training has been plagued by the difficulty of offering students courses with suitable laboratory facilities.

If one considers that an IE needs to be taught how to design, implement, maintain and improve processes and that these processes are often unique due to the personalities and particular parameters of the process, it follows that such processes could only be re-created in a laboratory with much coordination and relatively high expenditure. Compare the more tangible case of designing an electrical circuit, building it on a test board and testing it. Clearly industrial engineering students need a very different type of exposure than their electrical counterparts.

IEs often have to contend with intangible problems and intangible processes. Added to this, the human element plays a significant role in typical IE projects. Although paper exercises go a long way in fostering a systematic thinking process with students, it lacks in encouraging practical and creative thinking processes.

2.2 Teaching and Learning at school-level

Moola [5] reports on the state of so-called low-fee private schools versus public schools. She reports on a case where a learner in a public school has not had a mathematics teacher for most of the year. While the story is tragic and unfortunate, it highlights a problem to which Beyers, Blignaut and Mophuti [6] have also alluded. Moola argues that the state of mathematics and science education in public schools is not conducive to the rigorous training required of engineers and many other professional and technical courses.

At the same time private and low-fee schools are becoming increasingly popular as parents take note of the looming crisis. The perception appears to be that private and low-fee private schools tend to be better able to maintain a higher level of education quality. According to Schirmer, Johnston and Bernstein [7], much of this success could be attributed to the competitive nature of these entrepreneurial schools where both learner and teacher motivation levels are reported to be higher than in public schools. Yet the majority of learners make use of public schools.

Collins and Millard [8] describe another dimension of schooling. They report on the situation where disadvantaged students have been failed by their schools on the basis of generating an ability to think critically; rather than having been taught *how* to think these students have been taught *what* to think.

Swartz and Foley [9] recount a UK situation where their government forced higher education to teach skills that would make the knowledge that was taught more usable to students and employers. They went on to encourage this practice during the early years of a democratic South Africa. While Technikons and Universities of Technology have been attempting to do exactly this, South Africa still faces a looming crisis in terms of engineering training and education in 2013.

2.3 Industrial Engineering at the Nelson Mandela Metropolitan University (NMMU)

At the NMMU, the school of engineering has intakes of students ranging from rural public schools to urban and private schools. According to a recent informal survey [10], the 2013 intake of 32 first-year students into the Industrial Engineering course originated from 26 different schools. These included suburban schools, township schools and rural schools, pointing to a wide range of intake students' scholastic experience and probable home backgrounds (refer to Figure 1, 2 and 3).

The NMMU makes use of a grading system, known as the APS score, as entry determinant into a particular course. This is based on the student's school performance, currently set at 34 points on the APS system for the National Diploma in Industrial Engineering. The grading system is intended to set a benchmark for the level of competence of students by setting a minimum level on Mathematics and Science of 50% and minimum level of 40% for languages. Conceivably this leaves scope for a wide range of cognitive abilities.

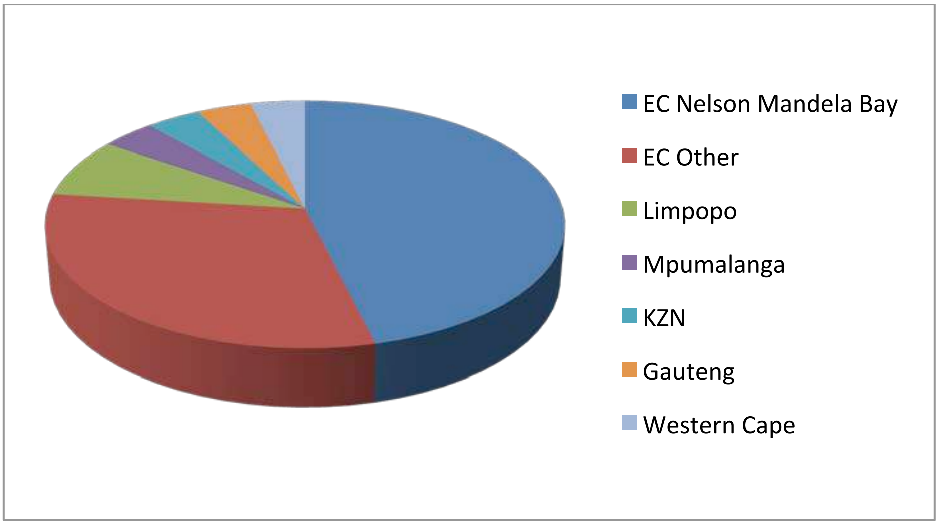

Figure 1: Provincial Origin of 2013 First Years

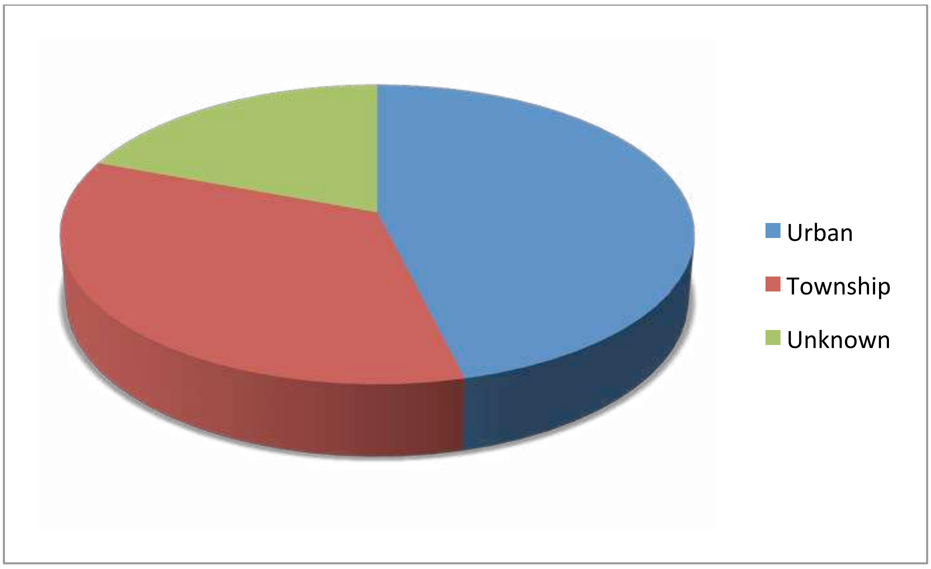

Figure 2: School Environment of 2013 First Years

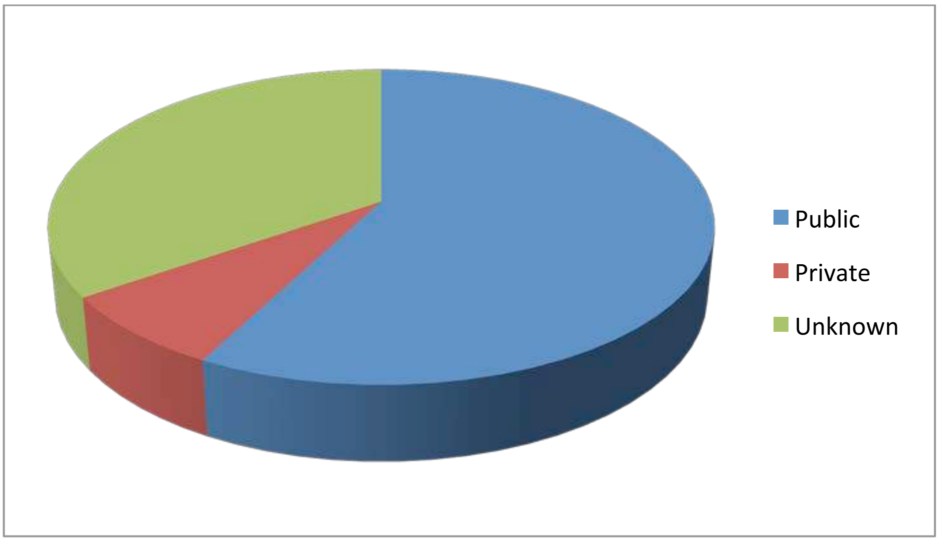

Figure 3: School Type of 2013 First Years

The Department of Industrial Engineering (DIE) at the Nelson Mandela Metropolitan University was established as a separate entity in the mid-1990s in the then Port Elizabeth Technikon (PET). In 2005 the PET merged with the University of Port Elizabeth and Vista University to form the new NMMU.

As a result of the differing backgrounds and scholastic experiences of students, and the practical nature of engineering as a profession, it has become imperative to create learning experiences for students rather than to simply transfer knowledge through lecturing. Dewey [10] wrote on experimentation, experience and purposeful learning in his 1938 publication. He argues that a student is not a clean slate to be filled in, but rather tends to build onto prior experiences to make new sense of information. Furthermore, he argues that as a result of such diverse backgrounds and personal experiences of students, the educator's role now shifts toward creating learning experiences that would lead the student to a directed growth.

In short, students need to experience concepts in order to make sense of them. Universities generally call these 'halls of experience' laboratories. In some cases the learning is structured as in the case of a hardness testing experiment in a metallurgical lab, while other laboratories tend to allow more freedom to explore.

The DIE has been struggling with the problem of creating suitable and sustainable laboratory facilities for its students for many years. These problems had origins at both funding as well as conceptual levels. The DIE functioned with minimal resources and where needed shared workshops and laboratory facilities with other departments. Resources included two poorly equipped laboratories – one was equipped with 10 computers and the second was a lecture room equipped with some basic workstations, components and bins. Due to the shared nature of the lab the inventory of materials could not be maintained.

Over time resources were added in the form of various supply chain games and production simulations. These were used to teach batching versus one-piece flow principles and were found to be relatively effective in illustrating various production principles. These simulations tended to follow a structured approach where a particular game would be played and the rules changed by the facilitator to show the intended progression and activate learning with students. Free experimentation and experiential learning has not been widely accepted into the course possibly due to time constraints.

2.4 Laboratory and Practical Training in Other Fields and Other Countries

Gershenfeld's article on the FabLabs [11] cannot be ignored by Industrial Engineers. He describes the start of a "Digital revolution in fabrication" where, true to pure Lean thinking, production in quantities of one is a reality. He describes how evolution and research have brought us CNC machine tools, Personal Computers and microwave ovens, things that we now treat as normal, but only 30 to 60 years ago were unheard of and very expensive.

Gershenfeld goes on to describe the birth of what he calls the FabLab or 'fabrication laboratory'. The success of this was such that his team then started copying the concept and selling it around the world, mainly to universities.

In a separate article Harkins, Tomsyck and Kubik [12] describes a concept of the future in an attempt to understand the direction the world of engineering is moving towards. They call this the Innovation Economy. It a conceptual time where knowledge workers (e.g. software engineers, architects, engineers, scientists and lawyers) are working in close relationship with highly developed software and where the only human value required is that of creativity and innovation. The software and digitized equipment will do the rest.

If this view of the future is overlapped with the work of Gershenfeld, it becomes easy to see the role of the future engineer. S/He will be a source of ideas and innovation who will use digitized equipment and software to create, maintain and improve on products and/or processes, with little physical contact with the product or the process.

To continue, in the Innovation Economy, education systems will look drastically different, where, among others "*Experiment/lab approach instead of lecture approach*" will apply and "*education moves from information downloading to knowledge generation*" [12]. The authors call on educational institutes to ensure that systems are in place to support creativity and innovation as a learning approach. Cooperstein and Kocevar-Weidinger [13] refer to this process as constructivist learning or discovery learning. They also refer to Good and Brophy [14] who described the process as one where:

- Learners need to construct their own meaning
- Learning is built on prior knowledge
- Learning is enhanced by social interaction and
- Learning develops through authentic tasks.

Gershenfeld's FabLabs are achieving exactly this. While they had originally been designed as a research facility to "study the boundary between computer science and physical science", they now found that students "just wanted to make things". The individual need to create and innovate had met the ideal vehicle to do just this.

3 TIME FOR A NEW APPROACH

Early in 2009, the DIE was informed that significant funding had been made available by the Department of Education for improvement of engineering laboratory facilities at the NMMU. This announcement came in response to a prior request for funding toward such developments. While macro plans and cost estimates were in place at the time, details still had to be finalized. For this purpose a research project was launched.

The findings of the proposed research project have led the DIE to consider using Gershenfeld's FabLabs as a potential experiential learning facility in the Department of Industrial Engineering (DIE) at the NMMU. Possibly the most pressing question to be answered was whether a FabLab would align with the strategies of the DIE.

This question resulted from the current practice of employing FabLabs mostly in mechanical engineering departments, as at the North-West University. In order to assess the applicability in an Industrial Engineering department, the researcher took into account the output requirements imposed on the DIE by its two customer groups as follows:

1. The Engineering Council of South Africa regulates the macro outcomes of all engineering qualifications in South Africa [15]. These requirements are listed in Table 1.
2. Industry acts as an end user of the qualification outputs and therefore has direct and specific output requirements for the products they receive. These requirements were collated through so-called advisory committee discussions [16] and are listed in Table 2.

Table 1: ECSA Output Requirements

Generic Requirements	Specific Requirements (National Diploma)
General Engineering	Math Application
	Statistical Analysis
	Problem Solving
Engineering Specific	Scientific principles
	Engineering science application
	Systems thinking
Engineering Specific	Evaluation & interpretation
	Thinking skills
Communication Abilities	Communication Abilities
Engineering Practice & Ethics	Engineering Practice & Ethics

Table 2: Industry Output Requirements

Industry Output Requirements
1. Software Skills
2. Problem solving
3. Industrial Engineering Skills (Work Study)
4. Other Production Knowledge
5. Communication/Language

Strategic management theory (Hitt, Ireland, Hoskisson [17]) dictates that if such a facility promotes and improves the outputs required by either or both of these customer groups, then by definition, the DIE will be successful in achieving its strategy.

Furthermore, since the core competencies of the DIE are to develop skills in Industrial Engineering, it follows that these competencies need to be supported by such a facility to allow the DIE to achieve its goals. This leads to the question of which skills are required by the DIE to achieve its goals and how such a facility will support these skills. The result of this thought process is presented in Table 3: Skills Development Matrix.

While the Table is arguably incomplete and most likely one-sided, it serves the purpose of identifying the potential value of a FabLab in the DIE. More importantly, based on the findings in Table 3, it has the potential of addressing previously identified areas where the DIE has been lacking in its offerings and in serving the needs of these customer groups.

Table 3: Skills Development Matrix

	Generic Requirements	General Engineering			Engineering Specific			Engineering Specific		Communication Abilities	Engineering Practice & Ethics
	ECSA Requirements (National Diploma)	Math Application	Statistical Analysis	Problem Solving	Scientific principles	Engineering science application	Systems thinking	Evaluation & interpretation	Thinking skills		
Industry Needs	Software Skills	Statistica, Excel models	Excel models	Excel models	Inventor, Excel Exercises	Excel, Inventor, CAD, Various Simulations	ERP Software, OEE Software	Inventor, Excel, simulation modelling	Flowcharts, Programming CAD/CAM (FabLab)	Word & PowerPoint	Copyright, Responsible use of ITC
Industry Needs	Problem solving	Math Software. Tutorials	Tutorials & Statistical Software models	-	Design & Analysis, Physics Challenge, (FabLab)	Mechanics & Model Building, Tool Design (FabLab)	Inter team assignments, Creative Challenges, Innovative Designs (FabLab)	PDCA, Experiential Learning, Design, Build, Test (FabLab)	Design exercises, Practical Exercises/Problems	Group discussion Techniques, Conflict resolution	Honest & Responsible research and reporting
Industry Needs	Industrial Engineering Skills	Feasibility Studies, Productivity Calculations	Observations, Time & Motion Studies	Feasibility Studies, Improvement Identification	Time Studies, Quality Control	Operations Research, Statistical Application	Production Principles, Lean Tools (FabLab)	Production Process Design, Layout Design	Design Exercises, SOPs, Layouts	Reports, Excel abilities	In-service training
Industry Needs	Other Production Knowledge	Production Planning, MRP Performance Measurement	Quality Control & Assurance	Process Improvements Implementat'n Projects	Material Sciences, Manufacturing Techniques	Manufacturing Mechanical, Electrical Subjects	ERP & OEE Software, Quality, HR, Mngt, Finance	Production Measures Interpretation	Practical Problems, Role Playing	Inter discipline problem solving, Integrated projects	In-service training
Industry Needs	Communication/Language	Review & Group Discussions	Reports, Graphs, Tables, Presentations	Brainstorming, Group Problem Solving	Report Writing	Presentations, Experiment Design, Report Writing	Group discussions	Case Studies, Presentations, Class evaluation	Group Discussions, Presentations, Reports	Technical Report Writing, Academic vs Business Report writing	Project planning & In-service training

3.1 Detailed Design

3.1.1 Class Interactions

The identified areas needed more clarity in order to design class interactions as well as finalise equipment requirements. The exercises noted in Table 4 served as departure examples. Many different options were possible and not all of these may prove to be finally acceptable and implementable. Clearly these would require more detailed design and testing. Table 4 summarises these, but more detailed explanations of the exercises are as follows:

- *Physics Challenge (Requirements: Scientific Principles & Problem Solving)*

The researcher met with an expert in the field of upliftment education, Dr Beyers. Dr Beyers has been using FabLabs to introduce learners as young as grade 4 (approximately 10 years old) to the use and capabilities of FabLabs by adopting a FabKids methodology within an innovative mobile and fixed FabLabs around the country. The typical exercise Dr Beyers would conduct with these children would be to pose a technical problem/challenge to them which they have to resolve in groups. The children would create a sketched design and then transfer the design to the computer using easy-to-use Open Office (open-source) CAD-like software. The Integrated equipment would then cut 2D parts from cardboard to be assembled into the 3D solution the groups had conceptualised. Finally the solution would be tested and compared with those of other groups.

Clearly the same exercise will find value at various levels of education, by tailoring the challenge to suit the level of expertise. Examples of such problems would be to design a scaled down vehicle that would be able to stop itself within a given distance after running down a pre-defined slope. Clearly gravity, forces, acceleration, friction and other physics principles are built into a simple to understand problem, yet potential answers are multiple as well as elusive and require a fair amount of reasoning, creativity and design skill to solve.

- *Mechanics and Model Building (Requirements: Engineering Science Application & Problem Solving)*

Mechanics textbooks are filled with applicable examples of gear, lever and pulley systems. Since the fabrication capabilities of typical FabLab equipment are far beyond normal hand-skills, students can physically create their own gears, levers and pulleys to test certain principles and the outcomes of certain exercises.

IE students could be challenged to build scaled versions of workstations and test ergonomics of the station by adding a manikin they made based on anthropometric values they had to research.

- *Inter-team assignments, integration of parts (Requirements: Systems Thinking & Problem Solving)*

Multidisciplinary teams and projects are often neglected in engineering courses. Many reasons might be offered for this, but the flexibility of a FabLab allows student groups to interact without the need to have physical contact. A typical exercise sees two (or more) small groups each be given a separate aspect of a larger product to design and build. The separate aspects need to fit together to complete the final product. Each group is marked on its own design, but the final product is also marked and so is the ease and quality of interfacing the separate parts in the final product.

The ease-of-use of a FabLab relieves the pressure on hand-skills and time-consuming manufacturing of separate parts, whilst allowing precision production of the intended components. In this way the focus is shifted away from manufacturing to design and teamwork.

- *PLAN-DO-CHECK-ACT (Requirements: Evaluation and Interpretation & Problem Solving)*

Evaluation of a design or an improvement is crucial in manufacturing. Often a product looks good on paper, but once produced its various flaws can immediately be identified. This 'reality check' is an important skill for engineering students.

Two exercises can be identified: The first asks the student to design and produce a simple assembly using 2D parts to create a 3D product. Once the parts are produced the student needs to assemble the product. The ease of assembly and strength or usability of the product became clear measures of the success of the design.

The second sees the student needing to improve on a fellow student's design of a product. PDCA principles will apply to assess the student's evaluation and interpretation skills and students need to clearly define these.

- *Production Principles (Requirements: Systems Thinking & Industrial Engineering Skills)*

While similar to the previous exercise, this exercise emphasizes different production problems. The student is given a part to produce, but the part was designed by an outsider. Clearly manufacturability and support issues will result and the fewer iterations the student needs to produce a flawless part, the better. Lean aspects could be emphasised by referring to zero defect and quick change-over techniques.

- *CAD/CAM (Requirements: Software Skills & Thinking Skills)*

Due to the nature of FabLab design, where all production equipment are linked to integrated computers with different software packages, students will have no choice but to learn to use the software in order to produce their assignments. As their skills improve, more advanced software is available that will enhance their capability to produce more complex parts with greater ease and accuracy.

Table 4: Exercise Design

SKILL IDENTIFIED	1. Analysis & Problem solving	2. Mechanics, Model Building & Tool Design	3. Inter-team assignments, integration of parts	4. Plan-Do-Check-Act, Assessment & evaluation	5. Production Principles	6. Software Use/Knowledge
Typical Exercises & Coursework	Physics Challenge (Perpetual motion or Gravity defying machine)	Build a machine. (Gear-set, Pulley Set, lever application.)	Build part of a machine to integrate with another team's part.	Prototype of new product. (Scaled or not, Jigsaw puzzle.)	Manufacture a part that had been designed by someone else.	Open source software
		Build a tool to do a unusual job. (Multi-tool, Around-a-corner screw-driver...)		Improve an existing product		CAD/CAM
Tools & Equipment Required	Laser Cutter	Laser Cutter, Hand Tools	Vacuum Former Laser Cutter Hand Tools	CNC Mill Vacuum Former	Vacuum Former Laser Cutter CNC Mill	Vinyl Cutter Laser Cutter CNC Mill

3.1.2 Laboratory Design

In 2003, Gershenfeld [11] and his team started assembling FabLab kits to be sold to other universities and centres of creativity. These kits consisted of a 2-D laser cutter, a 3-D printer and large and small computer controlled milling machines as well as some materials and electronics manufacturing equipment.

These FabLabs have now been spread around the world into highly developed and developing countries. Youtube videos of FabLab produced artifacts are streaming in continuously. Clearly the idea has caught on. At the DIE the last remaining question was how to equip such a lab to suit its particular needs.

From the suggested exercises it was clear that a computer controlled 2-D laser cutter would be crucial to allow for easy and quick part production. Controlling software for this is open source and the DIE merely had to invest in some mid-range computer equipment.

- A 3-D printer was under consideration, but put on hold due to cost limitations.
- CNC milling equipment offered more versatile (albeit more complex and slow) production capabilities.
- For moulding purposes, a vacuum forming machine was chosen. This is a fairly low-cost option with a wide application and would be very useful for the inter-team exercises.
- From a practical point of view, it was decided to add some hand-tools and basic power tools.
- A Vinyl cutter was added to allow students to decorate their work as well as providing a prelude to working on the laser cutter.
- Safety measures and PPE were added to the list of equipment as and where needed to adhere to regulations.

3.1.3 Laboratory Name

All the FabLabs in South Africa have been introduced into South Africa by the Department of Science and Technology (DST) and managed by the Council for Scientific and Industrial Research (CSIR). All FabLabs also subscribe to a code of conduct that allows a measure of free access to the public. This requirement made it impossible for the DIE to join the global FabLab network.

Instead the DIE saw the opportunities that such a laboratory would present as specific, and course related. For these reasons the decision was to create a more targeted work space to teach Industrial Engineering students about the complexities of science, engineering, production and team-work.

The DIE called the facility the “Thinklab” to reflect that nature of the activities involved. In order to develop higher quality and a sense of sharing of ideas and thoughts, the DIE further created a Facebook identity for this where students would be required to share their ideas and solutions. In this way the DIE intends to give back to the global FabLab community.

4 CONCLUSIONS AND RECOMMENDATIONS

The DIE is acutely aware of the need for producing high quality ready-for-work engineers in South Africa. The state of the education system in the country is, however, not conducive to feeding learners at the required level and in the required volumes. As such the DIE cannot afford to increase the minimum entry requirements to its courses.

Instead the DIE decided to ensure that students have sufficient opportunities, while studying, to be exposed to applied math and science to prepare them. This preparation is based on the collective knowledge and expectations of both the Engineering community (ECSA) and the industrial advisors of the DIE.

Many other industrial engineering departments around the country have similar problems of exposing their students to suitable experiential learning. The DIE at the NMMU believes it has found a viable solution to this problem. Through research in both the national and international spheres at written and practical levels the DIE has been able to identify a potentially successful approach to this issue.

This new approach is a modification of an existing concept called the FabLab which was created, initially for research purposes to investigate the nature and possibilities to integrate digital technology with production and measure a variety of objects and structures. These FabLabs have since been 'found' by undergraduate students, artists, entrepreneurs and R&D personnel in major companies and are being used to manufacture in "quantities of one" (Gershenfeld).

The DIE intends to use the same philosophy to expose, challenge and prepare students to design, create, evaluate and solve typical engineering problems with the support of digital technology.

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A FRAMEWORK FOR A TECHNOLOGY TRANSFER DECISION SUPPORT SYSTEM (TTDSS)

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ABSTRACT

Technology Transfer (TT) has been fundamental to the development of new products and the transformation of manufacturing systems and processes in both developed and developing countries. Given the historical technology gap between developed and developing countries, it is necessary to develop tools and strategies that stimulate and support technology transfer to, and within developing countries. This paper identifies the critical factors, selection criteria and technological positioning indicators that should govern the adoption and implementation of transferred technologies in the sheet metal working industry in Zimbabwe. A survey of local sheet metal working companies revealed that the companies view technology transfer as a complex process that needs decision support. All respondents regard financial and environmental implications as very important while 80% believe technical implications are important. Based on the survey a framework for a Technology Transfer Decision Support System (TTDSS) application which is a systematic tool to assist decision makers in making effective and informed technology transfer decisions is developed. The TTDSS framework approaches the technology transfer problem as occurring in three domains namely necessity, feasibility and selection. Decision support for these three domains is derived from consideration of financial factors, technical factors and environmental and social factors.

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1 INTRODUCTION

Technology transfer (TT) is the process by which the applications of new or existing technological expertise, production processes and systems are transferred from one institution to the other [1]. While some countries have benefitted more from domestic TT, a developing country like Zimbabwe might realise more significant progress by adopting an international business-to-business TT model. Such a model has been effectively used by countries like Japan, from which they then built their own capacity to innovate. However, such a TT model involves a lot of dynamic local and global considerations; parameters and constraints that must feed into the decision making process. The fact that this might take place between entities coming from countries with very different technology levels makes it more complicated [2], thus arriving at a decision on what technology to transfer and how to do it is often a formidable task. Hence there is a need to develop a framework for a decision support system that will close the decision support gap at the functional level. A review of the relevant literature that deals with the main issues covered in this research is provided in section 2 while section 3 covers the research methodology that was adopted. Section 4 is focussed on the presentation of research data and is followed by a discussion of the research findings in section 5.

2 LITERATURE REVIEW

In this section the ideas and assertions of various authorities on technology transfer and decision support systems will be briefly discussed as a way of building rationale and basis for the direction of this research effort.

2.1 Technology

Technology refers to a set of knowledge contained in technical ideas, information, personal technical skills and expertise, equipment, prototypes, designs or computer codes. It is the useful application of knowledge and expertise into an operation [3],[4]

2.2 Technology Transfer

According to Ramanathan [2] technology transfer (TT) may be defined as a mutually agreed upon, intentional, goal oriented and proactive process by which technology flows from an entity that owns the technology to an entity seeking the technology. Bennett [1] similarly defines it as a transaction or a process through which technological knowhow is transferred normally between businesses or agencies representing businesses. He maintains that the transaction takes place when both parties perceive gains and where it can be integrated with other dimensions of the business to improve the competitiveness and performance of the business [1].

The authors found most of the literature on international TT as falling under three main categories namely:

(a) Making a case for technology transfer [5], [6]
(b) Developing a conceptual framework for technology transfer [1], [7]
(c) Investigating the impact of technology transfer [3], [4], [7], [9]

Such literature, though quite thorough and informing, somehow remains in the abstract. It deals with the high end of the TT process, providing information mostly for knowledge workers and TT experts to better understand the process. As Ivarsson and Gorschek [10] point out, such research publications are written for researchers, not practitioners. Thus it fails to address the functional aspects of the process especially with regards to the decision making processes involved at the taker’s end.

Hamzei [11] comes closer to the objectives of this research, in terms of designing a decision support system for TT. The paper however is mainly centred on choosing a technology provider and informing technology transfer policy. This research will therefore endeavour to close that gap by addressing the decision making function that builds rationale for acquiring any particular technology, as this is clearly a pivotal aspect to any successful technology transfer process.

2.3 Decision Issues in Technology Transfer

Hamzei [11] admits that TT is a complex and difficult process that requires decision making at any stage of its progression, including choosing the project, choosing the providers and choosing the TT method. In all cases decisions have to address the potential benefit that will be realised against the costs and expenditure that will be accrued by the technology acquisition and implementation process [10]. Prominent TT decision issues include technological positioning, communication, market impact, environmental performance and change management, as outlined in the succeeding paragraphs.

Technological positioning is an important TT decision factor. The technology taker needs to do a self-check to establish whether they will be able to realise the benefits of the proposed technology. This is described by many authors as the absorptive capacity of the recipient, that is the capacity of the recipient to assimilate value and use the knowledge transferred and is linked to various technological positioning indicators within the company [5].

Effective communication is also cited as a determining factor in TT transactions [12]. Any TT process begins with contact between the company seeking the technology and the providers of that technology. Yakhlef [13] points out that interaction is the locus of significant activity in the processes of knowledge transfer, involving various forms of documentation, correspondence, mediation and face-to-face interactions. Top level managers should be involved in the TT process as their experience and personal attributes enable them to connect the elements of a complex heterogeneous network for effective interaction [7].

For manufacturing companies, the desire to increase productivity and efficiency for competitiveness and profitability remains the major motive for technology transfer. According to Bozeman [14] this is usually termed the market impact criterion, which measures the commercial success of the new technology. Increase in productivity and efficiency is mostly a direct result of increased technical capacity. The technical capacity may come in the form of electro-mechanical, computerised, designs, code, blueprints, as well as in tacit form. Tacit technology refers to knowledge and expertise possessed by people and organisations through experience and learning **Error! Reference source not found.**.

Further, in this age of earthman-ship environmental conservation has become a major factor governing the design and use of technology. The main environmental aspects related to technology transfer are concerned with (a) reducing the unfavourable environmental effects of industry and (b) ensuring that new investment is environmentally sound technology (EST). Any responsible TT process should therefore consider the possible impact, ether positive or negative, of the new technology [1].

Lastly the introduction of new technology translates to significant changes to the way people within the company operate. It also affects the company-customer interface due to changes in products or product functionality. As a result the company may face inertial challenges, or resistance to change [9]. Change management becomes vital in these circumstances. Molina *et al* [9]also suggest that changes that are instigated by customers will be implemented more easily.

2.4 Decision Support Systems

Mallach [16] defines a decision support system (DSS) as a computer based information system whose primary purpose is to provide knowledge workers with information on which to base informed decisions. According to Gasmelseid [17], DSS are used by institutions in developing countries to assess the feasibility of investment projects. These usually utilize models for determination of return on investments and system productivity.

DSS are basically an integration of three components namely a database, graphical user interface (GUI) and the application software. A database is a storage location for data obtained in real time or as a historical record. The GUI is the visual interaction point through which the user communicates with the DSS system software. DSS software comprises the computer code that powers the application. This may contain online analysis processing (OLAP) tools, data mining tools, mathematical and analytical models that are used for decision support [18].

Decision support systems are classified in various ways. Some classification focus on what the DSS does. Under this classification mode many categories of DSS exist some of which are file drawer, data analysis, analysis information system, accounting, representational, optimization and suggestion systems [16]. These categories can be grouped by consideration of the main concept behind each one to come up with four major classes of DSS. The four classes are data oriented, model oriented, expert system and hybrid DSS. Model oriented DSS process input data according to a pre-defined or inbuilt criterion which may be a set of equations, ranking or grading criteria, optimization algorithm or any similar rule for manipulating the data. Accounting and quantitative multi-factor optimization DSS are examples of model based systems. This class of DSS does not require large databases as they handle minimal data storage.

Chandrasekaran [19] emphasises the use of models in DSS design, noting however that models have some inherent limitations because the decision criteria are probabilities and no model is entirely complete. Design of a DSS also requires drawing up a concept that shows the interactions between the various components of the system. This conceptual representation is called the system architecture [17], [20]. A system architecture representation makes it easy for users to understand how the system works and how its components interact without the requirement for technical capacity. It also offers a clear basic structure for the system designer to deduce system requirements.

3 METHODOLOGY

The research methodology constituted the plan for data collection, measurement and analysis aimed at fulfilling or facilitating the attainment of the project objectives. This comprised a review of relevant literature, collection of technology transfer data through a questionnaire, analysing collected data using statistical methods and follow-up interviews to verify or clarify collected data. The literature review has been presented in section 2 and provided the basis for the research questions that were included in the questionnaire.

3.1 Questionnaire Design

The questionnaire was designed for practitioners in industry as the project is aimed at developing a framework for a decision support tool for practitioners. It solicited company and industry specific technology transfer data that was mainly aimed at providing input for modelling the decision support system framework. The questionnaire was designed so as to build a rationale for TT first then point to the need for a decision support system and finally establish decision making factors and criteria. The Research questions were motivated by the literature reviewed and the focus was to get data that would be useful in structuring a framework that can bridge the decision support gap at the operational level.

3.2 Research Questions

The questionnaire included a number of major research questions which we will highlight in this sub-section. The research questions were designed to capture those aspects of the technology transfer process that need decision support at the takers end together with the nature of decision support required. This was done to ensure congruence of decision support functionality and the actual needs within the sheet metal industry. A total of six main research questions were identified as listed below:

(a) What are the main company objectives when undertaking international technology transfer?
(b) What factors do companies consider when undertaking a technology transfer project?
(c) What benefits of new technology are companies most attracted to?
(d) What challenges do companies face when making decisions pertaining to technology transfer?
(e) What criteria do companies use when selecting technologies?
(f) What functions do respondents expect from a technology transfer decision support system?

3.3 Sampling

The survey necessitated the selection of a sample population within the sheet metal working industry from which standardisations regarding the whole industry could be drawn. In coming up with the research sample due consideration was placed so as to select companies with considerable influence within the local sheet metal industry. Eight companies were targeted as the sample for this research. The companies selected represent a wide coverage of the most common sheet metal products ranging from kitchen-ware, piping, packaging, containers, building hardware, fridges and farm implements. Figure 1 shows the output of sheet metal products as a percentage of total output volume for the companies that responded.

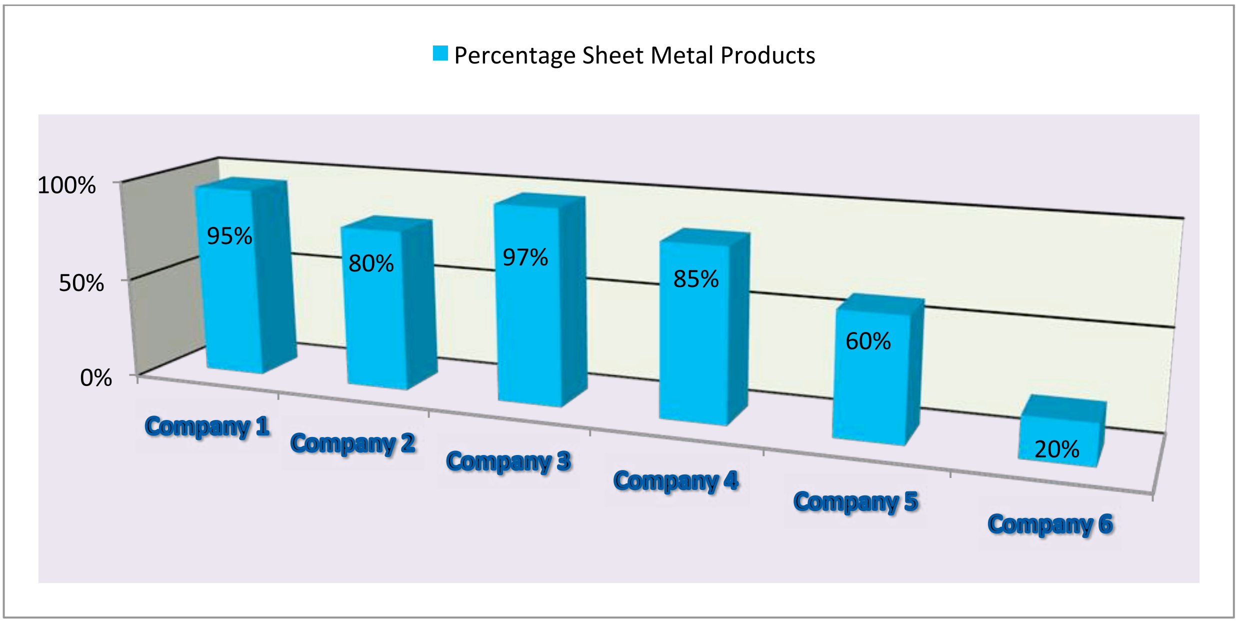

Figure 1: Sheet Metal Products Output for Survey Companies

3.4 Questionnaire Responses

Of the sixteen questionnaires submitted, twelve were filled and received back. Two were turned down and two are still pending. This represents a 75% response rate on all the questionnaires submitted. The results presented here reflect the responses in the twelve questionnaires that were received back.

4 RESULTS

The main findings of the survey will be presented using simple statistical tools in this section. Relevant information for the model framework and subsequent decision support application will be derived from the analysis of this data.

4.1 What are the main company objectives when undertaking international technology transfer?

This question was posed as an open ended question to capture company specific motives for engaging in technology transfer. The result reflects that the main drivers to technology transfer are replacement of out-dated machines and the need for high and consistent quality standards. This was followed by reduction of production and maintenance costs which are major issues affecting the competitiveness of local companies. The responses are listed in Table 1 together with the raw and transformed (percentage of total respondents citing the objective) frequency of each response.

Table 1: Company Technology Transfer Objectives

Objective	Frequency	Percentage
Replacing out-dated machinery	12	100%
Achieving high and consistent quality standards	12	100%
Improving manufacturing efficiency	7	58%
Reducing energy costs	5	42%
Reducing production costs	10	83%
Improving response time to changing customer needs	2	17%
Reducing maintenance problems	8	67%

4.2 What factors do companies consider when undertaking a technology transfer project?

Respondents were asked to rate a list of given factors according to how important each factor was as a technology transfer consideration. This was done to ensure that the decision support system reflects those factors deemed relevant and important by respondents. Financial implications are shown to command the highest priority in all the responses. 92% of responses also rated environmental and legal implications as being very important while 83% regarded technical implications as important. Overall all the factors included were rated at least important in all responses. The technology transfer consideration factor rating results are summarised in the chart shown in Figure 2.

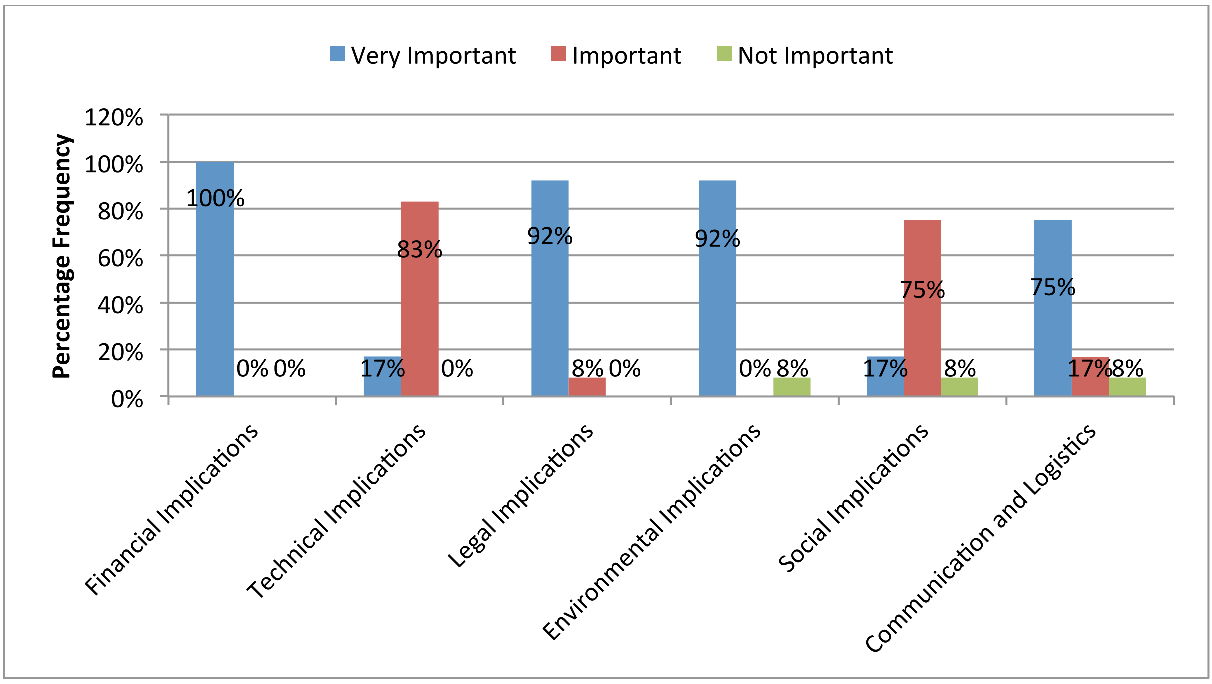

Figure 2: Technology Transfer Consideration Factors Rating

4.3 What benefits of new technology are companies most attracted to?

A rating scale was provided for respondents to express the importance that they attach to a set of potential benefits from a technology transfer transaction (a decision support system that evaluates the margin of 'popular' benefits would be useful). Ratings for all the factors were found to be concentrated towards the high end of the scale. The responses are summarised in Table 2. A rating of 1 represented the least and 10 the highest priority.

Table 2: Rating of Potential Technology Transfer Benefits

Benefit	Rating Frequency									
	1	2	3	4	5	6	7	8	9	10
Increase in production output									25%	75%
Improved quality						8%	8%		17%	67%
Decrease in environmental pollution			8%			33%		42%		17%
Reduced labour cost									17%	83%
Reduced maintenance cost			8%			33%				58%
Improved energy			8%			8%				83%

efficiency										

4.4 What challenges do companies face when making decisions pertaining to technology transfer?

Respondents were asked to rate a list of given challenges that can potentially hinder effective technology transfer. The intention was to establish those factors against which companies should weigh themselves before committing to a TT transaction. The results reveal a wide distribution in the responses that reflects a lack of common ground and attitude towards technology transfer challenges. The distribution of the responses is presented in Table 3 below. A rating of 1 was used to indicate the least challenge faced while 10 represented the biggest challenge faced.

Table 3: Technology Transfer Challenges

Challenge	Rating Frequency									
	1	2	3	4	5	6	7	8	9	10
Inadequate technical skills base				25%	25%		8%		17%	25%
Access to the required hardware			8%	17%	17%			25%		33%
Access to the required software			8%		50%	8%			17%	17%
Facilitating institutions			50%		33%	8%			8%	
Bargain power against transferor				33%	25%				42%	
Capacity to fully utilize technology			25%	50%	8%					17%
Matching output with demand			25%		58%	8%			8%	
Communicating with transferor			42%			17%	8%		33%	

4.5 What criteria do companies use when selecting technologies?

The fifth main research question was addressed by asking respondents to rate a set of selection criteria on a scale of 1 to 10; with 1 representing the least importance and 10 indicating the highest importance rating. The results indicate that the selection criteria provided were regarded as relevant as shown by the concentration of responses towards the high end of the rating scale used. The responses came out as appears in Table 4.

Table 4: Technology Selection Criteria Rating

Criteria	Rating									
	1	2	3	4	5	6	7	8	9	10
The quality of the technology									25%	75%
Training of personnel by the provider of the technology						17%		33%	42%	8%
The technology source country			17%						42%	42%
Product Guarantees								17%	33%	50%
Provision of spare parts by the provider								8%	17%	75%
After- sale service								17%	42%	47%
Provision of documentation and technical knowledge of design									25%	75%
Provision of hardware or equipment.							8%		50%	42%

4.6 What functions do respondents expect from a technology transfer decision support system?

An open question was asked to gather the respondents' expectations on a decision support system. Follow up interviews were also used to capture respondents expectations of what the decision support system should offer. The main expectations are listed in Table 5 together with the percentage of total respondents that cited a particular requirement.

Table 5: Technology Transfer Decision Support System: Respondents' Expectations

Expectation	Frequency
Allow consideration of multiple options	75%
Outline margins of improvement	50%
Calculate return on investment	92%
Capture acquisition costs	83%
Opportunity costs analysis.	17%
Comparison of existing to proposed systems	100%
Report generation for effective presentation	25%

Cash-flow analysis	33%
Resource consumption analysis	8%

5 DISCUSSION

The survey results on company technology transfer objectives reveal a consensus by all the respondents on the need to replace out-dated manufacturing methods within the sheet metal working industry. Improving product quality and reducing production costs are also high priorities. These observations are also consistent with the ratings given to potential increases in production output, reduced labour cost and improved quality which were rated at least nine in 83% of the responses. However, while only 42% of respondents mentioned energy consumption as a technology transfer objective 83% of them gave reduced energy costs a rating of ten. This might be explained by the fact that in Zimbabwe at the moment energy problems are viewed in terms of inadequate power generation and not as a company technology problem. This also reinforces the observation that companies are concerned about the high cost of production and therefore are attracted to most cost-reduction solutions.

All the technology transfer consideration factors are confirmed as important from the ratings obtained. It is interesting to note that at least 8% of respondents regard environmental, social and communication factors as not important. This result is likely due to the fact that most of the respondents were in the engineering and production departments in these companies and as such may not be very sensitive to the challenges that these factors pose from a strategic management perspective. It also shows that some companies may approach the technology transfer process with a bias towards the bottom line; increasing productivity and reducing costs, without due consideration to other factors that might determine the success of those technology transfer transactions in the long term. This observation points to a need for a decision support system that helps decision makers to take cognisance of all important factors including green manufacturing consciousness so that technology transfer is undertaken in a holistic manner that ensures effectiveness and attainment of intended goals.

Another important observation in this research is the distribution of responses on the technology transfer challenges being faced by companies. The responses are widely distributed and show no clear indication of what the major challenges might be. This phenomenon may be justified given that companies have different levels of resources and competencies. On the other hand, this might reveal discrepancies on the level of understanding of technology transfer by the respondents. This may be a result of limited exposure and participation in technology transfer activity, given that 42% have personally participated in such activities before, and the scope or significance of the transactions involved for those that have been involved. However, given that these challenges were general (not focussed on a particular technology) this might be an expected result. It supports the assertion by Bozeman [14] that the challenges to, hence effectiveness of, technology transfer can only be quantified in the context of all the entities participating in that particular transaction.

Further, respondents confirmed the applicability and relevance of all the technology selection criteria that were included in the questionnaire. At least a rating score of eight was given on each criterion in 83% of the responses. This result largely concurs with that of Hamzei [11], although in that case the selection involved a single identified technology. These factors are found to be applicable to a general technology transfer case, although a separation of criteria to apply to the transferor and to the actual technology may be necessary. A further investigation especially on the ratings given to the desired potential benefits of new technology and the consideration factors will achieve this goal.

Lastly the respondents' expectations on the technology transfer decision support system provide a foundation for the development of a framework thereof. 75% of respondents cited the ability to compare alternatives while 92% expected analysis of return on investment (ROI). All respondents mentioned the capacity to compare existing and proposed systems as a necessity. Comparison of alternatives corresponds to the technology selection decision while return on investment analysis implies a decision for the feasibility of a project. Similarly, comparison of existing to proposed systems leads to a decision on the necessity of adopting a new technology or disposing off an old system. It can be argued that all of the expectations cited correspond to these three decision requirement. Hence we propose 'necessity', 'feasibility' and 'selection' as the three principal domains that should be supported by any technology transfer decision support system.

5.1 Research Implications

As highlighted in the preceding discussion of the results it can be concluded that a technology transfer decision support system should be able to support technology transfer decisions in the three domains namely;

(a) Supporting the perceived need for technology transfer (Necessity)
(b) Establishing the feasibility of the technology transfer process (Feasibility)
(c) Selection of the optimum technology (Selection)

It can also be concluded that these decisions have to be based on considerations of certain decision support factors. The decision factors identified in this research can be aggregated into four main decision factor dimensions namely financial, technical, environment and social dimensions. The financial dimension deals with quantifiable aspects that relate to the 'monetary' benefits of technology transfer. Those aspects of the decision that pertain to organisational capabilities, interaction, communication and support services make up the technical factors dimension. The impact of technology on the environment and the social fabric of the organisation comprise the environment and social factors dimensions. Consequently we propose a technology transfer decision support system framework model as depicted in Figure 3. Translation of this model framework into a technology transfer decision support system (TTDSS) application is currently underway as a follow-up to this research. The TTDSS will utilise the Analytic Hierarchy Process (AHP) as one of the decision support tools especially for technology and provider selection. It will also encompass a web application to facilitate interaction among technology transfer stakeholders.

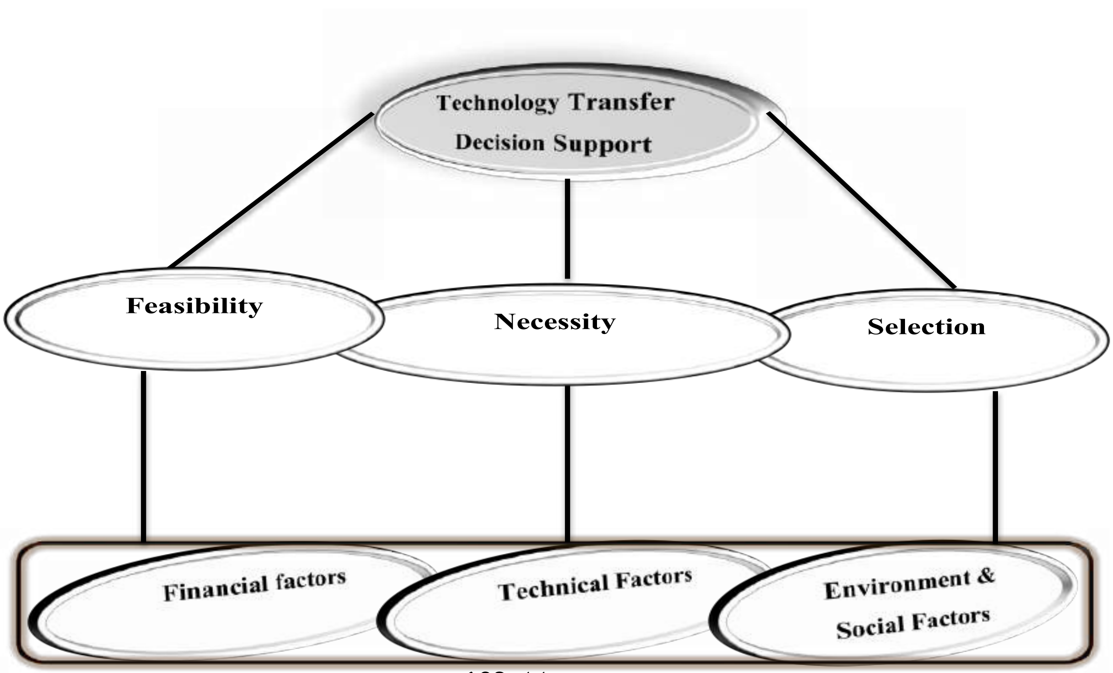

Figure 3: Technology Transfer Decision Support System Framework

The TTDSS application that is being developed following this framework comprises three modules namely a financial module, technical module and environmental and social factors module designed to address the three technology transfer decision domains (i.e. necessity, feasibility and selection). The financial module covers resource consumption analysis, quality and opportunity cost analysis and net present value analysis while the technical module includes technological positioning rating and multi-criteria supplier and technology selection. The environmental and social factors module consists of templates that will be used to track environmental performance and change management within a company. The proposed TTDSS architecture is shown in Figure 4.

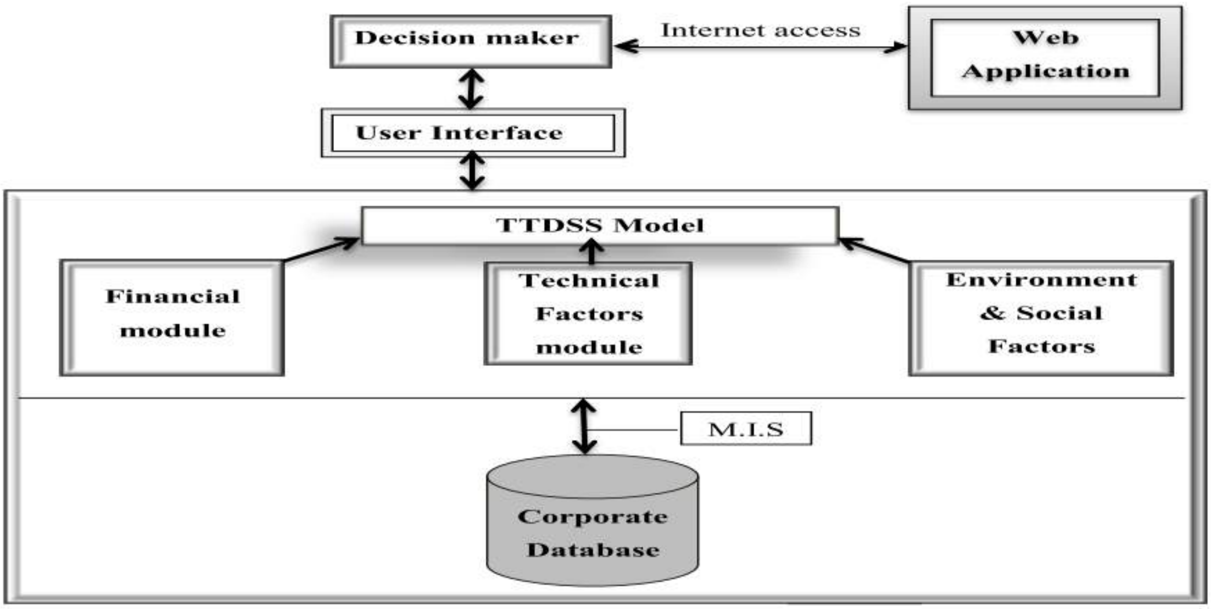

Figure 4: Technology Transfer Decision Support System Architecture

A distinguishing attribute of this framework is that it departs away from the usual academic research discussion platform and instead adopts an application perspective. For instance comparing this model to the Interactive-Recursive Model of Knowledge Transfer [12] one realises that the former can be readily developed into a TT decision support tool while the latter is more inclined towards TT strategy.

This framework is meant to be versatile so as to be applicable in any situation. This seems justifiable since basically all technology transfer decision problems revolve around the three domains namely building rationale for the transaction (Necessity); evaluation of key success and effectiveness factors (Feasibility) and trading off selection criteria (Selection). Thus while the context and scope of technology transfer projects will always change, the underlying motives will hold in all circumstances. It should also be noted that the three decision criteria dimensions all feed into each of the three decision-support domains. For example confirming the feasibility of a project would normally imply financial feasibility, technical feasibility and environmental and social feasibility. Similarly, selection of a technology must take account of its financial implications as well as its technical, social and environmental impact.

6 CONCLUSION

Technology transfer is a complex process that requires decision support tools. Following a survey of the sheet metal working industry in Zimbabwe a framework model for a technology transfer decision support system was developed. The framework model is based on the application of four technology decision factor dimensions namely financial factors, technical factors, environmental factors and social factors to support technology transfer decisions. The technology transfer decisions being supported are those involving determination of technology transfer necessity, project feasibility as well as technology and transferor selection.

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INVESTIGATION OF THE EFFECTS OF LUBRICANT FAT CONTENT ON DRAWN COPPER WIRES

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ABSTRACT

The Lean Manufacturing goal of reducing waste and increasing productivity has made it a necessity to produce good quality products in manufacturing industries at a low cost. In the cable manufacturing companies this can be achieved by optimising the wire drawing process. One way to meet the desired quality of the drawn wires is to improve lubricant efficiency through installation of an automatic, continuous lubricant fat content control system on the drawing machine. The paper shows a method of finding the optimum lubricant concentration for producing good quality copper wires using Taguchi experiments. Taguchi experiments are employed to analyse the effects of different lubricant fat content levels on the tensile strength and lubricant temperature. The results from the experiments indicated that the tensile strength of the wire is affected by low lubricant fat content. The lower the lubricant fat content: the lower the tensile strength drawing lubricant resulting in numerous wire breakages that affect the quality of the final product, namely the cable

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1 INTRODUCTION

Lubricant is one of the main elements in wire drawing that has a large influence on the quality of the produced wire and efficiency of the tool (die).The introduction of tungsten carbide and diamond dies and the increase in drawing speeds due to drive technology has posed the need to provide sufficient lubrication for long die life and intensive cooling that lessen the effects of higher drawing speeds. Most researches done in the past focused on provision of effective lubrication but overlooked the monitoring of its effectiveness during wire drawing process. Ineffective lubrication results in compromised drawn wire mechanical properties and in turn this causes frequent wire breakages and poor surface finish. The efficiency of a lubricant is measured by its emulsion strength and the focus of this paper is to provide a means to continuously control the lubricant fat content. This paper investigates the effects of low lubricant fat content on the mechanical properties of copper wire and its quality.

2 WIRE DRAWING PROCESS

Wire drawing is an operation done to produce wires of various sizes within certain specific tolerances. The process involves reducing the diameter of rods or wires by passing them through a series of wire drawing dies with each successive die having a smaller bore diameter than the one preceding it as stated by Yoshida, Ido, and Denshi [1]. According to Byon et al [2] wire drawing can also be defined as a process that pulls the rod manufactured in the groove rolling process through a die with a hole by means of a tensile force applied to the exit side of the die. According to Vegas, Imad and Haddi [3] the drawing capability process depends on three main parameters: (i) the wire material properties, (ii) the die geometries (such as die angle and die length) and (iii) the processing conditions such as drawing speed and friction at the interface between the die and the wire. The friction phenomenon has a major influence over the wire quality and the die wear in the wire drawing process.

2.1 Lubrication in wire drawing process

Lubrication is a determining parameter for productivity in cold heading. Therefore, the lubricating strategy adopted must be defined in the product design phase. The product geometry, certain client specifications, the materials involved and the various surface stresses in the wire drawing process all influence the choice of the lubricating systems to be used. Once the lubricating strategy has been defined, the performance level must be maintained to ensure a reliable process as shown by Dubois et al [4]. Lubricant performance is important in wire drawing processes as it acts as a coolant that helps reduce the temperature at the die thus prolonging die life. According to Yoshida et al [1] two primary variables that control die life in any metal forming operation are pressure and temperature and consequently, temperature is often a far more critical factor in controlling die life. According to Wright [5] increased drawing speed can increase drawing temperature thus impacting lubricant stability and performance. Beyond this, drawing speed generally has a direct effect on lubricant film thickness and the related coefficient of friction. This is shown generically by way of the Stribeck curve displaying generic dependence of lubricant film thickness and coefficient of friction on drawing speed as shown in Figure 1.

2.2 Temperature effects on wire drawing process

According to Vegas et al **Error! Reference source not found.** the heat generated for high drawing speeds due to plastic deformation and friction between the wire and die has a major influence on the final wire quality, the lubrication in the process, the mechanical properties of the wire and lastly, the wear of the dies. The unfavourable influence of friction during the drawing process can be observed by the non-uniform distribution of strain intensity and by the redundant strain across the wire. Friction causes the non-uniform distribution of mechanical properties on wire cross section.

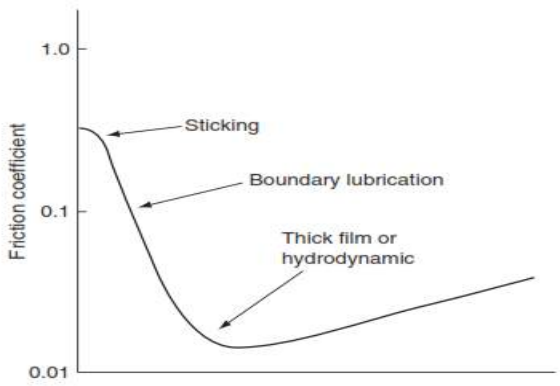

Figure 1: Stribeck curve [5]

The complementary longitudinal internal stresses that remain after the drawing process have a significant influence on mechanical properties of wires, because the stresses from external forces and longitudinal, tensile internal stresses will have an impact on material’s plasticity. According to Haddi et al [6] as the die angle becomes larger for the same reduction, the deformation across the part becomes less homogeneous. Under die angle-reduction combinations, a large hydrostatic tension component exists along the wire central axis, which can cause local tensile failure. The effect of the increase of the strain makes the deformation less homogeneous over the cross section, principally near the die-wire interface, causing the damage of wire. The use of high speeds in the wire-drawing process to meet the demands for increased productivity has a considerable effect on the heat generated due to plastic deformation and friction between the wire and the drawing tools. Most of the mechanical energy converts to heat and results in a temperature increase of the order of hundreds of degrees. This temperature rise significantly affects lubrication conditions, tool life and the properties of the final product. The use of a proper lubrication technique substantially reduces the amount of heat generated during drawing and consequently reduces energy consumption.

2.3 Taguchi analytical methodology

Taguchi's techniques are based on direct experimentation. Taguchi defines quality as loss imparted to the society from the time the product is shipped as stated by Feigenbaum [7][7]. The loss includes the cost of customer dissatisfaction that leads to the loss of company reputation.Taguchi methodology is a powerful tool for the design of a high-quality system and it provides a rather inefficient, but systematic approach to optimize designs for performance and quality. The study of the effects of experimental parameters requires extensive experimentation and some statistical techniques for quantitative evaluation of the effects as shown by Rajurkar, Yu, and Tandon [8].

Khamba et al [9] describes Taguchi's approach to the product design process consisting of three stages: system design, parameter design and tolerance design. System design is the conceptual design stage where the system configuration is developed. Parameter design, in some case referred to as robust design, identifies factors that diminish the system sensitivity to noise, thereby enhancing the system's robustness. Tolerance design specifies the allowable deviations in the parameter values, loosening tolerances if possible and tightening tolerances if necessary. The uncontrollable factors that cause the functional characteristics of a product to deviate from their target values are known as noise factors. A standard Orthogonal Array (OA) has been selected in order to accommodate the data. The Signal-to-

Noise (S/N) ratio is used as the quality characteristics of choice in the Taguchi Methodology of optimization.

The Design of Experiment (DOE) methods result in an efficient experimental schedule and produce a statistical analysis to determine easily as to which parameters have the most significant effects on the final results as shown by Jeon, Park and Kwon [10]. Robust design is described as a product or process that is said to be robust when it is insensitive to the effects of sources of variability, even though the sources themselves have not been eliminated. In the design process a number of parameters can affect the quality characteristic or performance of the product. Parameters within the system may be classified as signal factors, noise factors, and control factors. Signal factors are parameters that determine the range of configurations to be considered by the robust design. Noise factors are parameters that cannot be controlled by the designer, or are complex and costly to control and constitute the source of variability in the system. Tarang and Yang [11] indicate that control factors are the specified parameters that the designer has to optimize to give the least sensitivity of the response to the effect of the noise factors.

A quantitative value for response variation comparison is provided by signal-to-noise (S/N) ratio analysis. Maximizing the S/N ratio results in the minimization of the response variation, and a more robust system performance is obtained. The most important task in Taguchi's robust design method is to test the effect of the variability in different experimental factors using statistical tools. The requirement to test multiple factors means that a full factorial experimental design that describes all possible conditions would result in a large number of experiments as shown by Lin [12]. Taguchi solved this difficulty by using OA to represent the range of possible experimental conditions. After conducting the experiments, the data from all experiments were evaluated using the Analysis of Variance (ANOVA) and the analysis of mean (ANOM) of the S/N ratio, to determine the optimum levels of the design variables. The optimization process consists of two steps: maximizing the S/N ratio to minimize the sensitivity to the effects of noise, and adjusting the mean response to the target response.

3 EXPERIMENTAL PROCEDURE

The experiments were performed on a Henrich Maschinenfabrik Rod Breaker wire drawing machine. The first step was the identification of factors contributing to wire breakages during wire drawing process. Lubricant fat content level was identified as one of the factors that causes wire breakages when below the optimum required level. The second step was the selection of the number of levels for the factors to be considered in the experiments. Appropriate Taguchi Orthogonal arrays were selected based on the number of levels and number of factors to be dealt with in the experiment and factors were assigned to the different columns. Experiments and tests were carried out under the various conditions listed in the orthogonal table and calculation of the relevant ratios and means using Minitab software. The last step was the analysis of results using Minitab software to identify the optimal experimental conditions to achieve the optimum wire quality. To verify the results, an experiment was conducted using the optimal experimental conditions obtained using Minitab and no wire breakages were experienced.

3.1 Experiment 1: Effects of high drawing speeds on the lubricant condition

Experiment 1 focused on determining the effects of excessive heat generated due to high drawing speeds on the lubricant condition. The range for the wire drawing speeds was set at 10m/s, 12m/s and 15m/s. The wire size was 1.76mm and the lubricant fat content was varied from 6% to 9% using readings from the refractometer. The temperature of the lubricant was measured on the die exit side using a resistive temperature sensor.

3.1.1 Application of Orthogonal Array (Experiment 1)

In this experiment, two wire drawing parameters, lubricant fat content and drawing speed were used with three different levels of each. The samples were organized into 9 groups to form an L9 orthogonal array with three levels. The orthogonal arrays and response of the various experiments conducted following Taguchi's methodology are shown in Table 1. The results show that at a constant lubricant fat content level, as the wire drawing speed increases, the lubricant temperature increases in turn. As the lubricant fat content level increases the lubricant temperature decreases thus reducing lubricant deterioration rate.

3.2 Experiment 2: Effect of lubricant fat content on the mechanical properties

Experiment 2 focused on determining the effect of lubricant fat content on the mechanical properties of the copper wire in particular tensile strength. The wire drawing process was performed using different input parameters. The lubricant fat content was varied from 6% to 9% and the wire drawing speed from 6.5m/s to 9.5m/s. The entire drawing system (capstans and dies) was immersed in the lubricant. The target population for the study was the rod breakdown machine outlet copper wires and the wire size used for the analysis was the 2.55mm copper wire. A refractometer was used for measuring the lubricant fat content levels and a tensometer for measuring the wire tensile strength drawn at varying lubricant fat content levels and drawing speeds. The lubricant collection point for measurement on a wire drawing machine is shown in Figure 2.

Table 1 Effects of lubricant fat content and wire drawing speed on lubricant temperature

EXPERIMENT NUMBER	**LUBRICANT FAT CONTENT (%)**	**WIRE DRAWING SPEED (m/s)**	**LUBRICANT TEMPERATURE (°C) (RESPONSE)**
1	6.0	10	61
2	6.0	12	63
3	6.0	15	65
4	7.5	10	55
5	7.5	12	58
6	7.5	15	60
7	9.0	10	46
8	9.0	12	48
9	9.0	15	52

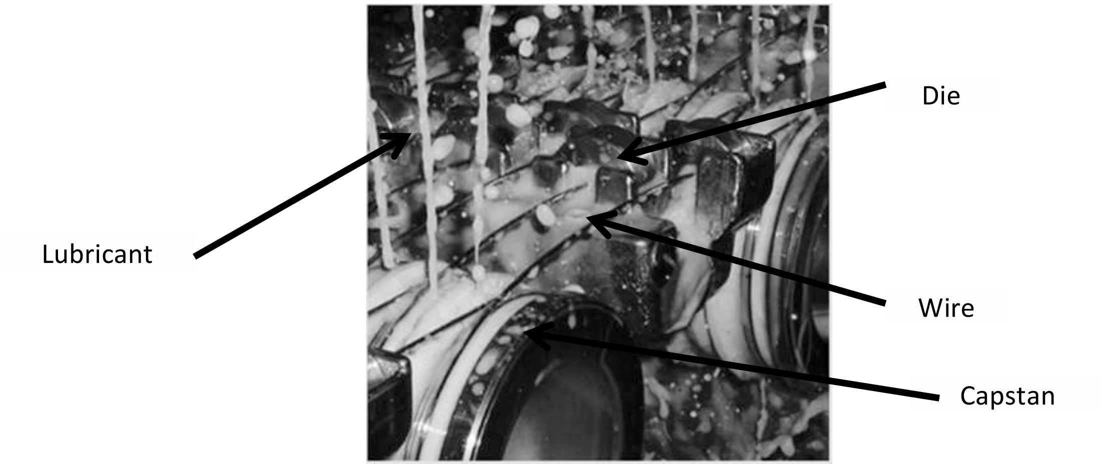

Figure 2: Lubricant collection point on a wire drawing machine

3.2.1 Application of Orthogonal Array (Experiment 2)

In this experiment two wire drawing parameters, lubricant fat content and drawing speed were used with three different levels of each. The samples were also organized into 9 groups. The orthogonal arrays of various groups following the Taguchi methodology are shown in Table 2. The results in Table 2 show that as the drawing speed is increased at a constant lubricant fat content level, the tensile strength of the wire decreases. The increase in lubricant fat content level increases the wire tensile strength in turn due to a decrease in the temperature between the die and wire.

Table 2: Effects of lubricant fat content and wire drawing speed on tensile strength

EXPERIMENT NUMBER	LUBRICANT FAT CONTENT (%)	WIRE DRAWING SPEED (m/s)	TENSILE STRENGTH (kN) (RESPONSE)
1	6.0	6.5	1.370
2	6.0	8.0	1.365
3	6.0	9.5	1.360
4	7.5	6.5	1.385
5	7.5	8.0	1.380
6	7.5	9.5	1.376
7	9.0	6.5	1.393
8	9.0	8.0	1.390
9	9.0	9.5	1.388

4 RESULTS AND DISCUSSIONS

The results for Experiment 1 after computations using Minitab are shown in Table 4 and Figure 3. The effect of the two factors, fat content and wire drawing speed on the lubricant temperature is determined by the signal to noise ratio, the ratio being directly proportional to the effect. From the results shown in Table 3, lubricant fat content level has the highest signal to noise ratio thus it has a greater effect on the lubricant temperature.

Table 3: Response Table for Signal to Noise Ratio

LEVEL	LUBRICANT FAT CONTENT	DRAWING SPEED
1	-35.85	-34.43
2	-35.17	-34.77
3	-33.16	-34.97
Delta	2.69	0.53
Rank	1	2

The most suitable settings for producing wires with the highest tensile strength are obtained from the Main Effects Plot for SN ratios in Figure 3 while lubricant fat content is 9.5% and wire drawing speed is 10m/s.

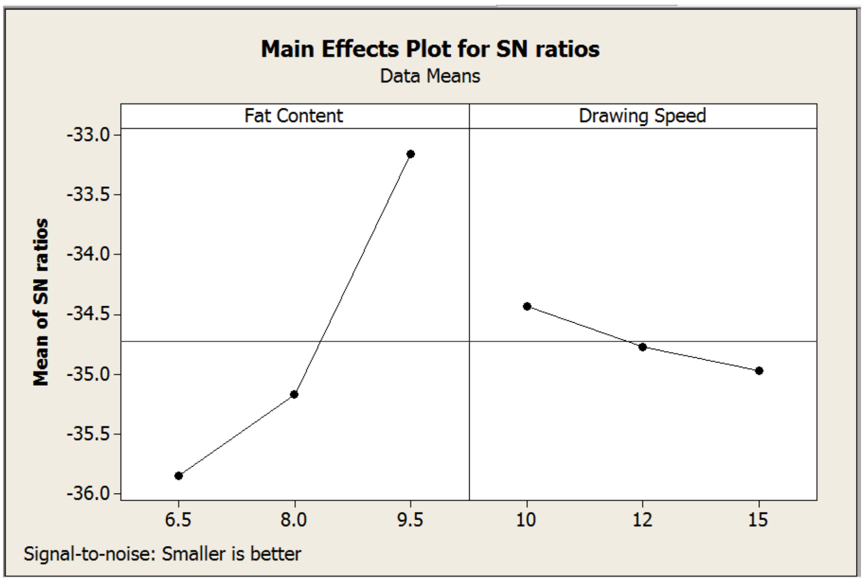

Figure 3: Experiment 1 Main Effects Plot for SN ratios

The results for Experiment 2 after computations using Minitab are shown in Table 4 and Figure 3. The factor that influences the tensile strength of the drawn copper wires is determined by the highest signal to noise ratio and from Table 4, with lubricant fat content having the highest signal to noise ratio. The most suitable settings for producing wires with the highest tensile strength are obtained from the Main Effects Plot for SN ratios in Figure 4 while lubricant fat content is 9% and wire drawing speed is 6.5m/s.

The lower the lubricant fat content the lower the tensile strength and the higher the wire drawing lubricant temperature. For high drawing speeds, excessive heat is generated and this in return accelerates the deterioration of the lubricants used, to the extent that the optimum lubricant emulsion strength is no longer prevailing. From the results obtained in the experiments, it can be concluded that as the emulsion strength of the lubricant becomes weaker, more heat is generated due to friction and the heat generated weakens the metallic bonds in the copper wire.

Table 4: Response Table for Signal to Noise Ratio

LEVEL	LUBRICANT FAT CONTENT	DRAWING SPEED
1	2.703	2.808
2	2.800	2.785
3	2.852	2.762
Delta	0.149	0.046
Rank	1	2

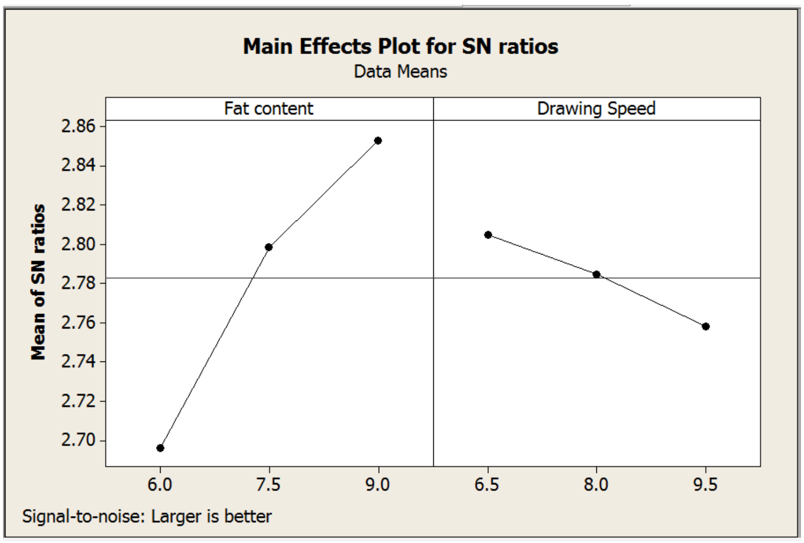

Figure 4: Experiment 2 Main Effects Plot for SN ratios

5 CONCLUSION

The experiments were conducted to determine the effects of drawing speed on the lubricant performance and the effect of the lubricant on the mechanical properties of the wire specifically the strength of the wire. This study confirms that there exists an optimum lubricant level for production of good quality copper wires in the case study company. The author proposes a continuous monitoring system of the lubricant fat content on a wire drawing machine using a Programmable Logic Controller as the next stage of the research. The optimum lubricant fat content level obtained from the Taguchi experiments is proposed to be used as the set point in the automatic monitoring system.

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COMPARISON OF RETURN ON INVESTMENT FOR AN ENTRY LEVEL MICROMILLING MACHINE VERSUS BENCHMARK STATE OF THE ART MACHINES.

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ABSTRACT

Entry level micromilling machines have a substantially reduced capital cost, and lower operating costs associated with them, compared to the state of the art micromilling machines. This paper presents the decision making process and complexity of comparing these two technologies given part requirements, time constraints and part features. Some decisions are trivial, while others require an in-depth understanding of the economics and technical aspects of the technology and the product. Insights gained from research and manufacturing of Micromilled parts are discussed as well as aspects that could impact a techno-economic model. The model aspects are then related to various product sectors each with an estimated market size. One of the outputs of the paper is a business decision framework to guide investors.

1 INTRODUCTION

Computer Numeric Control (CNC) micro milling machines differ extensively on price, functionality and quality, which creates uncertainty for the first time buyer or even seasoned users. With so many options available at such a range of costs it becomes vital to determine what is required in specific applications and to ensure the best return on investment. This study looks at batch volume and one-off production of micro-milled products. The techno-economic model allows comparisons of some real and various estimated costs due to capital repayment, training, software, operations and maintenance.

Various authors define micromilling as related to small machine sizes, tool sizes, work piece sizes and feature sizes [1], [2], [3], [4], [5] and [6]. Simoneau [7] promotes the idea that the difference between conventional and micromilling is the cutting mechanisms or chip forming. In this paper, micromilling is defined as using small milling machines, appropriate for part sizes up to about 300mm on the longest dimension.

The techno-economic model presented in this paper is the result of mostly primary research and manufacturing performed by either the author or under supervision of the author. By analysing requests made to the author "to manufacture parts using micromilling", it is estimated that likely part sizes could be described as a Weibull distribution with Alpha = 2 and Beta = 110. By plotting this distribution in figure 1 it can be seen that approximately 70% of the micro milled parts are expected to be between 50mm and 150mm on the longest dimension. A further restriction is placed on the collet size to be a maximum of 3.175mm. The milling machines in the comparison must be able to machine in any machinable metal. There should also be a cooling and lubrication system that is comparable for the milling machines. This definition of micromilling restricts the machine and tool size to allow a fair comparison to be made.

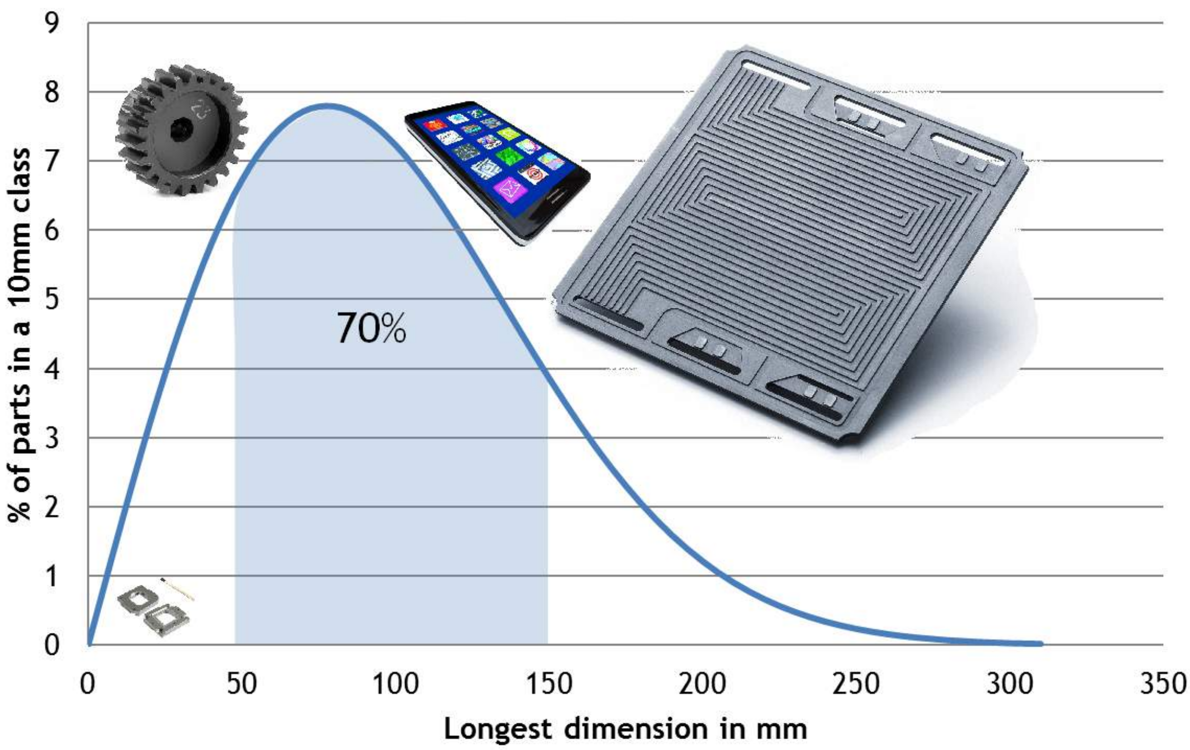

Figure 1: Typical Micromilled part sizes distribution

Micromilling can produce final parts or collaborate in various manufacturing chains, such as moulding, stamping and embossing [1] and [3]. The way that micromilling is used in a specific company will determine the cost and profitability. Enabling multiple uses could increase the utilisation and contribute to recapitalisation.

2 MICROMILLING MACHINES AND ACCESSORIES

CNC Micromilling machines require various supporting functions to be present. These functions include clamping the work piece, providing work piece zero positions, moving the cutting tool relative to the work piece, rotating the cutting tool, lubricating and cooling the cutting tool, changing cutting tools and protecting the environment and operator from harm [1] and [3].

By visiting manufacturers, reading through their brochures or visiting their web-pages, it is evident that various micro mills have different levels of sophistication with regards to the listed functionality. On top of the listed functionalities, add-on tools can be used or operator ingenuity must compensate if lacking.

2.1 Workflow of a micromilling process

According to the author’s experience, the typical CNC micromilling workflow will follow a variation of the processes in figure 2. Other authors [8] and [9] have published similar workflows.

Figure 2 : Typical CNC workflow

In this workflow it is assumed that the first two processes are not dependent on the milling machine used, and will be essentially similar for all milling machines in the model. Software is used throughout the workflow, and will be addressed at a philosophical level only. The workflow processes are discussed in more detail below.

2.1.1 Software considerations

Most customers will expect the manufacturer to improve or adapt the final CAD design and do the required transformations to produce a file or code to control their micro mill. There are numerous software solutions to do this; some are free, open source and others commercial systems ranging in prices from R1000 to R50 000 per licence, sometimes valid for only one year.

If your main business is designing of complex and integrated mechanical and mechatronics systems, then comprehensive commercial software solutions could prove to be indispensable for the added benefits of flow, strength or thermodynamic analysis, and dynamic aspects of the design. However, extensive training and highly skilled personnel are required for this type of business.

In the business of manufacturing, simpler solutions, such as dedicated tool path generators or open source solutions could prove cheaper and more efficient. From a practical point of view, it is the author’s preference to use the least complex software solution that will do the job.

For sustainability some believe that open file formats are non-negotiable, since the re-use of files and data are ensured [10], [11], [12] and [13]. If files or data are stored on proprietary systems, there could be many reasons why the data could be lost without a method to recover it. These include specific companies that fail in the marketplace, software version changes that are not backwards compatible or when a company decides to switch to a competing product and cannot convert its own data.

> *"The metadata schemas, standards, and architectures must themselves be sustainable, and open and well described, so that their purpose and essence can be mapped and transformed to support the new systems that will emerge"* [10].

Arms [12] lists seven sustainability factors that could influence your data or files at some future date namely disclosure, adoption, transparency, self-documentation, external dependencies, impact of patents and technical protection mechanisms. Most of these factors will be problematic when using proprietary software and file formats, since many proprietary software systems do not disclose their file structures, are not transparent, use technical protection mechanisms and foster dependence on their expertise.

2.1.2 Processes in the workflow that is expected to have comparable cost and resource requirements

Essentially, comparable work will be required for the Order, Design, Rough stock, Consumables and Finishing processes, regardless of the specific micro mill used. For this reason these topics are not discussed further in this paper.

2.1.3 Setup of the machine for individual products

Every product manufactured on the micro mill has a unique setup, which must be repeated before the product can be milled. For products that are made in volume, special jigs and standardised setup procedures could be used to save on setup times [1] and [3].

2.1.3.1 Cutting tool setup

Normally the first step in the setup is making sure the correct tool is mounted in the spindle. This could be done manually, and at the same time the operator should set the spindle speed to an appropriate value for the cutting parameters required. In more expensive machines this might be controlled by the cutting file via software. It probably takes the same time to set the speed in the software, as setting the speed on the spindle controller manually. For batch production the software control method will save more time, since the setting is done once only in the file and executed as required.

2.1.3.2 Work holding

Normally the next step in the setup is providing work holding for the work piece. This could be done using mechanical systems such as a vice, direct mounting, and parallels or v-blocks with step blocks. For faster production, vacuum and magnetic clamping are used extensively. New research has shown [14] that even natural adhesive forces namely electrostatic, surface tension and van-der-Waals forces could have application in micromilling work holding. Some automated systems might save time on this setup aspect, but it will not be significant for single items in the larger scheme of costs. When batch and mass volume production is considered, the state of affairs could change significantly. Mass production will not be considered further since that area deserves a study on its own. For batch production there are strategic options that could provide large time savings. The most noteworthy of these include batching of multiple products on a single milling program and pallet mounting [15]. Batch production of less than 50 items also comprises about 70% of engineering output [15].

2.1.3.3 Work piece zero position

More expensive milling machines will have built-in systems for setting the Zero positions of the X- and Y-axis of the work piece, faster than the operator could do manually. It would also have automated cutting tool setup, to ensure the Z-axis zero position or offset is done very accurately. This could prove invaluable on work pieces where the absolute position of the Z-machined surfaces have tight tolerances. For one-off products the effect of setting the work piece zero position will consume a larger percentage of the total time than for batch production, where this is standardised across batches. When using a pallet system it is also possible to increase the utilisation of the milling machine, since the setup can be done in parallel while another batch is milled.

2.1.3.4 Load cutting file

The final step in the setup is to load the correct cutting file, normally a file containing g-code.

2.1.4 The milling process

The milling process can be split in rough cuts, intermediate cuts and final cuts as required. Each cut could require a specific size and geometry of cutting tool.

2.1.4.1 Cooling and lubrication

During milling, many materials might require cooling and lubrication to achieve an optimal material removal rate (MRR). A popular traditional cooling is flood cooling, but Minimum Quantity Lubrication (MQL) such as mist cooling or micro-flood are gaining popularity [16], [17], [18] and [19]. The foremost reasons are occupational health, economic and environmental concerns. Marksberry [16], Sreejith [17] and Li [20] claim that lubrication costs are significant and higher than labour and overheads. In occupational health, respiratory and skin disorders are major complaints; however, there are also risks of airborne lubricants that present problems similar to aerosols. Cooling and lubrication also influences the surface and subsurface changes in the work piece, with possible work-hardening and micro-cracks, stresses and dimensional inaccuracies [17], [18] and [19].

Dry machining is also possible, but would in general require a larger number of cutting tools due to excessive wear. It is however highly dependent on the cutting tool and the material being cut.

2.1.4.2 Rough cuts

For rough cuts, the material removal rate is one of the foremost considerations. Various methods have been used to optimise the removal rate, such as genetic algorithms, cutting force calculations [21], [22], [23], [24] and experimental studies [25]. To increase material removal rate we may either increase the depth of cut, the step over distance or feed speed. If this is done at a constant spindle speed, the chip and forces on the cutting tool becomes larger. At the same time, there is a resultant increase required to the spindle energy requirements. For this reason the maximum spindle torque at various rotating speeds can become a limit to material removal rate. In the section discussing lubrication it also became clear that choosing the correct lubrication method will influence the material removal rate.

2.1.4.3 Intermediate cuts

Intermediate cuts might be required for a variety of reasons. These include inside radius requirements, deeper cuts that could not be done with the roughing tool and similar geometric situations. These intermediate cuts are still doing roughing work, but with specialised roughing tools that are either of a smaller radius, longer or deeper reach or of a different type to the optimal first roughing tool.

2.1.4.4 Tool changes

The major difference between using an entry level micromilling machine compared to the state of the art micromilling machines would be tool changing and setup times. On almost all state of the art micro mills, the cutting tools will be changed automatically, and the Z-position of the cutter tip will be set automatically. Such tool changes will take less than five seconds in many cases and can be seen to have an almost zero effect on cost. On entry level micro mills, each tool change has to wait until an operator is present to do the change and then it will take about one minute to change the tool, and another two minutes to set a new zero position [26].The wait time for the operator is an unknown, since that depends on whether the operator is operating multiple machines and processes. This complicates the comparison process and adds complexity to managing entry level micromilling machines.

2.1.4.5 Final cut

The final cut in the milling process has to give a surface finish that conforms to the specifications. The surface finish is specified by smoothness and could also include work-hardening type specifications including allowable residual stresses. To ensure a high smoothness finish with micro tools, it is required that high spindle speeds can be achieved. For the benchmark comparison, it was required that the micro mills must have a spindle that can rotate at speeds up to 60 000 rpm.

2.1.5 Overheads

Some important overheads not included in the above discussion include energy cost, training requirements and maintenance. Since the current comparison is on machines with a similar power output, the energy requirements should be substantially similar. It would in any case be nonsense to compare the energy requirements in the general case for all micro mills. For this reason the energy cost is not considered further.

However the cost for training and maintenance will be of interest. In the case of state of the art micro mills there are costs that are locked into the system at the time of purchase, in the form of company specific software as well as high skills requirements from the operating personnel. This means that in general the additional requirements for state of the art micro mills will add additional overheads to the process. These costs will differ from company to company and were estimated using real training costs and software costs.

3 PRACTICAL MODEL FOR TECHNO-ECONOMIC EVALUATION OF MICRO MILLS

A reasonable comprehensive cost model to allow product pricing of micro milled items is presented. The model has nine major parts, specifically capital, training, software, order, design, rough stock, consumables, operating and overheads. In previous work Essmann [26] showed that finding the optimal machining parameters could be a multi-objective problem. Essmann solved these problems by applying a Simulated Annealing Algorithm. Other types of genetic algorithms could also be applied with success. Figure 3 illustrates the author's understanding of cost in terms of when it is committed versus when it is incurred over the product life. The dotted line is the traditional view of this graph applied to product manufacturing and it can be seen that as much as 80% of total product cost is already committed in the design stage. The upper line labelled "Technology buying Cost fixing" shows that this tendency is highly reinforced for buying technology. Thus, when buying a specific technology to manufacture products, the cost is committed very early in the timeline, specifically at the time when you buy the machine. Once the capital is spent, the ability to influence cost is reduced. The lower line labelled "Actual Cost at the time" (assuming the capital to purchase was borrowed) shows that the real costs are actually accrued at this time. This makes the choice of technology critical.

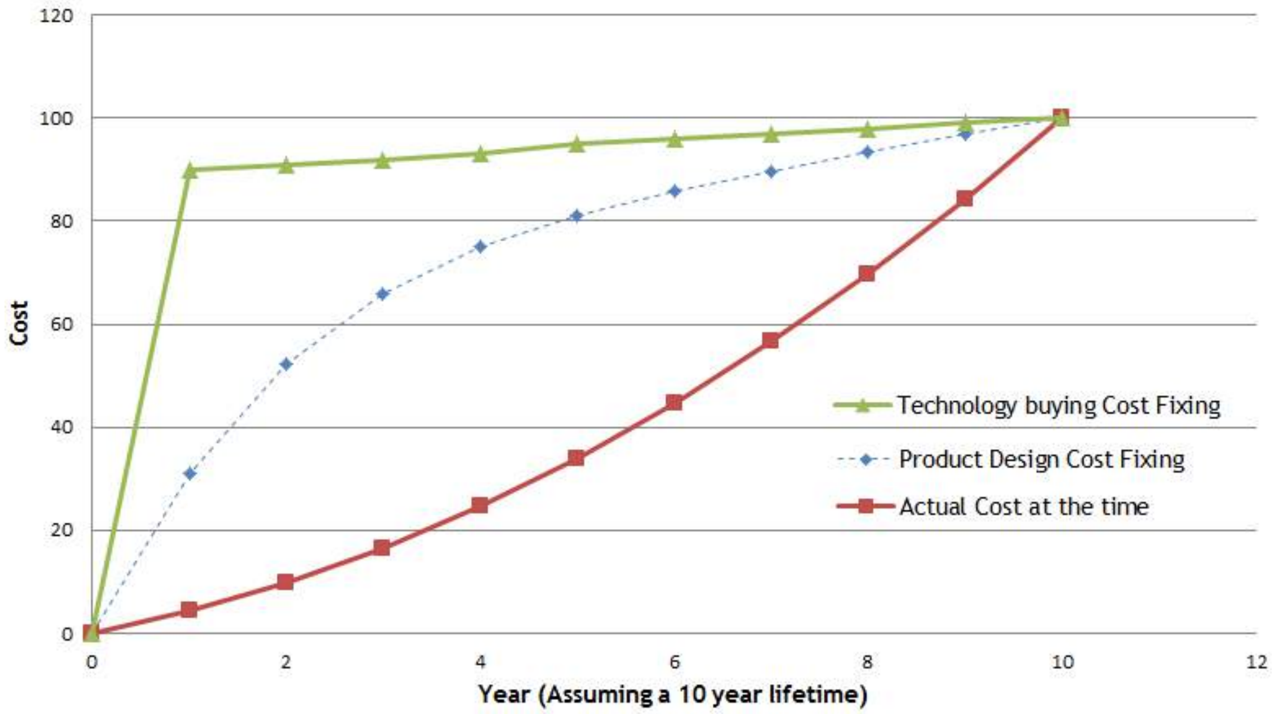

Figure 3: The nature of cost committed versus actual cost at the time

Cost is however only one aspect of the model, since profit is the only mechanism to generate a positive return on investment. The second aspect of the model includes the drivers of sales as market size, number of competing suppliers to the market and market share. The market size and number of competing suppliers are estimated from government statistics, while market share that the specific company may attain is quite fickle and is left as a user variable in the model.

3.1 General assignment of cost

In the model all costs must be assigned to products that are manufactured on the micro mill. The assignment of costs to products can be done using several approaches. The cost assignment methods that will be considered are direct cost and unit cost.

3.1.1 Direct cost

Direct cost, as the name suggests, tries to assign real and directly attributable costs to each product. In many cases it is not possible to know these costs in detail, specifically not if the micro mill is a new product with no historical data available. This means that most costs cannot be assigned using this method. The costs that could be assigned, given proper measuring systems are in place, include material used, real energy use, real operator hours, cutting tools used and lubrication.

3.1.2 Unit cost

For costs that are difficult to measure it is possible to use either hour-based or volume-based unit costs. In many companies, direct energy use is not measured at every machine or process, similar for things such as lubrication, personnel time or even cutting tools. It is however possible to assign average cost based on historical use of resources in such cases.

3.2 Specific assignment of cost

In the next section some specific costs are discussed, estimated and assigned. The reader is reminded of some requirements; specifically the restriction on the collet size to be a maximum of 3.175mm and that the mill must be able to machine in any machinable metal. A minimum quantity lubrication system should be present. Repeatability below 10µm is required and axial movement increment of 2µm or less. Other differences between the micro mills will be considered in the various following sections.

3.2.1 Capital to purchase

To calculate return on investment, it is required to factor in the risk of the investment in the interest or required return rate. For items in the category of manufacturing tools, an acceptable rate could be 15% return over a lifetime of 10 years. Since technology changes quickly, looking at a machine payback period of longer than 10 years is considered unrealistic. The real or quoted capital cost will be used in the model. An average price for an entry level micro mill (given the required specification) ranged from R190 000 to R300 000. These mills generally do not have tool changers, especially at the lower end of the spectrum. For the purposes of this comparison it is estimated that an average capital outlay would be R240 000. Given a 10 year repayment period at 15 % interest, this gives a required contribution of about R48 000 per year.

High end micro mills are available in a variety of machines, typically ranging in cost from R1 million to R2 million. The wide range can be attributed to perceived quality of these tools in the marketplace, which is mostly underpinned by real quality in these products. A large factor in the costs of these mills could also be in the systems that they could contain, such as automated temperature control or compensation, safety systems and higher accuracy or power. Assuming a capital cost of R1.5 million and given a 10 year repayment period at 15 % interest, yields a required contribution of about R300 000 per year.

Comparing such widely different systems might create unease. However, in the marketplace, these widely different systems are all touted as micro milling systems and therefore some part comparison is possible, while also stressing the differences. This could improve the decision making process of a potential investor in these technologies and prevent a potentially ruinous investment.

3.2.2 Training and software

Part and parcel of the market leading state of the art micro mills, are specialised training and software requirements. This is inherent and was shown in figure 3 previously that when you buy the technology you commit most of the lifetime expenses. It stands to reason that if you are willing to spend R1.5 million on a micro mill, then you will want to protect the investment and maximise its profitability. To do this you will require some of the best operators, trained in high-productivity software to optimise your product quality and throughput. From current experience these costs will be repeated over the lifetime of the investment. A conservative estimate of additional yearly cost (above the entry level micro mill) is about 5% to 10% of the initial capital cost. At 7% this will add a yearly cost of R100 000 to a R1.5 million micro mill.

3.2.3 Material and consumables used

The real rough stock material and consumables prices are used. The cost is the same for all micro mill machines.

3.2.4 Setup, finishing and overhead cost

Experimental data is measured and averages are calculated to be used in hour-based unit costs [26]. These costs are different for the compared technologies due to the differences explained in section 2.1, such as different operator wages and time spent by the operator.

3.2.5 Milling Cost due to operator hours and cutting tools

Historical data is logged for cutting graphite-composites and the averages can be used in volume-based unit costs [26]. For the cutting of aluminium, published data is available for a similar estimation of average cost [17]. Similar to setup costs, these costs are different for the compared technologies. A major contributor to the differences is using optimised software that gives proper cutting parameters and increased throughput. The effect of this is highly variable but estimated from previous research to be in the order of 30% to 50% savings in milling time as well as doubling of cutter tool life [27], [28], [29] and [30].

3.3 Sales estimation

The company sales are dependent on the total market size, the number of competing suppliers to the market and market share. For this reason it is logical to investigate the potential market segments that are currently using micromilling processes.

3.3.1 Market size

The model must be supplied with the most recent and best estimate of market size. Typically the only sources of such information are government statistics and competitiveness reports. The markets that are considered as examples for this study are the medical implant and automotive sectors.

3.3.1.1 Medical

Hip replacement average estimates was 13 procedures per year per 10 000 inhabitants in the late 1990's, with estimated annual growth of about 5% [31]. The global dental implant market was estimated to be about €1 billion in 2005 and was estimated to grow to €2.4 by the year 2010. At the time, around 600 000 dental implants were used annually in the world. The implant industry was made up of four or five large companies and maybe 200 smaller manufacturers [32]. In the USA there were about 370 000 hip replacements and 380 000 knee replacements in 2005. The estimated cost of the individual procedures were $14 500 per hip and $13 200 per knee [33].

Using available data from knee replacements as an example, the following process could be used to estimate figures for South Africa. Using data from Kurtz et al [34] and the global competitiveness report of 2010-2011 [35] it was possible to derive a relationship between real knee replacements, obesity and three of the factors of the competitiveness report. The factors used were health, innovation readiness, income per capita and obesity [36]. There are 18 countries' real data shown in figure 4 (number 2 to 19 on the x-axis), with South Africa added to the graph as number 1 ("Real Value" for South Africa on this graph was set to be equal to the Predicted Value, since no real data is shared by the industry in South Africa). The best predictive values, with an R^2 value of 0.846 were found using the following equation (with the two outliers removed the R^2 improves to 0.944):

$$(H^{2.59} \times I^{0.926} \times \$^{0.607} \times Ob^{0.457}) \times 0.008 = \#\, of\ knee\ replacements\ per\ 100\,000 \qquad \textbf{(1)}$$

Where H is the Health score [35],
I is the Innovation readiness score [35],
$ is the income per capita in 1000's of dollars [35] and
Ob is percentage of obese people in the country [36].

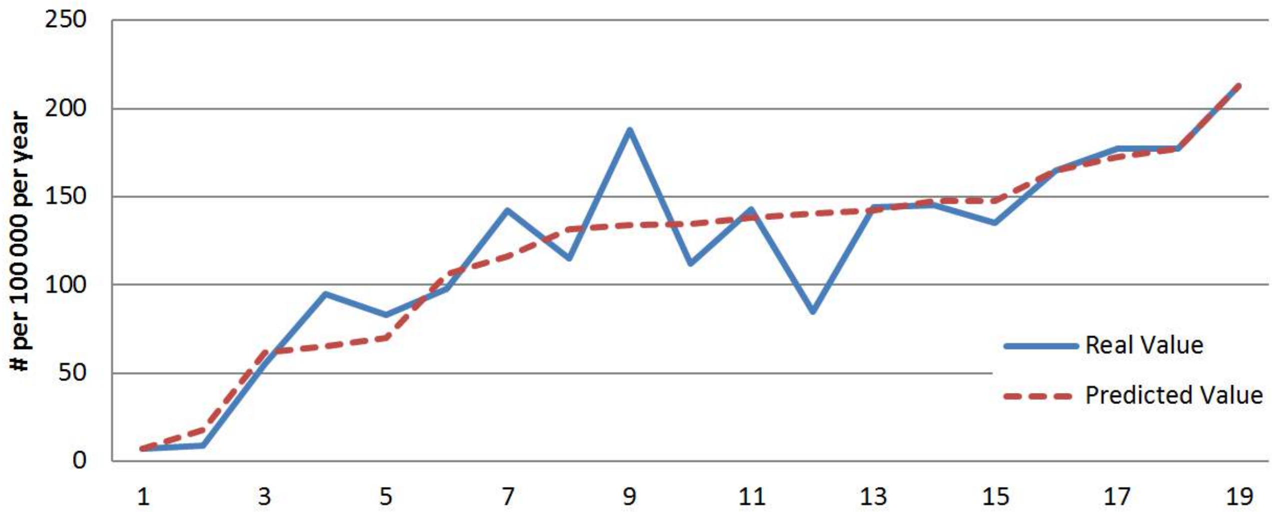

Figure 4 : Real and predicted number of knee replacements per 100 000 people per year

Estimating the market size in South Africa for the year 2011 using equation 1 gives 3614 knee implants and assuming a growth of 8% it may increase to 4215 knee implants in 2013. An estimate from personal communications within the industry suggests the number of knee implants in South Africa is higher, possibly 10 000 to 12 000 per year. It is claimed that up to 50% of the knee replacement cost is in implant cost [33]. Assuming a conservative R20 000 for the implant in South Africa, the total cost of 10 000 knee implants are estimated to be R200 million.

In 2009 there were about 30% more hip than knee replacements done in countries belonging to the Organisation for Economic Co-operation and Development (OECD) [36]. Knee replacements are however gaining ground in the past few years [36]. Repeating the previous calculations for hip replacements, the total cost of 13 000 hip implants are estimated to be R260 million. Dental implants are a lot cheaper and the total cost of all dental implants is estimated to be less than R30 million in South Africa [37].

The global bio-microsystems medical implant market, including accessories and supplies, was estimated at $16.3 billion (R146 billion) in 2012 and is projected to grow to $24.8 billion (R221 billion) by 2016 [37]. In bio-microsystems, devices such as biosensors, micro-arrays, DNA chips, lab on chips, cell chips, bioMEMS, and total analysis systems are used [38].

3.3.1.2 Automotive

Micromilling has several possible roles to play in manufacturing automotive parts. Direct milling of some smaller metal parts is possible, though the more significant application would be making moulds for injection moulding of plastic parts, sintering or stamping of metal parts.

Sales of motor parts and accessories for motor vehicles and their engines were R63 866 million in 2012 [39]. Since South Africa also exports motor vehicles, the overall vehicle production in South Africa could be a more useful measure, and this is expected to reach about 650 000 units in 2013 up from 539 424 units in 2012 [40].

The four 'Pillars' of the Automotive Production and Development Programme (APDP) will influence the automotive industry from 2013 [41]. It could also act as an added incentive for investment in micro mill technology. The Pillars are:

1. Import and customs duties of 20%
2. The Volume Assembly Allowance (VAA) for volumes above 50 000 per year

3. The Production Incentive (PI)
4. The Automotive Investment Scheme (AIS)

To qualify for the AIS at least 25%, or R10 million, of a company's automotive turnover should be local and, or, export sales to original equipment manufacturers. These incentives provide strong incentives for investors in the automotive sector, since most manufacturers have less than 50% local content.

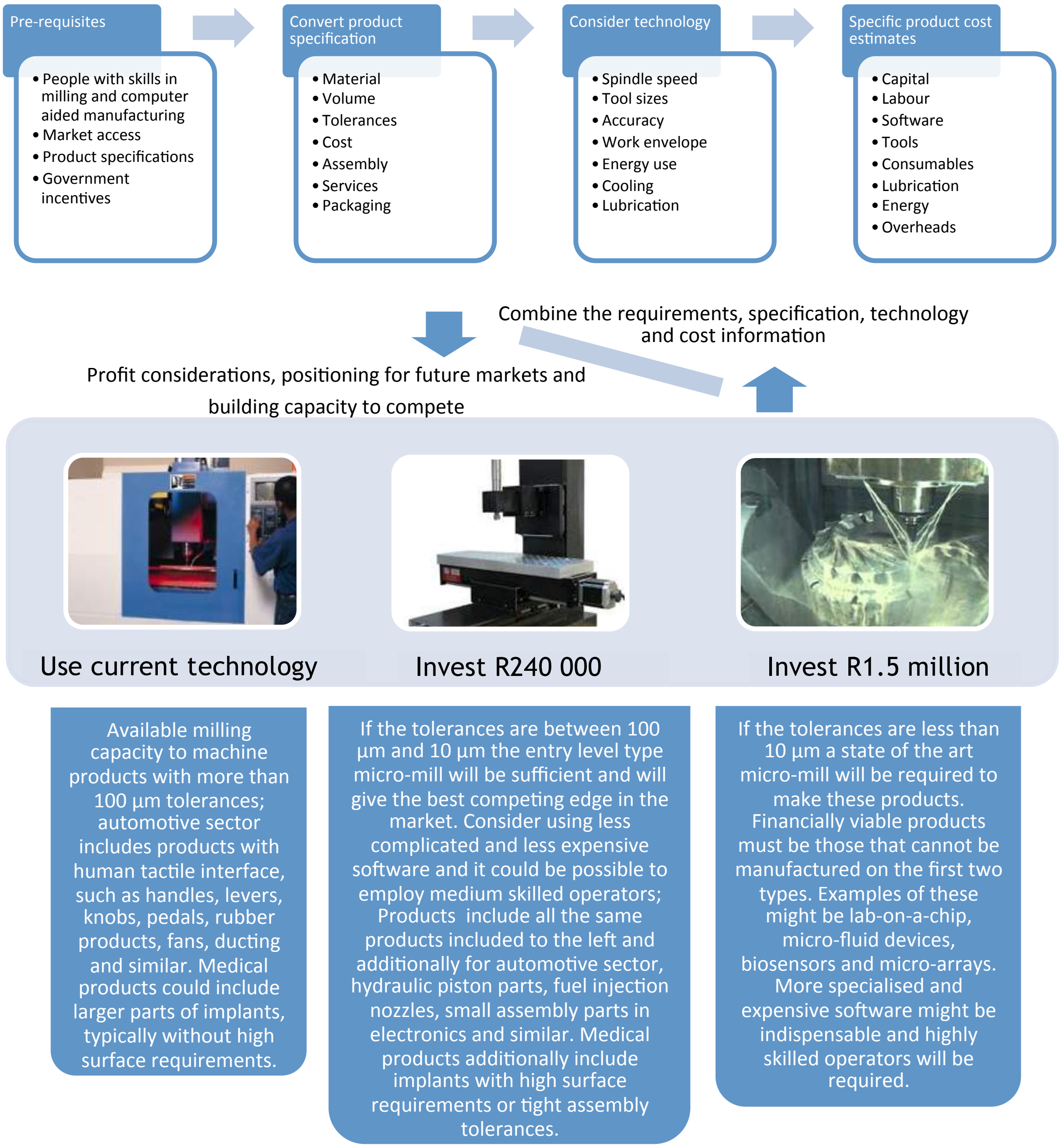

Figure 5 : Business desicion framework for Techno-Economic model

4 MICRO MILL BUSINESS DECISION FRAMEWORK

Previous research suggests possible reasons for investing in micro machining [1], [3] and [42]. These include smaller business sizes or lower throughput, more affordable start-ups, the ability to change technology more frequently, lower maintenance and insurance costs and reduced floor space requirements. To ensure a profitable business however, it is not enough to only understand these strategic reasons. The most important decision will be to choose a micro mill that is capable of delivering the requirements of the market, but no more. Additional capability will cost dearly, and is normally associated with additional operating expenses as well, which drives the price of the products to be only viable for high technology or exotic products. Knowing exactly what your specific market requires in their products will be crucial to choosing the correct micro milling technology and support levels. This will ensure a competitive price, potential market share and a reasonable return on the investment. The pertinent areas to consider before buying technology and possible opportunities in the markets are identified and shown in figure 5.

5 CONCLUSION

It was shown that there are large and somewhat untapped markets for micromilling in South Africa. Many products that are imported for the automotive and medical sectors can be manufactured using micromilling as part of the manufacturing chain. It is fundamental to understand the market and product requirements before choosing the appropriate technology. Additional considerations, including incentives from government, were identified for those interested in investing in micro mill technology. Thinking about those considerations in detail will help investors to choose the appropriate technology and limit the risks of overinvesting in too sophisticated technologies. In those specific cases where state of the art technologies are required, the model shows that significantly more investment will be required and higher operating costs will be experienced. Due to a highly specialised market, subsequent higher financial and technological risks can also be expected.

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TELEMETRIC DATA LOGGER AND MONITOR FOR MINING VEHICLES

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ABSTRACT

Telemetry is the technology that allows data measurement at a distance. It uses data loggers which record data over time or in relation to location, either with built-in instruments or through instruments and sensors. The system discussed in the paper is based on a Peripheral Interface Controller (PIC18F4550), a series of sensors, a Radio Frequency (RF) link and a Graphical User Interface (GUI) developed using Visual Basic (VB). The system was designed to monitor mining vehicles by measuring engine temperature, transmission temperature, hydraulic oil temperature and hydraulic pressure in pumps and hoist cylinders. The data measured by the sensors in the mining vehicles (the plant) is transmitted to the Supervisory Control And Data Acquisition System (SCADA) through the RF link. The RF link uses a transmission frequency of 433.95 Mega Hertz (MHz) to enable flawless communication between the plant and the SCADA. The developed prototype was simulated using small pressurized containers and heating systems and the results were displayed on the GUI. The whole system development process was a multi-discipline project and it showed that RF communications are very reliable in data transmission.

1 INTRODUCTION:

Telemetry commonly refers to wireless data mechanisms that use radio, hypersonic or infra-red (IR) frequencies to transfer data between sensors and data monitoring stations [1]. The technology also encompasses data transfer over telephones, computer networks, optical links and other wired communication links. Telemetry was used as early as 1914 in the Panama Canal where telemetry systems were used to monitor locks and water level [2]. However, wireless telemetry came into use around the 1930's when Pulse Position Modulation (PPM) was used. PPM was later replaced by Pulse Code Modulation (PCM) and now modern telemetry systems take advantage of the low cost Global System for Mobile Communications (GSM) networks by using Short Message Service (SMS) to receive and transmit telemetry data [3]. Global Positioning Systems (GPS) are also now used to enable the location of equipment while monitoring them .Early developments of mining equipment positioning technologies involved the use of laser sensors as proposed by [4], but with GSM, the limitation of laser beacons is removed and the range is increased.

Measurement without storage is of little use especially in manufacturing, production and other industrial systems. Data loggers become very useful when the measured data is to be used for future planning so as to prevent accident and unnecessary down times [5]. The primary advantage of data loggers is that they can automatically collect data on a twenty four hour basis if required [6]. They are left unattended and record data for the duration of the monitoring period. Standard protocols have been developed to allow some instrumentation to be connected to a variety of data loggers. These include Serial Data Interface at 1200 baud (SDI-12), the MODBUS and the ISO 11897 standards. The data loggers have managed to increase productivity and reduce accidents and unforeseen problems wherever theusers give themselves time to study the data trends shown by the records.

When production is to be optimum, especially in the precious minerals mines, the down time has to be minimized. The down time normally increases due to insufficient or inadequate monitoring of critical vehicle systems and parameters [5]. Danger and potential danger conditions are avoided by continuous monitoring and precisely noting any divergence from the norm [7]. It is against this background that a system was developed to monitor the mining equipment parameters with the aim of minimizing the down times and hence increase production.

2 THE TELEMETRIC SYSTEM BUILDING BLOCKS

A number of components, concepts, protocols and systems were integrated in designing the functional data logging and monitoring system. These include sensors, communication systems, a GUI and data storage systems. A microcontroller, the PIC85F4550, has been used as the major communication interface between the plant and the SCADA by allowing data transmission using serial communication to the personal computer (PC) and the RF transmitter.

2.1 Sensors

Two classes of sensors were used on the whole sensing mechanism. The LM35Z temperature sensor was used to measure the temperatures of different plant components. It is a three-pin analogue temperature sensor that can measure temperatures between 0^oC and 100^oC. The output of the sensor is a voltage which is proportional to the ambient temperature and 10 milli-volts (mV) correspond to a temperature of 1^oC [9]. The MPX4115A pressure sensor was used to measure the ambient pressure and is also an analogue sensor. It can measure pressure up to 400kPa. The analogue output voltage is such that 46mV correspond to 1kPa [10].

2.2 Data communication components

The PIC18F4550 microcontroller was used as the major component to enable data communication between the plant and the SCADA. Two of these microcontrollers were used in the project. On the plant, the microcontroller converts analogue sensoroutputs to digital values that correspond to the temperature. It has a 10-bit analogue to digital converter to perform this task. It also performs digital signal processing on the data so that accurate values are sent to the SCADA via the RF link. It has a built-in Universal Synchronous Asynchronous Receiver Transmitter (USART) circuit which provides special input/output pins for serial communications. The USART handles all data communications and is configured by the user before it can be used.

The communication link between the microcontroller and the PC is a USB connection. The circuit uses USB type A connection to transfer data from the EEPROM of the microcontroller developed to allow smooth communication between the RF side and the USB side. A phase locked loop is used to drive the 48MHz CPU of the microcontroller using an 8MHz clock.

RF communication uses the RadioMetrixTXL2® RF transmitter connected to the microcontroller using the USART and generates a 433.95MHz signal. The transmitter uses a quarter wave antenna to transmit its signal.

2.3 The SCADA GUI

The developed hardware has to communicate with the user who monitors the system. A GUI was developed to allow the human operator to have access to the process. The GUI is used to initialize communication, set the communication parameters and to test for connectivity. The database and the buffers are configured in the software of the GUI. The database developed is a Microsoft Access database and the data from the plant is first stored and then displayed on the screen. The database updates itself whenever new data records are available. Visual meters show the level of the measured values on the GUI.

3 SYSTEM DEVELOPMENT

The system was developed under three sections. The sections were developed first in sequence and then in parallel. The GUI was developed first until it was ready to be used for displaying data. This was followed by the development of themicrocontroller software and the drivers until one was ready to be connected to the PC and the other was ready to be connected to the plant. The PIC to PIC RF link was then designed and the three sections were then integrated for the development of the whole system. The sensors were connected to the plant and the system was then designed for data communication at last. The system block diagram is shown in Fig.1 below

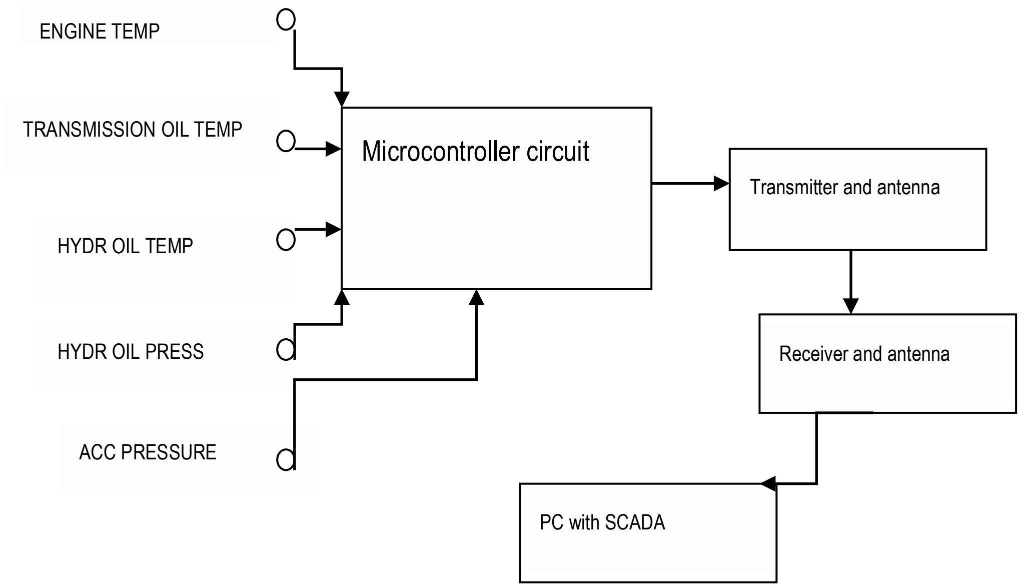

Figure 1: System block diagram

3.1 Development of the SCADA GUI

The man-to-machine interface was developed using VB. The design followed the flow chart shown in Fig.2.The processes involved in the SCADA system are described briefly in the following sub sections.

3.1.1 Initialization

The variables are declared and the PIC, the USB and the database drivers are initialized. Initialization includes defining variables, setting serial communication baud rate and setting microcontroller pins for input and output. Most settings were done using the mikroC integrated development environment. The drivers were designed and customized for the hardware used in the project.

3.1.2 Hardware checking and sensor reading

The system checks whether it is connected to the communication module or to the plant directly. The plant and the communication modules have embedded identification data which enables them to be differentiated by the SCADA system. If the data communication module is detected, the SCADA starts reading the USB buffers but if it is the plant, the system requests for data and then reads the buffers.

In order to read the temperature and pressure values, a special program was written in C code and a snippet of the code is shown below.

```
IntGetTemperature(int pin)  //read temperature
{
Float Vin;
int  Temperature;
Vin = Adc_Read(pin);        //Read from channel 0(AN0)
Vin = 488*Vin;              // Scale up the results
Temperature = Vin/10;       //Convert to temperature in 0C
```

Return Temperature;

}

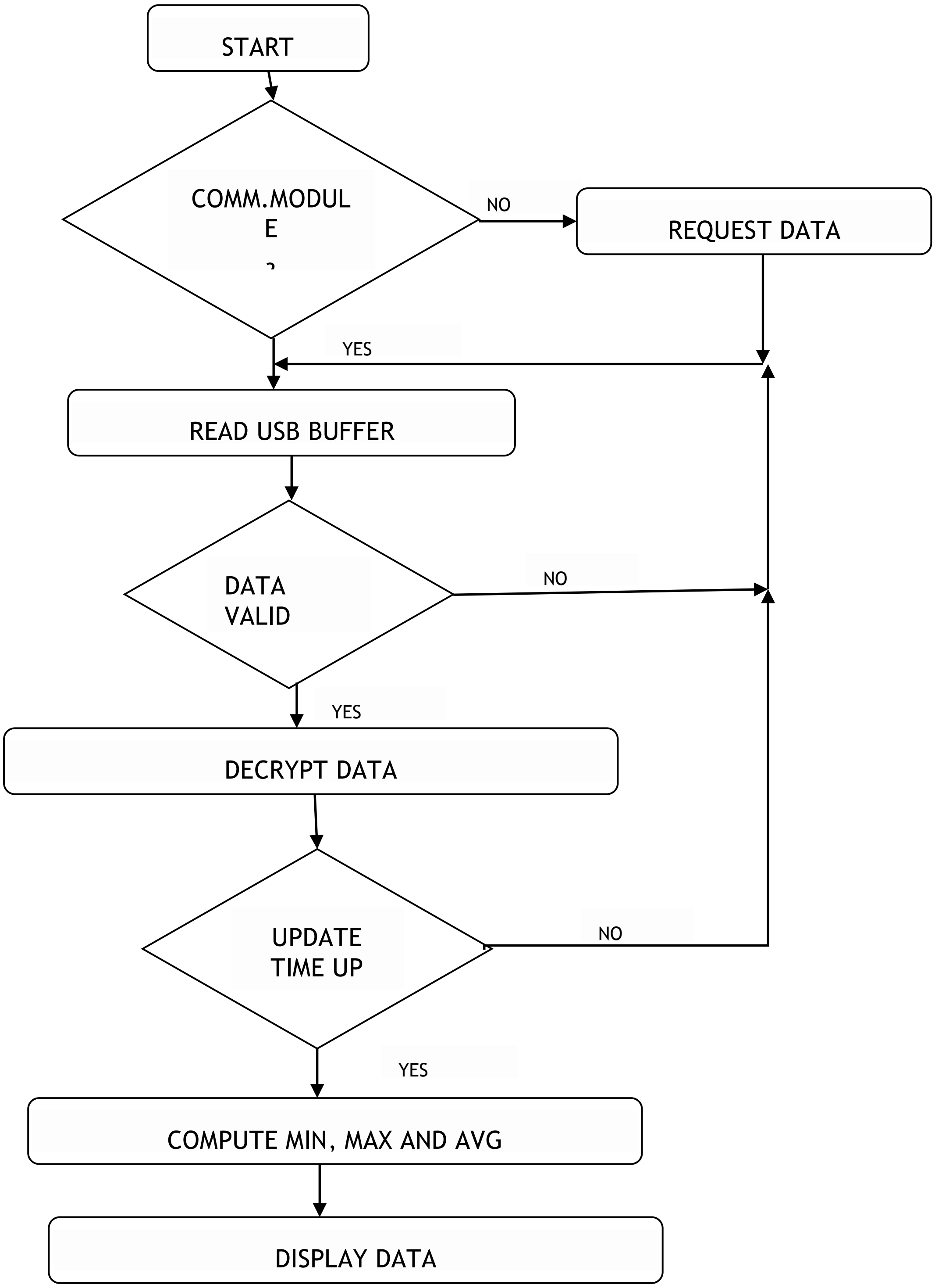

Figure 2: SCADA GUI design flow chart

The above code starts the analogue to digital conversion and receives the converted data which it converts to ^{0}C. The code differs from the one for reading pressure in that the pressure conversion uses a different formula to convert the data to mB measurement. The code is as follows:

```
{
…
…
mV = (Vin*5000)/1024;
V = mV/1000;                    //Pressure in Volts
Pressure =  (2*V+0.95)/0.09; //Pressure in10mB
Return Pressure;
}
```

The data read from the sensors is sent to the SCADA for further processing and display.

3.1.3 Data transmission, reception, validation, decryption and display

After the values has been captured and assigned to their respective variables, they are sent to the USART for transmission. A dummy signal was sent first to tune the receiver to the appropriate signal level and then the data is sent, followed by the checksum to check for errors. The PIC18F4550's 256 byte EEPROM stores the values and sends the values to the USB buffers. The computer triggers the USB to read from the microcontroller EEPROM and store the data in the buffers.The USB buffers are mapped in the SCADA. The data they receive is encrypted for security reasons and the SCADA has to decrypt it before is sends the data values to the display. For the data communication module, four data buffers are read for the plant. The system checks two bytes in the received data to decide on the identity of the connected component. The first byte is an ASCII character 'P' in both cases and the second byte is used to determine which module is connected. The character 'T' is located in the in the fifth byte for the data communication component and in the sixth byte for the plant. The data is decrypted and then it can be identified with the correctparameter for display. The hardware sends numbers to denote the parameter type using 'n' as the variable representing the parameter type. After correct identification, the values are displayed on the gauges in the GUI.

4 RESULTS

During the development of the system, the EasyPIC development kit was used to program the microcontroller. The MikroC IDE was used to develop the communication drivers and VB was used to develop the SCADA. Each sensor was tested to see the variation in output voltage with the physical quantity being measured. The results of the tests were used to calibrate the sensors.

The plant was then tested for communication by sending known values and checking them on the SCADA display. Accurate results were given at the transmission frequency of 433.95MHz. Fig. 3 is a snap short view of results displayed on the GUI for monitoring the mining equipment.

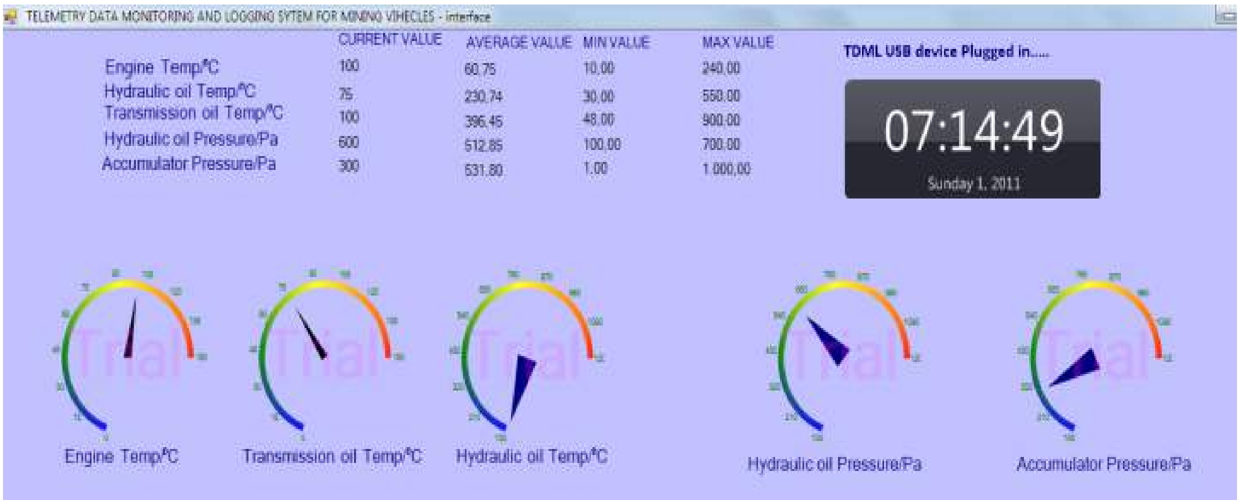

Figure 3: The visual display of the equipment operational values of temperature and pressure

5 DISCUSSION AND CONCLUSION

The project prototype was tested and displayed at the Zimbabwe International Trade Fair exhibitions. It was a multi-discipline project involving research in automobile engineering, machine maintenance, hydraulics and electronic engineering. Such a project enabled the development of many skills essential for an engineer and these include project management and electronic system design and development.

It can be concluded from the results that with dedicated research, RF communications can bring industrial systems management back into the office for proper monitoring and even control without necessarily having to be physically checking systems on site. This is very useful for the management of processors by planners and other interested stake holders.

However, there is need to research on the applicability of the used sensors in the actual mining environments and the effects of noise and distance also need to be analysed.

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IMPROVEMENT OF PLANT FACILITY LAYOUT FOR BETTER LABOUR UTILISATION: CASE STUDY OF A CONFECTIONERY COMPANY IN THE WESTERN CAPE

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ABSTRACT

South African companies are generally labour intensive, especially confectionery companies specialising in handmade products. Labour resources are not effectively and efficiently utilised because of inappropriate facility layout and lack of Lean, JIT and OPT principles, in some cases. This study highlights how a facility layout can be improved for a confectionery company so as to improve labour utilisation. Optimised Production Techniques (OPT), Lean and other production management methods are used to improve the facility layout by improving product flow and eliminating common waste that occur in manufacturing plants. Enterprise Resource Planning (ERP) system, time studies, observations on the facility floor, interviews with Subject Matter Experts (SME), production managers, shop-floor personnel and historic data in company reports were used to generate the information required in measuring the labour utilisation for an existing facility. A labour performance standard is identified and evaluations are made with respect to the degree of this performance standard. Line balancing is applied on product line(s) contributing most to revenue in alignment with marketing strategies. Using a Western Cape Province confectionery company as a case study, the current facility layout and its labour utilisation are compared to an improved-alternative plant layout. Line balancing alternatives are modelled with discreet event simulation software to effectively evaluate them, and present recommendations.

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1 INTRODUCTION

In South Africa, where labour cost are constantly rising and accounting for a substantial percentage of the total cost of production [1], the manufacturing industry continuously strives to improve labour utilisation and reduce labour cost. The measurement of labour utilisation is a key performance indicator relevant to almost all industries. Various factors influence productivity in the manufacturing industry, especially regarding labour. Environmental, ergonomic and facility layout principles all have an effect on labour utilisation. In some cases labour is underutilised emanating from poor facility layout which might include environmental and ergonomic factors. Facility planning and design related to Lean, Optimised Production Techniques and other production management philosophies can provide a practical solution to a South African company with an inefficient workforce. The study addresses how labour can optimally be utilised in a chosen confectionery company by employing an improved-alternative plant layout. In coming up with a viable solution the paper attempts, as its sub-objectives, to: identify bottlenecks, reduce wastes, balance workloads between workstations, minimise processing time, and finally improve labour utilisation. The proposed optimal solution is presented taking into consideration spatial constraints at the facility under consideration.

2 LITERATURE REVIEW

Many researches have been done in facility planning area. Effective facility planning can reduce significantly the operational costs of a company by 10-30% [2]. Proper analysis of facility layout design could result in the improvement of the performance of production line. This can be realised by optimising the capacity of a bottleneck; minimising material handling costs; reducing idle time; maximising the utilization of labour, equipment and space [2].

Facility planning is an overall approach concerned with the design, layout and incorporation of people, machines and activities of a system [3]. Huang [4] emphasises that facility layout design defines how to organise, locate, and distribute the equipment and support activities in a manufacturing facility to accomplish minimization of overall production time, maximization of operational efficiency, growth of revenue and maximization of factory output in conformance with production and strategic goals.

In as much facility redesign and implementation may be considered imperative; however relocating equipment can be an expensive and time-consuming endeavour. In addition, determining whether a potential new layout or staffing scenario would perform better than the current configuration is difficult to determine until the new setup is complete. If the new layout fails to produce the anticipated positive results, then a lot of time and money would have been wasted. Therefore, ability to test the proposed layout before relocating equipment or even purchasing new equipment is desirable. Simulation models provide an alternative of evaluating the proposed layouts so as to obtain the near-optimal solution. Simulation software has the capability to determine factory conditions which include the determination of plant capacity, balancing manufacturing and assembly lines, managing bottlenecks and solving inventory and work-in-process problems [5] [6]. Simulation also enables the ability to model “what-if” scenarios to test changes in labour levels. In this research Simio® simulation modelling software is used to identify and optimise the bottleneck and perform line balancing by comparing different scenarios and selecting the near-optimal solution.

3 COMPANY INFORMATION & METHODOLOGY

The confectionary company studied has a product range of over a 100 products of handcrafted rusks, cookies, biscuits and snacks. Most product families have different packaging and labelling requirements. Owing to their variableness in processing requirements, automation is rarely used; instead highly intensive manual labour is utilised. With the objectives of the study in mind, the case study would be limited to the labour intensive packaging department of the confectionery company. The packing department has three shifts of 8 hours each from Monday to Friday, and a workforce of 30 labourers. On Saturdays a 12-hour shift is scheduled. The packaging area consists of 8 permanent packaging lines of which two are dedicated to the rusk product family.

The approach followed to address the problem of a poor facility layout was by employing production philosophies to improve labour utilisation. The following steps were followed to solve the poor facility layout at the confectionary:

- Collection of data from Enterprise Resource Planning; time studies; and from Subject Matter Experts, line and production managers through interviews.
- Conducting of floor observations.
- Employment of Pareto profit-volume analysis of product range.
- Analysing of single model packaging line and facility layout.
- Employing facility layout and lean principles.
- Developing the base simulation model.
- Verifying and validating the base simulation model.
- Simulating and comparing different scenarios.
- Measuring improvements and making recommendations.

4 PARETO PROFIT-VOLUME ANALYSIS OF PRODUCTS

For the confectionery company being considered as a case study, a Pareto analysis was executed. The production data of the previous year was processed to analyse the products packed by the company. The approach taken was to identify the distribution of the production volume multiplied by the gross profit contribution of each item. The reason for analysing the profit-volume as a combination instead of only the profit contribution is as follow: certain products have high profit margins but contribute to less than 1% of the turnover of the company. An example of such a product is the Shop Rusk Tins with a 140% profit contribution but 0.59% contribution to the total revenue. On the other hand if only the volume figure of products were considered for the Pareto analysis, it would not be aligned with the financial and marketing strategies to increase turnover while decreasing cost. The distribution is depicted in Figure 1. Out of the 75 products packed at the specific factory, 16 products or 21,6% of the products make up 79% of the profit-volume, indicating the 80/20 spread. For illustrative purposes only the first twenty products (instead of all 75 products) are included in the Pareto chart in Figure 1.

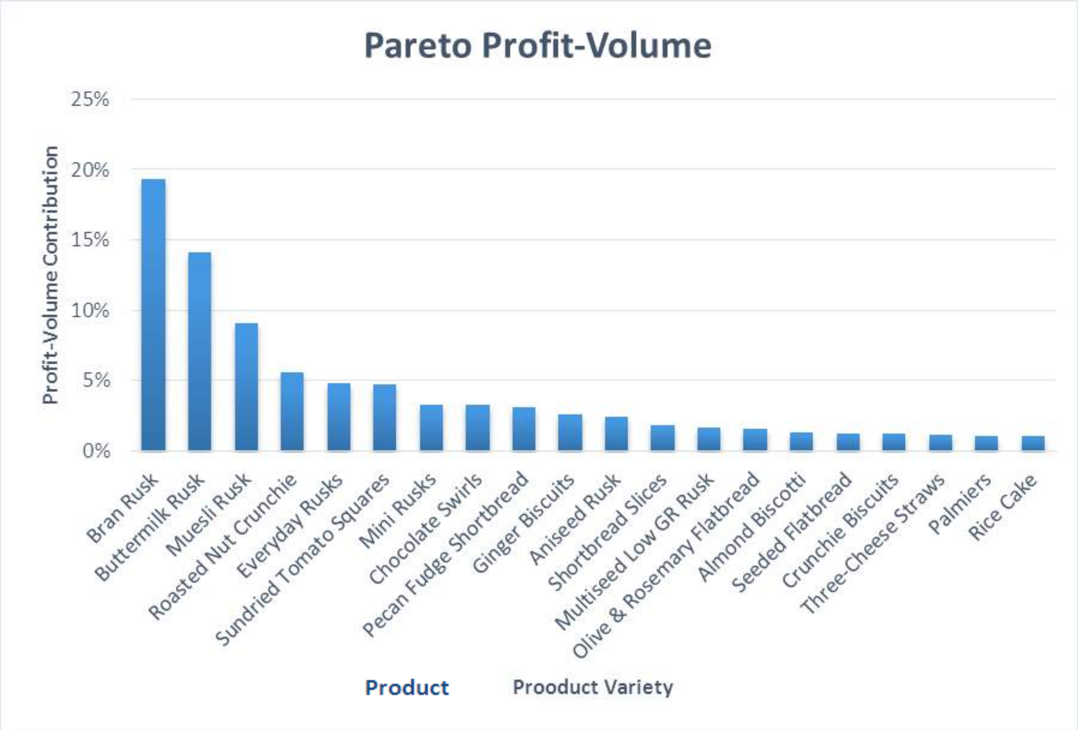

Figure 1: Profit-volume contribution to product variety in which a Pareto distribution is observed

The 80/20 spread was further categorized by product family. Figure 2 illustrate the family categorization of the first 16 products by the profit-volume contribution. It is seen that rusks make up 55,5 % of the profit-volume of all the products.

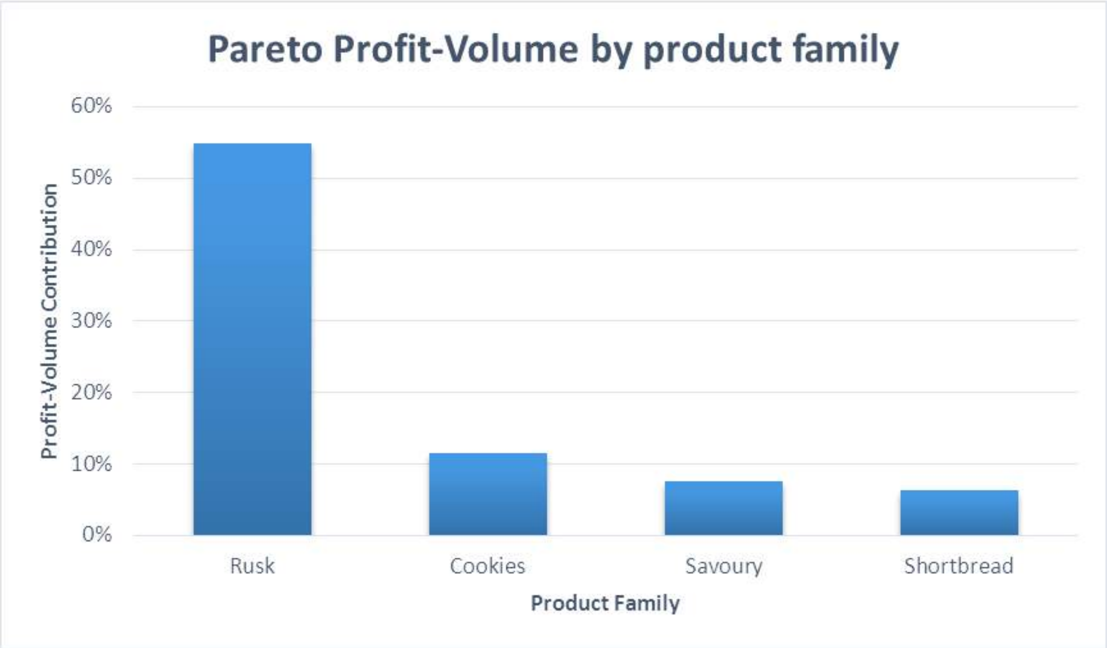

Figure 2: Pareto distribution by product family of first sixteen products.

The packaging area has 2 packaging lines dedicated for processing rusks. Thirteen types of rusks are produced and these can be sub grouped into 7 categories with respect to their packaging requirements. When further application of the Pareto analysis was executed, it was established that Bran and Buttermilk rusks make up 60% of the profit-volume contribution of the Rusk product family which translates into 60% of the 55,5% of the total profit-volume analysis. This equates into a 33% contribution of the total profit-volume by a single product. Figure 3 depicts the 80/20 distribution of the Rusk categories.

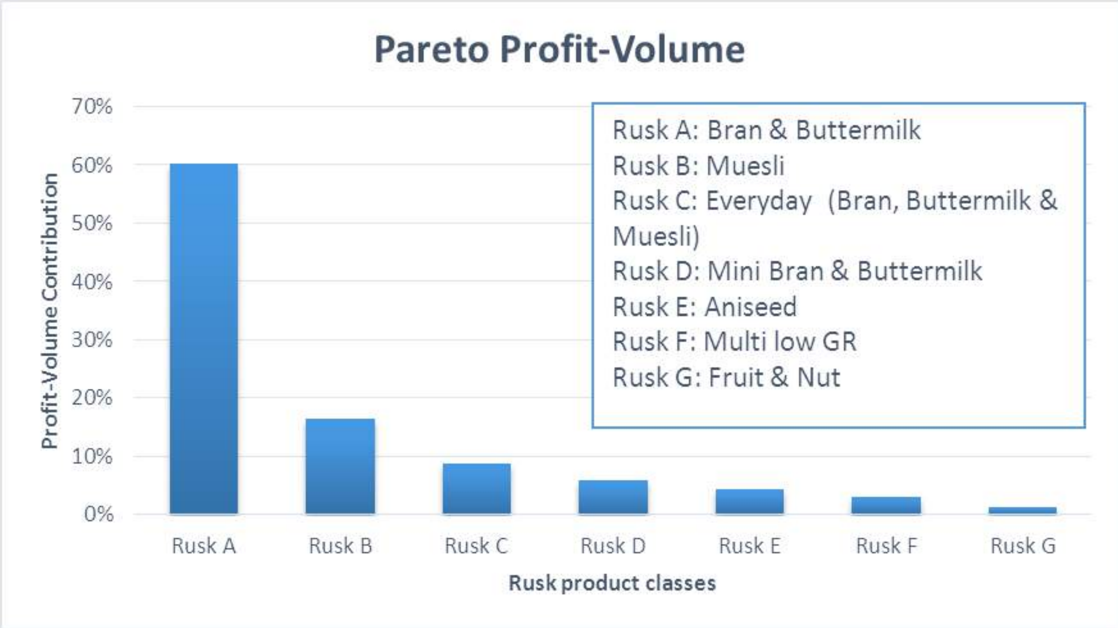

Figure 3: Profit-volume distribution of the rusk product family

Packaging data from the company Enterprise Resource Planning system and interviews with line managers confirmed that one of the two rusk lines was dedicated to pack class A rusks. After consulting the marketing team about the findings they indicated that the Bran and Buttermilk rusks are the flagship products and since new labelling was released on these products in February 2013, they aim to increase sales in the coming winter months for the Bran and Buttermilk rusks. With the above factors in mind, the decision was made to start with class A rusks as a single model packing line to improve facility layout and labour utilisation and then continue with the next product category of the Pareto profit-volume analysis. The line packs on average 535 batches of the Bran and Buttermilk (Class A) rusks per month.

5 LAYOUT AND PROCESS ANALYSIS:

The following section is an overview of the approach followed to analyse the current layout and packaging processes.

5.1 System Description

Products flow through production to packaging in batches, where it is packed and boxed. For class A rusks, a batch consists of twelve pans with loose rusks in the pan. On average, 4 workers operate the line of which one worker is the roaming line manager. The entire packaging process is conducted in 3 stages. Rusks are packed and weighed at the first station, sealed at the second, labelled and boxed at the third. Figure 4 shows the entire flow from arrival to dispatch.

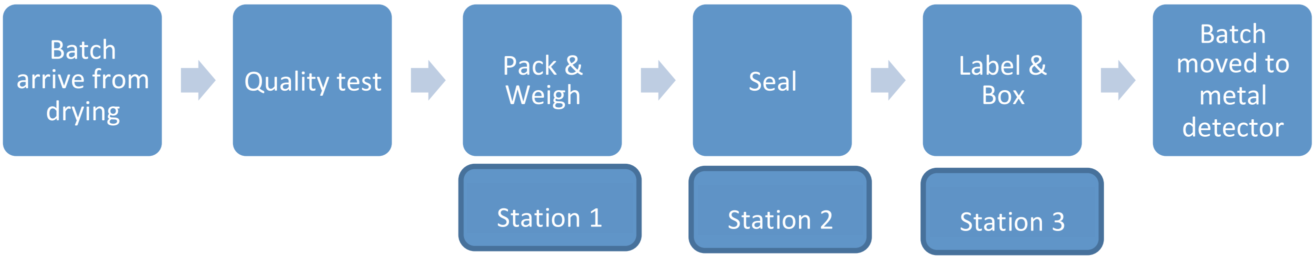

Figure 4: Packaging Process Flow

Rusk batches arrive from the drying area and are staged in the staging lanes. Before being packed, moisture and taste test are done to meet product quality specifications. After the rusks are packed in boxes they are moved as a batch to the metal detector before being sent to the outbound loading docks.

5.2 System Analysis

The current packaging line is setup on tables placed in a straight line. The floor layout of the Rusk A packaging setup is illustrated in Appendix A. With the current configuration the ***Pack & Weigh*** station is operated by two workers each equipped with a portable scale to weigh the packets. The ***Sealer*** station is manned by one operator using a sealing machine next to the packaging table. The fourth worker labels the packets by hand and places them into a box.

The red path indicates the current flow of batches on trollies from the drying area to the staging lanes and then to the packaging line. After leaving the packaging line, all the boxes of a batch are moved to the metal detector.

Observations on the packaging floor revealed some of the most common wastes that occur in a facility. These were identified as wastes arising from poor transportation, waiting time and unnecessary motion. Inventory waste was also identified as evidenced by the generally untidy appearance of the packaging area with: congestion of batch trolleys in staging lanes, product trolleys not grouped and staged orderly. Time was wasted through unnecessary back-and-forth movements of checking arrival times on batch traceability sheets; unnecessary long travel distances of batch trolleys from drying area to staging lanes; double handling of rusks' boxes as they were transported to metal detector.

Tompkins [7] emphasises that labour time is reduced by reducing waste and according to Ohno [8] reducing man-hours is a means of improving efficiency in lean manufacturing. The company currently measures the utilisation of labour as the time taken to pack a batch multiplied by the number of workers on the line to indicate the effective man-hours spent on a batch.

5.3 Improvements and Proposed layout

Appendix B illustrates the improved proposed layout. The blue lines and arrows indicate the flow of batches through the system. The total transport distance has been significantly decreased from 89m to 43.7m by the opening of a blocked door and the elimination of double movement of the box transporter from the end of the packaging line to the metal detector. The total transport reduction is depicted in the From-To chart (Figure 5).

	Unimproved [m]		Improved [m]	
From/To	**Node Distance**	**Transport distance**	**Node Distance**	**Transport distance**
A-B	10,94	10,94	6,25	6,25
B-C	9,38	9,38	9,38	9,38
C-D	12,5	12,5	6,25	6,25
E-F	18,75	37,5	12,5	12,5
F-G	9,38	18,76	9,38	9,38
Total Transport distance		**89,08**		**43,76**

Figure 5:From-To chart comparing actual distance travelled of batch from node A to G for unimproved and improved scenario.

The line configurations were tilted to compliment the flow and create marked staging lanes that accommodate first in first out (FIFO) principle. This would decrease time wasted to look for the first arrived batches on traceability sheets.

The line balancing problem is evaluated in the following section making use of discrete event simulation.

6 SIMULATON MODEL:

This section will discuss the use of simulation to compare different staffing scenario combinations to determine the near-optimal configuration to reduce the man-hours spent to pack a batch.

6.1 Model Assumptions

During the development of the model assumptions were made:

- Line workers are trained to perform all operations at all of the workstations. No learning curves were modelled and as a result it was relatively simple to add and subtract workers to balance or rebalance the line and adapt to change configurations.
- Boxes were set up before a batch was packed, thus the time taken to setup boxes was excluded and the labeller only needed to pack a finished packet in a box.
- The portable sealer machine(s) and portable scale(s) are the resources on the line. No breakdown times were modelled for these resources.
- Quality rejects were not included in the model, i.e. no batches were sent back to the drying area and in effect upheld the packing line.
- Quality inspections were done while batches were staged and was not included in the simulation of the model.
- The line is operational 123.25 hours a week. Monday to Friday have three 8-hour shifts with a 30min break. Saturdays are scheduled as one 12-hour shift with 1h15min of break time included.
- Customer demand is 8 batches per shift of the Rusk A class.
- Transfer times from staging lanes were considered to account for repositioning losses.

6.2 Input Data

The process of collecting input data can be very time consuming. All input variables were determined from the conceptual model. Sources of input data include ERP systems, floor observations, design estimates and information from SME's. To acquire accurate results from a simulation study, it is important obtain the right fit of a statistical distribution of processing times at each workstation [9]. However samples are often not large enough to apply goodness-of-fit tests. Banks *et al.*[10] recommends that for conditions with inadequate or limited data one is to assume uniform, triangular or beta distributions.

Time studies were conducted on the processing and transfer times of Rusk A line using the Android Time Study application developed by Hartman & Lambert [11].The sample sizes were inadequate to perform theoretical goodness-of-fit tests. However with the data available the distribution fit tool, EasyFit, was used to fit and propose possible distributions. The available data was also processed in Microsoft Excel® to look at minimum, maximum and average processing values. The suggestion of Banks *et al.*[10] to use triangular and uniform distributions where data samples are inadequate for goodness-of-fit test were followed. For all three station processing times the assumed distribution used was ranked in the top 5 distribution fits by the EasyFit software.

A summary of the distributions used for the station processing times are illustrated in Table 1 below.

Table 1: Distributions used for the processing times per packet at each station

Operation	Distribution	Parameters [seconds]
Pack & Weigh	Triangular	9,25,44
Seal	Uniform	4,7
Label	Uniform	4,8

The inter arrival time of batches occur in bulk arrivals of 4 batches every 2 to 4 hours with a limit of 8 batches per shift arrival.

6.3 Verification and Model Validation

The current layout was modelled to be compared to historical data. A statistical analysis was performed to establish the number of replications needed to yield the valid results as proposed by Law [12]. The base processing model of 2 packers, 1 sealer and 1 labeller compared within a 95% confidence interval to the current batch average processing time of 55 minutes. Figure 6 shows the model animation in Simio®.After the verification of the base model different scenarios are compared by utilising the experiment tool combined with the Kim Nelson method to compare variability.

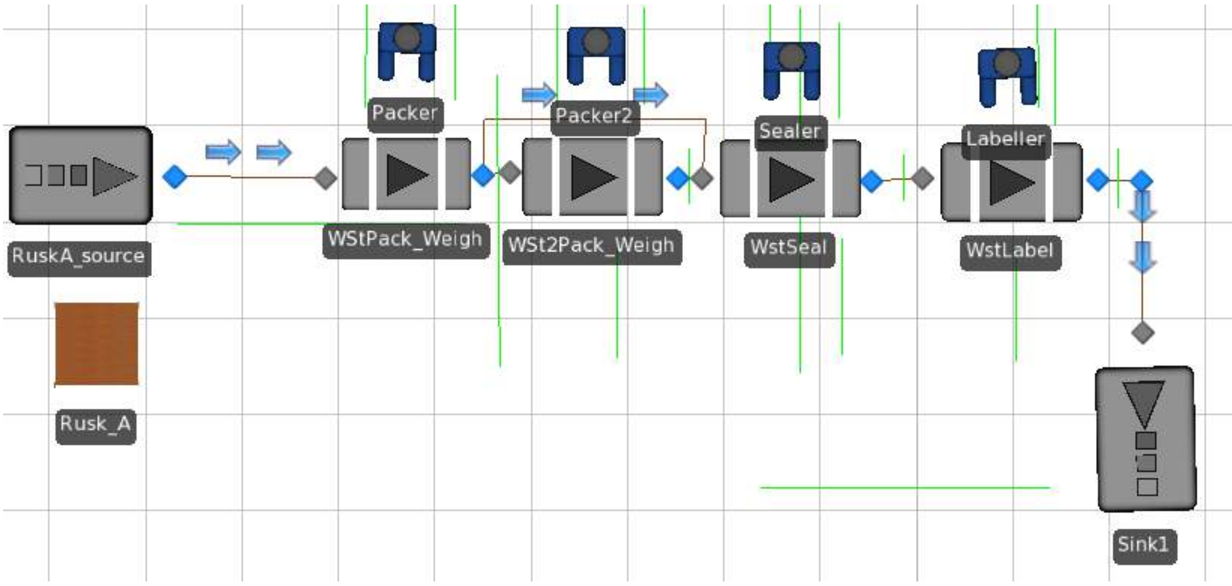

Figure 6: Screenshot of animation of simulation model in Simio®.

6.4 Analysis of Line Balancing and Labour Utilisation

Six different staffing scenarios were setup using the *experiment* tool in Simio®. These scenarios compared various staffing configurations at the rusk packaging line. The scenarios considered only include physical possible configurations. The *Pack & Weigh* station was identified as the bottleneck station with a 65% utilisation for the "As-is" configuration. This could be verified since the *Pack & Weigh* station has an average processing time of 25 seconds compared to an average of 5,5 seconds for the *Sealer* station and 6 seconds for the *Labelling* station. Figure 7 is a graphical representation of the Kim Nelson comparison of the different scenarios. The Kim Nelson method aims to compare scenarios and on a statistical significant level indicating process variation [13].

Scenario 3, consisting of 4 packers, 1sealer and 1 labeller, operated the line under the least process variation and brought the average batch packing time down to 27 minutes. This scenario overlapped with scenario 6 where 4 packers, 2 sealers and 2 labellers were involved in the line. Table 2 is a comparison of the scenario's station utilisations, average batch packing times and man-hour per batch indications.

It can easily be seen that scenario 3 offers the most viable improved solution. The line is better balanced and the average batch packing time is the least without any significant investment in an additional sealing machine.

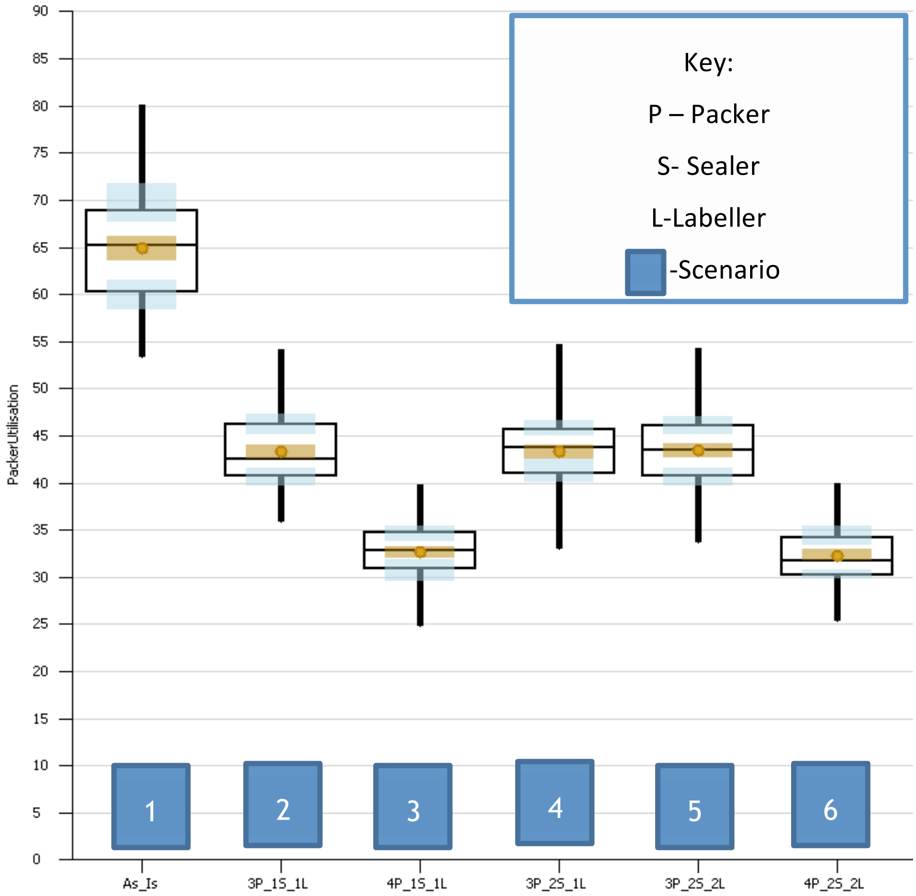

Figure 7: Box and Whisker plot of the Packing station utilisation

Scenario	Packing Utilisation [%]	Sealing Utilisation [%]	Labelling Utilisation [%]	Average Batch Pack Time [min]	Man-hour per batch [min]
1	64.9	27,5	28,7	55	220
2	43,3	27,5	28,7	42	210
3	32,7%	27,6	28,9	27	162
4	43,3	13,7	28,7	42	252
5	43,5	13,8	14,4	42	294
6	32,4	13,7	14,3	27	216

Table 2: Comparison of Scenarios

Scenario 3 also accomplishes to complete the batch in the shortest man-hour time of 162 minutes. This scenario was implemented on the packaging floor. The outcome was that it is possible to pack a batch within 25 to 30 minutes with 4 packers,1 sealer and 1 labeller.

7 CONCLUSION

The study demonstrates the application of Lean and Optimised Production Techniques incorporated to facilities design and how the employment of these techniques can improve labour utilisation.

The distance of batches travelled was reduced by routing the flow of batches along a shorter path. At the same time unnecessary motion and waiting was reduced by dedicating staging lanes to products and orderly grouping products together in a first in first out manner. The reduction of such wastes ultimately increases labour efficiency.

The study further integrated lean line balancing techniques and utilised simulation modelling to compare and balance the rusk packing line. Bottlenecks were identified; processing times minimised to finally improve labour utilisation in terms of man-hours per batch. The proposed optimal solution was presented and tested successfully to validate the simulation model as a representation of the real world.

With the near-optimal number of workers determined to pack batches, the limit exists that, when it comes to practical implementation, staff scheduling is a problem to allocate the amount of workers to pack a batch as effectively (least man-hours) as possible.

With the Pareto Profit-Volume approach followed it is recommended that the next product or family lines be analysed in a similar manner, staff scheduling be done in accordance with demand and production to allocate the amount of workers to a packaging line to pack a batch as effectively as possible.

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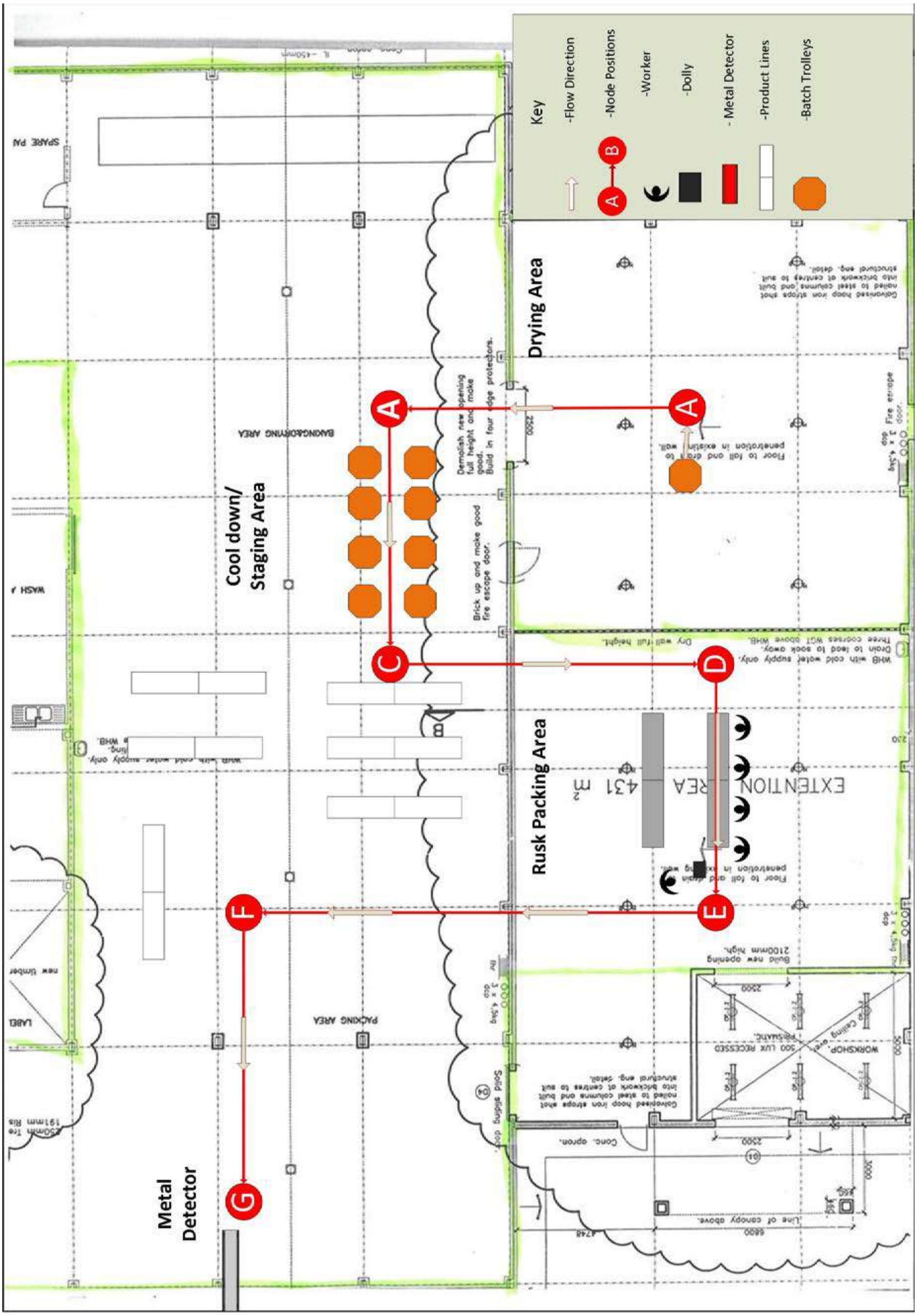
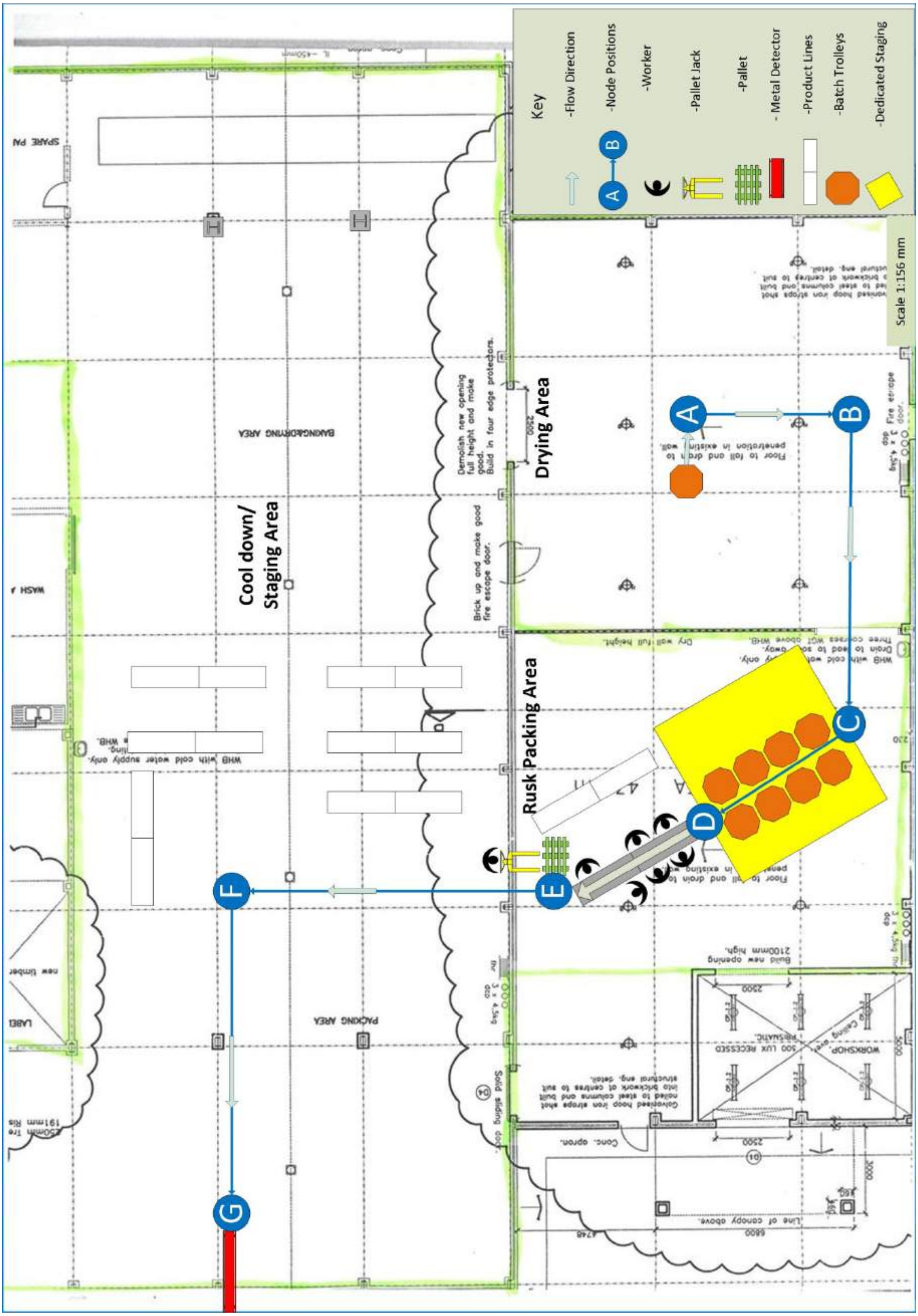
9 APPENDIX A: "AS IS" FLOOR LAYOUT OF RUSK A PRODUCT FAMILY



APPENDIX B: PROPOSED FLOOR LAYOUT FOR THE RUSK PACKAGING AREA



THE IMPACT OF PRODUCT MODULARISATION ON SUPPLY CHAIN RELATIONSHIPS: A FURNITURE INDUSTRY PERSPECTIVE.

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ABSTRACT

This paper aims to present research which explores the application of product modularization within a furniture industry supply chain to demonstrate the degree to which supply chain practices are aligned with product architecture in the furniture industry. The paper uses a case study approach to examine the main elements of modular supply network in the furniture industry. The study focused on the key stages of a modular supply chain in order to identify the application of supply chain practices within the context of modular operations. The findings suggest that there is need to increase supply chain integration to ensure that modular products can compete with traditional integral products. The paper provides useful insights into the dynamics of modular supply chain operations, which illustrate the difficulties associated with integrating modular operations and competing with the traditional integral products.

[*]Partson Dube

1 INTRODUCTION

Product modularity provides flexibility and responsiveness that enables firms to serve a variety of customer needs. An advantage of modularity in relation to supply chain design is that pursuing product variations has only a limited impact on production and assembly processes. Modular design allows a firm to differentiate its product to a high degree by combining a limited number of standard parts [1]. There has been a considerable body of knowledge investigating the development of product modularisation [2], the impact of buyer-supplier relationships [3]. Modularity has been extensively applied successfully in the in electronics and automotive sectors [4] & [5]. This paper seeks to demonstrate the extent to which supply chain practices in the furniture industry are aligned to product modularisation. Using loosely-coupled structures enables firms to achieve greater scope flexibility and scale flexibility. The supply chain must be aligned with product development decisions; it should be designed and managed, so that the products are delivered at the targeted cost, time, and quality [6].

Using modular product design as your new product development strategy decreases time to market, increases the number of product variants, increased flexibility, reduced cost and decreases the number of unique parts in your product architecture [7]. Product modularity offers many advantages to the manufacturing industry which are: reduced labour, reduced waste, reduced inventory, increased quality, improved productivity and enhanced cost and quality performance [8]. Modular supply chain and modular product design allows firms to link together the capabilities of many organizations to support product development [9].

Several barriers exist for the increased use of modular product solutions, which include difficulties associated with complex interfacing between systems, the inability to unfreeze design decisions and higher capital costs.

The local furniture industry has not kept pace with the growth in worldwide furniture trade and has steadily been losing its share of the global furniture manufacturing, having moved from the 34th largest exporter in 2005 to 43rd in 2006 [53]. The escalation of cheap Asian imports, the declining investment in skills development and technological innovation, insignificant research and development funding over the past five years or so has resulted in the declining levels of competitiveness in the industry. This has also contributed to job losses and the reversal from being a net exporter to being a net importer of furniture products. Whilst the largest furniture manufacturers have to some extent managed to hold fort in the face of increasing imports, the biggest casualties have been the small and medium-sized enterprises [53].

It remains doubtful if the local industry will ever effectively compete with the Asian imports [53]. However, it is possible to position the local industry as the producer of high value niche furniture products that are globally competitive based on quality and/or differentiated designs. This requires a concerted effort on the part of the public and private sector to develop programmes that address the challenges that constrain the industry from achieving potential growth levels and significantly raise the levels of competitiveness.

In the following sections the literature relating to modularity and supply chain management will be discussed. This will be followed by research methodology, analysis of case studies and discussion of findings. The implications of the research will be discussed, together with suggestions for future study, in the conclusion.

2 LITERATURE REVIEW

Sections 2.1 and 2.2 hereby review modularization and supply chain management, respectively and relationship between modularization and supply chain management.

2.1 Modularization

Modularity is an approach for managing and developing complex products and processes efficiently by decomposing them into simpler subsystems without compromising the system's integrity [10] & [11]. It is also considered as a new product development strategy in which interfaces shared among components in a given product architecture become specified and standardized to allow for "greater substitutability" of the components across product families [12]. Therefore, Modular product architectures are used as flexible platforms for leveraging a large number of product variations [13] & [14].

Modular design can be viewed as the process of producing discrete functional units that are connected together to provide a variety of product functions. Modular design emphasizes the minimization of interactions between components in order to design and produce those components independently. Each component, designed for modularity, is supposed to support one or more functions. When components are structured together to form a product, they will support a larger or general function [15].

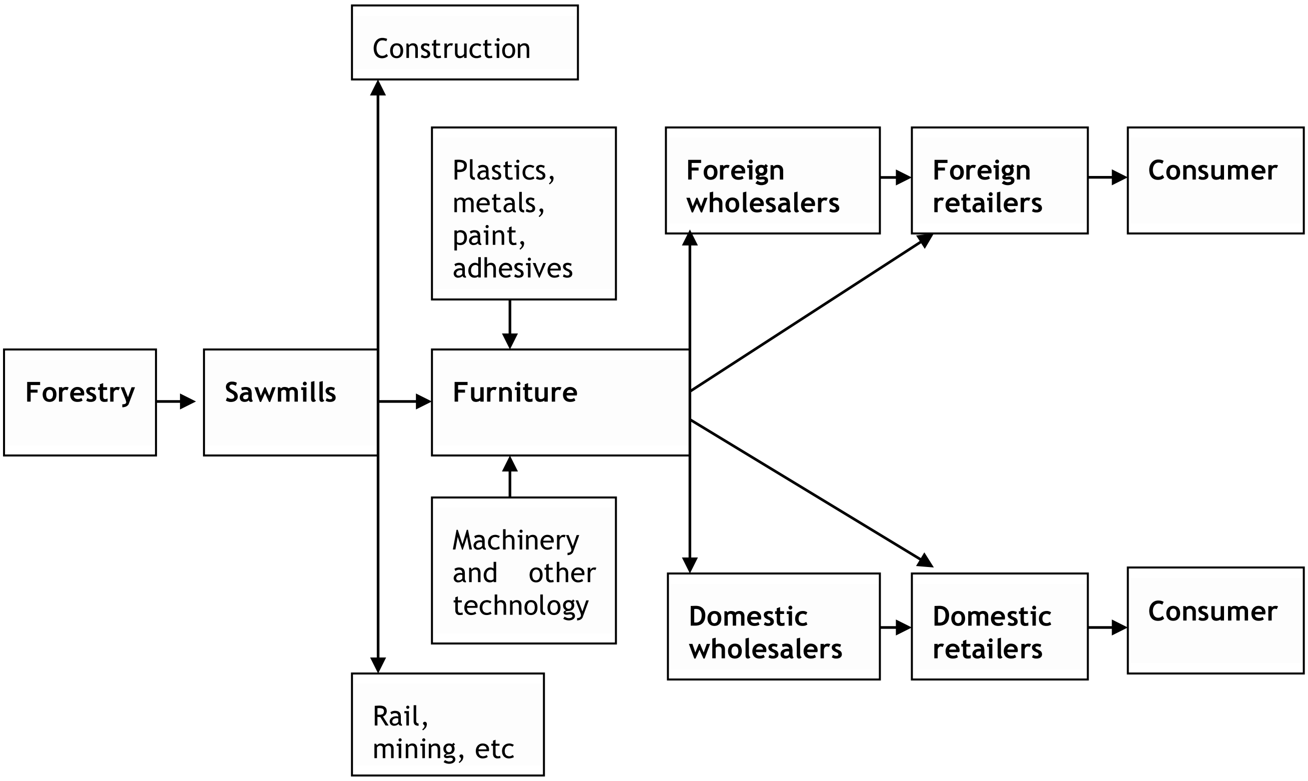
Modularity is an example of architectural innovation that enables greater flexibility for mass customization but "without changing its components" [16]. Modularization enables mass customization not only by providing a means for the repetitive production of components [17]. One of the great advantages of modularization is the ability to assemble repetitive units in controlled conditions. Modular product architectures require physical independence and functional independence. Simply splitting up a product for later assembly is not necessarily termed a modular approach; there need to be a certain level of flexibility in the way that parts are recombined. Modularization requires standardized interfaces to provide embedded coordination that greatly reduces the need for overt exercise of managerial authority to achieve coordination of the product development process [18] & [19] states that a modular product or subassembly has "a one-to-one mapping from functional elements in the function structure to the physical components of the product" and that all interfaces between the components of different modules are decoupled. Modularized product architecture can be disintegrated into loosely coupled components offering high possibility to outsource design to suppliers.

Three rules that define Product architecture are [20]: (1) Architecture, which specifies what modules will be part of the system and what their functions will be. (2) Interfaces, describe in detail how they will fit together, connect, and communicate. (3) Standards, for testing a module's conformity to the design rules and for measuring one module's performance to another. Two types of macro types of modular product architecture are function-based and manufacturing-based [21]. Function-based is partitioning a product into discrete scalable, reusable modules consisting of isolated, self-contained functional elements. Manufacturing – based modularity is the application of unit standardization or substitution principles to create modular components and processes that can be configured into a wide range of end products to meet specific customer needs.

Besides reduction in cost (due to lesser customization, and less learning time), and flexibility in design, modularity offers other benefits such as augmentation (adding new solution by merely plugging in a new module), and exclusion. Examples of modular systems are automotive industry [22], computers and high rise buildings. Earlier examples include looms, railroad signalling systems, telephone exchanges, pipe organs and electric power distribution systems. Computers use modularity to overcome changing customer demands and to make the manufacturing process more adaptive to change (see modular programming) Modular design is an attempt to combine the advantages of standardization (high volume normally equals low manufacturing costs) with those of customization. A downside to modularity (and this depends on the extent of modularity) is that modular systems are not optimized for performance. This is usually due to the cost of putting up interfaces between modules

2.2 Supply Chain

In order to grow timber, inputs such as seeds, chemicals, equipment and water are needed. When the timber has reached a mature age (from 12 to 25 years depending on the type of timber) it sent to sawmills, where machinery and other inputs are used for production. The sawn timber is then delivered to the furniture 5 manufacturers. The manufacturers in turn obtain inputs from other industries such as plastic, metal, textiles machinery and paint. In addition to this the furniture manufacturers also source inputs such as machinery as well as inputs from the service sector in the form of design and branding expertise. The finished product leaves the manufacturers, generally through a buyer, into either the domestic or foreign wholesale or retail sector, before it reaches the consumer.



Source: Adapted from Kaplinsky *et al*, [53]

The changing nature of the industry, often represented by large-scale retailers has led to an increasingly common practice of retailers buying straight from manufacturers in a cost saving-initiative. The last step of the value chain is then the consumer who will, in time, either recycle or dispose the furniture.

Value-transfer theory states that in order to concentrate on its core business, a manufacturer will transfer non-core value-adding activities to its supplier also, the supplier reorganizes its own business to accommodate the increased production and management responsibilities and then passes down some value-adding activities to its own suppliers [23]. Value-added activities are shifted from a single organization to the overall modular supply chain as the key modules are outsourced to technically competent module suppliers in modular product design [24].

Product modularization cuts down too much variety in development by simplifying design activities, improving coordination and information sharing across production, sales and engineering [25]. Modular design improves competitive performance, facilitates supplier, manufacturing and design integration by simplifying communication and information sharing and building trust among supply chain partners [26]. Supplier proximity changes due to different types of modular product design. Reference Ulrich *et al*, [27] argue that, under holistic customer requirements, when components are designed for a specific product, internal and external integration is required. The decisions about modular design have a substantial influence on the supply chain environment.

A modularized product has a set of independent modules, which allows standardization [28]. Standardized modules can be better outsourced to suppliers [29], using a loosely integrated approach [30]. Iterative communication and coordination among suppliers and manufacturers in the development process can be reduced when the supplier can focus on its predefined specifications without being too concerned about other modifications [31].

Modular product design may reduce the need for extensive internal integration [32] & [33]. The development of modular systems can lead to vertical and horizontal disintegration [34].

In order to ensure the conformance of different product components the supply chain must be integrated as closely as possible for ease of communication and coordination. Extensive integration should help the suppliers to develop innovative new products through collaboration [35]. Reference Diez [36] says close supply chain design improves information sharing, especially tacit knowledge sharing, e.g. physical co-location and face-to-face communication. The tacit knowledge then promotes innovation that leads to a competitive advantage [37]. Modular design can lead to more supply chain collaboration as it increases the supplier's need for relationship-specific investments and for agreement on the design of common modules [38].

3. RESEARCH METHODOLOGY

Shaw [39] and Gill et al, [40] warn the use of hypo-deductive approaches to understanding small firms which can restrict the generation of knowledge. Advantages of qualitative research tend to be behavioural stressing qualitative differentiation and innovation [41]. Therefore, it calls for an approach that allows the researcher to "get close" to participants, penetrate their internal logic and interpret their subjective understanding of reality [42]. Thus, we consider that our research enquiry on The impact of Product Modularisation on Supply Chain relationships is of interpretive kind. The present study focuses on theory development which is mainly of exploratory kind and aims at identifying the factors that appear to influence the supply chain focusing on product modularisation. The selection of qualitative case study research is based on the reasons such as:

- there is little formal theory describing supply chain complexities in the context of small medium enterprises [43]; and
- the issue needs to be explored in its most natural and social context to learn about possible unforeseen variables influencing the phenomenon [44].

A multiple case study approach is adopted to increase external validity [45]. We chose to visit each company thrice. For all companies, a number of quantitative and qualitative data were collected: business specific characteristics (volume, turnover, lead time, position in supply chain), issues related to various business functions (production, marketing, manufacturing), perception and vision of CEO/GM. The first visit consisted of an introduction, a plant visit and a semi-structured interview based on the researcher's questions. The second visit helped to interact with various departmental heads in more detail and uncover some of the more issues affecting the premise of present research. In the final visit, gaps and missing data were filled. Moreover, the key informants reviewed the tables with quantitative data, and the researchers' interpretations, increasing triangulation [45] and construct validity [46]. Most interviewees (20 in number) were CEO/owner or other departmental heads with a clear view and knowledge of operations, products and buyers. The varying motives, differing control structures and owner-led planning process of small to medium enterprises organization requires triangulation utilizing multiple sources and means.

In order to limit the effects of subjective biases and improve the validity and reliability of study, approaches like questionnaire, interview schedules, observations and study of organization's archrivals were adopted. In addition, all the interviews were recorded and transcribed, thus allowing further detailed analysis.

The interview schedule has included questions on various sections such as marketing/sales, purchasing, manufacturing, and production planning and control. The interview questionnaire has collected responses on a Likert scale of 1-5 related to the profile of company, basic supply chain issues, buyer-supplier relationship, and enablers/barriers to SCM implementation. However, the purpose of using interview questionnaire was just to ensure the consistency of qualitative data and not to use for any further statistical analysis. We attempted to capture the notion of SCM from operations point of view. For the purpose, departments like manufacturing, production planning, marketing, and purchasing were studied in detail. In order to avoid a too narrow collection of data and

understand the effect of overall environment of organization, we also asked for variables related to overall business approach/orientation, operations strategy, products, markets, business strategies and relationships with their major suppliers and buyers. In line with Voss et al. [45], we will first describe our sample and then do cross case comparison followed by the analysis. Pseudonym (for example, Company V, Company X. . .) has been used to protect the anonymity of the case organizations involved in this study.

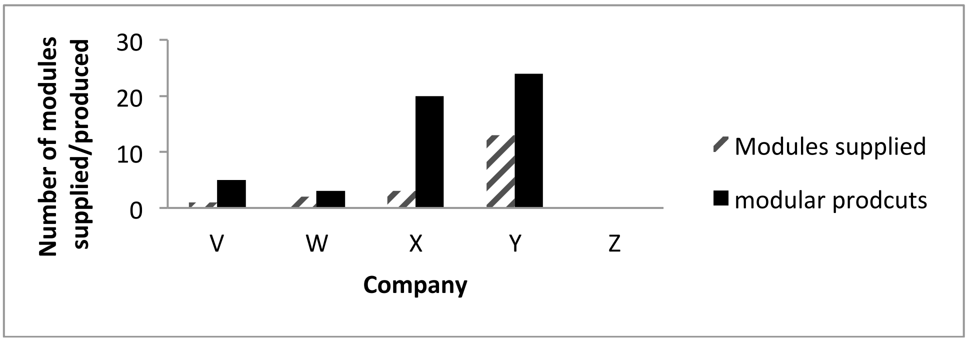


Figure 1. Number modules supplied and number of modular products

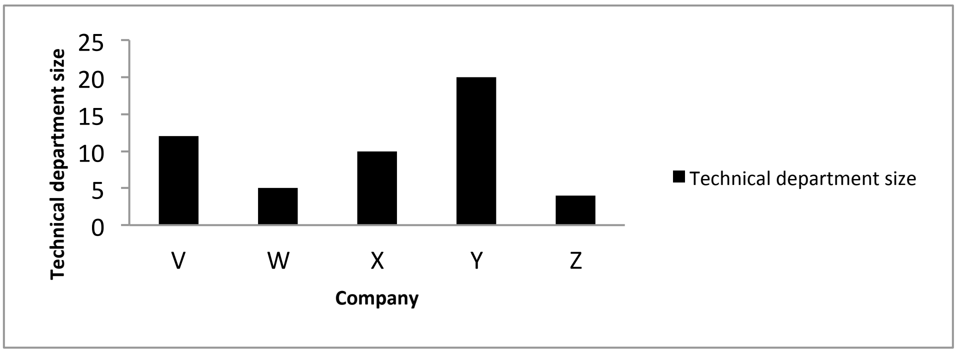


Figure 2. Size of the technical department

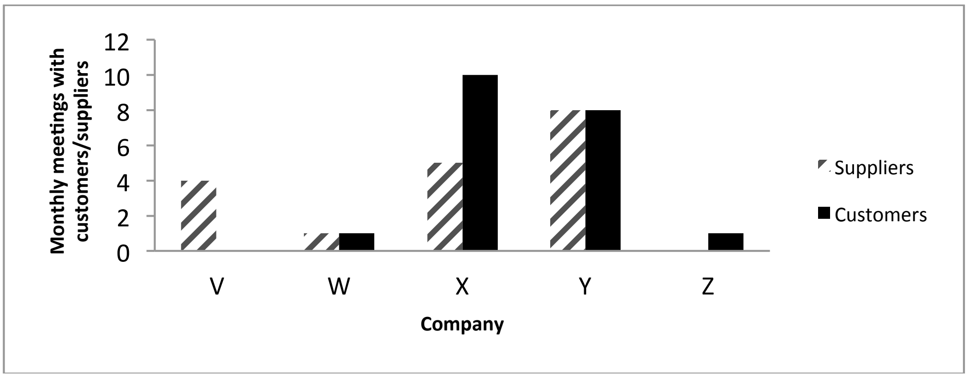


Figure 3. Number of monthly face to face meetings with suppliers and customers.

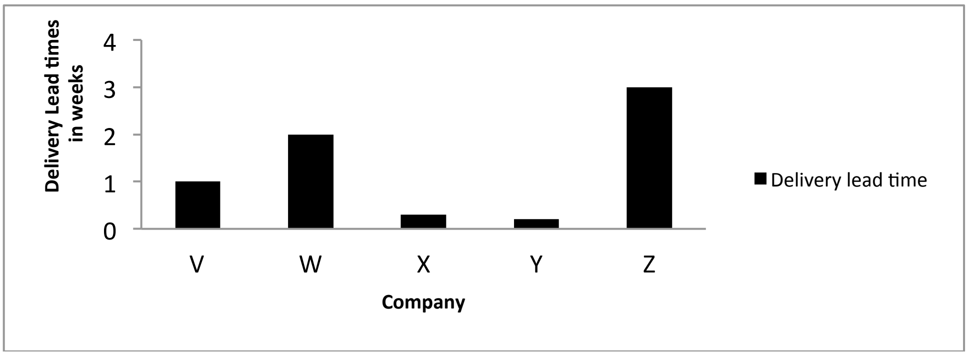


Figure 4. Delivery lead times

Company V

A lounge settee is an innovative consumer product that adopted modular design to increase product variety for company V. In the context of supplier integration (SI), the preliminary product design was created in-house, product modules were co-developed with the key module supplier. The module supplier was involved early in new product development (NPD) by designing a recliner mechanism to create an innovative settee(s). This module was critical to the overall quality and comfort of the settee. The module could be mixed and matched with other components without sacrificing the quality of the settee. The manager said that since the product module was innovative, extensive communication with the key module supplier was very important, they could assess and modify their manufacturing processes through frequent face-to-face meetings with the case company's engineers. Suppliers were closely involved in the whole NPD process including new product idea generation, business/technical feasibility assessment, product/process conceptual development, prototype building and full-scale production. The knowledge sharing between the case company and these suppliers had helped ensure that the suppliers' production processes were suitable to manufacture the innovative recliner module. Company V and its supplier shares inventory information weekly with the suppliers. With respect to customer integration CI, company V only shared forecast inventory information with its retailers. Company share information concerning product performance with the retailers, and failure mode effect analysis is conducted to improve the quality of the product. The company conducted market research, such as customer surveys, to identify customers' needs. Thus, CI is appropriate in improving the quality of the settee. The supply chain network for company X is illustrated in Figure 5.

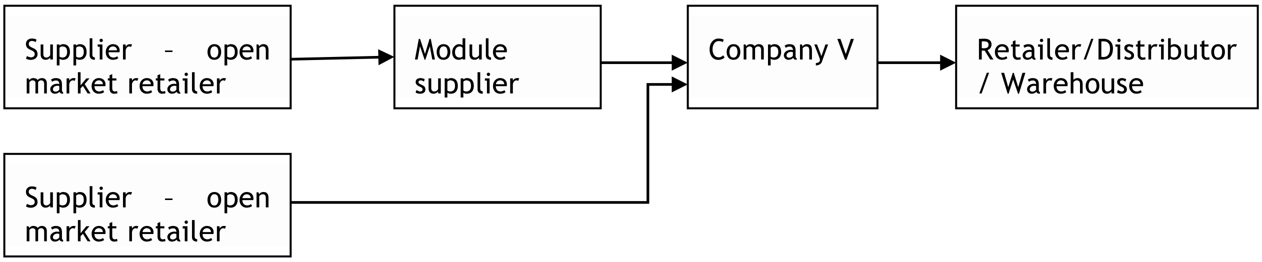


Figure 5

Company W

An office desk is an innovative product for Company W. The product was modularized to enable mixing modules with minimum architectural modifications. Modules are designed internally leading to faster product customization as requested by the customers. Company W developed and manufactured the desks in-house. Company W modularized the product and commonized some of the components in order to use standard parts. The standard parts were purchased on the open market and the modules were made in-house. In this way, the company could not only control architectural and modular knowledge and production capability but also gain greater sourcing flexibility and low-cost opportunities. However, the company did share quarterly inventory levels and yearly forecast order information with the supplier to ensure on-time delivery. Company W relied on the input from the customers to co-design and refine new product structure. When customers were directly involved in the design the company could ensure the customized functions fitted the customer's requirements. The technical department size had five workers one engineer and his assistance. The supply chain network for company X is illustrated in Figure 6.

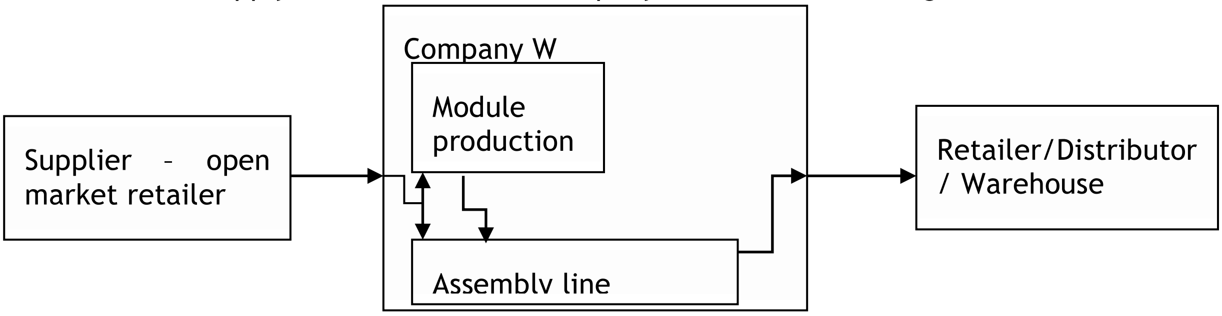


Figure 6.

Company X

Kitchen fitting is a conventional single product development project for a customer who makes decisions about the product architecture and material use. As required by the customer, the case company adopted a cut to fit modular product design and manufactured all the product modules in-house. The company depended on informal and trusted relationships with the suppliers to get modules like granite stones for kitchens cabinet tops. Forecast inventory level or other production information is shared with the suppliers to ensure on-time delivery. The functional modular product did not require close supplier integration; however production information was shared for supply chain efficiency. For customer integration, the customer was involved in the project because the s both the customer and the case company understand the product's design. In the II context, as the project was relatively simple and the project team was small, the case company only assigned one engineering manager as a coordinator to manage the development project with five internal staff, each of whom was assigned to develop a specific component or module. As most of the development activities were routine, formal integration mechanisms, as the project manager argued, would lead to higher development costs and extra planning time.

Thus, tight formal internal integration mechanisms were not adopted in this case. The supply chain network for company X is illustrated in Figure7.

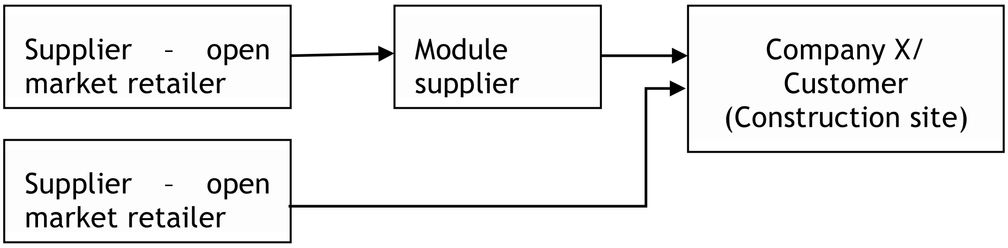


Figure 7

Company Y

Reception furniture is a single innovative product for Company Y, The reception furniture has many product designs depended on special requests from the customers, customers are concerned about physical dimensions and appearance, functional requirements and production cost. Company Y purchased modules from suppliers like sheet metal design and glass material design. The company integrated suppliers and customers in the in new product design. This supplier co-development practice helped the development team select appropriate materials for the product. Throughout the development process technical know-how was continuously shared. To ensure on-time delivery, forecast orders and other production information was shared with other suppliers. To develop the reception furniture, the development team worked closely with the suppliers and customers through frequent face-to-face communication and communicated with the international customers via internet-based information systems. Project management was adopted to integrate multiple internal functional units in this project. The supply chain network for company Y is similar to the one for company V Figure 5.

Company Z

The main products for company Z are tables and chairs and there are integral products, no modules are used to create these products. The company only shared the forecast inventory and order information with the supplier to gain supply chain efficiency. The customer coordinated closely with the project team through frequent sharing of technological and marketing knowledge. The product and resulted in a good relationship with the customer. The case company had no formal integration mechanisms to coordinate the technical members because the team only had four members and the products are very simple structure with very few components. Supply chain network for company Z is shown in Figure 8.

Figure 8

4. KEY FINDINGS AND DISCUSSION

Figure 1,2,3,4 shows the relationships between PM and SCI in all the cases. In the case discussion, SCI consists of three dimensions: suppliers integration, Customer integration and internal integration. In each dimension the cases were divided into tightly coordinated or loosely coordinated. According to the degree of PM, the cases were divided into modular design or integrated design. This classification was agreed by the interviewees in all the case companies.

Many authors argue that modular design is aligned with a loosely coordinated supply chain, whereas integrated design is associated with a tightly coordinated supply chain Fine et al, 2005[47]; Sanchez, 1995[48]). From case information discussed above PM is related to a loosely coordinated supply chain. This is based on empirical evidence that the product modules were standardized (Company X), the team size was small (Company, V,W). However, this study found some exceptional cases in which a tightly coordinated supply chain was adopted. This was because a new module was developed (Company X and Y) and technological knowledge was captured from the customer (Company Y). Company Y and X has a highly integrated supply chain, figure 3 shows that the number of meetings downstream and upstream is very high.

In Figure 4. the delivery lead times for company X and Y are low indicating that product modularity increases the supply chain efficiency leading to high flexibility.

Integrated design was associated with a tightly coordinated supply chain. This association was due to the nature of integrated design (Company Y and X). However, this study found an exceptional case in which a loosely coordinated supply chain was adopted. This was because the product modules were standardized (Company V) and the team was small (Company V).

By comparing the five cases, product design complexity is affecting the relationship between PM and SCI.

Complexity and Product design

This study suggests that the relationship between PM and SCI is strongly affected by the complexity of the product architecture. For supplier integration, in the reception furniture (Company Y), the case company co-developed the new module with the module supplier, who was involved early in product design, business meetings and design workshops. The other modular products like lounge settee (Company V) and office desks (Company W), were much less coordinated with their suppliers because the supplied materials were of a conventional type available in the open marketplace. For innovative product architecture, like the reception furniture (Company Y) required the supplier and customer to co-develop its new product. Company Z was a contrasting case that did not coordinate suppliers as the raw material was standardized and the product architecture was is integral.

Our case comparison indicates that modular design may be related to a loosely coordinated supply chain, whereas complex product architecture is associated with a tightly coordinated supply chain. The interrelated relationships among PM, SCI in this study found that if product modules or components are innovative, it is important to work closely with the key suppliers or customers regardless of whether modular or integrated design is adopted. This result is consistent with the view that product innovation requires information sharing and product co-development in the supply chain [49]. When complex product design is adopted, integration with critical component suppliers may not be avoidable. This finding suggests that the alternative of module commonization can lead to a loose supply chain for modular design.

Although literature suggests a loosely coordinated supply chain for modular product development [50], our empirical findings show that, for innovative product development (Company X and Y), SCI is indispensable. This finding is consistent with empirical studies which found that integrating supply chain partners and internal functional units is crucial in solving technical problems and specifying the interfaces of new product modules [51].

This study extends the extant literature in that it uses product innovation as a key factor to explain why modular product design needs SCI.

5. CONCLUSION

By studying five companies in the furniture industry, this study provides further explanations of the impact of PM on SCI. According to the findings, the authors have verified that there is a direct relationship between PM and some dimensions of SCI [52]. A highly modularized product will result in increased supply chain integration, tightly coordinated supply chain. Further research should focus on information management, product innovation or value-transfer activity across a supply chain.

It should be acknowledged that the present study is subjected to some limitations. Perhaps, the most serious limitation of this study was its narrow focus on South African manufacturing companies and hence without supporting replication of studies like this, our results should be considered tentative and should be generalized with care. Further, research should endeavor to test the inductions and process model offered by this research based on a large survey and cross-industry study. The purpose of this research is to raise select concerns in supply chain integration and product modularity in chosen South African companies and not to opt for statistical generalization.

Further research could be aimed at empirically testing the findings of this research. Interesting in this respect is also to explore the possible link between supply chain structure, SME's position and product modularity. This link is important because mutuality between supply chain partners and hence motivation to invest depends upon the structure of the supply chain.

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THE EFFECT OF TECHNOLOGY ON THE ECONOMY AND EMPLOYMENT

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ABSTRACT

Technological progression and scientific understanding are a key part of modern society and the economy. As our understanding and ability to automate and streamline processes through the implementation of new systems and components improves; our dependence on manual labour decreases. The goal of a business is to create more profit now as well as in the future. This study covers the effect that optimizations and improvements in processes and technology have on business by creating more productive employees and subsequently creating less need for large workforces.

The models adapted for this study find that as businesses become more reliant on work completed by technological components, the requirement for higher skilled employee's increases. This research shows that there is already and will continue to be, a large divide in compensation between individuals of different skill levels. Technology has made countries more competitive globally, allowing benefits to flow between nations. This has also resulted in the world economy growing, and poorer nations catching up to their richer counterparts. Technology is not inherently good or bad, the uses to which it is put it can improve the quality of life for all, but understanding of the implications and benefits should be considered.

1 INTRODUCTION

The initial outcome of findings and research indicate that implications of the current employment crisis and the effect of technology on this is not fully understood or documented. Articles such as that by Hornstein & Lubik in 2010, fail to contain any mention of the effects of computers, hardware, software, process or technology in general on employment or business models. [1]

There is a growing long-term unemployment problem. Understanding the drivers and conditions behind this is critical in a country such as South Africa with unemployment of almost 30% [2], and understanding how the adoption and pace of technological progress affects business and the rate of employment is crucial to understanding the skills, training and development required on a national level to fulfil the needs of the business and manufacturing sector and as a result reduce unemployment.

The long term effects and implications are not considered nor addressed in any government policies or legislature, nor are the benefits and risks to a growing and emerging economy fully realised. Following a full understanding of the effects and market changes certain policies in place may not be optimal.

Recent technological progress has become so extreme that the ability to create new positions due to this technology, or in another sector adjacent, falls short of the loss of roles due to technological advancement. [3]. Although the major theme of the book by Rifkin was that technology would create large scale unemployment, statistical proof of this was not producible at the time. In fact a research paper was produced prior to this publication addressing this phenomenon; Erik Brynjolfsson wrote a paper titled “The Productivity Paradox of Information Technology: Review and Assessment” [4], which describes the discrepancy between the investment into Information Technology and the measurable output at a national level.

This article deals with a number of mathematical models for work and output. Each model will build on or enhance the fundamental understanding for the overall effects of technology on the output produced in a closed environment.

2 OBJECTIVES

The research objectives associated with this report are as follows:

1. To determine what the requirement in terms of skills and infrastructure is that will take the most advantage of the new business models and economy changes.
2. To build a set of models that will help in understanding the effect of technology on business output and employee compensation.
3. To determine extent South Africa is already impacted by the current global trends.
4. To find if the current technological progress a cause for concern in the global marketplace.

This article will be structured as follows; firstly the relevant research and literature study will be outlined and summarised, followed by the creation and explanation of the models and their implications. The results and data gathered will be summarised and then followed with the conclusions and findings as well as direction for future studies.

3 LITERATURE REVIEW

The literature that was used in this study for the creation of the economic models should be divided into two main segments. The first being the Solow model, dealing with the effect of capital on the employee output, followed by the O-Ring theory of economic development, which investigates the effect of skill on the output of an employee and the relationship of skill to capital. Other literature used further extrapolates the methods of measurement and the reasoning for its selection. In this case our most common reference is that of an output on a per employee basis. This measurement on the effectiveness of each employee as per the Solow and O-Ring theory is done to demonstrate the effect of capital expenditure

3.1 Solow Model

Robert Solow produced a report in 1956 titled "A contribution to the Theory of Economic Growth", [5], in which the various contributing factors in output produced and growth were analysed and modelled. The new model allowed for labour as a factor of production and accommodated for distinct variables for changes in returns to both labour and capital and constant returns of scale to these variables. Robert Solow was also the first to introduce the concept of the effects of technology on output as a variable.

Prior to Robert Solow writing this report, certain observations and technological trends had yet to emerge. Moore's Law is a description of a technological trend which was observed and theorised by Gordon E. Moore in his paper, "Cramming More Components onto Integrated Circuits" [6], and was written almost ten years after Robert Solow first proposed his growth model. A limitation on Solow's model was that the original considerations of technology and its impact were not fully realised. The growth of technology was identified as following an exponential growth pattern, but the full implications of this were not considered until Moore's paper.

Solow had never even considered the possibility of a device such as a personal computer and yet in the early 1990's a paper was written and a paradox found and named after him. This report found that there is a lag in the insertion of the technology and the expected productivity growth. The effects were not immediately noticeable, this is also known as the Solow computer paradox. [4]. The fact that the effects of the new technologies were not noticeable at the time of adoption does not imply that the adoption would never effect the economy.

3.2 O-Ring Theory of Economic Development

The O-Ring Theory of Economic Development written by Michael Kemper (1993), and named after the Discovery Shuttle disaster which was caused by the failure of the O-Ring part. [7]. This naming was intended as a referral to how the failure of one small component in a larger system can have disastrous effects.

The O-ring production function provides a mechanism to describe the effect which small differences in skill have on creating large differences in productivity and wages. Higher skilled workers are intuitively less likely to make mistakes causing a waste in the rental value of capital (the cost of maintaining equipment and facilities); therefore it becomes more efficient for higher capital expenditure to be used in their function.

The model predicts that it is possible to solve for a competitive equilibrium defined as the assignment of workers, the wages set $w(q)$ and rental rate, r, such that the profits are maximised, workers of all skill levels are utilised and the capital is fully cleared.

There are a number of implications that emerge due to the model described:

1. There is a large wage and productivity differential between wealthy and poor countries.
2. Workers will earn more doing a similar task in a high-skill organization then an equivalent worker in a low-skill organization.
3. Firms will hire workers of different q values in relation to the current q and technological level within the firm.
4. Bottlenecks are magnified and reduce the expected returns on a specific skill level.
5. If q is considered to be distributed symmetrically then Income distribution is skewed to the right.

The result of increasing the complexity of a production chain or changing a production technique to have more complex procedures or sets, results in a higher quality and skill level per employee to complete the task successfully and profitably. As a result the higher the technological level or quality of a product the higher the effective wage of the employees due to their expected skill level. The corollary is also true, if there is a high surplus of high quality workers then the system is better able to adopt and benefit from higher lever technology and is more likely to have more advanced technology. If this was not done then the highly skilled workers would migrate to an area or location which most benefits them and offers the greatest returns on their skill.

This O-Ring theory becomes especially interesting when the implications of labour skill are viewed in conjunction with the Solow theorem and its effects of capital on the output and break-even cost per employee.

3.3 Measurement on a Per-Employee Basis

Between 1995 and 2005 the 30 largest companies of that timeframe, were seen to have an increase in profit per employee from $35,000 to $83,000 [8]. The same increase was not seen on the balance sheets for the Return on Invested Capital. In other words the capital directly invested in the improvement of employee operations gave greater returns than physical capital value growth.

The equations and outputs measured are compared on a per employee basis in order to provide an accurate assessment on the effects of capital and investment in specific labour enhancing technologies on the output of the employee and firm productivity, rather than looking at the pure output levels. Thus equations in other sections of this document are in units of output per employee instead of a change in total output for a company.

3.4 Compensation and Education

From the outcome of the O-Ring model it would be expected that as the systems become more complex, wages would be increasing for those able to adapt to these systems. Additionally as the economy changes from output based to skill based due to systems becoming more advanced, the result is a higher wage per employee for a higher skill level. More so than in the past when systems were less complex and output per employee was lower and measured in pure production.

The most effective way to view this competition is by comparing the relative change of wage over the past few decades between education levels. Figure 1: Change in wages by level of education , shows how this has occurred over the last four decades. This figure shows that there has been a distinct differentiation in compensation per employee skill level. Skill can not only be measured in the level of education obtained, but this is an accurate approximation of the skill for that employee.

The requirements and skills from employees are undergoing a shift of expectations. Education is playing a vital role in advancement of economies and value generation.

4 PROPOSED MODEL

This article has two unique models which are related and can be used together to determine the effect of technology on the economy and employment.

4.1 Solow Model

The determination of growth for an economy is by the increase of the ability to produce goods and services. The economy will use the inputs of labour augmented by technology and capital to produce these goods and services when combined with the knowledge of how to combine them. Some of this knowledge on combining the two inputs can also be considered to be a form of technology, an example is an improved process or methodology, more efficient project management or a system analysis technique like the theory of constraints. This mixture of inputs in shown as Capital (K), Labour (L) and Technology (G), create and produce output shown as (Y) in the equations below.

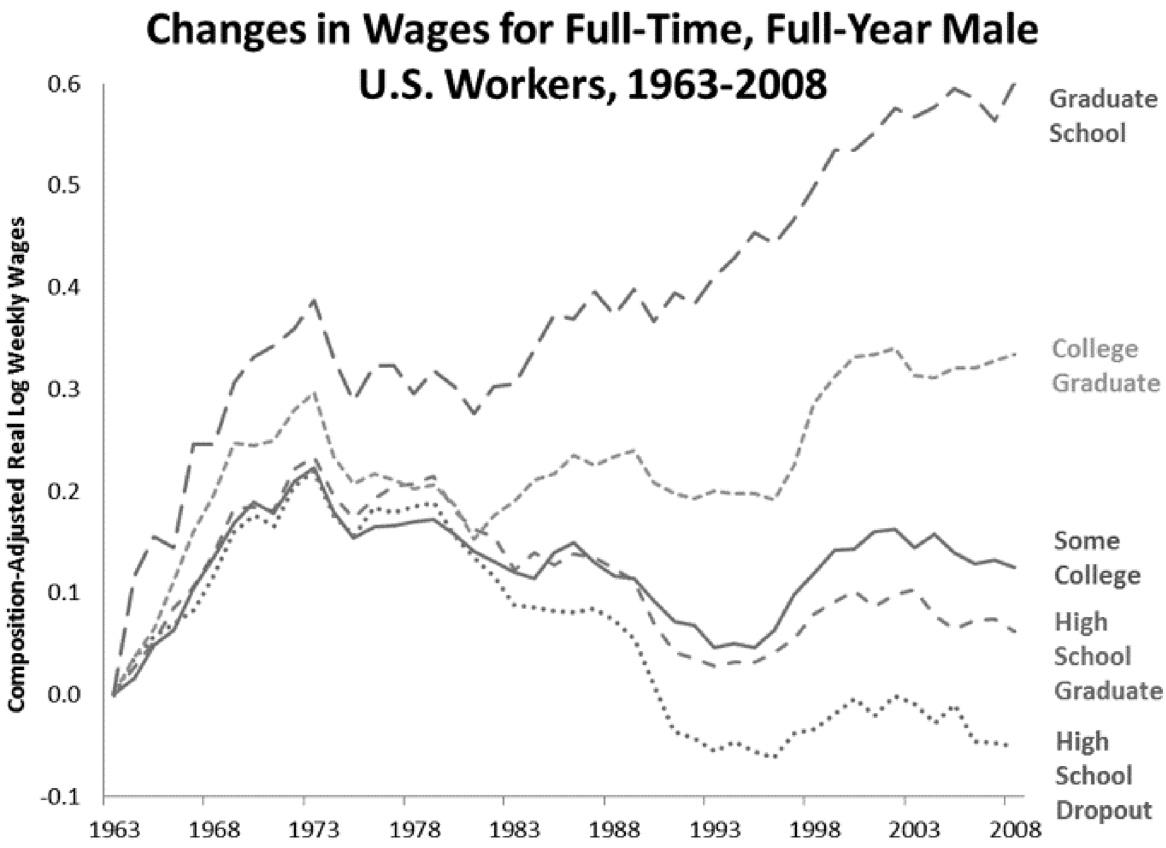

Figure 1: Change in wages by level of education [9]

The Solow model makes use of two equations, the Cobb-Douglass production function shown in equation 1* below [10], and the Capital Accumulation model as shown in equation 2. [11].

$$Y = K^{\propto} L^{1-\propto} \quad (1)$$

$$K_{t+1} = sY_t + (1\text{-}\delta)K_t \quad (2)$$

In the Capital Accumulation in equation 2, the Capital at time $t+1$ equals the Savings (s) of the output Y at time t and the capital K minus the depreciation δ. These two equations can be used to derive the final form of the Solow model, for a per-worker basis denoted by the non-capital lettering, as shown below in equation 3. This is verbally stated as the change in capital is equal to the saving from the previous time periods output, minus the depreciation of capital and the required capital expenditure required for new workers n.

* The following mathematical function using logarithmic differentials is used:

$$\frac{d(ln(x))}{dt} = \frac{d(ln(x))}{dx}\frac{dx}{dt} = \frac{1}{x}\frac{dx}{dt} = \frac{\dot{x}}{x}$$

$$\dot{k} = sy - (\delta + n)k \qquad (3)$$

The rate of saving and depreciation are influencing factors on the model. Some important factors that will become relevant are:

- If $sY > \delta K$
  - Capital stock is increasing and $\dot{K} > 0$
- If $sY < \delta K$
  - Capital stock is decreasing and $\dot{K} < 0$
- If $sY = \delta K$
  - Capital stock is steady and $\dot{K} = 0$
  - This is the steady state point of investment.

This model can be further expanded to calculate the effect on output on an effective worker basis as augmented by technology, g. The term for technology g is derived from an adjusted equation 1, where instead of pure Labour *L* we have Augmented Labour (*AL*) shown in equation 3.

$$Y = K^{\propto}(AL)^{1-\propto} \qquad (4)$$

$$\dot{\tilde{k}} = s\tilde{y} - (\delta + g + n)\tilde{k} \qquad (5)$$

The result of these equations are that unless sufficient investment is made to supply each new worker with the same capital as before, invest in capital to remain constant with technology requirements of g, and invest in capital to replace depreciation δ, then the capital per effective worker in the economy will fall. The amount of investment required to break even is equal to $(n + g + \delta)\tilde{k}$.

The following figure shows the Solow model including technology and the breakeven point as indicated by $\tilde{k}^*$, as well as the system adjusting for a change in the level of technology.

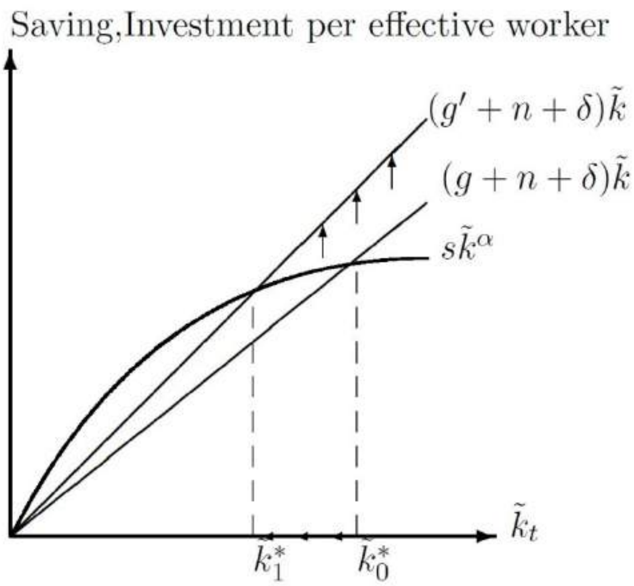

Figure 2: Revised Solow including technology [5]

Should either the number of employees, technology level or savings rate change, then the system would adjust to a new steady state that produces either a higher or lower output. Because the Solow model makes use of the diminishing returns to scale, any new technology or increase in employees result in essentially a lower return per employee overall. Technology is able to do this as a unit of technology g creates and 'effective employee' when combined with a normal employee. This results in increased output per employee and can be equated to hiring an equivalent number of additional employees without technology.

4.1 O-Ring Theory of Economic Development

This model proposed by Kremer covers the expected wage of a worker of quality q, taking the final form of equation (5).

$$w(q) = (1-\alpha)q^n Bk^\alpha + c \qquad \textbf{(6)}$$

This equation is derived from maximising the output of an equation with terms required to pay a sum of wages, $\omega(q)$, to employees while covering a rental and expenses amount for working capital, rk, and maximising this against the adjusted Cobb-Douglas equation.

This equation highlights the requirement that should a profit dependant entity, business or government, be required to replace a worker with a different worker of higher skill value, then the increase in the wage bill must reflect an appropriate increase in the output to the firm. Essentially the cost must be covered by proportional improvement, that is, the marginal product of skill, must equal the marginal cost of skill, show in equation (6).

$$\frac{dw(q_i)}{dq_i} \leq \frac{dy}{dq_i} \qquad \textbf{(7)}$$

The previously mentioned implications of the O-Ring Theory in section 3.2 of this article, result in certain requirements within a business. The model requires firms to choose a technological level to solve for maximum profit. Firms with higher values of q can make the most use of more technological steps, but if the technology is too complex it becomes a drain on the firm.

The relationship between the skill of the worker and the level of technology leads to the statement that the value of the employee is very strongly related to the technology of the company and the level of capital participation in the production path.

4.2 The Solow and O-Ring Interaction

The more a firm is able to save for investment into operations, the more capital should be used in production to meet the output of equation for the Golden Savings point, which is calculated for the maximum point of steady state consumption.

$$s = \alpha \qquad \textbf{(8)}$$

As this value increases the tasks become more complex and dependent on an increased number of steps requiring a higher quality of worker to complete successfully. Following which, the output produced is more profitable to a firm and once again allowing for a large savings and investment value.

This also indicates that firms with a higher quality workforce will complete more complex tasks for higher profits, with more capital as a driving force in the production function.

5 RESEARCH METHODOLOGY

Due to the nature of this report, in that the performance end effects of technology and employees must be tracked. The usage of secondary data played a large part of this report. These secondary data figures allow for a comparison of performance over a large span of time. Correlations and verification of models has been done before, specifically in the creation of the models such as Cobb-Douglass and Solow. [10], [5].

The data for use in this report is freely available and part of the public domain. However, official statistics are often found to have a number of issues:

- Unreliability
- Missing data
- Broad aggregation

- Inconsistencies

The yearly and quarterly statistics on employment, population size, labour market and other factors are released by StatsSA officially on a regular basis.

The following reports were used to collect and analyse the data, this information is available on the Stats SA website.

- CPI and CPI history, under key performance indicators, survey type: P0441
    - Frequency: Monthly/Quarterly updates
    - Previously captured under survey type: P0211
- General Household Survey; under publications, survey type: P0318
    - Frequency: Annual updates
- Quarterly Employment Statistics; under publications, survey type: P0277
    - Frequency: Quarterly updates
- Quarterly Labour Force Survey; under publications, survey type: P0210

There are certain advantages to using this specific kind of data from a reliable source:

- Large sample size,
- the data is considered clean and without any specific bias,
- with ability to perform trend analysis as multiple surveys of similar data are compiled regularly,
- and cost and time benefits.

There are however disadvantages as well to using this method of analysis.

- Contextual information behind the statistics is often not available,
- the volume of information is often large and difficult to filter,
- because the secondary data is not collected with the intent of creating the same analysis as intended in this report, data may be imperfect,
- and conflicting information from multiple sources.

Yearly and quarterly financial reports are also released by publicly traded firms. Additionally Government spending and the yearly budget for countries such as South Africa and the United States of America are freely available to the public as well.

The analysis of the financial reports of various publically traded firms will give information on the employee count, research spending and acquisitions. The growth with regards to profit, both gross and net, were used to identify how productive a firm is in comparison to previous years of financial reports and the employee count in the firm.

Finally these figures are automatically generated using the financial data available on a yearly basis from registered firms along with a tracking of their employee statistics. This is done through a computational engine by MathWorks.

This information is collated and collected from licenced sources paid for and updated by 3rd party companies. Due to the licensing agreements and the cost involved some of the raw data is unavailable to the consumer.

Some of this specific information would take months to collate as they are spread over multiple years and informational data-sheets. Much like how this report advocates technology and its ability to increase output and performance of employees, this statistical data can be used as a real world example of how technology can help and improve analysis and research on long term trends[†].

6 RESULTS

6.1 Education and unemployment

The first information that is important and gathered from the statistical reports was the education and unemployment data from South Africa. This information will be used to show the increasing importance of education in the current work environment.

In a paper prepared for presentation at the DRPU conference by Rosa Dias and Dorrit Posel, [12] the qualifications of the labour force and skills shortages were investigated; their results shows the effect in South Africa of employment and the lack thereof. The trend within the paper again shows that higher degrees of education are better utilised. As already discussed in the previous sections a growth in the quality of the workers has an exponential effect on the growth of output, allowing more complex and profitable businesses and products.

South African education does not succeed in creating a strong enough workforce to meet the needs of an economy. This is evident in the number of the employable workforce that is unable to find placing within the economy. Additionally wages are growing faster than inflation which unless there is a significant increase in output per worker which is not evident in the growth of the economy, would lead to a disruption of the wage equation (4).

Any change in wage for a worker must be balanced by an equal change in production which currently is not evident. Indeed such a growth of labour costs would lead to a suppression of new employee adoption and require an offset of higher quality workers.

The state of the educational system in South Africa and the level of education amongst its employed and unemployed population display a huge need for education from an individual's point of view. However, while diploma's, degrees and education is currently the de-facto means of measuring quality of workers, this may not always remain so. Experience, adaptability, skills absorption and interpersonal relationship building may become the new measurement standards as information becomes more freely available and capital adopts more of the production role.

6.2 Assets and Profitability

Since the technology could be divided into two separate distinct categories, physical technology and logical processes, a distinction must be made or identified between the two. Unfortunately there is no method of measuring or identifying a process or its value over time from an external point of view. The acquisition of physical assets such as buildings, equipment and hardware however is tracked in the company yearly asset reports and the

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[†] Some examples of this kind of controlled generation of output:

- Unemployment by education South Africa:
  http://www.wolframalpha.com/input/?i=unemployment+by+education+South+Africa
- Net-income per employee against net assets per employee for Cisco Systems:

  (assets per employee of NASDAQ:CSCO) and (net income per employee of NASDAQ:CSCO)

  http://www.wolframalpha.com/input/?i=+%28assets+per+employee+of+NASDAQ%3ACSCO%29+and+%28net+income+per+employee+of+NASDAQ%3ACSCO%29 major acquisitions are tracked in various documents and online articles. This is not a perfect measurement but provides information on the adoption and absorbance of capital into a company and its effect on profits.

6.2.1 Apple Inc.

The first company to analyse would be Apple Inc., a major firm which designs and sells consumer electronics, software and computers. In the below figure, shown is the relationship between assets acquired and output per employee.

Two scenarios exist for this increase, the improvement in the quality of the employees either through augmentation of ability or because the employees employed are of a higher q value than previously. Alternatively the proportion of work done between capital and labour is shifting within the Cobb-Douglas function resulting in a larger value of $\propto$.

From the understanding of the Solow model, if the output is increasing along with a temporary change in k, then this results in the same behaviour as described in the Solow model. The system would revert back to the previous levels of output to reach the steady state. If this output change is a permanent steady state change then the acquisition of the technology is also increasing the output of the company and augmenting the employee abilities, the information available on the economic sheets and for Apple acquisitions are limited in their original source data.

Figure 3: Apple Inc. profits per employee tracked against assets per employee

6.2.2 Google Inc.

As with Apple Inc. it is possible to track the usage and profit changes for Google Inc. as shown in Figure 4: Google Inc. profits per employee tracked against assets per employee.

It is noticeable that the profits and assets per employee track each other to a significant degree. Assuming that Google Inc. has not recently begun hiring employees of a significantly higher q value than before, the additional profit per employee indicates that either a larger proportion of capital is producing output or that the capital is augmenting the employee ability to be productive.

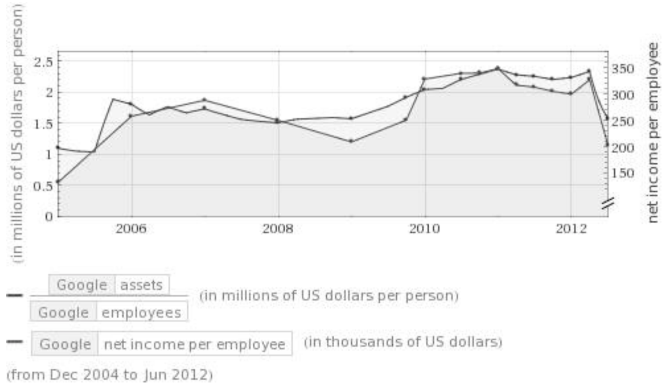

Figure 4: Google Inc. profits per employee tracked against assets per employee

As there is a reduction in capital per employee the system correspondingly adjusts the output per employee. This indicates that Google is quite linear in their investment per employees and that each employee has a significant and valuable amount of capital. Additionally as the employees are worth a significant amount of capital, it stands to reason that the quality of these employees is extremely high.

6.2.3 Cisco Systems Inc.

Cisco Systems Inc. is the largest networking equipment provider worldwide and is ranked number one in the IT hardware sector. Much like Apple and Google, Cisco Systems has been increasing its capital per worker; however the correlation between the newly accrued capital and the output per worker does not track as closely as the previous two companies. While there is a correlation, this remains minimal. Certain acquisitions in recent times have been dropped by Cisco; examples are the camera maker Flip, and the set top box producer Scientific Atlanta.

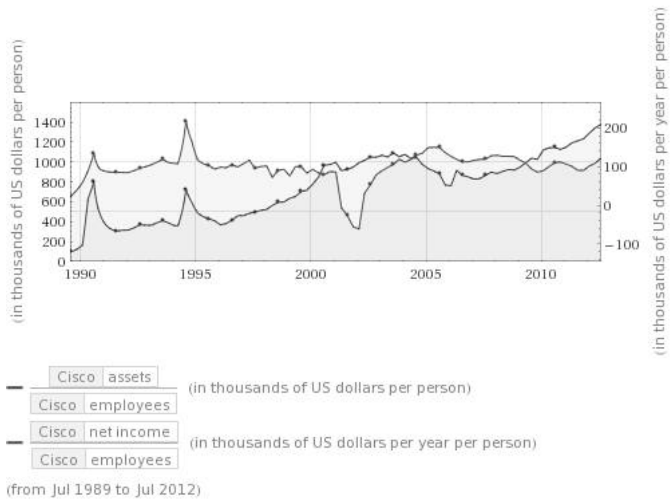

Figure 5: Cisco Systems Inc. profits per employee tracked against assets per employee

The relationship between the type of acquisitions purchased and the gain in output is unclear and due to the restricted nature of the balance sheets; employee output enhancing asset increases may be overshadowed by the other poor acquisitions. Additionally the profit and gain from these acquisitions are redirected into other operational tasks such as research and development or inventory. It may also be that the capital and technology change within Cisco is higher than that of the other companies.

As previously mentioned in the discussions on the Solow theorem, in addition to the depreciation experienced, there are new workers which require capital investment of $(n + g)\tilde{k}$, to keep capital per effective worker unchanged. The cost of this technology g, which is hardware based and more difficult to adjust and manufacture then software has a much higher cost and payback period in the industry which Cisco operates in, then that of Apple in the consumer market.

The items produced are also not consumer based and typically have a much longer lifespan then the yearly changes in Apple products and as a result only growth and profit manages to remain stable per employee instead of losing value. The inherent limitations and competition within the industry may be a point to consider for further study.

7 CONCLUSIONS AND RECOMMENDATIONS

Kremer's O-Ring shows that even a small change in quality results in large changes of output. This in turn results in an unequal output of wages and profit between companies and individuals with high skill levels. The models proposed in this article show that inequality will arise naturally within any system, but should be considered from the correct viewpoint and that equality of opportunity is preferable to equality of outcomes. Societies, policies and governments should endeavour to allow opportunities for all to equally improve themselves and move within the societal strata.

Education and training should not be considered an absolute goal, but rather a means to an end. Education should facilitate a transfer of skills useful to the workforce and valuable to the individual. Currently, despite changes in policy and funding, education still favours the rich, but technology is changing this slowly by increasing the availability and quality of material available freely to all. Technical tools such as the internet and online sources that offer free education could drastically improve the quality of the workforce and the lives of the poor if proper use of these facilities is made. Technology need not be the cause of unemployment but rather the driver to self-improvement.

From this study and work it is clear that trends are emerging; some of those being the increasing importance of education, and the increasing role technology plays in our value chain. The final result of this change in society is still not clear. It is a strong recommendation that the work on this is continued.

Currently information is lacking on the effect of technology in specific instances some recommendations for research are the effects on these fields:

- Education and improvements on educational quality,
- manufacturing ability and product quality,
- financial control and management,
- Average quality of life improvements.

The following are theorised experiments and test that can be done once more information has been gathered. This will specifically allow for the testing of the effect of technology on employee productivity and the rate of change of technology level g. Evaluate the change in productivity per employee to determine whether the rate of change between two significant periods of time are statistically different for firms within the same field or technological adoption rate. Additionally work can be done into the time between deployment and adoption, which can be used to identify trends and expected impact times of technological developments.

In conclusion, technology progress is unavoidable and the world is able to communicate, produce and develop more quickly, effectively and in greater detail than ever before. The rate of change is known to be exponential; and our ability to adopt and make use of this will determine who benefits and is who is left behind. There is most definitely an impact and all that remains to be seen is how much larger this effect will become.

Technology can at once magnify the effects of inequality and bring about the solutions to this problem and is not inherently good or bad. The uses to which we put it can improve the quality of life for all. With any change comes opportunity and change has never taken place as quickly as now.

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DESIGN OF AN AUTOMATED GRINDING MEDIA CHARGING SYSTEM FOR BALL MILLS

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ABSTRACT

The parameters of mill load (ML) not only represent the load of the ball mill, but also determine the grinding production ratio (GPR) of the grinding process. Monitoring and recognition of milling conditions have significant effect on the operating efficiency, product quality, and energy and grinding media consumption for the milling circuit. This paper presents an automated grinding media charging system incorporating a multi-agent system developed in Java Agent Development Environment (JADE). A control logix program is designed to determine the precise quantities of grinding media to be charged in an incremental manner such that shock loading is avoided. The multi-agent system created in JADE monitors the power drawn and the mill load of the ball mill such that proper charging conditions are established. High quality of the regulation process is achieved through utilization of the control logix and the multi-agent system.

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1 INTRODUCTION

Grinding or milling in ball mills is an important technological process applied to reduce the size of particles which may have different nature and a wide diversity of physical, mechanical and chemical characteristics. On-line monitoring and recognition of milling conditions has significant effect on the operating efficiency, product quality, and energy and grinding media consumption for the milling circuit. The key issue of concern however is monitoring the way grinding media is being replenished over time as it is subject to excessive wear as a result of the stringent milling process. As of 2006, 0.23 billion kg of steel in the US and over 0.45 billion kg in the world were estimated to be consumed each year in wet grinding alone owing to increased grinding media consumption rates, and this is very much inconsistent with principles of Sustainable Development. The high consumption rates are primarily attributed to poor charging practices, wherein overcharging is resulting in increased wear as a result of increased and rigorous collision between grinding media itself as stated by Kotake et al [1]. The principal aim in optimisation of grinding media charging is to reduce the costs of procuring the grinding media, replacing liners inside the ball mill and electricity consumption and bills due to running over-loaded ball mills. This paper focuses on optimized grinding media charging through integration of a multi-agent system created in JADE and a control program developed in Siemens S7.

2 GRINDING MEDIA WEAR AND EFFECTS OF OVERCHARGING

Most organisations are faced with difficulties with replenishing grinding media during or after a milling operation has been performed, especially those who run continuous milling processes. In such instances grinding media is supposed to be replenished as the ball mills are running. Poor charging practices in the yesteryears have seen over charging occurring. Some of the adverse effects of overcharging are outlined below.

2.1 Excessive wear of Steel Balls (Grinding media)

Over loading has some adverse effects on the grinding media. Generally when all things are equal, the expected wear on the grinding media should be caused by the interaction of the media, water and ore, but due to over loading there is increased and rigorous collision between the media resulting in breakages and increased wear as stated by Kotake et al [1] and Zhao and Yuan [2].

2.2 Increased Mill Load

Mill load or charge volume is the cumulative sum of the grinding media, process water and ore. The grinding media constitute the bigger percentage of the mill load. Empirical information show that 40% load by volume of ball mills result in optimum operation or grinding as supported by Erdem [3], Yang & Li [4] and Bernard et al [5]. Increasing mill loads way above this value may result in mill over loads. The subsequent result or effects of overcharging is increased power consumption by the ball mills.

2.3 Increased Power Consumption

Power consumption by ball mills is directly proportional to mill load/charge volume, and specifically the amount of grinding media added at a particular time. Increased power consumption normally results in high electricity bills. Equation (1) outlines this relationship between power draw and mill load as used by Fuerstenau et al [6] and Powell et al [7].

$$Power\ Drawn\ =\ A\ x\ B\ x\ C\ x\ L \qquad (1)$$

Where:

A = factor for diameter inside the shell liners.

B = factor for mill type and charge volume (% loading).

C = factor for mill speed expressed as a percentage of mill critical speed.

L = length of grinding chamber measured between head liners at the junction of the shell and head liners.

2.4 Excessive wear of Liners

Overcharging of grinding media has also been seen to been a cause of excessive wear of liners inside ball mills. This is a cause of great concern as it has of late resulted in increase of the cost associated with replacing these liners. Dimeas & Hatziargyriou [8] highlighted the other effect as being the increase in the frequency of changing or replacing these liners earlier than expected by the manufacturers.

2.5 Increased frequency of Over-load trips and down times

Increase in mill load as a result of overcharging grinding media has of late seen frequent trips as a result of over loads. Generally the motors driving the ball mills have a rated maximum capacity that they can power. Overcharging mills, especially running ball mills has been seen as a cause of these frequent over load trips. Besides overload trips, frequent break downs have also been realized. This has subsequently resulted in increase in the number of down times the milling circuits are experiencing.

3 OVERVIEW OF THE AUTOMATED CHARGING SYSTEM

The relationship between the multi-agent system designed in JADE for decision making and the control system developed in Siemens S7 for control of the hardware is outlined in Figure 1. The exchange of information and messages is facilitated by the use of an Object Linking and Embedding for Process Control (OPC), wherein the JADE program acts as the OPC server and the Siemens program as the OPC client. Vu Van Tan [9] state that OPC is a standardized interface for accessing process data and is based on the Microsoft Component Object Model (COM) and Distributed Component Object Model (DCOM). The OPC server is not a passive subprogram library, but an executable program which is started when the connection between client (PLC) and server (JADE) is established.

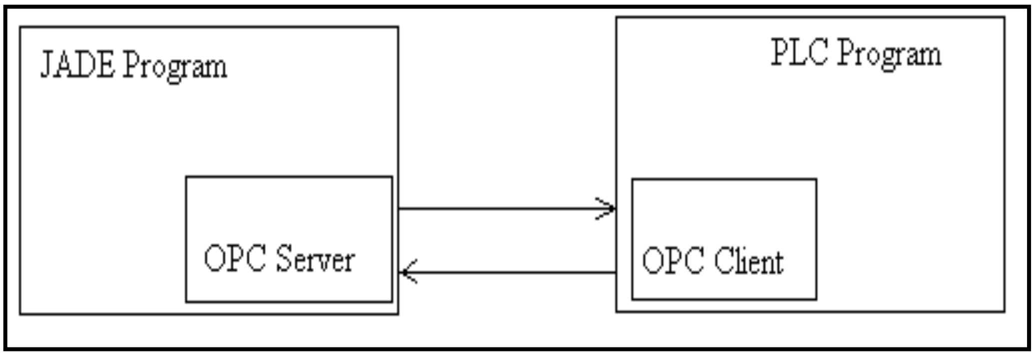


Figure 1: Link between JADE and PLC

The typical operating strategy of the automated charging system relies on the decisions made by the multi-agent system. The multi-agent system comprises of two agents namely the control and charging agents that interoperate to accomplish the requirements of the charging system. The idea behind the multi-agent system is to break down the complex problem of charging grinding media optimally, into smaller and simpler problem easily handled by the agents. The multi-agent system monitors the system parameters and then makes Boolean decisions corresponding to zero and one in control systems language. A zero is equivalent of a denial, while a one corresponding to an acceptance to charging. The system parameters of concern are mill load and power drawn by the ball mill. The milling operation is governed by equation 1.

The proposed agent architecture reduces the number of messages exchanged among agents and simplifies the overall complexity of a multi-agent implementation in automated charging system. In the automated charging system, each agent has unique objectives and responsibilities to be accomplished in order to meet the overall goal of making a decision on optimal conditions to charge grinding media.

4 METHODOLOGY

A company audit of MINE XXX was performed wherein charging quantities for the period February to March 2012 were compiled. Power-draws trends for the period from July 2011 to June 2012 were also monitored for Mine XXX after charging grinding media using the current conventional way of estimating the amounts to be charged. The challenges in the current systems of charging saw the variations in power draws as outlined in Figure 2. High levels of fluctuations in power draws are attributed to poor charging practices. The graph is not smooth owing to times when ball mills were run in extreme overloaded conditions and also in extreme under loaded conditions.

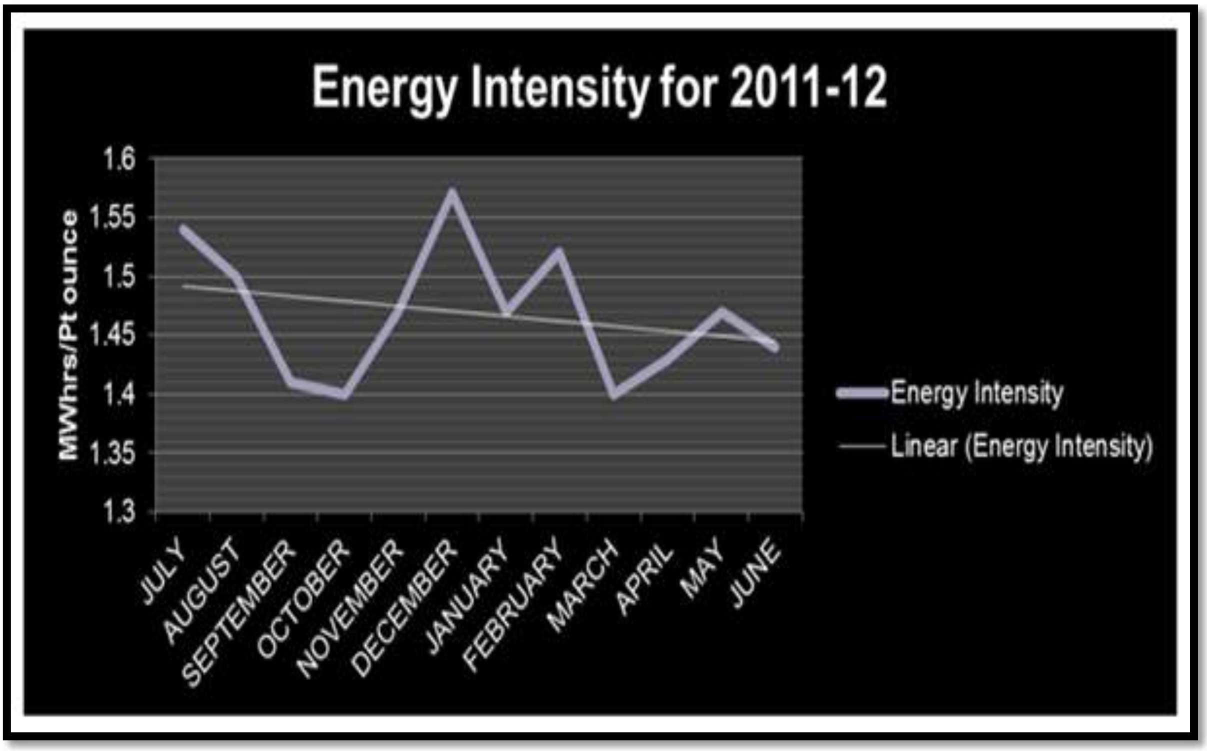


Figure 2: Power Draw Intensity Graph

Table 1 outlines the data that was collected for the primary ball mill in February and March 2012. It is expected that the mass of steel balls (grinding media) in kg/ton of ore milled should be approximately 0.24kg/ton, but one can clearly see the great deviation from this value. It therefore means that the wear rate of the grinding media in the current system is increased. Charging too much grinding media has been seen from literature to be a major contributor to escalated wear rates by Chen & Li [10], and Keshav et al [11].

An average value of 0.94kg/ton from the current wear rates was found after computing the highest and minimum wear rate during the period under study. The second column in Table 1 also shows a great deviation from the amounts that are supposed to be charged. At an ore feed rate of 300ton/hr and a media wear rate of 0.24kg/ton, after 8hours, 576kg of grinding media is supposed to be charged. The values given are therefore a witness of overcharging that is occurring in the system.

Table 1: Charging values in kilograms ad kilograms per metric ton in primary milling

Date	Mass of steel balls in Kg	Mass of steel balls in kg/ton of ore milled
6-Feb-12	2276	0.32
7-Feb-12	2222	0.31
9-Feb-12	5031	0.69
11-Feb-12	5160	0.72
12-Feb-12	5140	0.88
2-Mar-12	2250	0.31
3-Mar-12	2342	0.33
4-Mar-12	2350	0.33
5-Mar-12	11936	1.64

Table 2 is also showing the same challenge of overcharging wherein a wear rate of 0.18kg/ton is expected, but there is a significant deviation from this mark as seen in column 3. The amounts of grinding media charged per day are also significantly high owing to overcharging. The adverse effects of overcharging as discussed in section 2 of this paper are therefore inevitable.

Table 2: Charging figures in kilograms ad kilograms per metric ton in secondary milling.

Date	Mass of steel balls in Kg	Mass of steel balls in kg/ton of ore milled
6-Feb-12	1471	0.205
7-Feb-12	1124	0.156
9-Feb-12	323	0.052
11-Feb-12	1244	0.169
12-Feb-12	1391	0.192
1-Mar-12	2113	0.291
2-Mar-12	1899	0.262
3-Mar-12	1514	0.224
4-Mar-12	2474	0.348
5-Mar-12	0	0.000

5 AUTOMATED CHARGING SYSTEM DEVELOPMENT

In developing the multi-agent system and the control program, their interoperability was of great importance.

5.1 Multi-Agent Implementation and Design

JADE was selected for the implementation of the decision support system for the automated charging as it meets the IEEE and Foundation for Intelligent Physical Agents (FIPA) standards as supported by Dimeas & Hatziargyrious [13]. Mark & Lazansky [13] and Woodridge [14] highlighted that the multi-agent system development for JADE involves agent specification, application analysis, application design, realization and implementation.

5.1.1 Agent Specifications

In this step, specifications of a control agent and charging agent in the Multi-Agent System are defined. Thus the responsibility of each agent is specified.

5.1.1.1 Control Agent

The control agent puts forth responsibilities that include the following:

- Monitoring the system's mill load and power draw.
- Making decisions on whether to charge or not based the status of the control parameters i.e mill load and power draw at the time of request to charge.
- Keeping the record of the media, its name and quantities to be charged.

5.1.1.2 Charging Agent

The charging agent is mainly responsible for making cyclic charging requests to the control agent. The charging agent is also responsible for:

- Accepting incoming registrations of milled tonnage from a weight meter on the feed conveyor.

5.1.2 Application Analysis

The second step involved formalization of agent roles and responsibilities that simplify understanding and modelling the problem at hand using a role modelling technique. This basically entails defining the roles played by each agent and also establishing the interaction with the external environment as summarised by Woodridge [14]. A collaborative diagram which defines the interaction among agents and their interaction with the environment needs shown in Figure 3 was developed.

The initialisation of the Multi – Agent System is performed by the control agent entering the media name and quantities to be charged in a harsh table. Both the control and charging agents have to register with the directory facilitator (DF) services so that they can adequately interoperate and get services from one another.

5.1.3 Application Design

The application design step involves a process of mapping agent responsibilities to problems that each agent attempts to solve. The charging agent is given a cyclic behaviour with a ticker time of one hour such that it requests to charge at that interval. Woodridge [14] illustrated that the control agent monitors the system parameters and then compliments the charging agent by making decisions on the right time to charge.

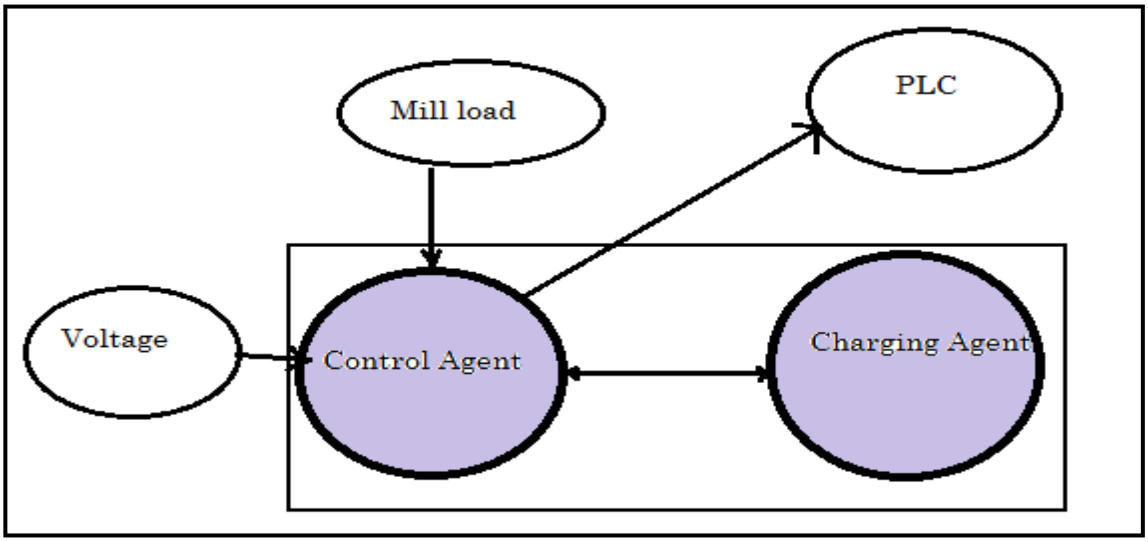


Figure 3: Collaborative Diagram

5.1.4 Application Realisation and Implementation

The application realization process consisted of protocol creation which involved the definition of the protocol used by the charging and control agent during communication. The messages adhere strictly to the Agent Communication Language (ACL) standard which allows several possibilities for the encoding of the actual content. Woodridge [14] highlighted how the multi-agent system developed makes use of the Call For Proposal (CFP). The request sent by the charging agent is such that it activates proposals by the control agent in terms of the optimum quantities to charge.

5.2 Control System Development

The control program in Siemens S7 1200 PLC developed will be controlling the hardware of the charging system. Basically the program is based on two inputs and two output devices as shown by Dunn [15]. Of the two input devices, the first input device receiving signals from the agent decisions works with digital signals, while the other work with analogue signals from the weighing modules. Table 3 summarises the equipment specifications for pneumatic gates which are actually the output devices.

Table 3: **Component Equipment Specification**

Equipment	State	Signal Type	Default State
Pneumatic Gate 1	Open-Close	Digital(1-0)	Close(0)
Pneumatic Gate 2	Open-Close	Digital(1-0)	Close(0)

The snippet of the ladder logix program controlling the hardware of the charging system was development and it is summarised in Figure 4. The first rung given shows how the first pneumatic gate is activated by the type of the agent message received via an OPC Server.

Assuming that the message was a yes, the first gate opens up to load the weighing bin. The preset value set on the weighing modules (load cells) is the mass corresponding to the ore milled at the time a charging request message is sent. The second rung shows how the first gate is reset and a subsequent opening up of the second gate to allow the media to be discharged into the ball mill.

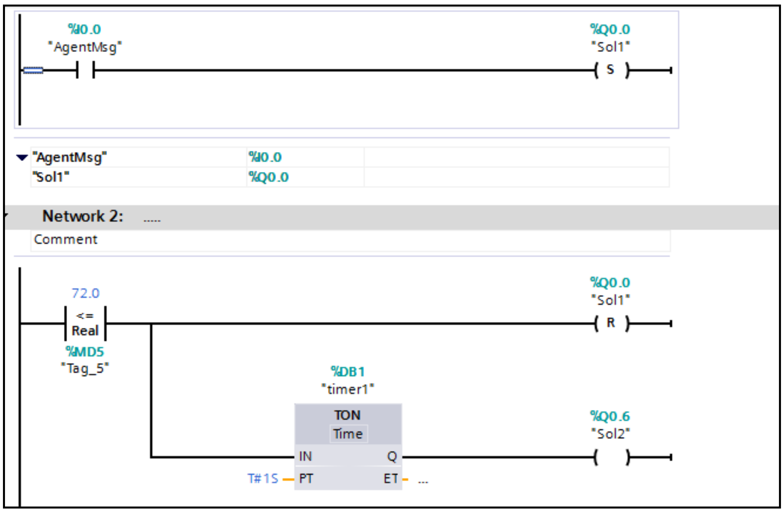


Figure 4: Ladder Logix Snippet

A flow diagram of how the ladder diagram works is illustrated in Figure 5.

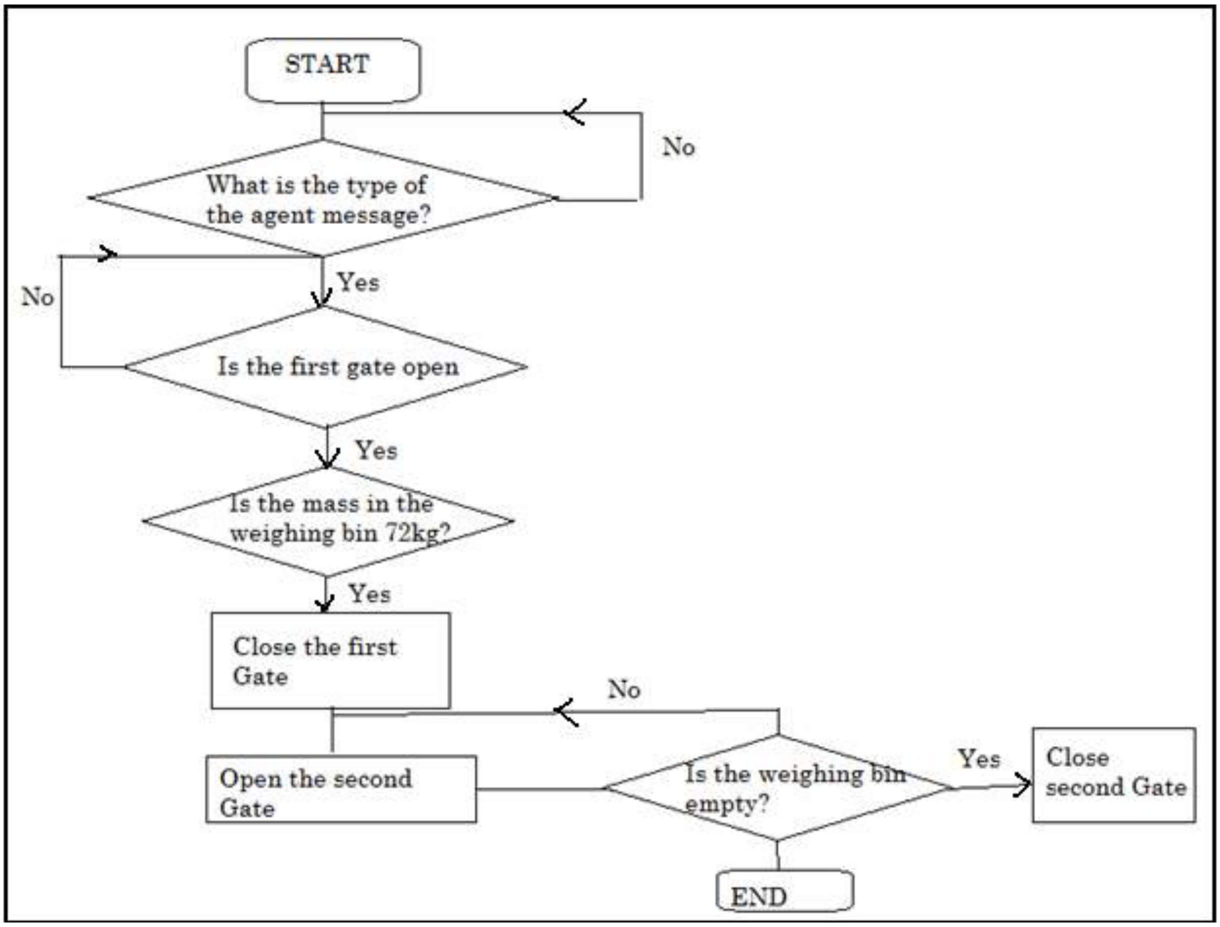


Figure 5: Ladder Flow Diagram

5.3 OPC COMMUNICATION LINK

An OPC Server must be used to establish the link between the JADE program and the PLC program. The OPC should solve the following challenges in the charging system designed:

- A constant value (e.g., a password) is to be written to the equipment automatically on startup. The Modbus RTU (serial) should be used as the communications protocol.
- Write this value on command from an operator.

- Allow monitoring of the communications status of the equipment.

The OPC Server should be linked to the JADE host computer and PLC central processing unit via TCP/IP serial ports. Figure 6 shows the block diagram of the link between the operator station which is basically the platform from which the JADE program is executed and the link to the PLC and ultimately to the equipment or hardware of the charging system as shown by Diaconescu & Spirleanu [16]. Similar work on communition optimization was done by Ndlovu et al [17] using multiple objective evolutional algorithm.

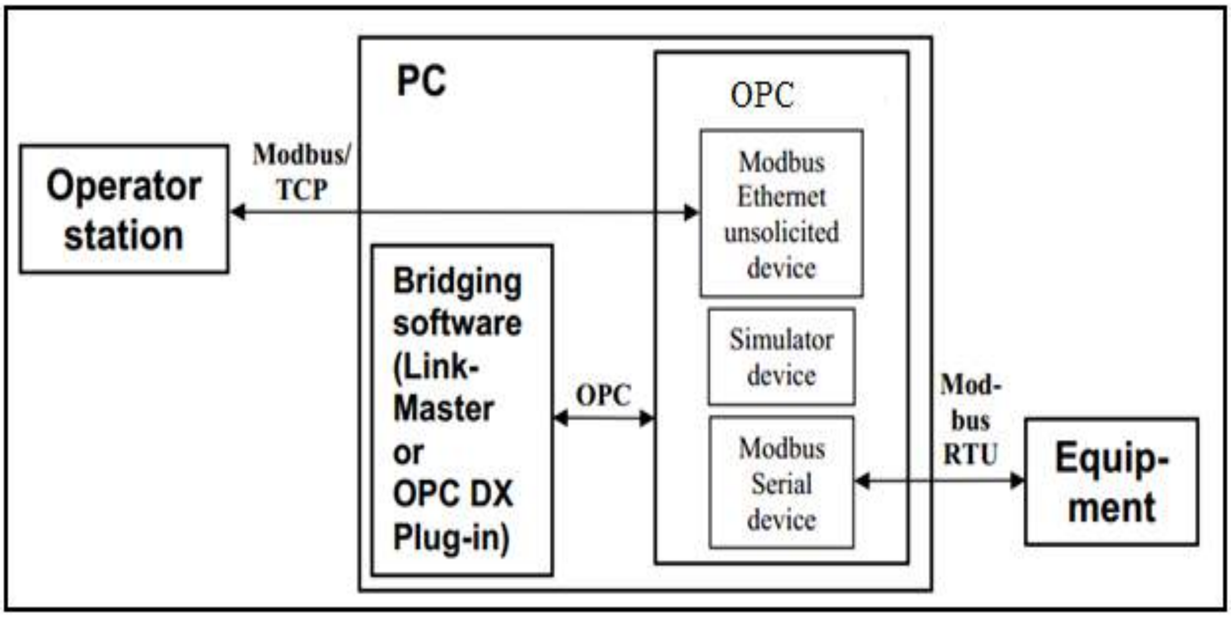


Figure 6: Block Diagram of the Software and Hardware

The application structure of the charging system incorporating the OPC Server, JADE program and PLC is based on a model by Diaconescu & Spirleanu [16] and will be outlined as shown in Figure 7 below.

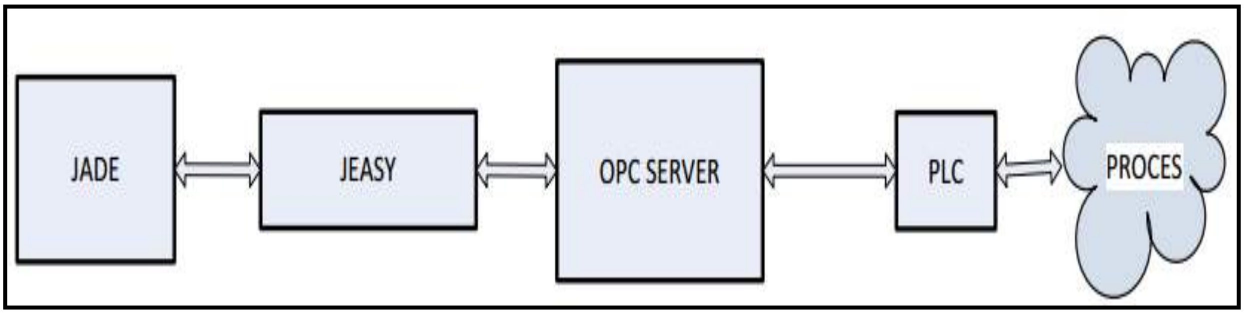


Figure 7: Application Structure [16]

The basic components of the application structure are defined as thus:

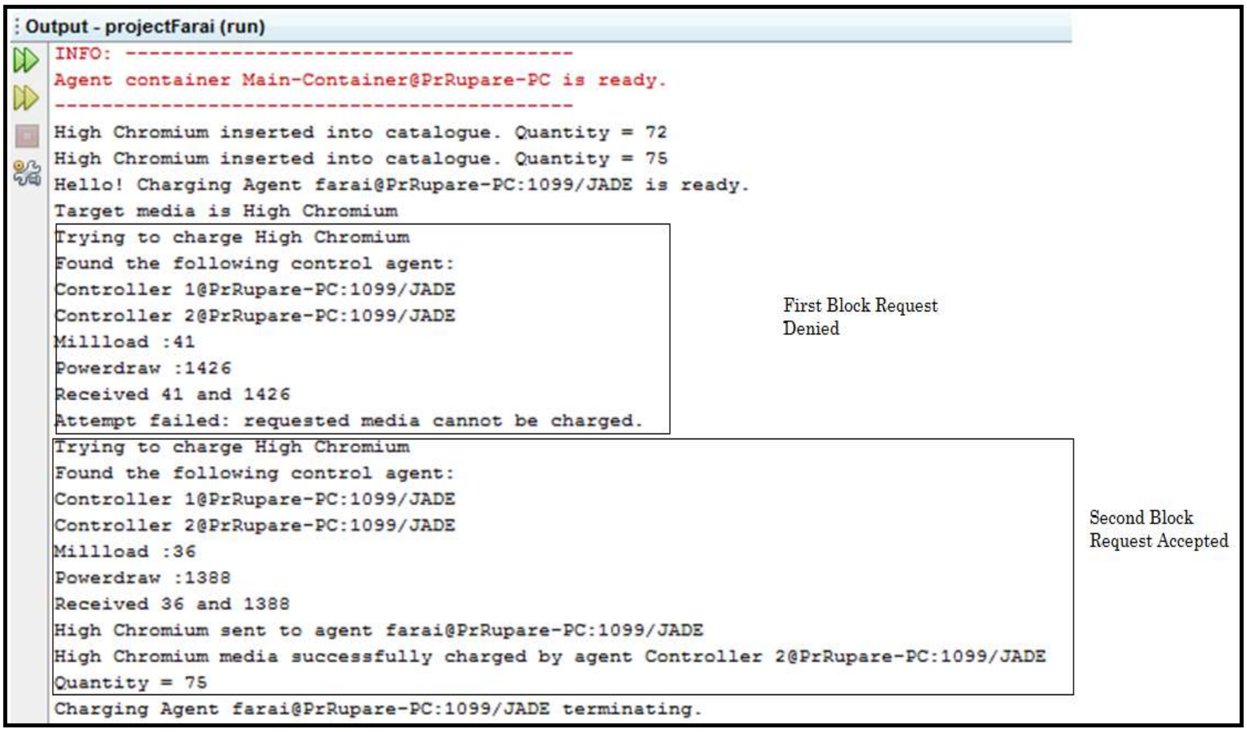
- Development environment (where JADE and PLC programs are running).
- Communication protocol (Modbus RTU).
- Jeasy OPC driver for interfacing with programs developed in Java.

6 RESULTS AND DISCUSSIONS

Discussed in this section are the results from the decision making process by the JADE program. The console applet was used for the discussion. The messaging between the agents is shown on a diagram similar to a UML sequence graph.

6.1 Jade Results

The outcome of the decision making process is outlined on a console platform in Figure 8. It also reveals some of the conversation messages being exchanged between agents as they perform their individual roles in making decisions.



```
Output - projectFarai (run)
INFO: ----------------------------------------
Agent container Main-Container@PrRupare-PC is ready.
---------------------------------------------
High Chromium inserted into catalogue. Quantity = 72
High Chromium inserted into catalogue. Quantity = 75
Hello! Charging Agent farai@PrRupare-PC:1099/JADE is ready.
Target media is High Chromium
Trying to charge High Chromium
Found the following control agent:
Controller 1@PrRupare-PC:1099/JADE
Controller 2@PrRupare-PC:1099/JADE
Millload :41
Powerdraw :1426
Received 41 and 1426
Attempt failed: requested media cannot be charged.
Trying to charge High Chromium
Found the following control agent:
Controller 1@PrRupare-PC:1099/JADE
Controller 2@PrRupare-PC:1099/JADE
Millload :36
Powerdraw :1388
Received 36 and 1388
High Chromium sent to agent farai@PrRupare-PC:1099/JADE
High Chromium media successfully charged by agent Controller 2@PrRupare-PC:1099/JADE
Quantity = 75
Charging Agent farai@PrRupare-PC:1099/JADE terminating.
```


Figure 8: Applet of the JADE Decision Process

Two blocks are outlined in Figure 8 showing two different scenarios in decision making by the agents. The scenarios shall be discussed as "Denial" and "Accept";

Scenario 1 "Denial- First Block"

The charging agent has a cyclic behavior of sending requests to the control agent after every hour. The target media to charge is a start up argument given a name "High Chromium". The system is prompted to search for the control agent. When the control agent is found, the system prints a message *"……Found the following control agents…"*, and also list their nicknames e.g. *"controller1"*. At this stage the system is prompted to get the mill load and power draw values in order to make a decision in response to the request by the charging agent. The condition for accepting requests from the charging agent is an "AND" condition such that mill load has to be less than 42% and power draw has to be less than 1400kW, else deny.

The last statement in the first block in Figure 8 says *"….Attempt failed: requested media cannot be charged…"* because the system parameters received are greater than the set optimum, thus 41% and 1426kW. The message in then converted to a Boolean zero such that the PLC is not activated to open first pneumatic gate on the storage bin side.

Scenario 2 "Accept- Second Block"

The second scenario is a reverse of scenario 1. The last three statements in the second block in Figure 8 show a case when an acceptance is given by the control agent because the system parameter received are lower than the set points, thus 36% and 1388kW. The acceptance message is converted to a Boolean one that is sent to a PLC to close the first gate on the storage bin side and open the gate on the weighing bin side.

6.2 Intercepting Messages between Agents

A Sniffer agent was used to intercept messages while they were in flight and displays them graphically using a notation similar to Unified Modeling Language sequence diagrams. Intercepting messages is useful for debugging the agent societies by observing how they exchange ACL messages. The outcome of this exercise is displayed and summarised in Figure 9.

Figure 9: Applet of the Messages Intercepted by the Sniffer Agent

7 FUTURE WORK

The configuration of the link between the JADE program and the PLC has to be performed to ascertain the integrity of the link in the charging system using an OPC Server as briefly discussed in section 5 of this paper. The integration of multi-agent systems into bigger mines and other organisations running ball mills also has to be explored further. Further research into the interoperability of multi-agents and control systems has to be done in order to improve the quality of information available so far in the knowledge body and also its application in other fields.

8 CONCLUSION

The automated charging system was designed to help optimize communition circuits and reduce the cost associated with running the process. The paper set to highlight background of the Case Study Company and possible improvements in steel ball charging systems. The system was developed that would increase the line production due to an efficient plant which will use agent based systems to control the process. The world has become increasingly aware of the need to optimize resources that are used in every stage of production; hence the Hybrid system comes in handy in this area. The ability by organisations to conserve energy and optimize the use of resources will result in sustainable development. The ability to reduce the cost associated with production is major tools that will see organisations escape the setting sun and current economic hardship in the world.

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THE EVOLUTION OF MANUFACTURING:
AN INDUSTRY CASE STUDY AT ALTECH UEC SOUTH AFRICA (PTY) LTD

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ABSTRACT

South African businesses operating globally are facing many economic challenges. This paper discusses Altech UEC South Africa's evolution of manufacturing and the importance of adapting to survive. This evolution entails changing facets of the business such as its structure, systems and technology. It requires implementing theories such as design for manufacture, changing the operational structure and the flow of processes, lean manufacturing concepts and investigating alternatives to reduce energy usage. All of these strategies have the goal of reducing operating cost.

An industry case study on the rare event of a factory relocation project, combined with a focus on design for manufacture and importance of corporate culture is investigated. Motivating for large financial expenses is a challenge, with demands changing with the agility of the market and the necessity to stay financially viable against other emerging markets. It is therefore an achievement not just motivating for an organisation-wide change, but also the development and progress brought about by embracing it.

1 INTRODUCTION

How to survive Darwin? It is argued by Enarsson [1] that companies need to transform and evolve into agile organisations, as the market's needs are fickle and quick to change. Being in the electronics industry and at the rate at which technology changes, this is especially important for Altech UEC South Africa.

There are, however, certain objectives that need to be achieved before a business can embark upon the mission to become agile, one of which is to be a lean or world class organisation, Enarsson [1].

This paper does not serve to present revolutionary academic theories to the manufacturing community, but rather give some insight into the applied integration of a number of common principles, and the results achieved in a case study at Altech UEC South Africa.

It discusses the historical performance of the facility, the strategies for change and the resulting performance evaluation. Strategies involve changing the structure of the company, which includes the facility, corporate culture, and product designs. The system infrastructure and newer technologies are also investigated. All of the discussed strategies are tools that assist in evolving manufacturing and striving to become a world class organisation.

It is estimated that the unit cost would have been 73 percent higher than the current cost, if the changes were not made, Manufacturing Executive [14]. This highlights the achievement that can be brought about by embracing these changes.

1.1 Background

Altech UEC South Africa, as a subsidiary of the Altech Group, is a manufacturer of digital encryption devices in the African and International markets. The main product lines consist of set top boxes for the pay television industry. Flat panel televisions and tracking devices are other lines of business which have been recently pursued. An interview with the Manufacturing Executive on 26 March 2013, revealed that Altech UEC South Africa has manufactured over 16 million devices to date. The set top box manufacturing processes consist of the production of plastic parts, electronic assembly and final assembly of the complete units. The flat panel televisions and tracking devices processes are slightly different, with most of the parts being outsourced and received as a complete knock down business. The printed circuit boards are populated with surface mount technology, then tested and assembled at the final assembly lines.

1.2 The need for cost reductions

Table 1 indicates the cost differences for South African versus Chinese manufacturing, according to Reed [5].

Table 1: South African versus Chinese manufacturing costs Reed [5]

Element	SA versus China
Labour	20 - 40 % more
Components	10 - 20 % more
Facilities and equipment	10 - 20% more
Management overheads	10 - 20% more

In order to stay competitive in the market, Altech UEC South Africa has had to decrease manufacturing value add and bill of material costs with inflation increases. Volume and efficiency gains have been, and still are, required to counter inflation.

Surviving Darwin at Altech UEC South Africa, therefore, required a combination of high level strategies to fundamentally change the structure, systems and technology together with smaller continuous improvements, in order to reduce costs and to be able to compete in the global market as a world class manufacturer.

2 THE EVOLUTION ROADMAP AND STRATEGY

Where does one start to plan a roadmap and strategy that evolves manufacturing in the direction that is required?

Enarsson [1] argues that companies need to evolve and adapt to the current environment to respond to the market's needs, at the right time and the right price. However, a lean and streamlined facility is required as the foundation. The key to successful and economical manufacturing lies with the manner in which the resources - consisting of labour, material and capital - are controlled and organised. The system needs to be designed in such a manner that everyone in the organisation understands how it works, Black & Kohser [4]. Departmental silos are to be removed in order for this to be achieved.

It is also vital that all the different costs of the business are understood in order to control, anticipate and reduce the costs. Cost management versus cost reduction strategies come into play. Drastic changes such as Kaikaku initiatives are sometimes required to meet cost reduction objectives.

Figure 1 indicates the baseline for a conceptual improvement strategy that can be followed for an incremented improvement and cost reduction approach. Each of the sectors entails one or more Kaikaku activities which take place, followed by smaller Kaizen activities. These Kaikaku activities refer to a paradigm shift, a transformation that affects all the sectors of the organisation. In contrast, Kaizen activities are smaller, incremental improvements on the current state of the processes. However, Kaikaku without a Kaizen culture is prone to failure, and vice versa, Miller [2].

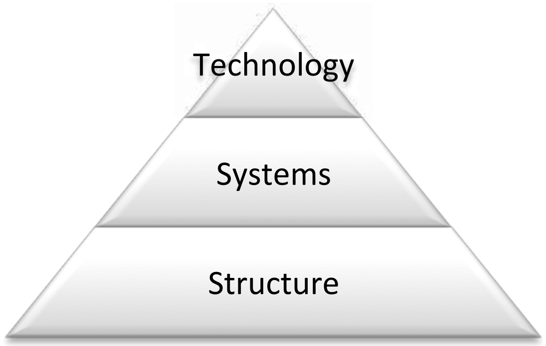

Figure 1: The conceptual improvement strategy

The structure of the organisation is the first Kaikaku activity that is to be addressed according to the conceptual improvement strategy. This entails, amongst others, re-designing the facility, improving or introducing design for manufacturing tools and possibly redesigning the organogram structure.

The next Kaikaku's focus lies within the organisation's systems, followed by a focus on new or improved technologies. The system paradigm shift can include re-designing the enterprise resource planning system, implementing a manufacturing execution system or changing the configuration management systems

Investigating newer technologies in equipment brings about advantages such as reduced electricity usage, less pollution, improved efficiencies, improved quality of the end product or increased ease of operation.

The chapters to follow explain these organisation-wide changes in the structure, systems and technology areas of the business, implemented at Altech UEC South Africa.

3 STRUCTURE DEVELOPMENTS

The structure of the Altech UEC South Africa facility required a paradigm shift. The business was relying on legacy systems, products were not designed to best optimise manufacturing processes, bill of material costs were steep, the site did no justice to the material flow and the site services' cost was breaking the bank. The production capacity needed to be increased while the variable labour and overhead costs needed to be reduced. The corporate culture became dormant and inhibited flexibility for change. Moreover, change was required throughout the organisation if the company wanted to be a world class manufacturer to open up opportunities for contract manufacturing and be able to compete against the global competitors. This chapter discusses the changes and benefits of the factory relocation project as well as the corporate culture and product design improvement initiatives, which all assisted in a paradigm shift in the company's structure.

3.1 Factory relocation project

In 2008, Altech UEC South Africa's management started working on the vision to relocate the manufacturing facility. It was a strategic move considering all the facility, logistical and staff cost savings to be achieved. It was apparent that this vision was not a small project to embark upon, as the motivation period took approximately three years. In JSE listed companies, there are many shareholders to be considered and such large investments need to be planned carefully.

The following two figures show the layout and movement of stock at the old manufacturing facility. The various material flows are indicated in the aerial view of Figure 2. This diagram was used in the motivation presented to Altech Group's executive committee. The site layout consisted of numerous different buildings where all the manufacturing departments and areas were situated.

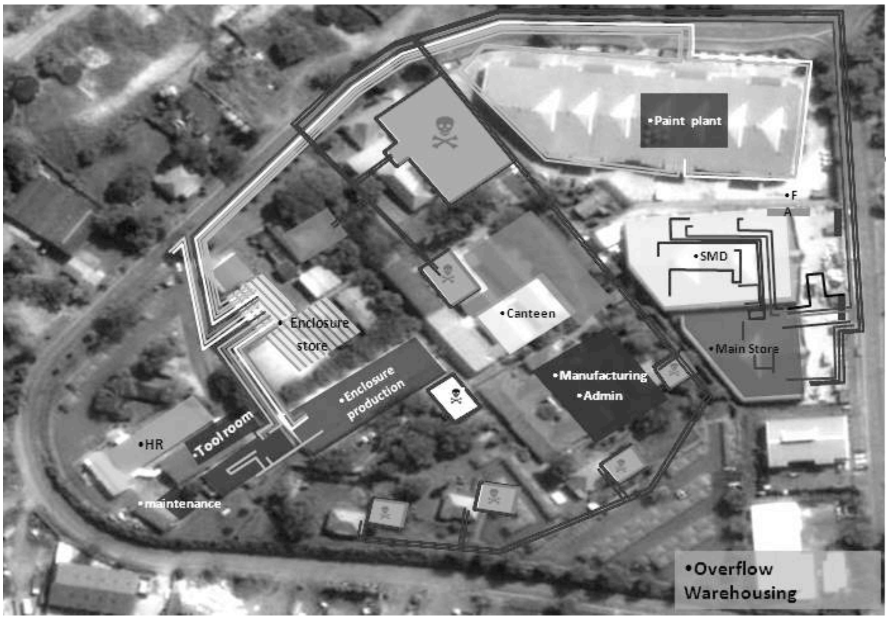

Figure 2: Aerial view of the old Altech UEC South Africa facility, Manufacturing Executive [11].

Work in progress (WIP) from one area had to be palletized and secured in order to be transported safely to the next process. In some instances, the palletized WIP had to be loaded onto a truck to be transported one kilometer away to the other side of the site. The logistical cost to move material was extensive. Moreover, departmental silos were created and the operation was divided. Figure 3 shows some examples of manual movement of inventory, including loading of trucks and storing in areas not suited for such flow.

Figure 3: Material movement at the old Altech UEC facility

Requirements for the new site included items such as available space for future expansion, location in close proximity to the harbour, airport and the sister company Altech Multimedia, which has many dealings with the manufacturing facility. Considering all of the above requirements, a Trade Centre warehouse situated just a few kilometres away was seen as a feasible location.

Considering the following potential cost savings associated with the relocation project, the business case proved to be fruitful. According to Manufacturing Executive [11], the annual savings were estimated as follows:

- Site services: R5 272 380
- Offsite storage: R1 000 000
- Direct labour: R3 600 000
- **Total annual savings: R9 872 380**

Allowing for the estimated relocation cost and the increase in the annual lease expense, the payback period indicated to be 1.82 years, Manufacturing Executive [11].

The site services savings included costs such as gardening, cleaning, security and waste removal. Offsite storage was required due to insufficient space onsite and direct labour savings included mainly the logistical operator savings, moving and transporting goods from one area to the next. Annually, 4000 tons of material, excluding waste, needs to be transported, Manufacturing Executive [14]. The energy and time required to do so is significant, and improving on the layout of the site confirmed similar for the benefits.

Figure 4 depicts an aerial view of the new manufacturing site in Siphosethu drive, Mount Edgecombe.

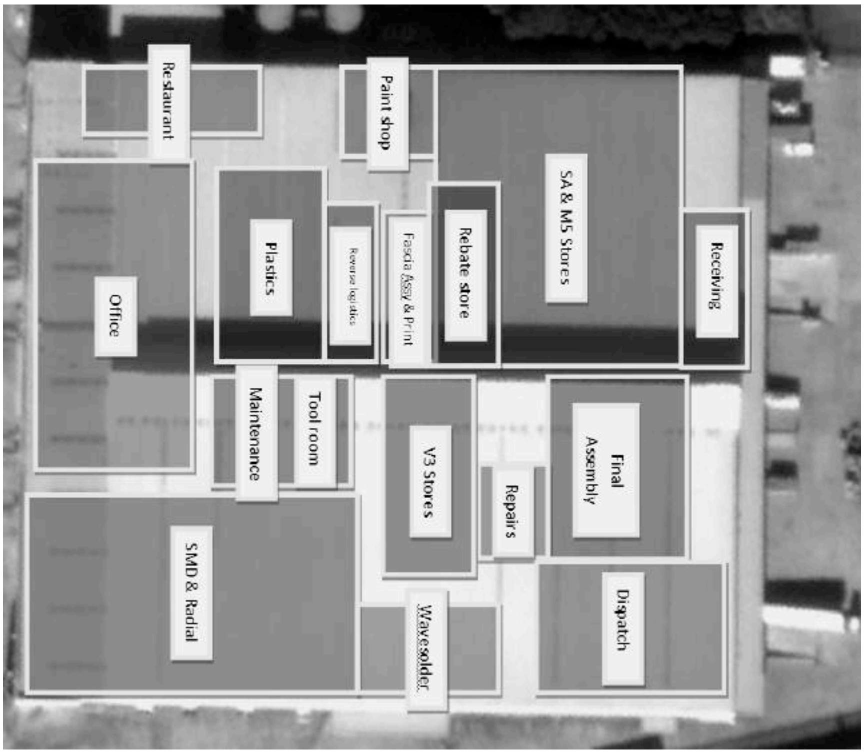

Figure 4: Aerial view of new Altech UEC South Africa site

3.1.1 Results and current state

Referring to Figure 4 Figure 4, all the departments and manufacturing areas are now under one roof, a start in becoming a world class manufacturer. Months were spent on the planning, and the efficient execution demonstrated the fruits thereof.

During an interview with the Manufacturing Executive on 26 March 2013, it was found that the benefits realised up to date are the following:

- Variable costs reduced, although fixed costs increased.
- Headcount per unit produced ratio, improved from 1:1500 to 1:5600.
- Annual capacity increased from 1,800,000 to 2,800,000 units.
- Distance travelled per unit from beginning to end reduced by a third.
- Site service cost reduced drastically.
- Departmental silos were removed.

It is important to note that the company's bottom line will only experience the cost benefit when the monthly production quantity exceeds 200 000 units, Reed [5].

3.2 Corporate culture

Lather [7] argues that corporate culture is an important factor to consider when managing an organisation-wide change. Even with the most detailed and planned projects, an organisational change must include not only improvements in structures and processes, but also develop the corporate culture. The theory states that "organisational culture creates both stability and adaptability for organisations".

Lather [7] mentions that organisational norms are developed from organisational values, which determine the actions and attitudes of employees. These norms become entrenched when employees get used to their environment, which may often lead to the slowing down of innovation and an idle acceptance of what happens around them. One great success of the factory relocation was to build up new ideas and disrupt many of the bad practices that may have previously become norms.

The facility was moved just a few kilometres from the previous site, so displacement of employees was not a factor for consideration. The move to the new premises has provided a more comfortable, safe and pleasant working environment and it has therefore achieved a substantial amount of buy in and willingness. A priority has been given to becoming an employer of choice. The facilities include the following:

- A staff restaurant with outside eating area and coffee machines.
- A clinic with a full time registered nurse for day-to-day ailments and a doctor visiting once a week.
- Lockers for personal items.

During the project, each department was given a large degree of responsibility and ownership in the design, capacity and physical layout of their areas. This has helped in bringing a certain degree of pride into the work area for shop floor managers, which in turn has the potential to reach the operators in their everyday activities. To maintain this sense of ownership, "green areas" have been placed at each manufacturing area on the factory floor. This is an open space with pin up boards showing targets, achievements, productivity history and statistics. Some personal and motivational posters are also encouraged. Daily meetings are held in each of the areas, where production matters and targets are discussed.

The layout of the office area allows for better communication between departments, as it is open plan. The idea was that this will minimise the common problem of departments working in isolation.

The new factory environment has allowed for significant changes during the relocation, but almost more importantly, has set up an environment and structure that promotes continuous adaptation.

3.3 Product design

Numerous factors need to be considered to achieve low cost manufacturing. There is a close relationship between the design of the product, material, equipment, process selection, tooling selection and design, Black and Kohser [4]. This is the reason why design for manufacturing is a key component of evolving the products and reducing manufacturing costs. Benefits include less labour intensive processes, reduced bill of material costs and shorter cycle times.

The graph in Figure 5 gives an indication of the decreasing trend in piece parts for the fascia and sleeve assembly for set-top boxes. The product unit cost reduced with an impressive 63 percent over five years, Process Engineering Manager [15].

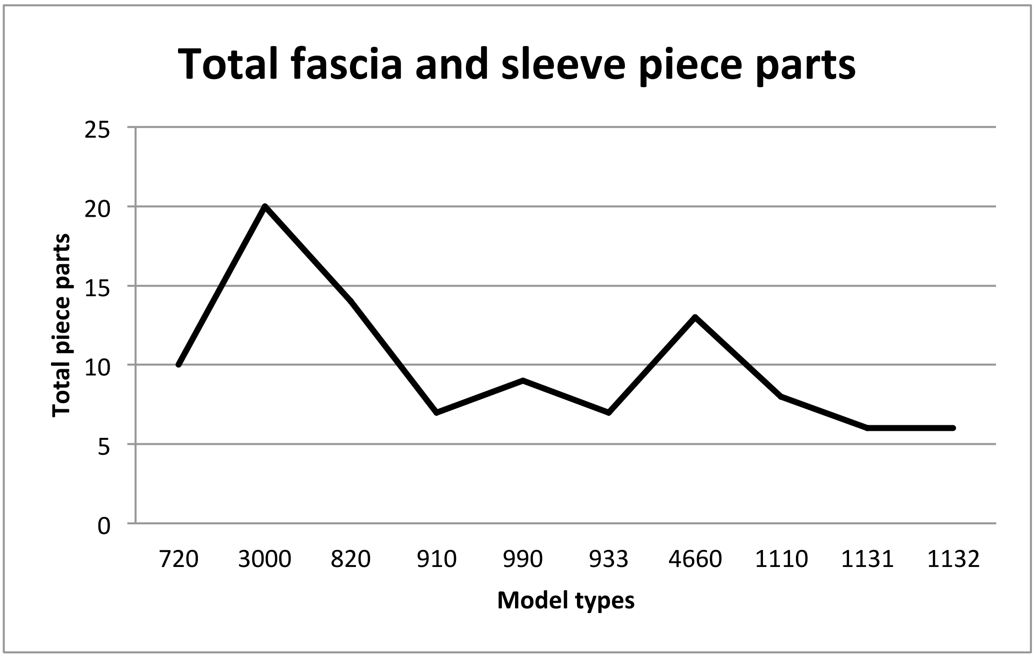

Figure 5: Total fascia/sleeve piece parts

Fundamentals that were considered to reduce the manufacturing costs include:

- Merging the fascia and sleeves in the moulding process.
- Reducing the painted plastic parts by moulding the parts in the required colour/s.
- Introducing hot runner technologies in the injection moulding plant.
- Moulding the buttons into the fascia/sleeve part.
- Eliminating screws in the final assembly process.
- Replacing steel bases with plastic bases, which made a clip-in design possible.

Design for manufacture has remained a focus of the company. New areas to be investigated lie in the tooling design for the plastic moulding plant. It has been identified that a greater involvement in the design stage is required. Many cost saving opportunities may be realised if there is a focus on the moulding tool material and design to reduce the cooling times, as well as the part design.

Figure 6 demonstrates the relationship between the typical moulding stages, the largest proportion being cooling time, Kimerling [3]. A scientific approach to the tool design will assist in optimising moulding cycle times while still achieving the required part functionality.

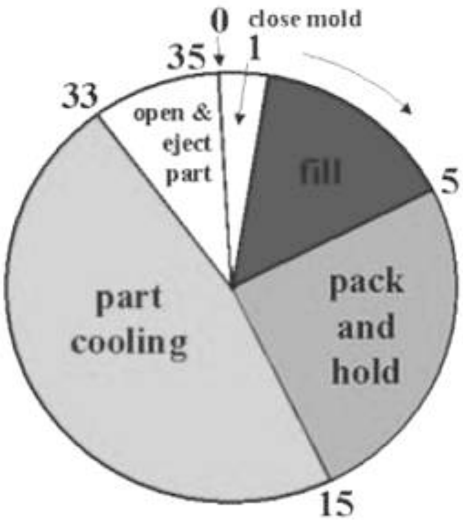

Figure 6: Typical injection moulding cycle clock, Kimerling [3]

Efforts to reduce cooling times include re-thinking the tool material selection and tool design. These entail selecting a better heat conductive material and increasing the cooling channels, while keeping the channel close to the part. An illustration of such improvements is shown in Figure 7, where the second image shows the improvements.

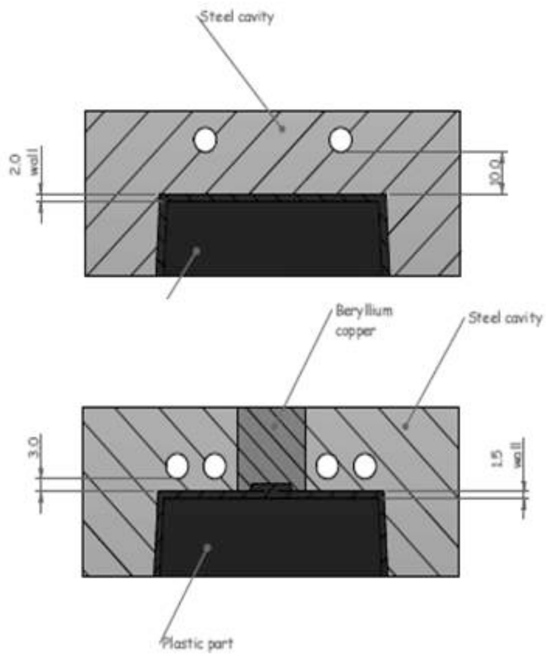

Figure 7: Illustration of improved mould designs, Engineering and Facilities Manager [13]

The trend in industry has been that tool design and manufacturing are outsourced to the East, with a larger disconnect between manufacturing and designers as a result. The ultimate cost of outsourced tools is yet to be investigated at Altech UEC South Africa. Expensive moulds make inexpensive parts and it is estimated that a 60 percent more expensive mould could have a three second cycle time improvement, paying back the costs in as little as two months at Altech UEC South Africa according to Engineering and Facilities Manager [13].

4 SYSTEM DEVELOPMENTS

A full time systems manager has been employed to investigate the improvement of the current infrastructure. The goal is to implement an integrated manufacturing execution system (MES) to close the loop between the enterprise resource planning (ERP) system and real time data from the machines on the factory floor. As it stands there is minimal real time data input reaching the ERP system, Systems Manager [12].

The Instrumentation Systems and Automation Society (ISA) – 95 International Standard of Integration of Enterprise and Control Systems lays out the ideal infrastructure and data flow for a manufacturing facility, Manufacturing Execution System [8]. Referring to Figure 8, five levels of data control are discussed. Through the design of applications, a track and trace system and a shop floor data collection system (SFDC), a valiant effort has been made in providing for an effective platform to work with.

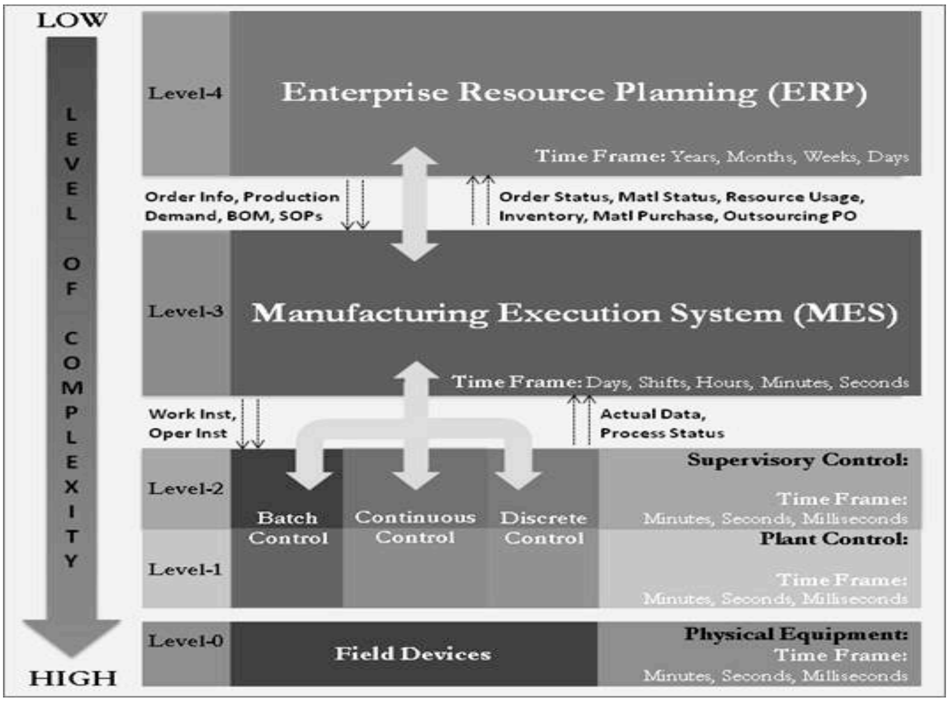

Figure 8: ISA – 95 International Standard of Integration of Enterprise and Control Systems, Manufacturing Execution System [8]

4.1 Current state

The inherited track and trace system has been custom designed for a much smaller transaction volume than the growing company has come to deal with. The Delphi (Legacy) applications have been converted into a .net framework. Even though this is an improvement, the .net framework still struggles to cope with a large volume of transactions.

An estimated 700 000 transactions have been performed in 2012 for television manufacture, and more than 18 million for set top box manufacture, Systems Manager [12]. With continuous growth and improvements required in the facility, an average of three new applications has been developed per month in the period 2011 to 2013. Figure 9 shows the new application requirement each year, with at least four new Kanban applications being implemented. The rest of the applications have been for modification and improvement of processes, and for the introduction of television manufacture in 2011.

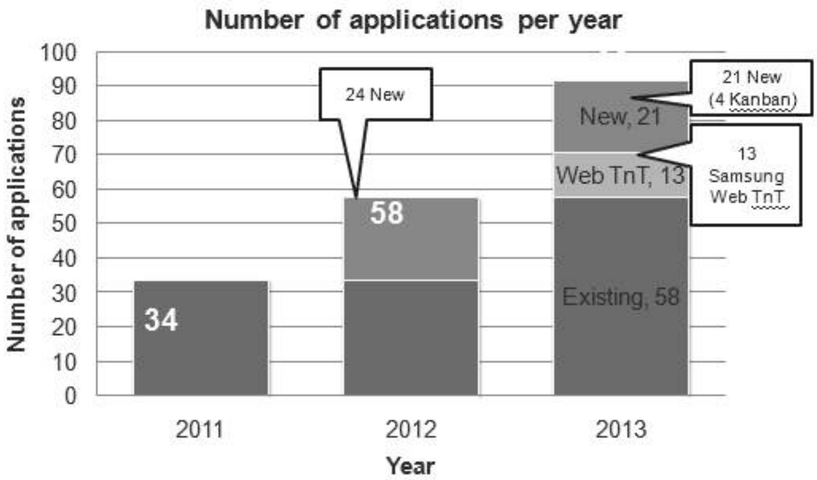

Figure 9: Additional applications required from 2011 to 2013, Systems Manager [12].

The ability to achieve a higher transaction volume would be expected to have a direct effect on productivity. In 2012, a total of 288 production support requests were received by the systems team. At an average of two hours downtime per request, this approximates about 48 hours of downtime per month, Systems Manager [12].

The facility runs a twenty-four hour operation, which calls for the need to have convenient methods of support from technicians and the systems team. A web track and trace system is currently being developed to allow for remote control and visibility of the systems as they run. This is a centralised server for all the applications. The aim of this is to allow the applications to be accessed over the web, and perform maintenance and adjustments according to the level of clearance the user has, without having to be on the premises. The web system is in the phase of site acceptance testing, with the hope of being implemented by mid 2013.

4.2 The capacity of the current systems

The shop floor data collection system (SFDC) has provided insight into the state of inventory and production statistics in each department. The combination of track and trace and SFDC, however, still has fundamental limitations. In Figure 10 a general idea of Altech UEC South Africa’s infrastructure is demonstrated. The production lines have certain critical modules that output information to the SFDC system. There are, however, some modules that do not have any interface, and this information needs to be captured manually. Other production elements have interfaces into the track and trace system. As noted in the diagram, the file transfer from the machines to these two systems can be unreliable. The interface to each machine needs to be customised in order to communicate with the various software types in machines from different suppliers. This complexity has been shown inFigure 8, demonstrating how the system needs to be more refined when communicating with levels 0, 1 and 2 of the controls system integration.

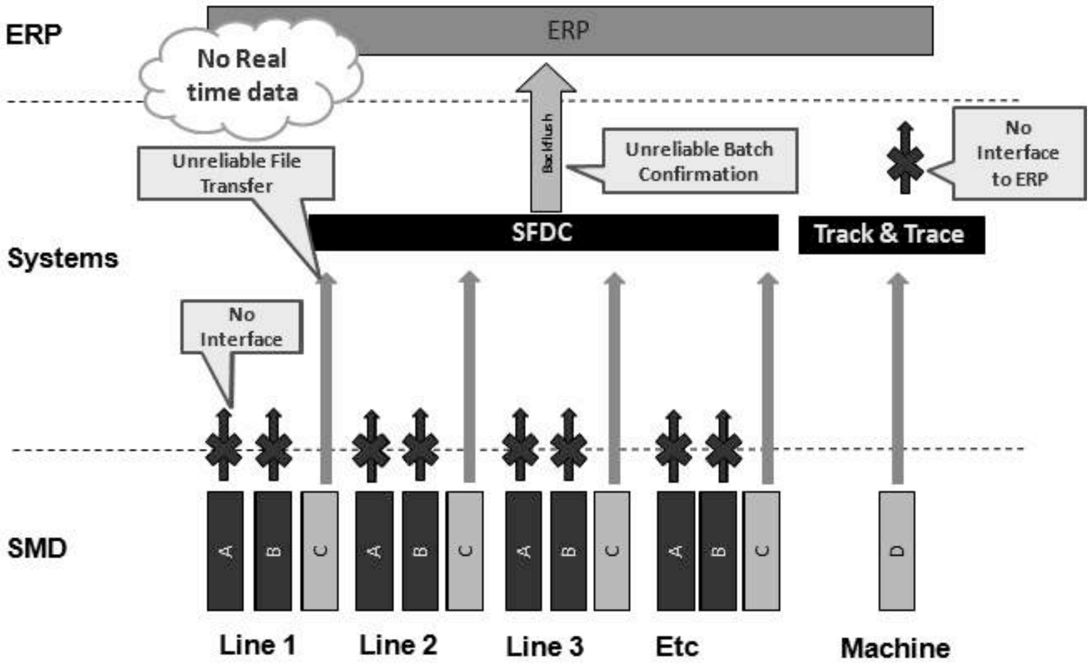

Figure 10: Current state system infrastructure, Systems Manager [12]

Another limitation comes from the fact that the track and trace system does not have an interface with the ERP system. So the information from track and trace has to be accessed and used in parallel, which is not necessarily an efficient task.

4.3 Manufacturing execution system

To address the discussed limitations, a major focus lies with the implementation of an MES system. MESA International [9] says that *"with MES the manufacturing process becomes information driven and a stronger contributor both to overall productivity and to the financial viability of the company."* This is seen as the fundamental element that will drive a process change and improve control with real time information. Due to the discussed data accuracy limitations, a new ERP system would encounter the same shortcomings as the current ERP system. This means the drive to improve the data collection interfaces needs to be rooted in the investigation of the MES system.

The functions covered by the ERP system include the following:

- Master Production Planning/Manufacturing Requirement Scheduling
- Warehouse management
- Finance
- Sales
- Human resources and customer relations management

These functions require all the inputs to be supplied by the MES system, from which it may use the information and feed back some form of response. Figure 11 shows how the MES system would fill the gap required. With a reliable interface to manufacturing equipment, real time data capturing may be accomplished. The motivation for this system is rooted in the advantages that are discussed below.

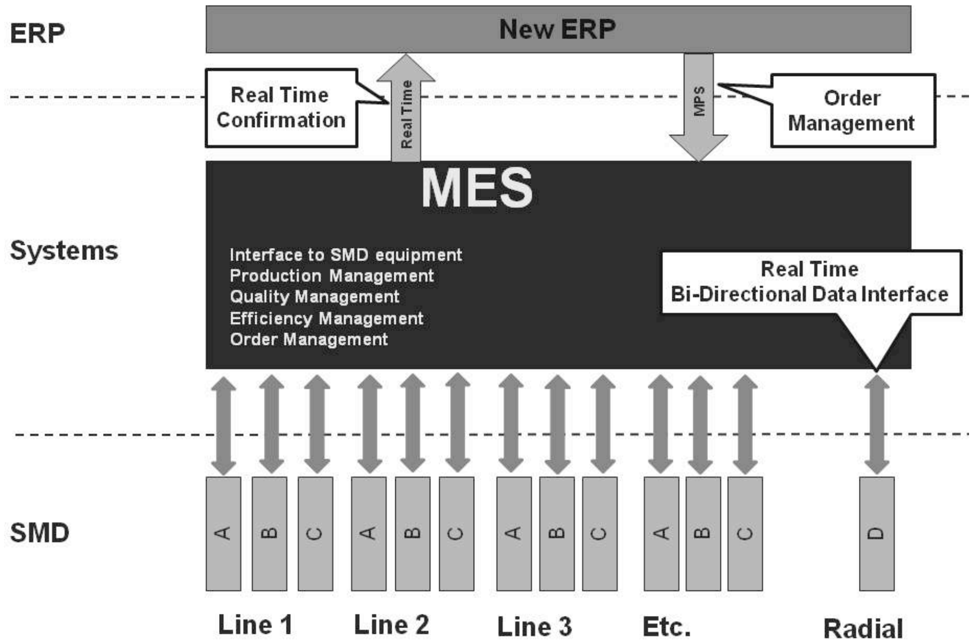

Figure 11: Proposed data flow improvement demonstrated by MES, Systems Manager [12]

4.3.1 Downtime management and analysis

According to studies in the US manufacturing industry, International Atomic Energy Agency [10] says that approximately one third of maintenance costs may be attributed to unnecessary maintenance. An automated analysis of a machine breakdown is useful, as it provides the technician with real time and detailed information of the error, straight from the machine interface through condition based monitoring. This includes monitoring key performance points and trends of the machines. Critical milestones of machine life are analysed, helping preventative maintenance procedures.

4.3.2 Management of raw materials within each work centre

The inventory levels at each work centre may be closely managed. This will provide material and production planning teams with accurate information regarding what material is required where and when. Together with the knowledge of machine status and production requirements from the ERP system, production planning may be optimised.

4.3.3 Quality and repair management

Quality measures can be controlled, with statistical process control being automated and continuously monitored. This helps the production team to fix problems as soon as they arise, reducing the defect rate. This is also a useful tool for the engineers during new product implementation.

Visibility on the material, build state and machine parameters can be achieved. With this information in the system, it is also possible to automate the generation of work instructions for the operator.

4.3.4 High processing power

A good MES system will allow for a large number of transactions to be performed at any time. This will be a noticeable improvement with respect to the current track and trace systems which struggle with the high volume of transactions.

4.3.5 Standardised reporting

With the collation of all the information that the MES system will process, reporting procedures may be automated. This has the benefit of quicker response times to daily production problems that may occur, and a summary of operations for management.

4.3.6 Execution plan

The implementation of the new system is in its final stages of approval at executive level. Many options have been considered and a decision has been made on the MES provider that is known to be well suited for electronics manufacture. The project is expected to be executed over two phases.

Phase one is expected to take approximately six months to implement. It will include automation of equipment interface, real time data capturing, setting up the centralised data repository, and fine tuning the operating equipment efficiencies structure. The second phase is the implementation of the MES system that will perform the three management roles:

1. Production management
2. Quality management
3. Efficiency management

The payback period for the MES expenditure is expected to be 1.1 years, Systems Manager [12]. As part of a survey performed by MESA International [9], findings show that the payback period of implementing an MES system range from six months to two years, with an average payback period of 14 months. This indicates that the Altech UEC business case is a strong one.

5 TECHNOLOGY DEVELOPMENTS

This Chapter discusses some of the current work in investigations within the technology domain. Although this has not yet been implemented at Altech UEC South Africa, unlike the other Chapters, it forms part of the holistic strategy as discussed in Chapter 2.

5.1 Automation

Automating certain processes or process steps can bring about benefits like consistent cycle times, reduced variable labour costs and increased production up time. Moreover, when considering the implementation of a MES system, both the systems are complimented by the two-way feedback loop. Some level of automation is required by the MES system is facilitate the interface requirements that have been discussed. The consistent cycle times achieved by automation also assist in master production and fixed finite scheduling.

5.2 New technologies

Although effort is often spent on reducing labour, other costs such as fixed and variable overheads are not to be overlooked. Figure 12 indicates where most of the cost and the biggest focus on saving generally lie for the injection moulding plant at Altech UEC South Africa. These costs should be understood to best control and possibly reduce.

Engineering and Facilities Manager [13] stated that drastic unit volume increases are the basis for the increase in overhead costs and can be negated by implementing newer technologies. This is achieved by reducing operating costs of machines such as power usage, maintenance and efficiency.

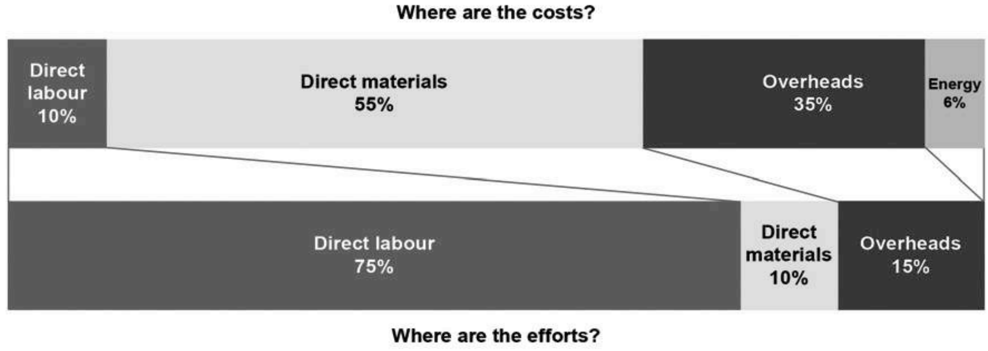

Figure 12: Cost breakdown versus focus of efforts in reducing costs, Engineering and Facilities Manager [13].

In the surface mount and plastic injection moulding areas, technologies such as dual SMD reflow ovens and electrical machines can be considered respectively. These are known to reduce electricity usage, improve cycle times and allow for better control.

Faster change over times are essential in increasing the machine availability. As other business opportunities bring about additional capacity increases, production up-time optimisation is essential.

All of the above assist in building the sound foundation to become a world class manufacturer.

6 CONCLUSION

The global market's needs are changing rapidly, resulting in reduced product life cycles, and possibly increases in demands and variety of products. Globalisation also demands competitive pricing from the manufacturers in order to stay financially viable against other global emerging markets. This paper discussed the need for manufacturing to evolve at Altech UEC South Africa. This evolution included changes in the structure, systems and technologies of the business.

The capital expenditure for the structure developing projects has not just met the expected benefits, but exceeded them. The production capacity increased by 55 percent, headcount per unit ratio improved from 1:1500 to 1: 5600 and the distance travelled to produce 1 part decreased by a third. Design for manufacturing initiatives showed a reduction in the unit cost of 63 percent over the past five years.

Other opportunities for cost reductions and improvements were identified in the systems, whereby implementation of a manufacturing execution system can assist in improving the current infrastructure. The payback for the capital expenditure is estimated to be 1.1 years.

The advantages that may come from implementing newer technologies for processes such as injection moulding, include reduced electricity usage, improved control and reduced cycle times.

With Altech UEC's current unit price being 73 percent lower than the projected price over five years, it is a testimony of the substantial benefits lying in the cost reduction initiatives discussed in this paper.

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MANAGING TRANSITION FROM A SMALL TO A LARGE BUSINESS - THE CASE OF A DRILL ROD MANUFACTURER.

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ABSTRACT

Transitioning from a small entrepreneurial company to a larger, "structured", organisation presents both organisational and management challenges to the founding entrepreneur and stakeholders. Various theories have been put forward that have studied the behaviour of the entrepreneur. However the dynamics that evolve with the change process from the behaviour and decisions of the entrepreneurial founder and managerial structures that emerge have not been well researched. Through a case study research this paper reports a longitudinal study done over three years on a company that is into manufacturing of drilling rods. Theory of organisation transition and a framework for longitudinal researching of entrepreneurial organisations making transition into structured organisations was used. The change process was studied through a conceptual framework that has five informational factors. New management systems and structures were put in place; a new manufacturing strategy and business model were developed. The "verbal culture", of small companies was replaced by written instructions and proper records keeping, the manufacturing process was documented and standardised through the implementation of Total Quality Management. This paper contributes to the understanding of how an entrepreneurial company transition to a structured one and strengthens our ability to assist entrepreneurs in achieving sustainable growth.

Keywords: Transition, entrepreneur, organisation, formalisation, manufacturing strategy and business model.

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1 INTRODUCTION:

The transformation of an entrepreneurially founded company to a large business brings challenges especially to the founder and if the process is badly managed, this can result in either business closure or stagnation. The growth stages of a company from start-up to resource maturity is complex, it brings in formalised structures and decentralisation of power, Solymossy and Penna, [1]. Entrepreneurial companies start without structures, but in order to gain efficiency due to entrepreneuriial strains they implement functional structures, Chandler, [2]. Various business development models have been put forward. Most of these models fail to capture how small businesses grow because of flawed assumptions, Churchill and Lewis [3], such as "an assumption that a company must grow and pass all stages of development or die, failure to capture the early stages of a company's origins and growth and using metrics like annual sales, number of employees, ignoring factors like number of locations, complexity of product line and rate of change in production technology".

Figure 1 shows a reconciled small business development framework. The framework shows five stages with each stage characterised by "an index of size, diversity and complexity". The five stages are described by five management factors; managerial style, organisational structure, extent of formal systems, major strategic goals and owner's involvement in the business", [3]. Most of these changes take place at the transition point where the entrepreneur and the firm transition to a functionally managed organisation. These five factors are the motivation of this study.

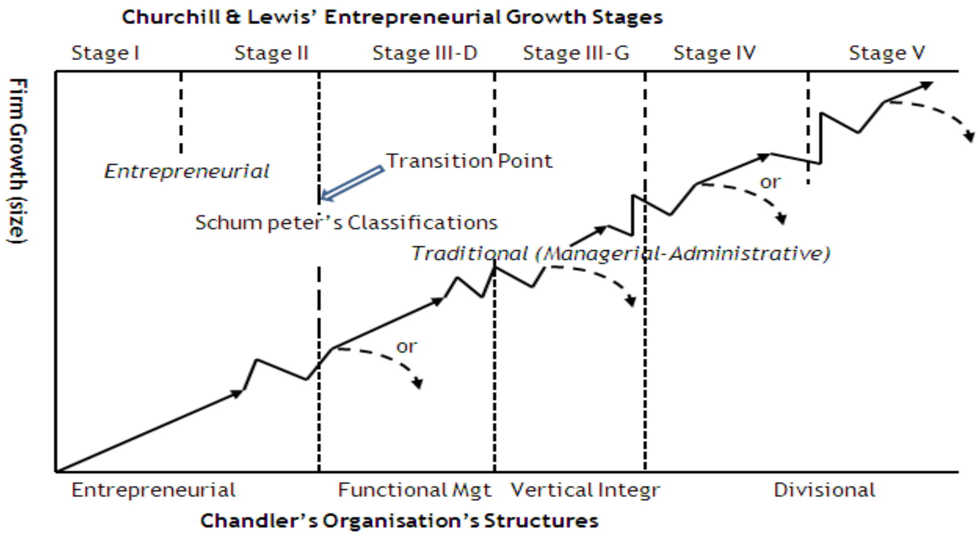

Figure 1: Reconciled Theories of Structural Stages of Growth

Very few small companies successfully transform into large companies. Fenn, [4] suggested that other transition processes leave the founder behind. Problems that stifles growth are the entrepreneur's lack of communicating his or her vision, Baum, et al,[5], unwillingness to surrender power, O'Neill, [6], and a failure to acquire specific management skills, Johnson, [7].

Succesful transtions have been supported by the organisation's ability to bring in new management personnel, Stevens, [8], and by implementing new organisational systems and structures, Lee, [9]. However these changes require a shift of mindset in the way the entrepreneur used to run the company. Past research has focussed on the entrepreneur and the organisation without paying much attention to the change process, [1]. This paper studies the dynamics that evolved in a drill rod manufacturing company that has been successfully transformed into a large international business over a period of three years.

The theory of organisational change has different organisational change models, Van De Ven and Poole, [10], which are categorised as ; life cycle (developmental models); evolutionary (systems theory and adaptive models); dialectical (political models and social interaction) and teleological (problem solving and organisational developlment) as shown in Appendix 1. The transition from a small company to a large international company will fit under the Teleological model. The Teleogical model assumes that organisations are purposeful and adaptive. Change occurs because leaders, change agents and others see the necessity of change. Individual managers are more instrumental to the change process, Carnall, [11] and Carr, et al [12]. Key aspects of the change process include planning, assessment, incentives and rewards, stakeholder analysis and engagement, leadership and scanning, strategy, restructuring and reengineering, Brill and Worth, [13], [11]. At the centre of the change process is the leader, (in this study the CEO), who aligns goals, sets expectations, communicates, engages, rewards and leads on the development of strategic choices, and this is the focus of this study. Scientific management tools such as Total Quality Management (TQM) and Reengineering can be used as change tools.

TQM is a management philosophy that focusses on issues like continuous quality improvement. Literature suggests that there are various TQM models such as ISO 9000: 2008, Baldridge Quality Award Framework, and European Quality Award Framework that companies can follow in implementing TQM, Das, et al, [14]. These TQM models gives emphasis on developing and focussing on a vision and mission including outcomes of the organisation; creative and supportive leadership,Goetsch and Davis, [15], implementing systematic individual development, making data driven decisions based on facts, Oakland, [16] , ensures collaboration, delegates decision making and proactively plan change, Tari, [17]. Implementing quality brings in new organisational culture, Almaraz, [18].

2 RESEARCH OBJECTIVES

i) The major aim of this paper is to investigate how an entrepreneurial company successfully transitioned into a large international business.

ii) Through the five informational factors the paper investigates the changes done on the entrepreneur and how managerial structures, manufacturing strategy and new business model were put in place.

The research framework of this study follows the five informational factors: 1) Evolution of formalisation; 2) Dilineation of functions; 3) Identification of motivating factors of the CEO; 4) CEO's cognitive process and 5) Development of strategic processes,[1], [3]. The unit of analysis is the behaviour and decisions made by the Chief Exucutive Officer (CEO) and new managerial structures that were put in place as the company transitioned from a small to a large established company.

3. LITERATURE REVIEW

3.1 Definition of a Small Scale Business

The qualitative description of a small business takes into account the ownership structure of the business. The business, must be a separate and distinct entity; not be a part of a group of companies; be managed by its owners; be a natural person, sole proprietorship, partnership or a legal person, such as a close corporation or company, National Small Business Amendment Act 26 of 2003, [19], not dominant in its field, no new marketing and no innovation, Carland, et al, [20].The same Act presented a quantitative description of a small business. It classified small businesses into micro, very small, small and medium with respect to number of employees, total turn-over and gross asset value excluding fixed property.

Table 1: Classification of small business in the manufacturing sector, Adapted from National Small Business Amendment Act, 2003.

Size of class	Total of full time equivalent of paid employees	Total turnover	Total gross asset value (fixed property excluded)
Medium	*200*	*R 51m*	*R 19m*
Small	*50*	*R13m*	*R 5m*
Very Small	*20*	*R 5m*	*R 2m*
Micro	*5*	*R0.20m*	*R0.10m*

3.2 Differences between a Small Business and an Entrepreneurial Venture

A small business and an entrepreneurial venture both need entrepreneurial action to start-up, Nieman and Nieuwenhuizen, [21]. They both serve different economic functions and fulfill the ambitions of their founders and managers differently, Sexton and Smilor, [22]. A small business owner is motivated by personal goals and the need for security and is not committed to growth of the business, [21]. However an entrepreneurial venture has growth as its main objective, [22]. The growth is identified by new products, new markets and becoming dominant in that field, [21]. An entrepreneurial venture is run by an entrepreneur, who has the willingness and superior ability to make decisions, raise capital, and assumes the risk of failure, Knight, [23]; can percieve new market opportunities and is an innovator, Schumpeter, [24]. This paper will investigate the entrepreneurial activities that were done by the owner-manager during the transition process of his small business into a large business. It is also important to note that the growth of a small business is due the entrepreneurial activity of the owner, [22].

3.3 Growth Determinants of a Small Business

Various theories have been put forward from both the business and economic literature that recognise the role of the entrepreneur in business formation and growth. These theories have noted that differences in attitudes and abilities among individuals are important in determining why some small businesses grow and others do not, You, [25].

3.3.1 The Entrepreneur in Theories of the Firm

Size of firm is determined by the efficient allocation of resources, including entrepreneurial resources and technologies. Growth is from profit maximising and shape of the cost function. Efficient managers will have marginal costs. Managers must delegate tasks, Lucas, [26]. More output is produced by managers who are willing to take risk, Kihlstrom and Laffont, [27]. Entrepreneurial abilities increase with time and learning, hence the variable growth rates among small businesses, Jovanovic, [28].

3.3.2 Theories of Entrepreneurial Choice

The theory of entrepreneurial choice states that people have certain charateristics that are associated with the propensity for entrepreneurship. Individuals who have more of these characteristics are more likey to become entrepreneurs than those who have fewer. “Most individuals create businesses inorder to maximise their expected utility. Utility is a function of entrepreneurial or wage income and of attitudes that affect the utility that the person derives from entrepreneurial activity, such as one’s taste toward work effort, risk, independence and working close to customers”, [27]. Income depends on the individual’s ability to generate profit, such as managerial abilities to raise capital and abilities to perceieve new market opportunities and to innovate. Firm growth is an indication of continued entrepreneurship. Javanovic, [28], argues that firm growth is a choice of the owner-manager and profit maximisation is only one of the possible motives for business growth. This paper will look at the characteristics of the owner-manager on how he influenced the growth of his company.

3.3.3 Theories of Stage of Development

Growth is part of the natural evolution of a firm, [3]. Five stages of growth were identified: existence, survival, success, and take-off and resource maturity. Each development stage presents different challenges e.g take-off stage: - ability of the owner to hire new people and delegate responsibility, [3].

These theories together with their assumptions will be used to formulate both quantitative and qualitative questions that will be used in this study with regards to how the small business transitioned into a large business

3.4 Business Model

A business model is part of a business strategy that defines how an enterprise creates, delivers and captures value, Zott, [29]. Every business makes use of a business model either explicitly or implicitly, Lambert, [30]. An enterprise operates as a complex system; it has various parts that interact to function as a whole and these parts are the components that form a business model. The business model concept is built on ideas from the theoretical frameworks of business strategy, strategic management, entrepreneurship, Amit and Zott, [31], Morris et al,[32], and systems engineering, Osterwalder et al,[33]. Figure 2 shows an example of a business model developed by “Bell, et al” in Salvendy, [34], and its associated components that are applicable to various enterprises.

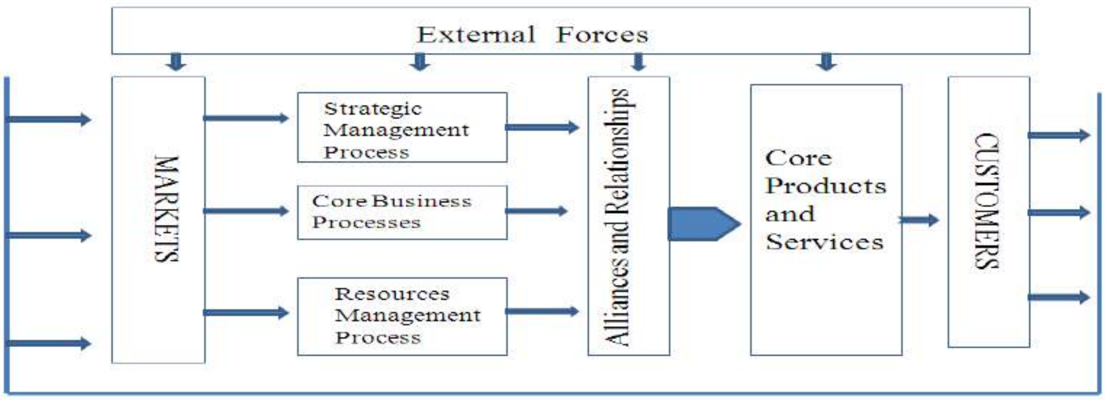

Figure 2: Enterprise Business Model Framework, Adapted from Bell et al, 1997.

3.5 Manufacturing Strategy

Strategy is the determination of basic long-term goals including objectives of and the enterprise, the adoption of courses of action and allocation of resources necessary for carrying out these goals, [2]. Strategy enhances management’s focus on linkages between external market requirements and internal organizational and technological resources, capability and competitive advantage, Sun. H., et al, [35]. Enterprise strategies include corporate / business strategy and functional strategies, [35]. Business strategy is the common theme or strategic posture at higher levels of the organisational, encompassing all activities in an organisation. Functional strategies include manufacturing strategy, market strategy and Research and Development strategy, [2], [35]. Manufacturing strategy is a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate to meet a set of manufacturing objectives which are consistent with overall business objectives, Skinner, [36], Hayes and Wheelwright, [37], Swamidas et al,[38]. Factors that influence the choice of a manufacturing strategy include market requirements, manufacturing resources, competitive intensity of the environment and how the manufacturing strategy is aligned to the business strategy, [36]. Five decision areas that are considered in coming up with and implementing a manufacturing strategy, include 1) plant and equipment; 2) production planning and control; 3) labour and staffing; 4) product design / engineering and 5) organisation and management, [36].

3.6 Training

Training helps subordinates to better understand their responsibilities, authority and accountability, Smit, et al, [39], as they contribute to achieving the objectives and goals of the organisation. The aim of training is to impart new knowledge, skills and attitudes (KSA), on employees for the sole purpose of performance improvement, Holladay, et al [40]. Burke, et al [41] argued that training is enhanced by the application of KSA through factors such as goal setting, workload, peer support, coaching, supervisor feedback, individual motivation and job design. Modern and competitive organisations enhance their capabilities by setting up structures that foster a culture of continuous learning and information sharing, Wickramasinghe, [42]. Training must enable workers to adapt to the fast changing global competitive environment, since this is one of the key organisational capabilities, Harvey, et al, [43]. Other key factors that help organisational superior performance is attained through sound knowlwdge management and proper organisational learning as suggested by Theriou, et al, [44] , and this is supported by Lee, et al, [45] who reported that learning capacity and knowledge capability factors can be sources of an organisation's competitive advantage.The impact of training can be evaluated through tangible and intangible factors, Griffin, [46]. Tangible factors include reduced errors and improved quality while intangible factors will include improved employee motivation and self esteem.

3.7 Leadership

Leadership initiates change, with a new vision for the organisation, encouraging as well as motivating people to support the new initiatives, Kotter, [47].Top management leadership creates goals, values and vision that guide the pursuit of business activities of an enterprise, through the promotion of creativity, developing integrated teams, defining and communicating the shared vision and generating compromise, Guillen, et al, [48], [15]. A good leader creates an enabling environment through their inter-personal relationships and influences others in the change initiative, such as during manufacturing strategy implementation, [14]. Leaders play three roles, namely setting direction, aligning people and motivating and inspiring people, [47]. Competent leaders have a global mindset, Brake, [49]. Progressive leaders keep abreast of world standards of competition, Birchall et al, [50]; they understand the global nature of their businesses and are able to analyze current trends and market conditions, [49].

3.8 Communication

Communication involves the process of transmitting meaningful information. At managerial level communication occurs in three levels intrapersonal, interpersonal and organisational, [39]. Of interest in this paper is the interpersonal and organisational communication spearheaded by the owner-manager and also how a small company managed to grow and implement communication standards found in large businesses such as systematically gathering, analysing data for quality problem solving activities, often called Quality Management Information (QMI), Schniederjans, [51]. QMI provides a wide range of data from purchasing, markerting, manufacturing, design, customers and suppliers, Phan, et al [52].

Communication has also been enhanced by use of software packages such as Enterprise Resource Planning (ERP) and use of Intranets within a company's different departments. Intranets with the support of relevant software such as Enterprise Performance Management (EPM) help employees including management to have a clear understanding of a company's strategy through the display of important information, Denton, [53]. EPM collects data from other applications such as customer relationship management and ERP.

3.9 Total Quality Management

Total Quality Management (TQM), is a broad-based approach used by world class companies to achieve organisational excellence, [16], and satisfying everchanging customer needs, Abdolshah and Abdolshah, [54]. Most reserachers agree that TQM is a useful philosophy for manangement, if it is properly planned and implemented, Thareja et al, [55], it can help management to deliver on organisational goals, targets and strategy, [16], including worker empowerment, improved teamwork and continouous improvement,Thortorn,[56]. Implentation of TQM brings about organisational transformation, Annop, [57]. If the process is not well managed it can result in mis-trust between management and employees leading to demotivated employees, [54], Duffin, [58]. Employee working practices and attitudes can be changed through sound training, open communication and top management support, [16], [18]. Organisations that have successfully implemented TQM have done so through a well planned and resourced training and education strategy, [17].

4.0 RESEARCH METHODOLOGY

The research methodology of this study involved a longitudinal study done over a period of three years on an owner-managed small business that has grown into a well structured large business. Yin, [59], defines case studies as "an empirical inquiry that investigates a contemporary phenomenon with its real life context; especially when the boundaries between phenomenon and context are not clearly evident". Case studies can be used to explore, describe, explain and compare phenomenons, [59]. Denscombe, [60] 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 Scandura et al, [61]. The method included extensive literature review and in depth interviews and document reviews conducted at the researched company. Triangulation offers more complex, overlapping descriptions of the case and makes the report more trustworthy, Lapan et al, [62]. Woodside, [63], identified three triangulation aspects that the researcher must do in-order to get a deep understanding of the case under study, namely:

- observations done by the researcher within the environments of the case,
- probing by asking case participants for explanation and interpretation of "operational data" and
- Analysis of written documents and natural sites occurring in case environment.

The interviews were face to face with promised confidentiality to facilitate candid responses. Site visits and analysis of company database, documents and face to face interviews, served as motivation for the findings.

5.0 RESEARCH FINDINGS

The owner-manager was raised in a family that had two workshops that were into general engineering and contract manufacturing. This background had exposed and developed the owner-manager on how to run a small company. The family helped him in setting up his workshop where he was in charge from the first day. However his company experienced some steady expansion of business into both new and existing markets from 2008 and 2009, as shown in Table 2. This placed pressures on the founding entrepreneur, [5], and few employees who were in employment then. The owner developed a vision and mission of the company, [2], and was able to share it with his employees, [8]. The mission statement contained three elements, Strong, [64], namely; strategic direction of the company with more emphasis on products, market leadership ambition, commitment to profit, and span of geographic interest. The second emphasis was on customers, employees and suppliers. The third statement focussed on strategy success factors which were related to quality, manufacturing strategy and innovation.

Table 2: Business Growth Factors

Year / Aspect	2008	2009	2010	2011	2012
Number of employees	20	35	58	65	65
Capital Assets (Million Rands)	R 7M	R 10M	R15 M	R 20M	R 24M
Yearly Turn Over	R 21M	R 26M	R 45M	R 51M	R 75M
Market served	Loacl	Local	Local and Export-	Local and Export	Local and Export
Number of products	5	7	8	8	9
Innovation (Incremental)	Low	Low	Medium	High	High
Development of new structures	None	Partial	Developed	Developed	Developed
Meeting Delivery dates	No	Partial	Medium	High	High
TQM Implementation	No	Partial	Medium	High	High
Manufacturing Strategy	None	None	Yes	Yes	Yes

Sharing of the mission statement with his staff helped the owner manager in getting a buy in from the workers, [11] and [12], who then worked hard towards the realisation of the owner's targets. As number of employees increased the owner realised the need to put in place new managerial structures, [8], and this pushed him to delegate responsibilities, [7], to shop floor, human resource and financial matters. Delegation of responsibilities freed the owner's time and was able to concentrate on planning and business development tasks. The owner-manager took the following steps during the transition of the company:

5.1 Evolution of formalisation

The owner started to communicate in writing with his employees. The verbal culture suddenly died out. The need to have written records, [9], within the company became apparent. Employees were given proper contracts with their detailed job descriptions. Working procedures were put in place, [55], with the help of the implementation of Total Quality Management, [16]. Policies were put in place to guide employees on matters such as of purchasing and recruitment. This proved to be the most critical factor as it supports the formulation of organisational structure, formalisation and standardisation of the working environment, [1]. The dominance of the owner-manager on all matters of the company started to disappear. Divisions within the company started to emerge.

5.2 Delineation of functions

With the emergence of different departments within the company the usual way of the owner-manager of performing multiple tasks started to disappear. Delegation of responsibilities became the order of the day. With the developed job description staff was assigned positions of authority in finance, human resources and managing the shop floor. The turning point of the owner-manager was when he was no longer able to carry out his managerial and functional tasks. Initially the structure of the organisation was as shown under "The entrepreneurial firm" in Figure 3. As the company grew the owner-manager assumed the role of Chief Executive Officer (CEO) and he appointed managers. The structure of the company assumed three levels as shown in Figure 3 below under the "functionally structured organisation", [1], and [3]. Of interest were two senior design engineers, four industrial engineers, two accountants and a production manager who were appointed. The production manager was given the responsibility of running the workshop while one senior accountant was given the responsibility of finance and human resources.

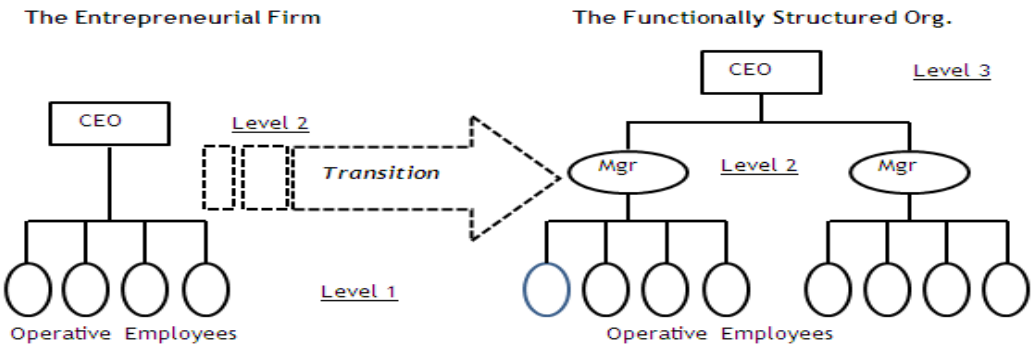

Figure 3: Transition in Organisational Structure for a Growing Firm, adapted from, Solymossy and Penna, 2001.

5.3 Identification of motivating influences on CEO

As the company grew, especially in the period 2009-2010, the CEO realised that he could no longer continue with micro-managing the company. The CEO had numerous visists in the region, where he was promoting the major product. He travelled as far as Ghana, twice in a space of three months. The CEO then realised that production and other business matters were stalling because he had non-decision making employees in his absence. Suppliers' were also complaining of not being paid on time. No one had the authority to approve overtime when demand was high. Skilled and experienced personnel were then recruited and integrated into the company. The CEO also realised that he did not have much experience on administrative, economic and financial tasks. The only way to grow his business was to recruit suitablly qualified people.

5.4 CEO cognitive process

Between year 2010 and 2011 changes in the CEO's behaviour were very explicit. His managerial tasks and capabilities were developed in that he was now spending more time in. planning and leading his company. Meetings and team breifings were now diarised. He created time for the three managers to rugalary update him. Delegation of responsibilities became embedded in the company's culture, [5] and [6]. With the installation of Material Requirements Planning (MRP) software the CEO was now able to check on items like inventory and production targets while seated in his office. However the research did not administer the Myers-Briggs Typological Inventory to measure the CEO's personal changes over the three year study period. From the interviews with the CEO it was established that his prefernces were action oriented, he sought knowledge and influence, frequently interacted with his employees and spend most of his time with either his satff or colleagues in the same industry, [7].

5.5 Development of strategic processes

In the year 2008 the CEO had mooted an idea to have a manufacturing strategy in place. When this was done in late 2008, the company was geared for expansion. The manufacturing strategy was developed as shown in Table 3. A consultant was brought in who had sveral meetings with the CEO and some of his senior staff. The meetings focussed on the current policies that were in place. These policies were verified whether there were detrimental or supportive for giving the company a competitive advantage, Tony, [65]. At the end of the exercise the team came up with a manufacturing strategy, [35], that had a strong focus on Advanced Technology and Innovation of new products and an improvement in quality. The new manufacturing strategy focussed on improving workshop equipment to reduce set-up times, quality to remove 100 % inspections, training of staff and improved product design. New CNC machines were bought in early 2009. Design softwares such as CAD/CAM, EdgeCAM and SolidWorks were installed. A new business model, [29], [33], was also developed to spearhead the implementation of the new manufacturing strategy.

5.5.1 Development of Manufacturing Strategy

A scale was used to verify each policy area. A value of -2 was apportioned to a policy that is detrimental to achieving a competitive edge and a +2 value was given to a policy that was supportive of achieving a competitive edge, [65].

-2	0	+2
Policy is extremely detrimental to achieving competitive-edge	Policy had little effect on competitive-edge performance	Policy provides strong support to achieving the competitive-edge performance

Table 3: Development of Manufacturing Strategy

Policy area	Current Practice	Quali-ty	Delivery Lead Time	Delivery Reliability	Flexibility in Design	Flexibility in Volume	Cost
Facilities	One factory. All products processed on the same site	-1	-1	-1	However +1	+1	+1
Capacity	Picthed at mean demand; subcontract and overtime for peaks	-1	0	0	+1	+1	-1
Processes	Old conventional m/c tools, long set-up times, functional layout	-1	-2 (fuct. layout)	0	+1	0	-1 (long set-ups, scrap)

Policy area	Current Practice	Quali-ty	Delivery Lead Time	Delivery Reliability	Flexibility in Design	Flexibility in Volume	Cost
Human resources	Single skilled, low training, low involvement	-1	-1	-1	+1	0	-1
Quality	100 % inspection of finished parts and assemblies	+1	-1	-1	+1	0	-2
Control Policies	Batch production No MRP	-1	-1	-2	+1	-1	-1
Suppliers	Multi-sourcing	-1	+1	+1	+1	+1	-1
New Product	CAD System	+1	+1	+1	+2	0	-2

5.5.2 New Business Model Development

To enhance competitiveness the company, through its consultant, developed a business model based on the framework proposed by [33]. The business model has nine building blocks. The nine blocks fall under four sub-headings namely Infrastructure, Offering, Customers and Finance. Under infrastructure there are Key Activities, Key Resources and Key Partners. On Offering there is Value Proposition, under Customers there is Customer Segments, Channels and Customer Relationships. Under Finance there is Cost Structure and Revenue Streams. All the nine blocks were designed and elaborated as shown in Figure 4.

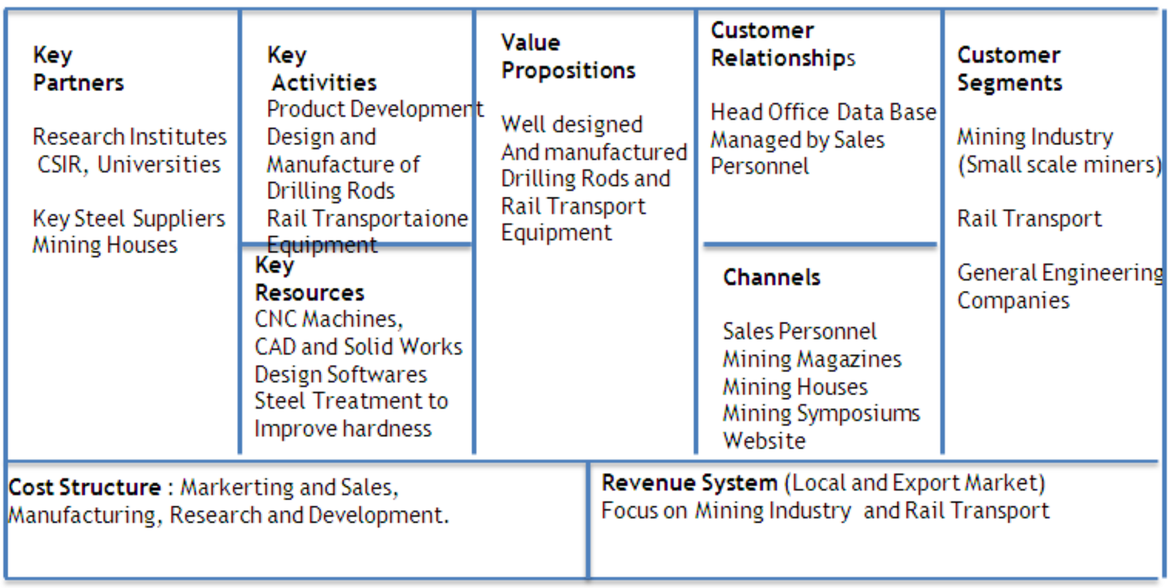

Figure 4: New Business Model Developed- model framework adapted from Osterwalder, 2010, [33].

5.5.3 Total Quality Management Implementation

The company made use of a quality expert, [54], who was hired to train both senior staff and key production personnel. The company is in the process of implementing ISO 9000:2008, in a staggered manner to accommodate shortage of both technical and human resources. TQM has been targeted to the manufacturing and design sections. The hired industrial engineers played a crucial part in documenting processes, [55] fulfilling one of the requirements for TQM implementation. Through training, top management committment and good communication, employees are focussed on quality objectives, Motwani, et al, [66], in-turn enabling a smooth implementation of TQM. Common features observed in this company contributing to improved performance are; quality efforts, customer focus, management leadership, employee involvement, open culture, fact based decision making, partnership with suppliers and continuous improvement,Thorton, [67], Kumar et al, [68].

TQM implementation barriers were avoided through education and training. Financial resources were made available. Mistrust between managers and shopfloor workers were avoided due to the fact that the owner clearly communicated his vision and ambition to all employees. Fear of losing jobs was dealt with by encouraging workers to attend further training and participating in quality meetings. Workers' suggestions were accepted and implemented were possible. The company is now using Statistical Process Control (SPC) and other quality tools to collect data. Tangible results that were noticed include reduction in number of defects, ste-up times, and downtime and delivery rates. These short term gains have boosted the confidence of both the CEO and his employees that TQM is a viable process. However by the end of the study period the company had not yet applied for ISO 9000:2008 certification.

TQM implementation also helped to strengthen new management structures, [7], that have been set up in this compnay. The compnay adopted a TQM implementation framewrok that has three components, namely; 1) Organisational Elements which focusses on Management, Processes, People and Customers , 2) Quality initiatives which focusses on use of quality tools, supplier development, quality systems ISO 9000:2008,customer satisfaction, quality steering committee, and 3) overall business goals that are aimed at business excellence and continuous improvement, [16].

5.6 Training

The research could not quantify, in terms of monetary value, the return on investement made by training activities. Another limitation was that the research did not look into the quality of training offered, the quality of the methods and techniques used, the quality of pedagogical resources used and the trainer's knowledge as suggested by Pineda, [69]. Barriers to job-related training that were discovered in this research were that workers were too busy at work, courses offered were too expensive and that some courses were offered at an inconvinient time and location. However with the CEO's support most workers managed to get training that enhanced their suitability and placement in the new structures.

5.7 Communication

Communication was found to be better in this company. Manufacturing strategy was well understood, there was greater manager-worker trust and improved employee satisfaction. Form TQM implementation, it was observed that the company had sound process management, quality perfomance data such as defect rate, scrap and rework were effectively collected, analysed and shared this showed an improvement in their quality. This agreed with the work of Zu et al, [70] who established that quality metrics when calculated from reliable and valid data can be used for quality improvement purposes. The research established that the company had made some meaningful investement in information systems, the link between costing office, drawing office and shoploor was put in place giving a positive impact on overall organisational performance, de Burca et al, [71]

6. LIMITATIONS

Only one enterprise which was owner-managed was studied making it difficult to genaralise these results. Growth of small family companies or companies with a partnership structure might behave differently with what was covered in this reaserch. The influence of foreign investment on small businesses and the role of worker unions as stakeholders in the transition process were also not covered and can be treated as future work. Detailed analysis of business results was not done.

7. CONCLUSION

The actual point at which the owner-manager shifted from micro-management to delegation- oriented approach was difficult to pin point. Records of new personnel who were appointed to managerial positions suggest late 2009 onwards. The owner emphasised on building a dynamic team that could respond to market and environmental challenges. More emphasis was placed on quality manufacturing and R & D activities. The compnay now has functional managers who are guided by operational budgets with financial, marketing and production systems in place.

At the end of the study employees were now asking for company shares. This had brought in a new dimension of partnership between the owner and his employees. While the practice is common in other South African large companies, in small and medium companies it is still a growing culture.

The experiences and challenges of owner-managers engaged in small business growth were found to have been influenced by, [1], [3], [8], and [12].

- The owner-manger's personal characteristics was shown by his ability to proactively deal with problems, keep his workers motivated, loyal and committed. The CEO's other ability was that he made effective decisions and had a willingness to take appropriate risks. His background played an important role in achieving his goals.
- The external market condition brought in some opportunities for market growth. The CEO targeted both small and large mining companies that operated in political and economically stable enviromnents.
- The CEO created a work environment where some of his workers became specialists in their jobs thereby giving them autonomy, thus agreeing with the empowerment philosophy expounded by Deming, 2000.
- The company structure of being under a single owner reduced organisational complexity. Decisions on investment, in advanced equipment and technology, in hiring new talented and skilled staff were made at appropriate times

Worker resistance to changing environment was minimised by a clear and effective communication process done by the owner-manager. Workers saw opportunities of learning more, earning more, getting new skills through training in new equipment and technology, being given greater responsibilities and working in a safe environment that guaranteed growth in their profession.

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Appendix 1: Organisational Change Models.

Types of Organisational Change Models	**Evolutionary**	**Teleological**	**Life Cycle**	**Political**
Aspect: **Why change occurs**	External environment	Leaders; internal environment	Leaders guiding individual's natural growth	Dialectical tension of values, norms or patterns
Process of change	Adaption; slow; gradual; non-intentional	Rational; linear; purposeful	Natural progression; result of training and motivation; altering habits and identity	First order following by occasional second order; negotiation and power
Outcomes of change	New structures and processes; first order	New structures and organising principles	New organisational identity	New organisational ideology
Key metaphor	Self-producing organism	Changemaster	Teacher	Social movement
Examples	Resource dependency,; strategic choice; population ecology	Organisational development, strategic planning; reengineering; TQM	Developmental models; organisational decline; social psychology of change	Empowerment; bargaining; political change; Marxist theory
Benefits	Environmental emphasis; systems approach	Importance of change agents; management techniques and strategies	Change related to phases; temporal aspect; focus on people throughout the organisation	Change not always progressive; irrationality; role of power

CUTTING STRATEGY SELECTION FOR TITANIUM MACHINING - A KEY FOR COST SAVINGS

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ABSTRACT

Titanium plays a key role in the competitiveness of the aerospace industry due to its advantageous properties and weight saving attributes. Research show that since 1970 the air traffic has doubled every fifteen years and it is expected that this growth trend will continue for the next fifteen years. This growth along with the highly competitive environment of aerospace companies creates the need for improved productivity and material saving, requiring a high efficiency for machining of titanium alloys.

Titanium is classified as a difficult-to-machine metal and therefore large costs are associated with the removal of material during machining operations. For this reason much research has been done improving the machinability of titanium and literature reveals many studies on cooling techniques, tooling design, coatings, wear mechanisms and thermal behaviour. However, not many have looked at the potential of cutting strategy selection for component manufacture. Every part has unique features and these require different strategies to remove the material efficiently. Certain strategies are better suited for specific features and therefore the challenge lies in making the best combination of choices. This paper presents results that illustrate the cost savings possible with implementation of the right strategies with a focus on aerospace applications.

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1 INTRODUCTION

Much research has been done during previous years on high performance machining of light metals with a special focus on the titanium alloy Ti6Al4V (further referred to as titanium). The focus of this research was to consolidate the existing knowledge base in the South African aerospace industry in machining of light metals such as titanium. As part of the research, state of the art in machining of titanium was analyzed and tested on benchmark parts. With these parts strategies were tested to learn how titanium behaved under different cutting conditions and revisions were done for the purpose of improving the operation. The ultimate objective in the revised programs was to obtain a highly efficient and realistic program for machining the titanium. With regards to the earlier results it was found that high efficiency was obtained by big cross-sectional areas of cut through high performance cutting (HPC) rather than by high speed cutting (HSC) [1].

Continuing the research much progress was made in terms of strategies and parameters that were used, but due to the exceptionally high tooling costs, it was clear that further improvements were necessary. Except for this research, extensive studies have also been done in the industry in the past couple of years to find ways of improving the productivity of machining operations. Numerous experiments and tests have been performed with different cooling strategies and cutting tools and there is a vast amount of papers published in these fields. Although the research have yielded positive results in terms of improved cutting time and material removal rate, it is not yet considered to have reached the near optimum conditions. This leads to the assumption that the biggest potential for further machining improvements lies with improved machining strategies which is the focus of this paper. The criterion that will be used to make the improvements measurable is cost optimization with the aim of reducing tooling as well as machining costs.

2 MACHINING CONSIDERATIONS

When analysing parts it becomes apparent that there is a vast amount of different shapes and geometries that can be machined with modern CNC machines. However, it is not possible to take every single one into consideration and therefore the general shapes and geometries can be grouped into a few major features. For this paper the main focus is on aerospace parts and therefore the main identified features are:

- thin walls
- undercuts
- compound angels
- pockets
- thin base areas

Obtaining information from these features during machining operations presents some challenges. Ideally the tool wear should be measured over a variety of constant time intervals up to the point of failure so that the behaviour of the tool can be analysed under the specified conditions. This would give a good distribution of wear data points over the lifetime of the tool for the cutting parameters of that setup. However, in practice this is not possible. Once a tool is engaged in a specific cutting strategy, the machine cannot be stopped so that the tool can be removed for wear measurements. The reason is that due to the software and setup of the machine, the exact position of the tool at any specific point in the program will be lost if the mode of operation is stopped and changed so that the tool can be removed.

A problem with stopping a cutting process during an operation is increased tool loading due to extra entry and exit motions. It is generally accepted that entry and exit motions should be kept to a minimum due to shock loading that are associated with it. To extend the life of the tool it is very important to keep the engagement of the tool in the work piece as constant as possible – thus avoiding unnecessary entry and exit motions [1].

Normal roughing strategies gradually rolls or spirals into the work piece to ensure a controlled increase in forces. Once the tool is fully (or to its pre-set depth) immersed into the work piece, it maintains relatively constant step-over, depth of cuts and feed rates to ensure the forces on the tool remains moderate. Stopping the cutting operation several times during a machining cycle will result in an abnormal amount of entry and exits with the corresponding fluctuation in forces. This will increase the wear and decrease the tool life in comparison with a normal constant engagement cutting operation. It will therefore not give an accurate representation of the actual tool life, and the model would ultimately not be effective in industry applications. In order to prove this, a cutting force model still needs to be created to evaluate the forces associated with certain cutting operations.

In machining real parts, to overcome these problems, the design of the cutting operations needed some specific changes, so the conventional way of tool path programming was altered to make it more accessible for data capturing. For example, the conventional way of roughing out a pocket is to use a toolpath that covers the entire pocket so that most of the material is removed in a series of cuts over the full area of the pocket [2]. Since it is not possible to stop a cutting operation during the cutting cycle, the area of the pocket was divided into smaller sections that each has its own toolpath. This made it possible to measure the wear after each successive section without interrupting the machine program. If the tool is removed for measurement after each section, the program can simply move to the next program and machine the following sections. It should however be noted that it is not always possible to divide any feature into arbitrary sections since the complexity of the part will determine which tool paths can be used. If division (in vertical sections) of a certain feature is not allowed by the software, another option is to break it up into different horizontal layers. The toolpath can then conform to the complexity of the feature in one level at a time, making it possible to still make measurements with minimal interruptions to the cutting process.

An advantage of using this adapted tool path method is that the possibility of catastrophic tool failures can be minimised. Being a difficult to machine material, it is not always possible to machine an entire titanium pocket or feature with one tool because the tool life does not allow it. This can result in one of two possible scenarios – either the tool will fail in the middle of the cutting operation or the tool would have to be replaced prematurely before machining a new pocket or section of the part. The tool is therefore either over-utilized to failure or under- utilized wasting remaining tool life. This also highlights the need for an effective model to predict tool life for each specific operation. Not only is there the danger of damaging the work piece, but it would also require the cutting process to start over again at the beginning of the tool path with “air cuts” up to the point where the tool failed which is an unnecessary waste of time.

With the smaller sections, it is more likely that the tool will last for the entire section and therefore improve the productivity of the cutting operation. This would also make it possible to make wear measurements after successive sections so that the progression of wear can be measured against cutting time without interrupting the toolpath strategy of the cutting operation. With less material to remove per section there is also more room for adjusting the cutting parameters so that the tool can be utilized closer to its full potential and see how this affects the tool life. The negative aspect of using these tool paths is that it will require more programming time and increases the complexity of the tool paths. However, it is believed that the valuable data that can be obtained with this method will outweigh the increased costs for programming.

3 MACHINING CHALLENGES

The benchmark part on which the cost optimization is tested is illustrated in Figure 1 below, which is a real aerospace part and forms part of the wing assembly of an aircraft. This part is machined from Ti6Al4V (referred to as titanium) and contains several geometric features that makes it difficult to machine. These features, as illustrated in Figure 1, are thin walls (1), undercuts (2), pockets (3) and thin base (4) and they require special processes to remove all the material. Based on previous results of in-house experiments, this part was machined with area clearance and trochoidal tool paths which did not give very good results in terms of costs.

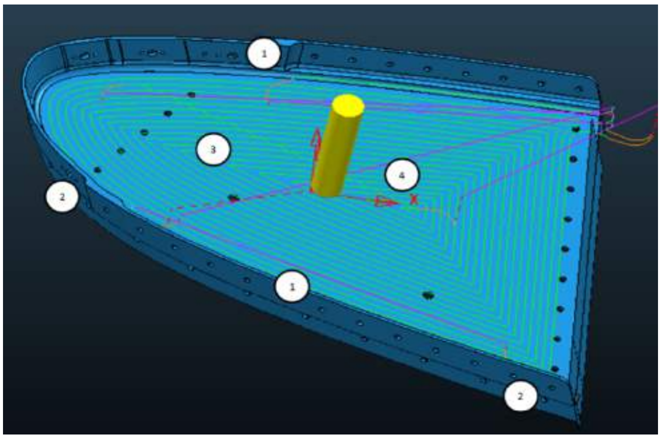

Figure 1: Benchmark part [2]

The main problem areas that were identified based on previous results of in-house experiments were that the wrong tool holders were used along with ineffective strategy – tool combinations. During some of the previous operations, the cutting forces on the tool were so high that the tool was pulled out of the holder while engaged in a cutting operation. This showed that the tool clamping system required for titanium cutting operations needed to be much stronger than that required for machining of general purpose steels [2].

Another factor that was revealed by the results of the in-house experiments were that the spindle load reached up to 60% of the maximum which indicated that very large forces were exerted on the cutting tools. The maximum tool life that was achieved was 16min which proved that better machining strategies are needed to utilize the higher material removal rates possible with solid carbide cutters [2]. This also highlighted the need for an effective strategy selection procedure so that the right strategy can be used with the right features and tools. A summary of the costs of the earlier in-house experiments are summarized in Table 1. With roughing operations, the tools are usually used until they reach their end of tool life criteria (300μm), however with finishing operations only a small amount of the tool life is used. The reason for this is that it is standard practice to use new tools for finishing operations due to the tolerances that are applicable to aerospace parts. Therefore, for the purpose of cost comparisons the total costs of each tool is used irrespective of the amount of tool life utilized.

Table 1: Cost associated with benchmark part during previous project [2]

Cutting Tools	Qty	Cost	Total
Roughing End Mill	6	R 3 467.00	R20 802.00
Finishing End Mill 6flute	1	R4 345.00	R4 345.00
Finishing End Mill 8 flute	1	R4 558.00	R4 558.00
Ball nose end mill	1	R1 175.00	R1 175.00
Tooling total cost			**R30 880.00**

Machining Cost	**hrs**		
Roughing	3.6	R500.00/hour	R1 800.00
Semi-finishing & Finishing	1.616	R500.00/hour	R808.00
Machining total cost			**R2 608.00**
Overall costs			***R33 488.00***

From this table it can be seen that the tooling costs completely dominated the costs of the machining operation. The machining cost only constitutes 8% of the overall costs where the tooling costs form 92% of it. With this relation it might be better to have a longer machining time with less expensive cutting tools. A trade-off between expensive solid carbide cutters and low-cost carbide inserts has to be made within the allowable time frame for a production unit.

For finishing operations only one tool per type of finishing operation is required, so those costs are already the required minimum. The main challenge lies with the high performance roughing operations, since this is where 80 - 90% of the material is removed. The reason for the exceptionally high tooling costs is that ineffective strategies were used which resulted in large force fluctuations that caused premature tool failure. The tool lives for these operations were therefore very short.

Looking further at the costs of roughing operations it is seen that 67% of the tooling costs are allocated to it in comparison with the 33% for finishing operations. This highlights the importance of improving the machining strategies for high performance roughing operations because this is where there is a potential for improvements and cost savings.

4 SOLUTIONS FOR IDENTIFIED PROBLEMS

The first alteration based on the results of the earlier in-house experiments was to use a new tool holder that provided enough clamping force. A tool holder from NT Tools was used as this could achieve a much higher clamping force than the previous holder. The second big problem that was responsible for the short tool lives was that ineffective strategies were used. As stated there are a large amount of features and shapes possible with modern CNC machines and the challenge is to use the right strategy for the right features and tools. Based on knowledge gained during previous titanium projects, the tendency in machining of titanium alloys is to move away from large and aggressive radial cuts and rather use lighter slicing type of cuts with a bigger axial depth of cut [2]. In this way the force fluctuations can be kept to a minimum while having a high material removal rate. Experience from past experiments indicates that maintaining a constant engagement angle is very important in machining titanium. For this reason a new strategy called Vortex developed by Delcam was identified that adhered to this requirement. This is a very new constant engagement strategy and it's development falls in with the needs of current difficult to machine materials such as titanium. The concept of a constant engagement strategy is described below.

With most cutting operations the cutting parameters are set up based on the biggest forces that might be encountered along a toolpath in order to prevent tool overload. The biggest forces usually occur in the corners where there is a big increase in the engagement angle and therefore determine the cutting parameters. As illustrated in Figure 2 about 90% of the toolpath has an optimal engagement angle but the remaining 10% where the tool enters the corners actually dictate the cutting parameters. In essence 90% of the toolpath is machined ineffectively [3].

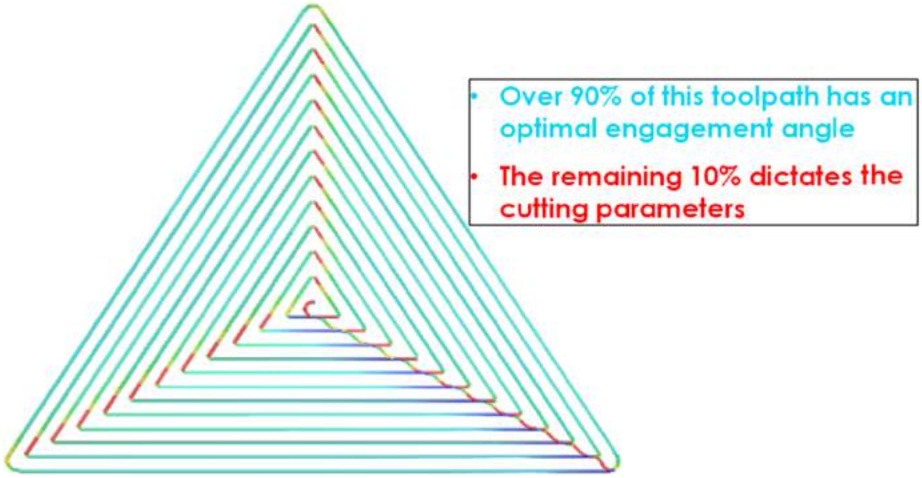

Figure 2: Conventional toolpaths [3]

The result of setting up the cutting parameters to machine a part as illustrated in Figure 2 is that a much smaller depth of cut is used, a suboptimal engagement angle is implemented and a lower feed rate is used. The overall cutting time of the part is therefore longer due to the influence of the engagement angles in the corners [3].

With a constant engagement strategy the focus is on keeping the engagement angle constant throughout the cutting operation. The best engagement angle is determined according to the geometry of the part and then the whole part is machined while the engagement angle is controlled accordingly. When the tool enters corners, smaller recurring slices are made with a distinct toolpath as illustrated in Figure 3. In this way the programmed engagement angle is never exceeded and the parameters can be determined according to straight line cutting [3]. The effect that this will have on the cutting forces is still theoretical at this stage but will be tested as part of future work.

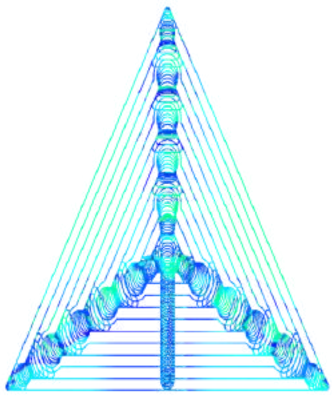

Figure 3: Constant engagement toolpath (Vortex) [3]

By controlling the engagement angle it can maintain a constant feed rate throughout the cutting operation. The advantages of using such a strategy are [3]:

- No tool overloading or vibration leads to improved tool life
- No shock loading leads to reduced chipping on flutes
- Constant cutting edge temperature prolongs the life of the tool coating

- Step downs of 2 to 3 times the diameter can be used so that the tool wear is distributed evenly over a much larger cutting surface (corresponds to the geometry of the solid carbide cutters that are used in this research study)

Figure 4: Tool utilization of Vortex and conventional machining [3]

With conventional machining the machine may not maintain the programmed feed rate due to the forces encountered in the corners. Also, due to the smaller depth of cut, the tool is not utilized to its full potential and much longer tool paths are used. With a constant engagement strategy the toolpaths are shorter, the utilization of the cutting tool is better (Figure 4) and constant feed rate gives a better material removal rate and reduced cutting time [3].

5 RESULTS

The effectiveness of the constant engagement toolpath was illustrated by the tool lives that were obtained while machining the actual aerospace part illustrated in Figure 1. As stated earlier, results of previous in-house experiments revealed a maximum tool life of sixteen minutes. With the same tools but a new constant engagement tool path strategy, much longer tool lives were obtained. A summary of the machining times and wear that were obtained for roughing operations is given in Table 2. The wear was measured using an optical microscope after each cutting program as discussed earlier in section 2.

Table 2: Summary of machining times

Cutting tool	Machining time	Wear
Mitsubishi 6 flute carbide end mill	3hrs 7min	125µm
Mitsubishi 6 flute carbide end mill (modified diameter)	3hrs 48min	90µm
Mitsubishi 8 flute carbide end mill	2hrs 38min	128µm

These results already prove that implementing the right strategy can prolong the tool life quite substantially. Although the tool lives are already much longer than the first trials, they have not yet reached the end of tool life criteria of 300 µm and could be utilized even further. The end of tool life criteria of 300µm is taken as a guideline from the ISO standards for tool life testing for end milling operations.

5.1 Cost summary of revised benchmark part

The costs associated with the improved machining parameters are summarised in Table 3 below.

Table 3: Summary of costs with improvements

Cutting Tools	Qty	Cost	Total
Roughing End Mill 6 flute	2	R4 200.00	R8 400.00
Roughing End Mill 8 flute	1	R 4 200.00	R4 200.00
Finishing End Mill 8 flute	1	R4 200.00	R4 200.00
Finishing Inserts	2	R119.30	R239
Ball nose end mill	1	R1 175.00	R1 175.00
Total tooling cost			**R18 214.00**
Machining Cost	**hrs**		
Roughing	9.59	R500.00/hour	R4795.00
Finishing	2.94	R500.00/hour	R1470.00
Total machining cost			**R6 265.00**
Overall cost			***R24 479.00***

When comparing the costs for this part to that of the part machined during the previous trial, it is clear that there are big improvements in terms of costs. Although it took longer to machine the part with the new strategies, there is a big reduction in the overall costs. The different results are compared in Table 4.

Table 4: Cost comparisons

	First machining	Improved machining	% Change
Tooling costs	R 30 880.00	R 18 214.00	41 (↓)
Machining costs	R 2 608.00	R 6 265.00	58 (↑)
Total Costs	R 33 488.00	R 24 479.00	27 (↓)

Due to a more effective strategy, the tool lives were increased substantially which meant that fewer tools were used to remove the same amount of material as with the part in the previous experiments. A 41% reduction in the tooling costs validates this improvement. The machining costs increased by 58% due to longer cutting times. However, since the machining costs only constitute 8% of the overall costs in the first part, these increased costs have a much smaller effect than the tooling costs. In relation, the decrease in tooling costs is much bigger than the increase in machining costs and therefore there is still an overall cost reduction of 27%.

5.2 Machining comparisons

The increased machining time for this part is a result of selecting very conservative cutting parameters. The reason is this new constant engagement strategy (Vortex) has not been tested extensively on titanium and therefore very conservative cutting speeds were used.

The results indicate that higher cutting speeds are possible and therefore it is believed that the cutting times can be reduced so that the machining costs will be lower. The overall costs can therefore be reduced even further with this strategy. The validity of this statement is confirmed by the wear measurements that were recorded during the cutting operation as illustrated in Figure 5- Figure 7 below.

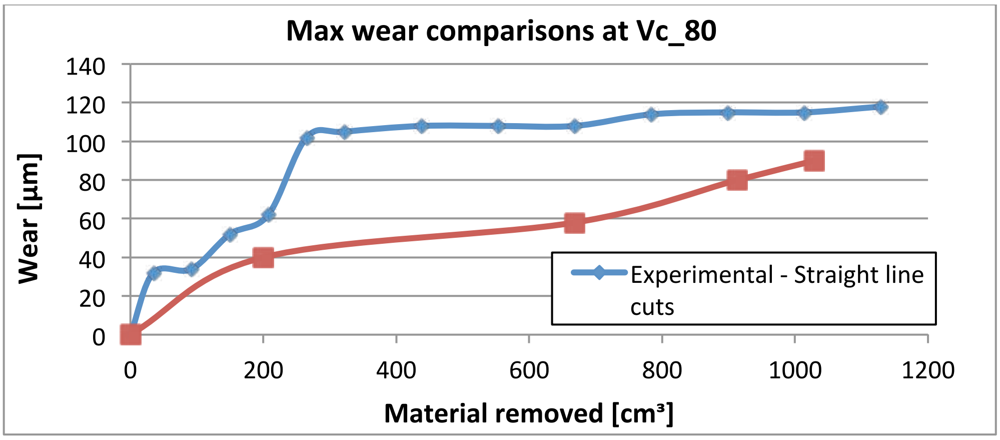

Figure 5: Wear comparisons between straight line cuts and machining of a real part with 6 flute cutter Vc_80

This first graph in Figure 5 is a comparison between the data recorded while machining the real part and data that was recorded during straight line experiments with the same cutting parameters and tool. Usually with conventional strategies, straight line cuts would be an indication of the best conditions because the tool moves in a simple straight line and forces are therefore kept constant on the tool. However, with the constant engagement strategy implemented on the real part, the results show a lower wear rate than for simple straight line cuts.

With the second 6 flute cutter the same tendency was found with the wear being lower than that of straight line experimental cuts as illustrated in Figure 6. It should be noted at this point that originally the wear measurements between point zero and one depicted a straight line because the wear intervals was very long. As described earlier, it is not always possible to split a toolpath into smaller sections and therefore the nonlinear tendency could not be captured. The normal wear tendency is a high initial wear rate followed by a more gradual wear rate and ending again with a high wear rate. This tendency is illustrated by the experimental values which were recorded in very short time intervals. With the real part, measurements could only be made once a program or toolpath was finished. Based on the tendency of the experimental values, the first point was therefore extrapolated to give a more accurate representation of the wear behaviour on the tool.

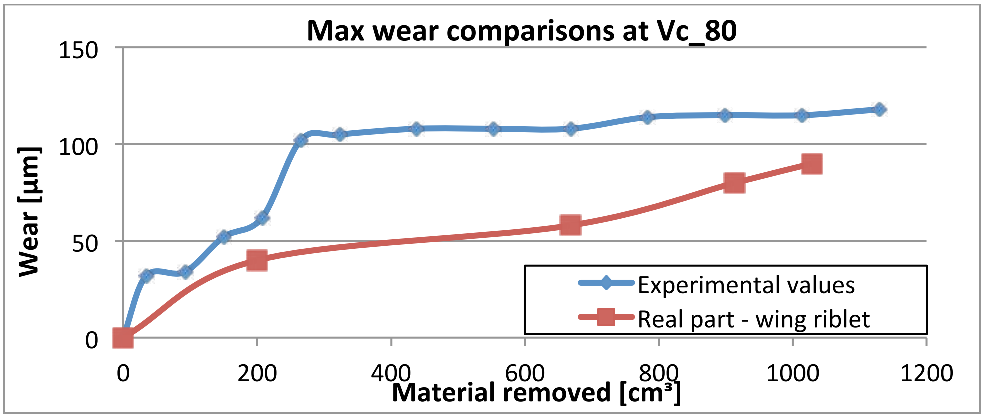

Figure 6: Wear comparisons between straight line cuts and machining of a real part with modified 6 flute cutter Vc_80

With the positive results that were obtained at a cutting speed of 80m/min, the cutting speed was increased to 100m/min and the feed was also increased by using an 8-flute cutter instead of a 6-flute cutter. The results are illustrated in Figure 7 and it can be seen that the wear was still lower than that with straight line cuts at 80m/min. The graphs for the experimental straight line cuts at 120 m/min were also given to compare it to the values of the real part at 100m/min. The real part however corresponded to the tendency of the 80m/min with actual values being lower than the 80m/min.

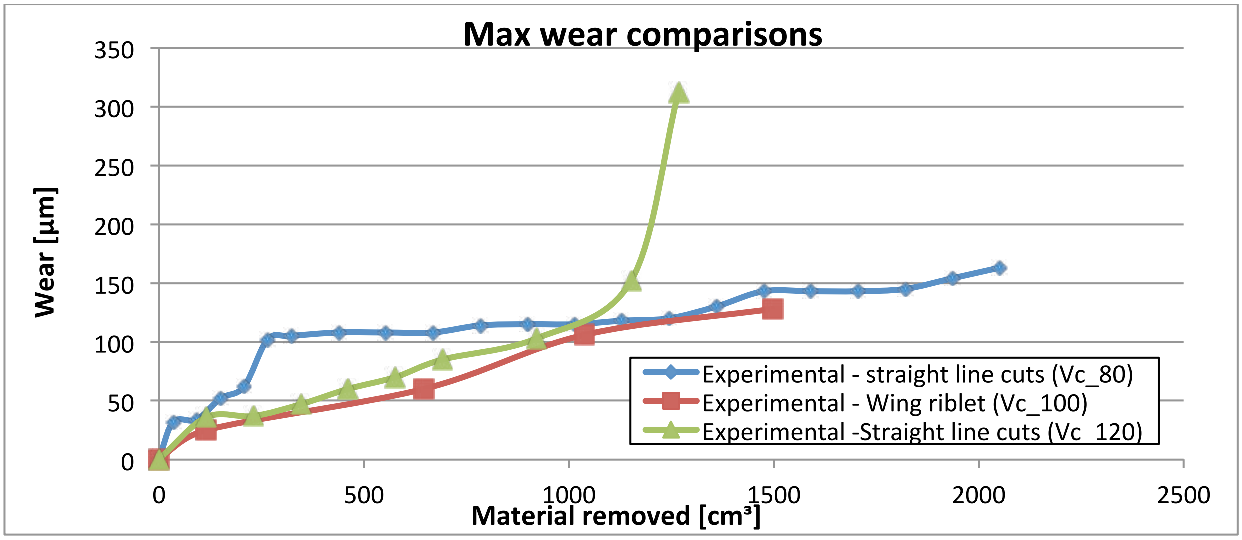

Figure 7: Wear comparisons between straight line cuts and machining of a real part with 8 flute cutter Vc_100

The reason the constant engagement strategy gives better results than the straight line experiments can be explained in terms of forces exerted on the tool. With the straight line experiments there are recurrent entry and exit motions at the two ends of the titanium block as the toolpath moves to each successive pass. This causes a fluctuation in the forces exerted on the tool which is detrimental to the tool life. With constant engagement, the toolpath is designed that tool remains engaged in the work piece while preventing overloads in the corners and therefore the force fluctuations are greatly reduced giving an improved tool life. It has not been proven yet, but it seems like this effect is more pronounced in titanium than with other metals.

5.3 Simulated cutting conditions

Although only part of the benchmark part was cut with a cutting speed of 100m/min, the results, illustrated in Figure 5 to Figure 7 revealed that the speed could be increased even further. With a conservative approach, if it is assumed that the whole part can be machined at a cutting speed of 100m/min rather than the 80m/min, there will be an improvement in the machining costs due to a shorter machining time. To model this cutting condition, machining of the entire part at a cutting speed of 100m/min was simulated with the software Powermill from Delcam and the results are illustrated in Table 5 and Table 6.

Table 5: Machining costs of machined part

Total tooling cost			**R18 214.00**
Machining Cost	**hrs**		
Roughing	9.59	R500.00/hour	R4795.00

Finishing	2.94	R500.00/hour	R1470.00
Total machining cost			**R6 265.00**
Overall cost			***R24 479.00***

Based on an evaluation that can be done from the results illustrated in Figure 5 - Figure 7, it can be assumed that the same number of tools will be used and therefore the tooling costs remains the same. The reason for this statement is that the tool wear were not even close to the end of tool life criteria and therefore by increasing the cutting speed (and material removal rate), the tool wear will be higher at the end of the operation and therefore the tool will be utilized much more efficiently. The only difference comes in with the machining time because the higher cutting speed of 100m/min will yield a lower machining time and therefore a lower cost.

Table 6: Simulated cost of machining part

Total tooling cost			**R18 214.00**
Machining Cost	**hrs**		
Roughing	7.12	R500.00/hour	R3 560.00
Finishing	2.74	R500.00/hour	R1 370.00
Total machining cost			**R4 930.00**
Overall cost			***R23 144.00***

It can be seen from Table 5 and Table 6 that a reduction in machining time is possible predominantly with roughing operations since most finishing operations are usually already done at higher speeds. There was however still an improvement of 7% with some of the finishing operations. With the roughing operations there was a reduction of 26% which brought about a decrease in overall machining costs of 21%. As stated earlier, the machining costs only makes up 8% of the overall costs of the part as illustrated in Figure 8(a) and therefore this contribution to the overall costs is 4%. This means that at a higher cutting speed of 100m/min and with a new strategy, it is possible to reduce the overall machining costs by as much as 31% in comparison to earlier in-house experiments as illustrated in Figure 8(b).

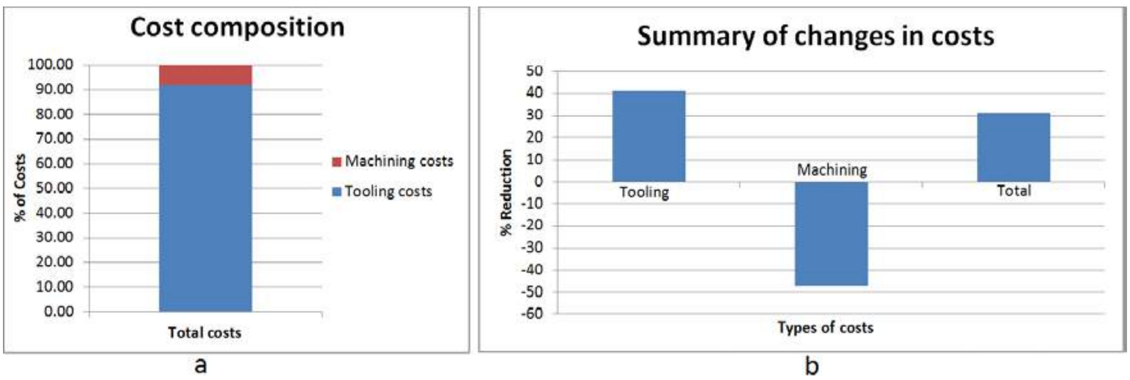

Figure 8: Cost comparisons

6 CONCLUSION

Forming part of a larger collaborative titanium research group, much progress has been made in recent years in terms of titanium machining. Titanium as a difficult to machine material has large costs associated with the removal of material. It has been illustrated that the toolpath strategies that work well for general purpose steels do not necessarily give good results for titanium. Tooling costs for machining titanium are extremely high and therefore a toolpath strategy was tested to reduce these costs. With titanium it was found that the best results are obtained by using constant engagement strategies. The results for implementing a constant engagement strategy were illustrated along with the costs associated with it. Comparing this to the results that were obtained on the same benchmark part with earlier conventional cutting experiments, it is clear that using the right strategy does have a big influence on the cost. Cost savings of up to 41% for tooling and 27% for the overall part was realized, which proved the potential that lies in strategy selection. Because very expensive tools are used for machining titanium, a reduction in the tooling costs is a key to overall cost savings.

The results illustrated in this paper are part of on-going research. The goal of this research is to use knowledge gained from previous projects and build on that to improve the competency in machining of titanium alloys. It was illustrated with the results that this has been achieved, but more than that, further improvements are possible. Investigation into strategy selection procedures proves to have potential and current research is pursuing that direction. Current research also looks into a cost model approach that can be used to find the compromise between the tooling cost and the machining time as a graphical aid. The ultimate goal of this is to optimize the machining operation by minimizing the costs with a simple and practical approach.

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DEVELOPMENT OF A COST OF QUALITY CALCULATION TOOL FOR A SOUTH AFRICAN PRINTING COMPANY

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ABSTRACT

The objective of this study is to develop a tool that the management of a high-end label printing company in South Africa can use to calculate and manage the cost of quality in their firm.

The tool will provide management insight into the true total cost of quality at the firm and will also afford management the option of calculating the specific cost of quality of a particular customer complaint. It is believed that such a tool will enable better understanding of the relationships between customer complaints, the actions taken to remedy these problems and the cost thereof.

This paper outlines the development of the cost of quality calculation tool, and illustrates the application thereof on a case study. The paper starts by introducing the cost of quality concept and establishing its importance. This is followed by a discussion of the methodology followed to enable the calculation of the cost of quality of the label printing firm. The typical managerial information that will be obtained from tool implementation is then showcased and discussed, followed by some concluding remarks and recommendations.

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1 INTRODUCTION

The cost of quality (COQ) has a direct impact on the overall financial goal of a company [1]. Even a small reduction in COQ may boost the profitability of a company by a significant amount. Many companies promote quality as the central customer value and consider it to be a critical success factor for achieving competitiveness. Any serious attempt to improve quality must take into account the costs associated with achieving quality, since the objective of continuous improvement programs is not only to meet customer requirements, but also to do it at the lowest cost. This can only happen by reducing the costs needed to achieve quality, and the reduction of these costs is only possible if they are identified and measured. Therefore, measuring and reporting the cost of quality should be considered an important issue for managers [4].

This study aims to develop a tool that will enable the management of a label printing company in South Africa to calculate and manage their cost of quality. This tool is developed through correspondence with company representatives in order to obtain information about the types of problems experienced by clients, the actions that are taken to respond to these complaints and the associated costs involved. As the prevention and appraisal costs of quality are presently absorbed in the overall production costs of the company, this tool is specifically developed to focus only on quantifying the failure costs as defined in the PAF model. Failure costs here refer to the costs incurred when the product has been sent to a customer and found to be defected afterwards.

The tool was developed by first standardising the data capturing of customer complaints so that the process of marrying corrective actions with complaints could also be standardised. These corrective actions each have their associated costs, which can then ultimately be linked to the complaints. The use of a standardised database of complaints therefore results in a standard set of costs, which simplifies the calculation of the cost of quality.

With the cost of quality tool in place, strategic decision making can be supported in the firm. It enables the determination of priority quality management areas and aids decisions between taking corrective action and writing off an order.

2 LITERATURE REVIEW

2.1 Cost of Quality

In essence, total quality costs represent the difference between the actual cost of a product or service and what the cost would be if the quality was perfect [1]. However, there is no general agreement on a single broad definition of quality costs [2]. According to Besterfield [3], the cost of quality is defined as the cost associated with the non-achievement of product or service quality as defined by the requirements established by the company and its contracts with customers and society.

The American Society for Quality's (ASQ) Quality Cost Committee classifies the cost of quality into four cost categories: prevention costs, appraisal costs, internal failure cost and external failure cost [13]. Prevention and appraisal cost fall within the broader category know as cost of conformance. Failure cost can also be seen as the cost of non-conformance.

2.1.1 Prevention Costs

Prevention cost refers to any costs incurred in attempt to prevent poor quality products or services. Activities that are seen as attempts to prevent poor quality include quality improvement initiatives such as meetings held, projects, planning and training. Product reviews, supplier capability surveys and process evaluations are also preventive actions [13].

2.1.2 Appraisal Costs

Appraisal costs are the costs of measuring how well a product or service conforms to the quality standards and requirements that must be met. This can be done by inspecting both materials used in the process and the product or service as it moves along the steps in the process [13].

2.1.3 Internal Failure Costs

Internal failure costs are the costs resulting from products or services that do not conform to the requirements that occur before it is delivered to the customer. These are the costs associated with producing scrap, doing rework and in general repeating any steps in the process that was not done according to the standards in the first place [13].

2.1.4 External Failure Costs

External failure costs occur during or after the delivery of the product or service to the customer. The costs of processing customer complaints, dealing with customer returns and customers claims are all external failure costs [13].

2.2 COQ in the industry

It has been shown that through implementation of cost of quality models, the cost of quality can be reduced significantly and quality can be improved for customers [1, 4]. Although most industries are aware of the benefits of cost of quality, only a few of them are using it in their organisation, because they often do not know how to calculate and implement this [1]. Companies rarely have a realistic idea of how much profit they are losing through poor quality [5]. Smaller firms most often do not even have any quality budget and do not attempt to monitor quality costs [6, 7]. Large companies usually claim to assess quality costs [8–10]; however, even though most managers claim that quality is their top priority, only a small number of them really measure the results of quality improvement programs [11,12]. Top management is typically reluctant to establish a rework account. Mistakes are buried and the extra costs incurred are treated as poor productivity. This act indicates poor management attitude towards quality and takes away any room for improvement. Quality costing, on the contrary, allows cost quantification of failure events and, thus, using it as a means for initiating improvement actions [13].

As average industries do not necessarily have the resources to hire the services of consultants to implement cost of quality systems in their industries, simple models are typically proposed [1]. The method most commonly implemented is the classical prevention-appraisal-failure (PAF) model; however, other quality cost models are used with success as well. The selected COQ model must suit the situation, the environment, the purpose and the needs of the company in order to have a chance to become a successful systematic tool in a quality management program [4].

3 RESEARCH METHODOLOGY

The methodology followed in this study to develop the cost of quality tool can be summarised into five generic steps. The steps followed in the development of the tool are illustrated in Figure 1.

The first step was to develop a standard categorisation system in order to enable consistent classification and categorisation of all complaints received by the company. This is discussed in more detail in section 4. The second step was to look at typical actions the company can take to address a complaint. This is further discussed in section 5. The third step was to associate specific complaints with remedial action sequences. In other words specify what complaints “trigger” what remedial action sequences. These are then stratified into a set of distinct action sequences that can be "triggered" by a complaint. An elaboration on this concept can be found in section 6. The forth step was to calculate the cost incurred when performing a remedial sequence (section 7). Finally the total cost of a specific customer complaint could be calculated (section 8).

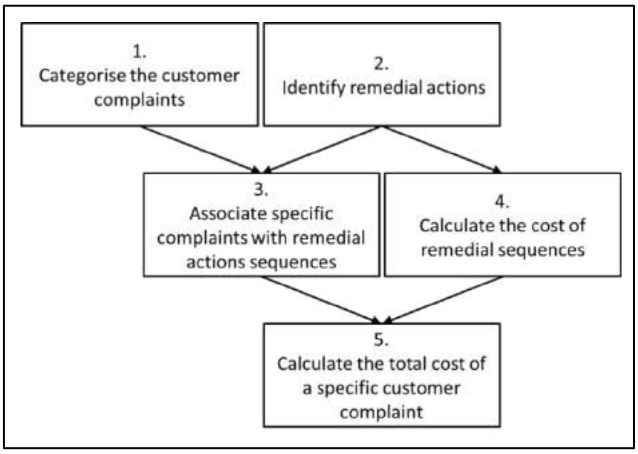

Figure 1 Methodology for the development of cost of quality calculation tool

4 CATEGORISATION OF CUSTOMER COMPLAINTS

Customer complaints received over a period of one year were used to develop a system by which complaints can be categorised into one of various standard defect types. A defect type can have at least two further distinctions, but not more than three. These distinctions provide more detail about the defects that occur during the manufacturing process.

The standardised defect types are tabulated (Table 1) stating the defect types and distinctions, identification codes for each defect, the department responsible for each defect and descriptions of the defects where applicable.

5 IDENTIFICATION OF REMEDIAL ACTIONS SEQUENCES

Various remedial actions must be performed to resolve a customer complaint. Table 2 lists the remedial actions available to the label printing company, the descriptions of the actions, the classification of the action types and the cost drivers for each action.

The actions identified were classified as either standard or as complaint-dependent. Complaint-dependent actions are actions taken by the company as and when requested by the customer. Standard actions are actions taken by the company as part of the process of resolving the customer complaint internally when a customer does not reject the company entirely and wants the job to be corrected.

6 ASSOCIATE SPECIFIC COMPLAINTS WITH THE REQUIRED REMEDIAL ACTIONS

Complaint-dependent actions can be required for any customer complaint. Standard actions can only occur in certain combinations. Seven distinct action sequences that could be triggered by a complaint were identified. A code was assigned to each Sequence. The sequence, its code, the reasoning behind each and the defect IDs of the complaints associated with each sequence is provided in Table 3.

A process flow chart of the response by the company to any complaint was also drafted. See Figure 2. This figure illustrates the process connections unique to each sequence as identified in the legend.

7 CALCULATION OF THE COST OF REMEDIAL ACTIONS

For the calculation of the cost of the remedial actions it is important to specify where the information required to calculate these costs will be obtained from. There are two generic ways to obtain this information: through user inputs or through database queries. The calculation of each remedial action is now discussed.

7.1 Investigation cost

The customer complaint investigation process is seen as a support function of the production processes within the firm and is accounted for as an overhead in the running cost of the printers and rewinders on the factory floor.

7.2 Additional transport cost

The additional transport cost for a customer complaint related site visit has to be accounted for. A site visit can be made to investigate a customer complaint, to fetch defective labels from a customer for repair or deliver new/updated labels to the customer. The labour cost for this action also falls under customer complaint investigation, which, as mentioned, is accounted for as an overhead in machine running cost.

The physical transport cost can be calculated by establishing the distance travelled to the customer's site and back and the fuel consumption of the vehicle used. This information will be obtained through user inputs. The transport cost can then be calculated using the following formula:

$$Transport\ \text{cost} = C_{transport} = \text{D} \times \text{F} \tag{1}$$

Where

$D = Total\ distance\ traveled\ for\ complaint\ (in\ kilometers)$

$F = Fuel\ cost\ of\ transport\ per\ kilometer\ (in\ Rand/kilometer)$

7.3 Cost of credit

When a customer's account is credited the credit amount will be the exact amount charged for the quantity of defective labels received. This information will be obtained through user input.

7.4 Cost of updating a specification

The departments that are responsible for the administration before the production of a job will update the specifications. They are also seen as support functions of the production processes and are included in the running costs of the printers and rewinders.

7.5 Cost of a claim

A customer may claim for costs incurred as a result of down-time due to defective labels. The claim will be investigated and compared to industry standards to verify whether it is valid or not. The amount will be specific to the customer complaint and different for each instance. This information will thus be obtained from user input.

7.6 Cost of ordering a die

The cost of ordering a new die is a once-off fixed cost. Even though a die can be used for multiple jobs, the cost for ordering a new one is a cost associated with that defect. The cost of a new die is obtained from database information.

7.7 Cost of making a plate

The cost of making a new plate is also a once-off fixed cost. Similar to a die, a plate can be used for multiple jobs but the cost for making the new plate is associated with the complaint where the plate was incorrect. Since the plates are made in-house, the cost of making a new plate can be obtained from database information.

7.8 Cost of rewinding

The cost of rewinding is calculated using database information relating to the specific job's information. This information includes the running cost per hour of the rewinder used, the setup time of the rewinder, the rewinding time per label of the rewinder and the number of labels in the job. The rewinding time is a function of the number of labels. The rewinding cost can be calculated by the following formulas:

$$Rewind\ cost\ =\ C_{rewind} = (T_s + T_R) \times R_R \qquad (2)$$

Where

$R_R = Running\ cost\ of\ rewinder\ per\ hour\ (Rand/hour)$

$T_s = Setup\ time\ (hours)$

And

$$Rewinding\ time\ (hours) = T_R =\ N_l \times T_{Rl} \qquad (3)$$

Where

$N_l = Number\ of\ labels$

$T_{Rl} = Rewinding\ time\ per\ label\ (hours)$

7.9 Cost of printing

The cost of printing is calculated using database information relating to the specific job's information. This information includes the materials needed for the job and their associated costs, the running cost per hour of the printer, the setup time of the printer, the printing time per label of the specific printer and the number of labels in the job.

All materials used at the company are received on consignment, which means that the materials are stored at the company, but still belongs to the suppliers until it is used for a job. Material cost is thus not a function of volume purchases and is the same for all jobs.

The reprint cost for a job can be calculated by using the following formulas:

$$Print\ cost = C_{print} = (T_s + T_P) \times R_P +\ C_m \qquad (4)$$

Where

$R_P = Running\ cost\ of\ printer\ \ per\ hour (Rand/hour)$

$T_s = Setup\ time\ (hours)$

And

$$T_P = Printing\ time\ (hours) =\ N_l \times T_{Pl} \qquad (5)$$

Where

$N_l = Number\ of\ labels$

$T_{Pl} = Printing\ time\ \ per\ label$

And

$$Material\ cost\ =\ C_m = N_l \times (R_{paper} +\ R_{ink} +\ R_{foil}\ +\ R_{other}) \qquad (6)$$

Where

$R_{paper} = paper\ cost\ per\ label\ (Rand)$

$R_{ink} = ink\ cost\ per\ label\ (Rand)$

$R_{foil} = foil\ cost\ per\ label\ (Rand)$

$R_{other} = other\ features\ cost\ per\ label\ (Rand)$

7.10 Calculating the total cost of a customer complaint

The total cost incurred for a customer complaint is the sum of the costs incurred for every action taken to resolve the complaint. The total cost of a customer complaint can be calculated by the following formula:

$$C_{complaint} = C_{transport} + C_{credit} + C_{Claim} + C_{die} + C_{plate} + C_{print} + C_{rewind} \quad (7)$$

7.11 Calculating the profit or loss of a customer complaint

The profit or loss made on a customer complaint can be calculated as the job asking price minus the combined original production and complaint remediation cost. This information will give management the overall consequence of cost of a complaint on the business's bottom line. The formulae used to calculate the complaint profit or loss impact follow. If the value obtained ($P_{complaint}$) is positive, this indicates that some profit is still made on the job. If negative, the job is repaired at a loss. The loss in good will and reputation based on complaints are not accounted for in this study, but needs to be borne in mind by management when reviewing the cost calculation results.

$$Job\ profit\ generated\ after\ complaint = P_{complaint} = m\ C_{job} - C_{complaint} \quad (8)$$

Where

$C_{job} = Original\ job\ cost$

$C_{complaint} = Total\ cost\ of\ a\ customer\ complaint$

$m = Mark\ up\ ratio\ of\ job$

8 APPLICATION OF TOOL: CASE STUDY

To illustrate how the tool will work after implementation, a case study was done. The customer complaint illustrated is for the defect type "cut" with distinction "too deep" and defect ID CU0300. This defect occurs when the die that cut the labels into the specified shape, cuts through the label as well as the backing sheet. This makes it difficult to lift the label from the backing sheet during application. This defect often occurs during the production process.

The action sequence associated with this defect is looked up by the tool and found to be rework and/or reprint (RWRP). In this case, rework could be done on a portion of the reel. This would entail laminating the backing sheet on a rewinder. Where laminating the backing sheet cannot solve the problem, the labels will have to be reprinted.

The first action triggered by this complaint is an investigation. Additional transport cost will be incurred, because the investigation is conducted at the customer's site and the labels have to be brought back to the company's factory to correct the job, as requested by the customer. The customer does not claim for down-time, nor asks for credit. The defective reel contains 20 000 labels.

An inspection yielded that half of the reel can be salvaged and that the other half of the reel cannot be salvaged, and thus will have to be reprinted. The complaint cost calculation follow in Table 4. No new tool (die or plate) is required in this action sequence. Table 4 also indicates the data that the tool will prompt the user to enter, the data that the tool will retrieve from the database and the calculations that the tool will make.

The next step is to calculate the complaint profit or loss (Table 5), revealing the true consequence of the complaint to the management of the business. The tool outputs the cost of the complaint and the consequence of the complaint to the user. In this case study the cost of quality was a loss of R 965.00 on the order. If management is aware of the expected profit or loss implication that a certain action sequence will effect, they can make better decisions in terms of their preferred response to customer complaints.

Table 1: Customer complaints defect classification

Defect	Defect type	Distinction 1	Distinction 2	Description
AD0100	Administration	Information	Quantity	Administration defects refer to defects that occurred during the creation of the job. The information that is provided include job quantity and the unwind direction specified by the customer. A proof is a computer artwork that is used to develop the dies and plates used in production.
AD0201	Administration	Information	Unwind direction	
AD0202	Administration	Proof	Colour	
AD0301	Administration	Proof	Cut die	
AD0302	Administration	Proof	Embossing/Debossing	
AD0303	Administration	Proof	Foiling die	
AD0304	Administration	Proof	Paper	
AD0305	Administration	Proof	Print plate	
AD0306	Administration	Quote/invoice		
AP0100	Application	Ice bucket test failure		These are issues that the customer picked up after application of the labels.
AP0200	Application	Lifting after application		
BS0100	Backing Sheet	Folding side		These are defects with the non-adhesive paper that the labels are printed on.
BS0200	Backing Sheet	Tears/punches/damages		
BS0300	Backing Sheet	Varying height/blade setup		
BC0100	Barcode	Scanning failure		Fails to scan correctly.
CL0101	Colour	Colour Standard	Different	A colour standard is the first print of a specific label approved by the customer which is used as reference for future runs. The variations distinction included all defects that vary from the colour standard in terms of colour.
CL0102	Colour	Colour Standard	Faded	
CL0103	Colour	Colour Standard	Incorrect	
CL0104	Colour	Colour Standard	Invalid	
CL0200	Colour	Incorrect		
CL0301	Colour	Variations	Buff	
CL0302	Colour	Variations	Colour	
CL0303	Colour	Variations	Gear marks	
CL0304	Colour	Variations	Paper	
CL0305	Colour	Variations	Varnish incorrect	
CU0100	Cut	Orientation incorrect		The defect type cut refers to defects caused by the miss use of cutting die.
CU0200	Cut	Register out		
CU0300	Cut	Too deep		
ED0100	Embossing/Debossing	Register out		The defect type embossing/debossing refers to defects related embossing/debossing detail.
ED0200	Embossing/Debossing	Too deep		
ED0300	Embossing/Debossing	Too flat		
FL0100	Foiling	Breaking up		Foiling is the metallic detail that can be present on a label.
FL0200	Foiling	Ink scratch off on foil		
FL0300	Foiling	Register out		
HB0100	Hi Build	Miss print		Hi build is a when the ink of certain detail is printed thicker than on regular detail.
HB0200	Hi Build	Not as prominent		
HB0300	Hi Build	Register out		
HB0400	Hi Build	Sticky labels		
OP0100	Overprint	Can not		Defects that can occur in the over printing department.
OP0200	Overprint	Register out		
PP0101	Print Poor	Gear marks		Technical defects that can occur during the printing processes in the printing and over printing department.
PP0102	Print Poor	Ink curing/text smudge		
PP0103	Print Poor	Ink keying		
PP0104	Print Poor	Miss print		
PP0105	Print Poor	Pinholing		
PP0106	Print Poor	Scuffing		
PP0107	Print Poor	Scumming		
PP0108	Print Poor	Text squashed		
PP0109	Print Poor	Varnish incorrect		
PR0100	Print	Register out		Defects that can occur in the printing department.
PR0200	Print	Waste prints		
RE0100	Reel	Creased		The reel defect type includes defects that occurred on the reel of labels delivered to the customers. These defects were missed on the production line during the printing and rewinding processes.
RE0200	Reel	ID on reel incorrect		
RE0300	Reel	Labels shifted		
RE0400	Reel	Missing labels		
RE0500	Reel	Mixed labels		
RE0600	Reel	Overs incorrect		
RE0700	Reel	Quantity incorrect		
RE0801	Reel	Tension	Sticky labels	
RE0802	Reel	Tension	Too loose	
RE0803	Reel	Tension	Too tight	
RE0900	Reel	Trim waste present		
RE1000	Reel	Unwind/copy direction		

Table 2: Remedial actions to resolve customer complaints

Remedial action	Description	Action type	Cost drivers
Investigate	The first action performed when a complaint is received is to investigate the complaint. During this process it is established what defect occurred resulting in the specific complaint. Such an investigation determines whether further actions will follow and what they will entail.	Standard	Labour time (Quality department)
Additional transport	It may occur that during the investigation of a complaint the quality and/or risk managers, has to visit the customers' site on request to assist with labelling line and possibly transport labels back to the company's factory.	Complaint-dependent	Labour time (Quality department) Distance travelled
Credit	When a defect is such that the customer cannot use the labels received, it might be requested that their account is credited with the amount they were charged for the labels. As a result, the customer will not pay for the defective labels.	Complaint-dependent	Credit amount
Claim	A customer might have incurred down-time during production, because of the defective labels. Defect-related down-time typically occurs when labels have to be removed from products and the production line has to be stopped.	Complaint-dependent	Claim amount
Update specification	It is required to update job specifications when administrative details of a job or label where specified incorrectly. Specifications include detail about the labels' proof (artwork), the quantity of labels ordered, the unwind direction and the quotation or the invoice.	Standard	Labour time (Administration department)
Order die	When a die used for cutting, foiling, embossing or debossing is incorrect a new die must be ordered from an external supplier.	Standard	Die cost
Make plate	When the plate used for printing is incorrect, a new plate must be made by the plates department.	Standard	Plate cost
Rework	When a customer requires that the defective job must be corrected and the defect is such that good labels can be salvaged from the reel, rework is done on the reel. Rework entails only rewinding a reel on a rewinder or removing defective labels while on a rewinder.	Standard	Machining time Labour time (Production department)
Reprint	When a customer requires that the defective job must be corrected and the defect is such that all the labels on the reel are defective and rework cannot be done, the job must be reprinted. Thus the job has to undergo the whole printing process.	Standard	Machining time Labour time (Production department) Materials

Table 3: Remedial action combinations to resolve specific customer complaints

Code	**Combination**	**Description**	**Defect IDs**
US	**Update specification**	When the detail on a quote or invoice is incorrect it is only necessary to update the specifications of the quote or invoice, since it means that an incorrect amount were charged and not that the labels was defective.	AD0306
RP	**Reprint**	A job has to be reprinted when all the labels on a reel are defective and no labels can be salvaged by rework.	AP0100, AP0200, BC0100, CL0102, CL0200, CL0304, CU0100, ED0300, HB0200, HB0400, OP0100, PP0102, PP0109, RE0600, RE0801
RW	**Rework**	When the labels on a reel are correct, but there is an issue with the reel or with the backing sheet that does not affect the labels, the defect can be corrected by rework alone.	BS0300, RE0300, RE0802, RE0803, RE0900, RE1000
RWRP	**Rework and/or reprint**	When only some of the labels on a reel are defective, the good labels can be salvaged by rework. In this case reprint might have to occur after rework is completed if the label quantity falls short of the quantity ordered.	BS0100, BS0200, CL0301, CL0302, CL0303, CL0305, CU0200, CU0300, ED0100, ED0200, FL0100, FL0200, FL0300, HB0100, HB0300, OP0200, PP0101, PP0103, PP0104, PP0105, PP0106, PP0107, PP0108, PR0100, PR0200, RE0100, RE0200, RE0400, RE0500, RE0700
USRW	**Update specification and rework**	This configuration only occurs when the job information specified the incorrect unwind direction of the reel. The specification has to be updated and the reel must be rewound to change the unwind direction.	AD0201
USRP	**Update specification and reprint**	When the job information (quantity, the paper to be used or the colour to be used) is incorrect in terms of printing the job the specification must be updated and the job reprinted.	AD0100, AD0202, AD0304
USNRP	**Update specification, new tool and reprint**	A die or plate can only be incorrect if the proof used to make the die or plate was incorrect. A new die cannot be ordered without updating the specification of the proof. The job cannot be corrected by reprinting without the new tool (die or plate).	AD0301, AD0302, AD0303, AD0305, CL0101, CL0103, CL0104

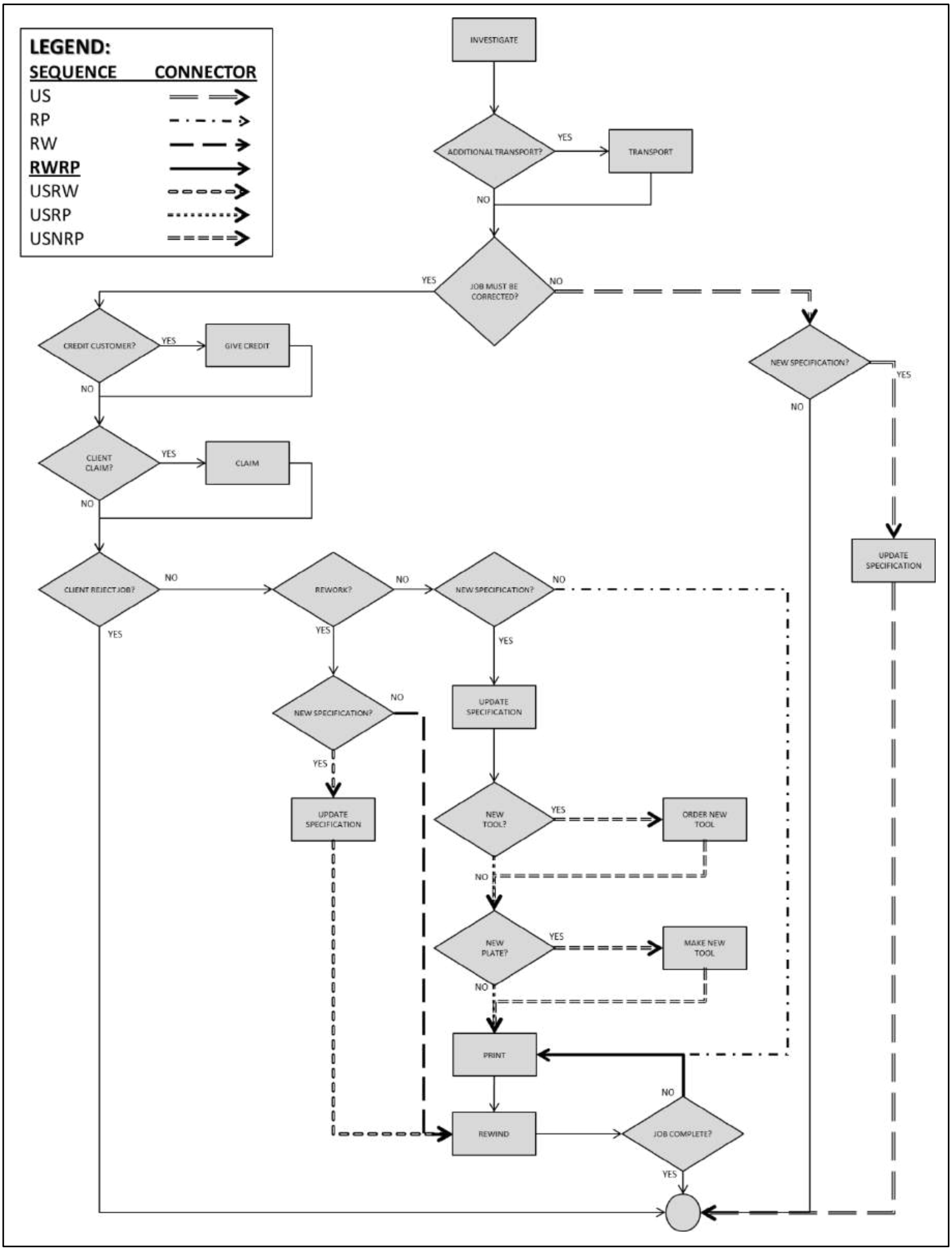

Figure 2: Process flow chart of the response by the company to any complaint

9 RESULTS

The same job specifications used in the case study was combined with different complaints in order to calculate the comparable cost of the other six remedial action sequences (See Table 6). By comparing the costs of the sequences it can be determined which sequence incurs the highest negative consequence. The defects associated with that sequence can be classified as the most important to management, since they are most expensive to the business. These defects can then become the focal points of quality management initiatives within the company. It was found that the USNRP action sequence has the highest negative consequence, since a new die (typically costing R 6 000.00) has to be ordered. It is evident that defects requiring new tools must be focused on in terms of preventive quality management.

Should the company implement the tool developed in this study, it will enable the collection of complaint frequency data combined with the associated costs per complaint over time so that, ultimately, the greatest contributors to overall failure-related quality expenses can be identified and managed. Further to this, the tool can serve to facilitate data benchmarking where the impact of quality management interventions can be assessed by comparing "old" statistics to "new" values.

10 CONCLUSION

In this day and age where competition has dramatically increased the importance of customer satisfaction, quality management has become an important aspect to be managed by production companies. It is, however, a management field that is often managed based on very little investigation into the causes of the quality issues in a firm. The literature has reached consensus that simple, tailored models are best suited to ascertain the cost of quality. The focus in this study was to develop such a model for a label printing company in South Africa. Several important preparatory work have been identified which needs to be completed before such a tool can be developed. This includes a data standardisation exercise, followed by an interrogation into the remedial actions a company can associate with each standard complaint type. Once this has been established, cost calculation formulae can be developed.

In the end, the tool can be used to calculate the expected cost of quality for failure complaints at the manager's whim. After long term implementation and use of the tool, the customer complaints received over a predetermined period can be used as inputs to perform a Pareto analysis that will determine which defects management should prioritise. Other managerial benefits can be obtained such as quality management performance measurement and the determination of cost thresholds where it might be more desirable to discard a job entirely.

The tool developed was applied to an example complaint and found to easily provide the answers desired. It can be concluded that the tool developed sufficiently addresses the cost of non-conformance. It is recommended that a tool to assess the cost of conformance component of the cost of quality be developed. The end goal would be to combine to cost of conformance model with the cost of non-conformance model in order to obtain a total cost of quality picture of the label printing company's operations.

Table 4 Calculation of case study complaint cost

Action	Information	Value	Data origin
Additional transport	$\boldsymbol{C_{transport} = D \times F}$	**R 390.00**	**Calculation**
	$D = Distance\ traveled\ (in\ kilometers)$	30	User input
	$F = Fuel\ cost\ of\ transport\ per\ kilometer\ (in\ Rand/kilometer)$	13.00	User input
Rewind	$\boldsymbol{C_{rewind} = (T_s + T_R) \times R_R}$	**R 283.33**	**Calculation**
	$R_R = Running\ cost\ of\ rewinder\ per\ hour\ (Rand/hour)$	200.00	Database
	$T_s = Setup\ time\ (hours)$	0.4167	Database
	$T_R = Rewinding\ time\ (hours) = N_l \times T_{Rl}$	1	Calculation
	$N_l = Number\ of\ labels$	30 000	Database
Print	$\boldsymbol{C_{print} = (T_s + T_P) \times R_P + C_m}$	**R 2833.33**	**Calculation**
	$C_m = N_l \times (R_{paper} + R_{ink} + R_{foil} + R_{other})$	1 500.00	Calculation
	$R_{paper} = paper\ cost\ per\ label\ (Rand)$	0.11	Database
	$R_{ink} = ink\ cost\ per\ label\ (Rand)$	0.02	Database
	$R_{foil} = foil\ cost\ per\ label\ (Rand)$	0.02	Database
	$R_P = Running\ cost\ of\ printer\ per\ hour$	800	Database
	$T_s = Setup\ time\ (hours)$	1	Database
	$T_P = Printing\ time\ (hours) = N_l \times T_{Pl}$	0.67	Calculation
	$N_l = Number\ of\ labels$	10 000	Database
Total	$\boldsymbol{C_{complaint} = C_{transport} + C_{print} + C_{rewind}}$	**R 3 506.66**	**Calculation**

Table 5 Calculation of case study complaint consequence

Consequence	Information	Value	Data origin
Profit or loss	$P_{complaint} = mC_{job} - C_{complaint}$	**-R 965.00**	**Calculation**
	$C_{complaint}$	R 3 506.66	Database
	$C_{job} = Job\ cost$	R 5 083.33	Database
	$m = mark\ up\ ratio$	0.5	Database

Table 6 Comparison of action sequences consequence

Code	Action sequence	Consequence
US	Update specification	-
RP	Reprint	-R 2 931.67
RW	Rework	R 1 935.00
RWRP	Rework and/or reprint	-R 965.00
USRW	Update specification and rework	R 1 935.00
USRP	Update specification and reprint	-R 2 931.67
USNRP	Update specification, new tool and reprint	**-R 8 931.67**

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MEASURING EFFECTIVENESS AND EFFICIENCY IN MAIL OPERATIONS AND BUILDINGS: 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 postal industry. Our approach to this energy management system emphasises on effectiveness and efficiency as tools that are capable for managing energy use in buildings. The South African Post Office is used to determine the scope and benchmarking of the energy management system for mail operations and buildings.

This study focuses on assembly of data that enables the identification of energy management opportunities with focus on efficiency and effective of energy usage. Historical data on energy usage of the buildings was collected in order to determine the baseline and tracking of the trends of energy utilization within the post office buildings.

The implementation of the system will focus on the high energy consuming buildings and phased out to buildings which are low in consumption. This continual improvement system will guide the efficiency and effectiveness indicators through measurable tools which focus on occupation and utilization of energy in buildings. As a result of monitoring, efficiency and effectiveness of energy usage will be realized when there's total synergy between innovative technologies and energy efficiency training of employees.

Keywords

Buildings; Energy Efficiency; Energy Management System; Kilowatt-Hour; Mail Operations;

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 [1].“The electricity generation in South Africa had a greater share of 92% from coal fired stations in 2004” [2], which leads to high GHG emissions. The South African Post Office operates over 2000 buildings. The buildings are categorised according to the type of operations and size, 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. 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 management system and also integrating the effective and efficient usage of energy in the buildings.

Currently the South African Post Office is in the process of implementing ISO 14001:2004-Environmental Management System. The basis of the system is to reduce pollution whilst ensuring effective and efficient use of natural resources. The application of ISO 50001:2011 in our energy management system (which will feed into ISO 14001:2004 system) will improve the system thereby better preparing the South African Post Office for the implementation of ISO 14001 or subsequently integrating the two systems and obtaining certification of the two systems (ISO 14001:2004 and ISO 50001:2011).

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 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 Centre	Location	Size (Sq. meters)
Tshwane Mail Centre	23 Potgieter Street, Pretoria 0001	28 600
Bloemfontein	Boemmark Fresh Market, Bloemfontein, 9300	4 679
Cape Town	Mail Street, Good Wood, Cape Town 7460	64 240
Witspos	Corner Northern Parkways & Roeland street, Ormonde, 2091	34 000

Figure 1. Map indicating the location of the studied sites [3]

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. Human behaviour was assessed through a survey using a questionnaire as a measuring tool.

2.3 Data analyses

Information was gathered on the recommended energy efficient technologies and existing technologies in Lighting, HVAC, Hot Water Systems Computers and Machines (sorting and stamping). 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 distributed consists of two options which were 0- which represented the responses that were Not Applicable (N/A) and the No; the affirmative was represented by the number 1. There were no interviews conducted to the employees. Responses enjoyed a high degree of freedom in completing the questionnaire without any possible influence from the interviewer, thus making the results more reliable. The number for Not Applicable as an answer indicates that the question does not apply to the individual; the 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 applies to the individual and it is practised. The responses received, indicated the impact the human behaviour has to energy efficient and ways of using energy.

During the analysis of the data the 0 and 1 (Not applicable and No) were combined to be represented by 0 as the activity for both responses were not carried out. The results of the questionnaire were displayed on a bar graph for the responses that were affirmative. The graph represents the number of individuals that responded with yes for all the questions and the difference from the number of individuals that responded represents the 0 (No and N/A)

The historic data of energy usage and cost was used to indicate the change in usage from 2010 to 2012. The data was analysed by comparing 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 [4].

3.1 Lighting

The table below shows the type of lights in the mail centres. The existing technology is compared with the recommended lighting technology by Eskom in terms of Watts the light use and the type of light. The comparison shows the difference between the recommended and existing technology which shows the effectiveness of energy used in lighting.

Table 2: Lighting technology comparison

Type of lights	Existing Technology	Recommended technology
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

The hot water system comparison compares the existing hot water systems in the buildings with the recommended technology by Eskom based on the power and type of technology. The comparison is meant to indicate efficiency of the existing technology and also determining the buildings effectiveness on energy technology.

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

In assessing the human behaviour factor toward energy technology usage in buildings, the responses received from the 98 survey participants were analysed. A graphical representation is shown in figure 2.

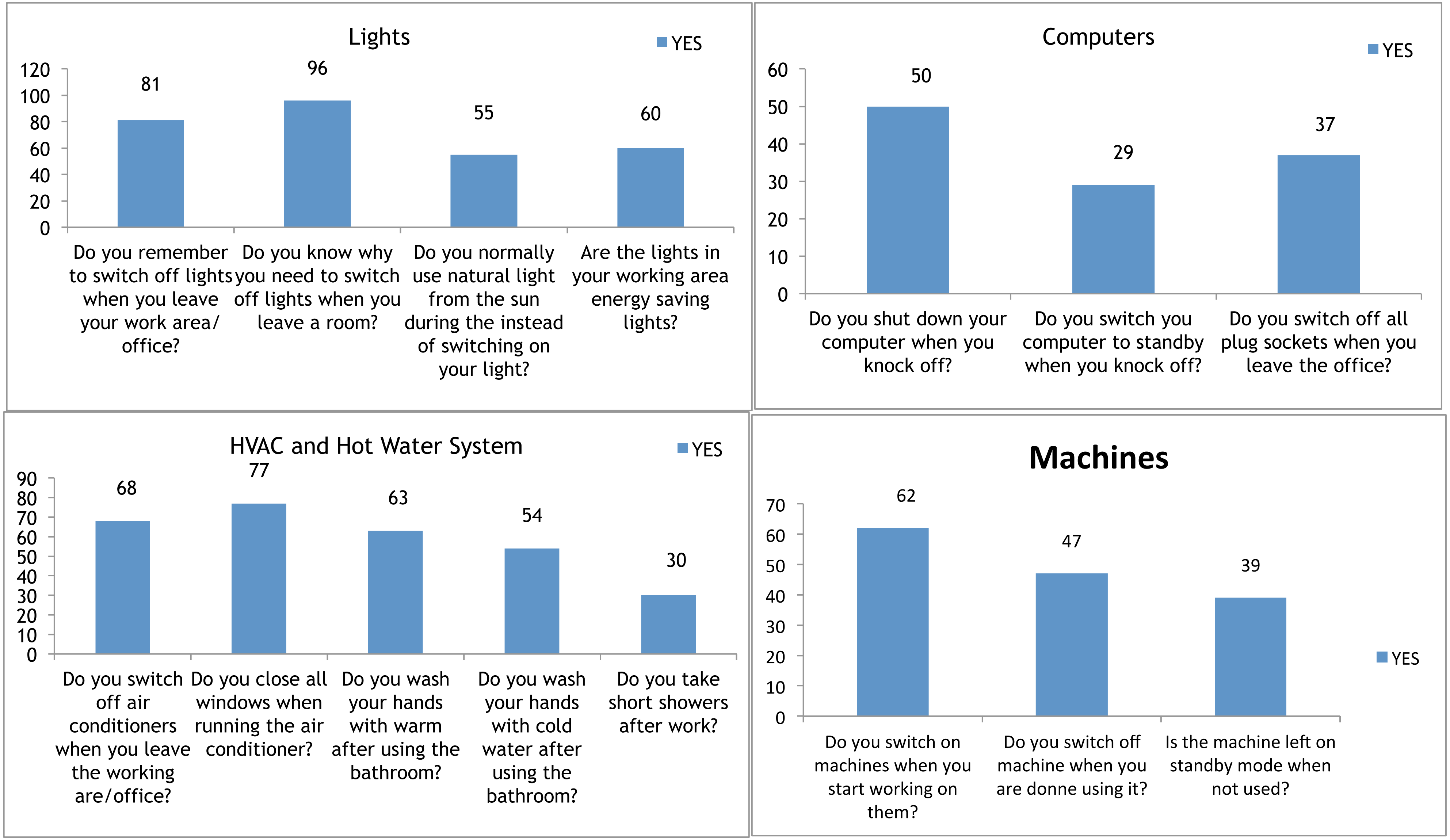

Figure 2: Responses per user category of technology

3.5 Efficiency

The SA Post Office energy efficiency is measured using the historical energy usage data for the four sampled buildings with the current usage. The baseline set for this study is 2010; the data is populated up to 2012; 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 four buildings that were sampled for the study.

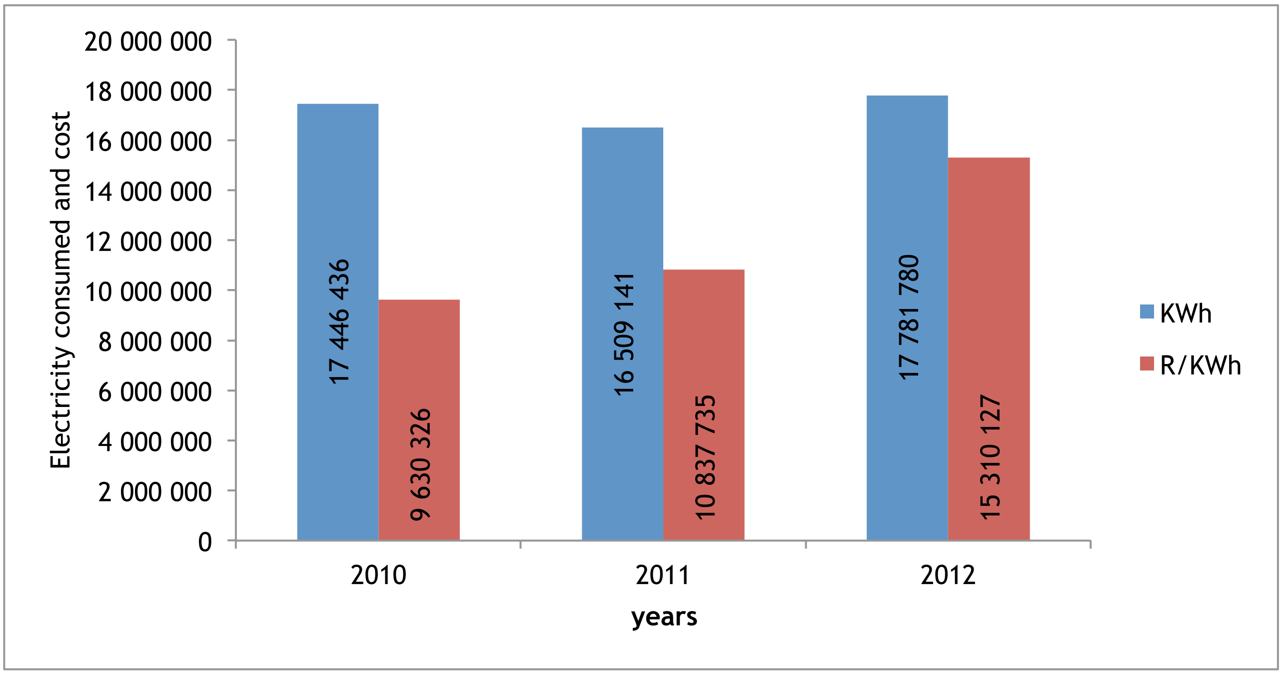

Figure 3. Sample annual electricity consumption

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 (2010 to 2012).

4.1 Effectiveness (Analysis of technology of electrical component)

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.

4.2 Efficiency

The results reflect the responses from 98 people who participated in the survey or completed the questionnaire. The figures representing the results reflect the response of people who responded with affirmative. The survey results indicate the role of human behaviour in energy usage and show that with sufficient training and awareness on effective and efficient energy usage the impact can be reduced.

4.2.1 Lighting

The human behaviour toward lighting indicates that employees are aware of the controlling usage in lighting; employees also show to be aware of the reasons of switching off the lights. However, it is evident that employees still have a high dependence on artificial lighting instead of natural lighting as indicated by lower percentage of people who use natural lighting according to the questionnaire responses. Awareness should be raised in terms of how much light is required in working spaces; this will assist employees in making decisions on when to switch on lights or rely on natural light in their activities.

4.2.2 Computers

At least more than 50% of employees do switch off their computers or put on standby mode when they knock off, although this is a rather satisfactory figure. It is without any doubt that with greater awareness on the importance of switching off appliances after use, the numbers can increase substantially. Employees should be made aware that putting their computers to standby is not enough to save electricity. The results also imply that employees should be encouraged to switch off their computers on the wall sockets given the lower number of respondents who said they do exercise this.

4.2.3 HVAC and Hot Water System

The Hot water usage in the buildings indicates that even though hot water usage is not part of the main operations. There are still 30% of the employees that take a shower after work and that employees mainly use hot water to wash their hands. This indicates that there is less demand for hot water. The results indicate that there is old technology in hot water systems and also the training of employees.

4.2.4 Machinery

The use of machinery indicates that the buildings machines are left on standby for most of time as compared to the machine being switched off after being used. The inefficiency of the energy usage in the sampled buildings is evident to be from the old technologies that are being used and the behaviour and understanding of the employees toward energy usage reduction and management.

4.3 Analysis of Annual Energy Consumption

The energy efficiency of the buildings from the baseline year 2010 shows a reduction in energy used in 2011 as compared to 2010 by 5.4% followed by an increase in 2012 as compared to 2011 by 7.7%. The result indicates 2011 to be energy efficient and 2012 to be inefficient. The data shows that two mail centres of the sampled buildings consumed high and they are currently using the 3000 litre boilers which consume more electricity at 36kW. The causes for the energy usage decline in 2011 and incline in 2012 usage could not be identified as there were previously no measuring tools in terms of building usage except for the municipal meters. The possible cause could be the increase in machinery in buildings, increase in work to be processed which may require more energy to be used. The energy usage requires smart metering that will enable the company to see inclines and declines in usage and specifically in each electric component as a measuring tool to improving where it is required.

5 CONCLUSION

The study has indicated that there is a need to integrate the effective usage with the efficient usage in managing the buildings energy usage. With the correct usage of energy technology and well trained employees, the company will be able to achieve an effective ("doing the right things right") and efficiency ("doing the right within cost, performance and quality").The change of technology and human behaviour to energy efficient technology and energy conscious behaviour will lead to reduction in energy which will reduce cost in energy. The system will yield to 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.

It is recommended that within the energy management system to be implemented at the South African Post Office measuring tools for energy be installed. Smart metering is one of the highly recommended systems as it allows the facility manager to identify the time of peak in usage and any decline that occurred. It is also one of the important factors in monitoring and continuous improving that it should be measurable.

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ENHANCING PROJECT MANAGEMENT IN SOUTH AFRICAN SMALL BUSINESSES BY FOCUSING ON PROCESS IMPROVEMENT METHODOLOGIES

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ABSTRACT

Execution of projects is important in the day to day management of any enterprise. The project management triangle, which consists of time, cost and scope, must be balanced in order to optimise project execution results. Within the project priority matrix these interrelated critical aspects can be balanced in three ways by either accepting changes to one or more of the aspects, constraining some aspects so that they don't change, or choosing to enhance an aspect by means of improvement if possible. This paper provides a framework that strives to enhance the project management decision making around the critical aspects by improving the overall balancing performance. The framework focuses on small and medium enterprises (SMEs) in South Africa that suffers from a lack of managerial and technical skills. Improvement methodologies are studied to provide tools and techniques that can increase the effectiveness, efficiency and agility of project implementation. Three methodologies were identified for consideration namely, lean thinking, the theory of constraints, and six sigma. The focus will be on the elements of these methodologies that apply to project management within skill constrained SMEs.

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1 INTRODUCTION

It is generally accepted that the nature of the modern business environment is best characterised by changing trends and events. Therefore the future success of enterprises depends on their ability to react, operate and adapt to a changing environment [1]. Evidently, a systematic approach is necessary for the successful structuring of change processes.

Project management is the process of achieving project objectives initiated by the need to change. It is a temporary group activity that has a defined beginning and end time and therefore defined scope and resources. Enterprises in South Africa are training their staff in the science of project management as the benefits of operating in a project capacity become more visible [2]. This training involves the discipline of planning, organising, motivating, and controlling resources to achieve project specific objectives.

Projects are unique and need to be performed and delivered under certain constraints or critical aspects. Traditionally, these aspects have been listed as time, cost and scope [3]. Together they form the project management triangle, which shows that these aspects are interrelated since one corner of the triangle cannot be changed without affecting the others. The project management triangle is displayed in Figure Figure 1 below.

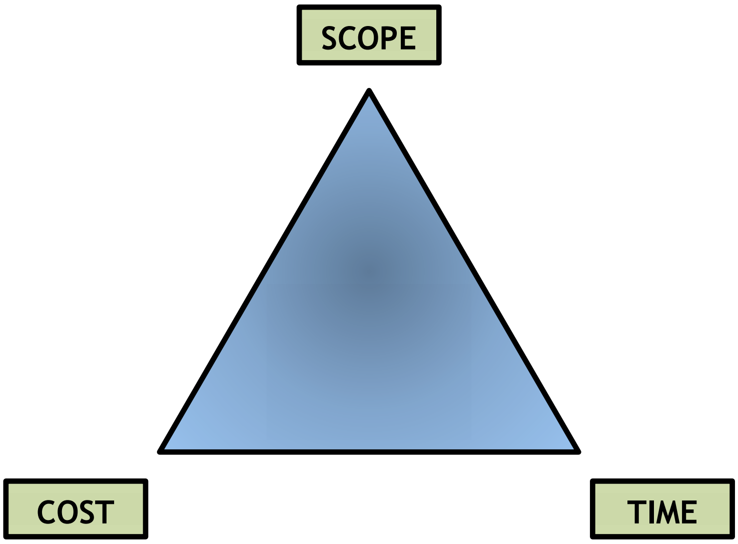

Figure 1: Project Management Triangle

The critical aspects represented in the project management triangle must be balanced in order to optimise the output of project execution. Within the project priority matrix these interrelated aspects can be balanced in three ways by either accepting changes to one or more of the aspects, constraining some aspects so that they don't change, or choosing to enhance an aspect by means of improvement if possible.

1.1 Problem Statement

Enhancing each aspect of the project priority matrix, as shown in Figure 2, means that projects are executed faster and cheaper within a refined scope. This is achieved through the application of project management knowledge, skills and techniques to improve project execution results. In SMEs this opportunity is limited by a number of factors, mainly access to finance, managerial skills and technical skills [4].

The lack of financial access limits the opportunity for acquiring advance technology and outside expertise, but it is the lack of internal skills that restricts project management optimising potential. This lack of skill renders management incapable of identifying inefficient practices and therefore ignoring the need to enhance critical aspects. Above all, insufficient technical skills cause a shortage of project management supporting tools and methods that enables planning and execution of successful projects.

	Accept	Constraint	Enhance
Cost			X
Time			X
Scope			X

Figure 2: Enhancing Project Priority Matrix

1.2 Objectives

The objective of this paper is to provide a framework that enhances project management decision making around the critical aspects by improving the overall balancing performance of the project management triangle in skill constraint SMEs.

A theoretical analysis is carried out to determine the connections between the critical aspects. Understanding how these aspects are related allows the manipulation of the connections to ultimately enhance their associated aspects.

1.3 Methodology

This study was done through a theoretical analysis of three commonly used continuous process improvement methodologies. These methodologies were chosen because of their relation with the project management triangle. A potential representation of how the improvement methodologies can be integrated into the project management triangle is displayed in Figure 3, after which a short explanation follows.

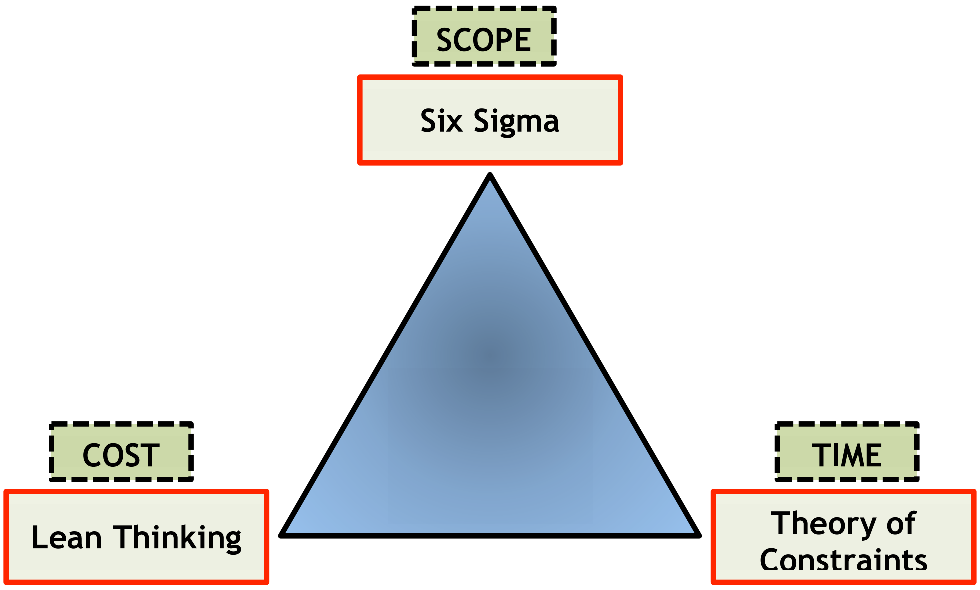

Figure 3: Integrated Process Improvement and Project Management Triangle

The first methodology, lean thinking, focuses on value adding activities. In other words, the primary objective is to increase value faster than accumulating cost [5].

The second methodology, theory of constraints, emphasises faster system throughput by means of constraint alleviation. The throughput is inverse proportional to the cycle time of a process. Evidently, by increasing throughput, cycle time decreases [6].

The third methodology, six sigma, focuses on improving the process quality and in affect process performance of improvement projects. These two characteristic is the results of a further refinement of the project scope [7].

2 LITERATURE REVIEW

This section explores the continuous process improvement methodologies that were identified to be integrated into the project management triangle. The focus of this literature review is on the elements that may be applied to project management within skill constrained SMEs.

2.1 Lean Thinking

Lean thinking focuses on increasing the rate of value adding activities, which is pulled by the customer, by using a set of tools to continuously improve this flow. Furthermore, it is an integrated way of thinking that relies on the cooperation of the entire enterprise. It also supports continuous learning and empowerment of the front line employees. [5]

During the 1950s and 1960s Taiichi Ohno and his colleague Shigeo Shingo developed the infamous Toyota Production System (TPS), which can be visually represented by a house with three pillars. The base of the house represents operational stability through continuous improvement, standardised work, visual management and a clean, organised working environment. This forms the foundation of the three pillars that represent just-in-time, jidoka, and workforce involvement. These pillars support the final goal of rapidly providing customers with cheap, high quality product and services. The fundamental concepts will be explained later, but notice how the roof (fast, cheap, high quality) relates to the project management triangle (time, cost, scope). [5]

Jim Womack, Dan Jones and Dan Roos popularised the term lean thinking when they wrote the book entitled “The Machine that Changed the World” in 1990 [8]. In this book they claimed that lean can be applied to a wider range of industrial settings, including service industries.

Lean thinking can be summarised according to four principles. These can be stated as the 4P principles: philosophy, people & partners, problem solving and process focus [5].

2.1.1 Philosophy

Top management should commit to a vision and support an implementation strategy to sustain improvement processes. This drives long term dedication to building a learning organisation that can easily adapt to changes in the environment.

Management base their decisions on the growth and alignment of the whole enterprise towards a common purpose, even at the expense of short-term financial goals. The starting point is to generate value for the customer, society, and the economy.

2.1.2 People and Partners

An internal continuous learning and improvement culture is necessary to guides the employees through the change process towards the values of lean thinking. A stable culture with shared values and beliefs is both a result and enabler of sustainable and successful lean operations [5].

Employees operate in cross functional teams to stimulate personal and professional growth, share the opportunities of development through education, and maximise individual and team performance. These teams also provide a diverse set of skills and knowledge that support internal learning. Furthermore, employees are empowered to take responsibility and use their own judgement to make decisions within the context of best practice methods.

The external network of partners and suppliers is treated as an extension of the business. They are respected and challenged to grow and develop through improvement assistance. Suppliers need fair and honourable business relations, stable and reliable processes, clear expectations, enabling systems, and learning assistance.

2.1.3 Problem Solving

The focus of a continuous learning system is to identify root causes and problems and preventing them from occurring. This can be done by going to the source and personally observing and verifying data for better understanding and analysis of the process.

When root causes and problems are identified it is important to make decisions slowly by consensus. All options are thoroughly considered, since the process of arriving at a decision is just as important as the quality of the decision, and final decisions are rapidly implemented after all alternatives are taken into account.

Throughout the execution of decisions it is important to reflect after reaching milestones to openly identify all shortcomings of the project. Countermeasures are developed to avoid future mistakes. However, best practices are standardised to support future project.

2.1.4 Process Focus

The real challenge of lean process improvement is to know how to start. Womack and Jones specified five steps that provide a roadmap for successful implementation. These principles are: (1) identify value, (2) map the value stream, (3) create flow, (4) establish pull, and (5) pursue perfection. [8]

The first step, value analysis, is the identification of customer specific needs to define value from their perspective. This is necessary to ensure waste free processes. Taiichi Ohno identified seven forms of waste: (1) unnecessary transportation, (2) excess inventory, (3) unnecessary motion, (4) waiting times, (5) overproduction, (6) and (7) defects. Unused talent is frequently added to list of wastes.

Secondly, value stream mapping is necessary to document and analyse process detail in terms of material and information flow that brings a product or service to the customer. Value stream mapping is adapted by Mike Rother and John Shook [9] from Toyota's material and information flow diagrams.

Thirdly, smooth flow is created to increase material movement as well as linking people and processes together so that problems surface right away. Flow is created through various methods such as standardised work, load levelling, visual management, total productive maintenance, quick changeovers and built-in error prevention.

Fourthly, pull systems are implemented to avoid overproduction and over processing. The concept of pull is to produce exactly what customers need, when they need it, in the quantity they need it, without defect at the lowest possible cost. Pull systems are usually initiated through the use of kanban cards that signals when an order is received.

The final step is to pursue perfection by repeating the all of the previous steps with constant attempt to increase the performance and quality of all business processes.

2.2 The Theory of Constraints

The theory of constraints (TOC) is an improvement approach that focuses on alleviating the constraining elements of operations in order to allow a business to perform at its optimal level. The theory purports that every business has a constraining elements that prohibit it from performing at a higher level. [10]

The method was introduced to the world by physicist and author Dr. Eliyahu M. Goldratt in his novel entitled “The Goal” which was published in 1984. [6]

One of the appealing characteristics of the TOC is that it inherently prioritises improvement activities. The current constraint is always the top priority. In environments where there is an urgent need to improve, TOC offers a highly focused methodology for creating improvement.

2.2.1 Five Focussing Steps

TOC is based on the premises that every process has a single constraint and that total process throughput can only be improved when the flow through the constraint is improved. Therefore the constraints should be identified, and the organisations efforts should be expanded to overcome the constraint.

The TOC systems approach requires that you first understand the system, its goal and measurements before applying the five focussing steps to alleviate the constraint. These steps are: (1) Identify the constraint, (2) exploit the constraint, (3) subordinate to the constraint, (4) elevate the constraint, and (5) repeating the process. [6]

The first step, identifying the constraint, looks for the weakest link in the most used processes. Constraints may not just be physical, but can include intangible factors such as ineffective communication, restrictive company policies, or even poor team morale. Tools such as flowcharting, Pareto analysis and queuing models can be used in this step.

The second step is the exploitation of the identified constraint. Basically it means maximising throughput of the constraint, by increasing its capacity, using currently available resources. This step focuses on quick wins and rapid relief through improved utilisation of the constraint while leaving more complex and substantive changes for later.

The third step is to subordinate the other operations in the process to the constraint. By definition, all non-constraining operations have some degree of excess capacity, which enables smooth operation of the constraint by ensuring that the constraint buffer is continuously filled. A useful technique is the Drum-Buffer-Rope system that synchronise operation to the needs of constraint by releasing material according to time buffers.

The fourth step is to elevate the constraint. This implies that substantive changes are implemented to improve the capacity of the constraint. These include, changing the layout of the process, acquiring additional external sources or working overtime. This may necessitate a significant investment of time and/or money.

Finally, the cycle should be repeated to prevent inertia. The reason is that when a constraint is broken, another part of the system or process chain becomes the new constraint and the performance of the entire system must be re-evaluated. [11]

2.2.2 The Thinking Process

TOC includes a sophisticated problem solving methodology called the thinking process. This process is designed to optimised complex systems with many interdependencies or variability. This is achieved through a scientific cause-and-effect approach, that strives to first identify the root causes of undesirable effects (referred to as UDEs), and then remove the UDEs without creating new ones.

This process essentially breaks down into three questions: (1) what to change, (2) what to change to, and (3) how to initiate the change. These questions are answered through the strategy and tactic trees that have been developed by Dr. Goldratt. There are four main trees which provide a roadmap from the as-is situation to the to-be situation: (1) Current Reality Tree, (2) Conflict Resolution Diagram, (3) Future Reality Tree, and (4) Transition Tree. [12]

The Current Reality Tree (CRT) is a type of flowchart that documents the current state of a process. It depicts the cause-and-effect relationship that exists for the object of interest, starting with a list of UDEs. The contributing factors that perpetuate these effects are associated with them and listed accordingly to identify the root causes. [10]

The Conflict Resolution Diagram (CRD) evaluates potential improvements. It is a diagram that helps to identify specific changes (called injections) that eliminate UDEs. Injections are conditions or actions that occur in the future and are geared toward overcoming any underlying assumptions that prevent the achievement of objectives. The diagram is particularly useful for resolving conflict between process prerequisites and different injections.

The Future Reality Tree (FRT) documents the to-be situation of the process, which reflects the results of injecting changes into the system. Starting with the injections identified in the CRD, the purpose is to identify all possible effects of the proposed injection when applied to the current reality.

The Transition Tree (TT) is basically a project management tool that provides the detailed action plan to move from the current process state to desired process state. This tree is used as the final implementation plan when you have completed your simulation activity and are ready to go forward.

2.2.3 Throughput Accounting

Measurement is the common language for a company and communicates priorities. There are three primary indicators that Dr. Goldratt identified to measure the performance of a business: (1) throughput, (2) operating expense, and (3) inventory. [10]

Throughput is the rate at which the system generates money through sales. Mathematically it is the money generated by the system less variable costs (typically raw materials, sales commissions, freight, and labour tied to pieces produced).

Operating expense is all the expenditures a business incurs as a result of performing its normal business operations. Basically it’s all the money that the system spends in turning inventory into throughput.

Inventory, also known as investment, is all the money tied up in physical assets such as product inventory, machinery, equipment, and real estate.

2.3 Six Sigma

Six Sigma is a structured, data driven, problem solving approach for improving processes. Its strength lies in the advance statistical tools that are implemented within a formal organisational structure.[7]

Originally pioneered by Bill Smith at Motorola in 1986, six sigma was popularised by Jack Welch, former CEO of General Electric, in 1995. It was designed as organisational initiative that strives to produce no more than 3.4 defects per million opportunities. This quantity is based on the assumption of a 1.5 sigma shift in mean.

The purpose of this methodology is to align all business processes with the needs of the customer. To achieve this purpose, six sigma seeks to find and eliminate causes of variation and defects in business processes by focussing on outputs that are of critical importance to customers. Furthermore, it required extensive training of employees since project members are selected according to their knowledge of statistical tools and improvement experience.

A five step model is implemented for reaching project objectives: (1) define, (2) measure, (3) analyse, (4) improve, and (5) control. This is called the DMAIC model [7]

The first phase, define, involves top management to define the problem and scope of the project according to customer feedback and the strategy of the company. The first step is to identify the critical needs of the customer. Thereafter, for each need, you identify its quality drivers which are the factors that the customer will use to evaluate the quality of the product. Finally, identify measurable performance goals that each driver must satisfy if you're to actually provide a high quality product to your customers. Useful tools include the SIPOC diagram that identifies the suppliers, inputs, process steps, outputs, and customers of the studied process, while the Critical-to-Quality Tree translate broad customer needs into specific, actionable, measurable performance requirements. [13]

The second phase, measure, involves the development and implementation of a data collection plan. Firstly, all the aspect that is critical to quality is operationally defined. Secondly, a repeatability and reproducibility study is performed to determine the validity of process measures. Finally, the collected data is used to develop a baseline for process capability and performance.

The third phase, analyse, determines the underlying cause of problems by converting raw data into information that that provides insight into the process. In this phase, the project team uses data analysis tools and process analysis techniques to identify and verify root causes of the problem. A good place to start is with non statistical Root Cause Analysis tools such as Pareto analysis and Ishikawa diagrams. Thereafter more advance tools are used such as linear regression, correlation analysis and analysis of variance.

The fourth phase, improve, entails the generation and selection of solutions that will eliminate the identified problems and reduce process variation. It requires improving or optimising the process based upon data analysis techniques like Failure Mode and Effect Analysis (FMEA) and Design of Experiments (DOE). FMEA is a analytical approach directed toward problem prevention through which every possible failure mode is identified and risk rated, while DOE looks at multiple levels of multiple factors simultaneously and make decisions as to what levels of the factors will optimise output. [13]

The fifth and final phase, control, involves the evaluation of the implemented solutions by controlling the process to ensure that any deviation from the target is corrected before they result in defects. The objective is to maintain improvement by measuring process performance and capability. Two primary tools of this phase are control charts, which presents a graphical display of process stability or instability over time, and process capability analysis.

3 INTEGRATED PROJECT MANAGEMENT FRAMEWORK

The focus of this section is the development of an integrated project management framework that strives to enhance project management by improvement the overall balancing performance of the critical aspects of the project management triangle in skill constraint SMEs.

The focus of the framework is not on the direct improvement of each critical aspect, but rather on overall improvement. Therefore connections between these aspects were identified to improve the understanding of their interrelatedness. The three connections are the focus of project improvement in terms of (1) effectiveness, (2) efficiency, and (3) agility. These connections are shown in Figure 4.

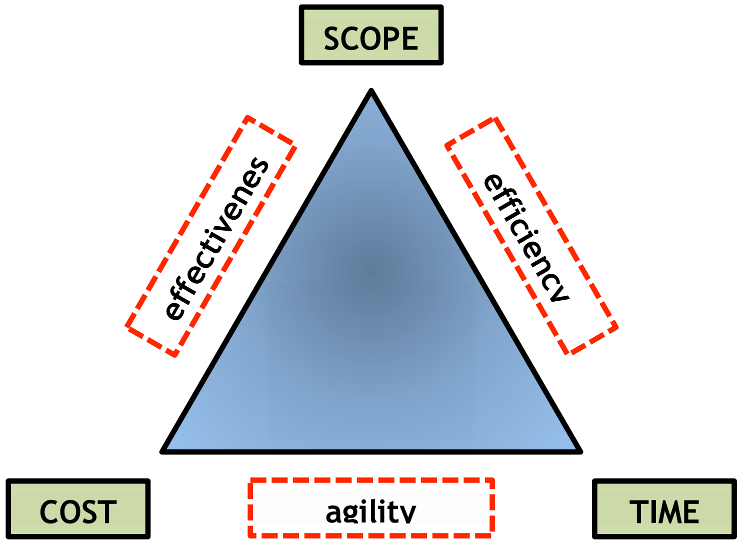

Figure 4: Project Management Triangle with Connections

Effectiveness connects cost and scope. It is defined in terms of how successful a process is in producing a desired or intended result. Being effective is about doing the right thing. In other words it is to create value from the customer's perspective.

Efficiency connects time and scope. In short it is to perform or function in the best possible manner with the least amount of waste and effort. Being efficient is about doing things in the right manner. Basically it describes the quality of the process.

Agility connects cost and time. It is defined as the ability of a system to adapt rapidly and cost efficiently in response to changes in the business environment.

3.1 Effectiveness

Effective project managing is to ensure that the intended or desired project objectives should be successfully achieved. This means that the right processes must be done in scope with the objectives to create value for the customer. Therefore the source of effectiveness can be seen as the initiation and planning phases of project management. The reason for this statement is that these phases determine why the project is initiated, how it will be executed, and what the intended or desired results will be. [3]

When planning a project, top management must identify the person, problem or opportunity that initiated the need for the project. Thereafter, customer related information is analysed and translated into defined requirements. The customer definition of value is important for refining the refined project scope and to ensure waste free projects. Goals are then set according to customer feedback and the company's strategy and mission statements.

The SIPOC analysis identifies the suppliers, inputs, process steps, outputs, and customers related to the process within the project scope. The suppliers are the sources of the inputs, such as material, tools, knowledge and skills, necessary for project completion. Furthermore, process steps are the activities related to the project. Finally, outputs are the intended or desired results that will satisfy the defined customer's requirements.

The Critical to Quality Tree translate customer related information into specific project objective. Feedback from the customer is documented to determine the critical drivers of the project. Thereafter, the requirements of these drivers are identified and replaced with requirement in a measurable form. The final part of this analysis is to set target values for these requirements.

When the target objectives for the project is set, the TOC thinking process can be implemented to optimise the project planning approach, even when it consist of a complex system with many interdependencies and variability. The scientific cause-and-effect approach is effective at identifying the possible outcomes of different actions that may form part of the project. Using the tactical trees it is possible to identify the requirement to reach certain objectives, along with their prerequisites. Assumptions can then be made why these prerequisites may be conflicting with each other. Finally injections (actions) can be initiated in order to prevent conflict.

3.2 Efficiency

Efficiency is a measurable characteristic that evaluates the performance and quality of activities. Therefore, the focus of project efficiency is on the execution and monitoring phases of project management. [3]

While executing project activities it is necessary to be able to identify non value adding activities so that they can be eliminated. A good start is seven types of waste defined by Taiichi Ohno. The wastes that can be best applied to project management are unnecessary transport, excess inventory, waiting times, over processing and non-conforming activities (defective work).

The flow of sequential activities is also important to shorten execution time. Smooth flow can be created by effective communication between the people responsible for activities. Communication is important to initiate time buffers between activities. Also, the right inputs for each activity should be provided at the right time at the right amount.

Measurement is a critical aspect to determine project efficiency. The goal of measurement is to compare activities, either against historical data or the target objectives. It can also be used to determining the efficiency of similar processes. Furthermore, it can be used to set benchmarks for future activities. For effective measurement an appropriate data collection plan is necessary to measure relevant aspects of the current activities. This requires the development of operational definitions which establish a better understanding of the necessary activities.

Throughput accounting provides three key performance indicators that can be used to measure the efficiency of activities if they're aligned to project management. These indicators communicate the performance of an activity. They may not always be relevant or even measurable, but they provide a starting point when developing a data collection plan. Throughput is the rate at which value is added to an activity relative to cost. Operating expense is the cost of skill and knowledge that are needed for the execution of an activity. Inventory is the money that is invested in the physical resources required for an activity.

3.3 Agility

Agility ensures flexibility in an environment with high variance by adapting rapidly and cost effectively to unexpected change. This is an important aspect primarily of the planning and execution phases of project management. The reason is that possible changes and different scenarios should be taken into account during planning of a project. Furthermore, when changes occur during execution the people involve should be able to rapidly adapt to the changes without adding unexpected costs. [3]

During the planning phase, the TOC thinking process can be used to detect different prerequisites with potential for future conflict. Furthermore, potential external conditions can be identified for different scenarios. Assumptions are made to include various different possible situations. When these situations are identified, injections can be developing to prevent them from escalating when they would happen.

Additionally, an FMEA can be made to identify different failure modes that may be related to project execution. Each failure mode is than rank according to the risk they pose to successfully completing a project. Furthermore, precaution can be implemented to decrease the possible of failure or to the decrease the severity should a failure occur.

During the execution phase, it is important that a flexible team is available that deal with changes in the project scope or if an activity deviates from the project plan. One way of instantly increasing team flexibility is by selection a cross functional team. These teams implement members from various departments and functions inside a company. This ensures a diverse set of skills and knowledge inside a team. Members must be empowered to use their own judgement for rapid decision making when necessary while taking responsibility for their actions.

Moreover, establishing a culture of continuous learning encourage teams members to expand their and improve their knowledge. Activity rotation can also be implemented to widen employee perspective on each function in a project. Knowledgeable team members that have perspective form areas and understand the full extent of a project improve decision making processes.

Finally, after each activity or milestone, it is important to reflect to openly identify all shortcoming of the project. Thereafter, countermeasures are developed to avoid future mistakes. However, best practices are standardised for future projects.

4 CONCLUSION

Based on the literature study, certain element of different process improvement methodologies can be applied to project management. Three connections were also identified between the critical aspects (time, cost, scope) of the project management triangle: (1) effectiveness, (2) efficiency, and (3) agility. These connections are the focus of improvement since they comprehend the interrelatedness of the critical aspects.

A framework was developed that potentially enhances decision making around the critical aspect by improving the overall balancing performance of the project management triangle in skill constraint SMEs. The framework consists of three connections, along with traditional process improvement elements, that are specifically related to certain parts of the project management process. The framework is concluded in Figure 5.

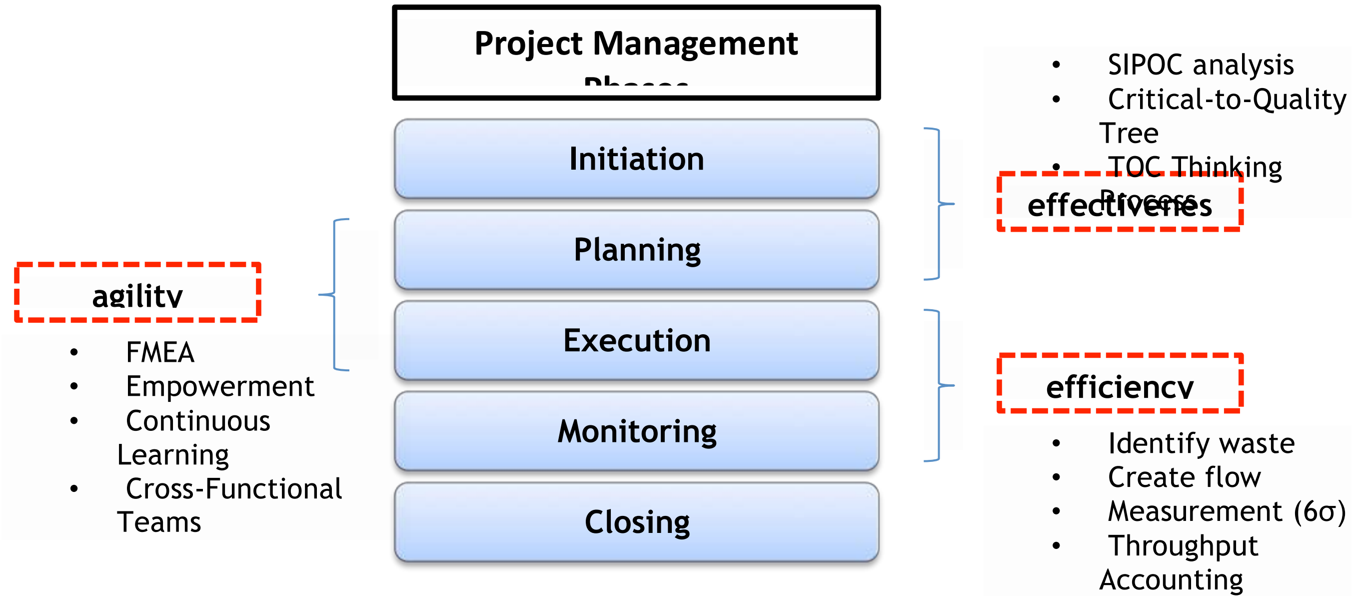

Figure 5: Integrated Project Management Framework

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TASK ASSIGNMENT IN HOME HEALTH CARE: A FUZZY GROUP GENETIC ALGORITHM APPROACH

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ABSTRACT

The assignment of home care tasks to nursing staff is a complex problem for decision makers concerned with optimizing home healthcare operations scheduling and logistics. Motivated by the ever-increasing home-based care needs, the design of high quality task assignments is highly essential for maintaining or improving worker moral, job satisfaction, service efficiency, service quality, and to ensure that business competitiveness remains momentous. To achieve high quality task assignments, the assigned workloads should be balanced or fair among the care givers. Therefore, the desired goal is to balance the workload of care givers while avoiding long distance travels in visiting the patients. However, the desired goal is often subjective as it involves the care givers, the management, and the patients. As such, the goal tends to be imprecise in the real world. This paper develops a fuzzy group genetic algorithm (FGGA) for task assignment in home healthcare services. The FGGA approach uses fuzzy evaluation based on fuzzy set theory. Results from illustrative examples show that the approach is promising.

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1 INTRODUCTION

Home healthcare service is an ever growing service industry concerned with the provision of coordinated and optimized healthcare services to patients in their homes [1]. In providing home care services, for instance, healthcare staff may have to attend to acute illness, post-hospitalization treatment, post-operation treatment, chronic illness, permanent disability, terminal illness, among other tasks such as drug delivery [2]. The services provided may include nursing, therapy activities, medical and social services, house cleaning, and drug deliveries. This is necessitated by the ever increasing ageing population, chronic diseases, pressure from societies to improve healthcare service quality, and pressure of governments to contain healthcare costs. Oftentimes, it is an advantage to allow elderly people and patients with varying degrees of healthcare needs to live in their own homes as long as possible, since a long-term stay in nursing homes is often much more costly. Consequently, healthcare service providers are compelled to offer home care services in an attempt to limit costs and to improve their quality of service. Overall, the provision of home health care services is known to improve the quality of life of the patients. Thus, home care services are an essential cost-effective and flexible instrument for modern social systems.

The relationship between care givers and patients (clients) is often meant to be long-term, lasting for several years [1] [2]. Therefore obtaining and keeping satisfied clients is crucial for service providers. Due to intensive competition among healthcare service providers, it is so important to optimize the homecare operations, taking into account the target management goals, client satisfaction, and healthcare worker satisfaction. To satisfy the healthcare professionals, overtime work and long distance trips to clients should be minimized while providing satisfactory service to the clients, visiting them at their preferred time of the day.

Decision makers concerned with homecare operations management and logistics are often faced with complex decision problems involving care task assignment, patient assignment to care givers, as well as routing [3] [4]. In particular, the assignment of home care tasks to nursing staff is a complex but important assignment problem for improving home healthcare operations. Designing high quality task assignments or schedules is critical [5]. Poor quality schedules often lead to low worker moral, job dissatisfaction, absenteeism, inefficiency, poor service quality, and the ultimate loss of business. To achieve high quality task schedules, care workloads should be assigned in the most equitable and fair manner; a high quality schedule is balanced or fair among the care givers. In retrospect, the desired goal is to balance the workload of care givers while avoiding long distance travels in visiting the patients. However, the desired goal is often imprecise as it is subject to human judgment; the desired goal should ideally satisfy the care givers, the management, and the patients. As such, the goal tends to be imprecise or fuzzy, adding to the complexity of the problem. In addition, the problem is characterized by a number of constraints which makes it difficult to use conventional optimization methods such as linear programming. In practice, the task scheduling problem is extremely time-consuming, especially when it is performed manually. To that effect, developing robust and interactive decision support tools is necessary to assist the decision maker in designing high quality task schedules for home care services.

In view of the above issues, the design of effective and efficient decision support tools is especially essential for the home health care service provider. The provision of robust decision support tools is necessitated by the desire to improve the service quality or patient care, to improve the schedule quality, and to satisfy the expectations of the healthcare professionals and the management goals. The purpose of this research is to develop a fuzzy group genetic algorithm (FGGA) for task assignment in homecare healthcare services. The specific objectives are as follows;

1. To describe the task assignment problem for homecare operations logistics;
2. To propose a fuzzy group genetic algorithm approach for care task assignment; and,

3. To provide illustrative examples, highlighting useful managerial insights.

The proposed approach uses a fuzzy evaluation technique, based on the concepts of fuzzy set theory. The next section presents a brief description of the home healthcare task assignment problem and its underlying assumptions. Section 3 provides a brief background to fuzzy set theory. Section 4 presents the FGGA approach proposed in this study. Section 5 provides illustrative computational experiments, results and discussions. Finally, concluding remarks and further research prospects are provided in Section 6.

2 PROBLEM DISCRIPTION

Briefly, the home care task assignment problem is described as follows [1]: We are given a set of home care tasks, $T = \{1,...,n\}$, where each task i is defined by a task duration p_i and a time window $[e_i,l_i]$; e_j and l_j represent the respective earliest start and latest start times of the task. In addition, the tasks may be patient visits, drug delivery, and any other administrative duties. The tasks are to performed by an available set of workers $W = \{1,...,w\}$, each worker j having a scheduled working time of day. Furthermore, each task must be allocated to a qualified care worker, with skills indicated by q_j, according to the required competency c_i. In this study, it is required to balance the workload allocation between the staff. The implication is that the variation of individual workloads should be within acceptable limits; the objective is to limit, as much as possible, the variation of care workers' individual workloads from the average workload. Time window constraints specified by the clients should be satisfied. Overall, this will maximize the schedule quality.

2.1 General assumptions

For the purpose of this study, we model the task assignment problem based on the following simplifying assumptions for problem;

- The travel times involving patient visits are treated as part of the task duration, measured in minutes;
- Care giver visits always occur via the home base, as some tasks are done at the base;
- The skills of care workers are expressed as q_j in the range $[1,h]$, in which case 1 and h represent the lowest and highest skills, respectively;
- Each task has a pre-specified time window $[e_i,l_i]$ during which the assigned care giver must begin the task operation;
- Each task should only be assigned to a care worker that possesses the right skills as required by the task.
- All tasks are to be completed within the care worker's working time of day, defined by $[e_j,l_j]$ for each worker j;

2.2 Problem objective and constraints

Following the above-described problem, the main objective of care task assignment is to minimize the variation of each individual care worker's workload from the average workload. The following constraints must be observed [1];

- Each task is assigned to one and only one care giver;
- Each task must begin within its respective time window $[e_i,l_i]$;
- The total workload for each care worker must be within the lower and upper bounds, m and M, respectively; and,
- All tasks assigned to a care giver must be completed within the working time of the care giver.

3 FUZZY SET THEORY: A BACKGROUND

Fuzzy set theory models imprecision and uncertainty in a non-stochastic sense [6]. A fuzzy number represents imprecise quantities, such as "about 10," and "substantially greater than

10." Thus, a fuzzy set is a class of objects with no sharp boundary between the objects that belong to that class and those that do not. Fuzzy set theory, unlike Boolean logic, deals with degrees of membership, rather than membership or non-membership [7]. To further clarify the concept of fuzzy theory, we distinguish fuzzy sets from crisp sets according to the following definitions:

Definition 1: *Crisp Set*. Let X be the universe of objects having elements x, and A denote a proper subset of the universe X; $A \subseteq X$. Then, the membership of x in a classical crisp set A is defined by a characteristic transformation function μ_A from X to {0,1}, such that,

$$\mu_A(x) = \begin{cases} 1 & \text{If } x \in A \\ 0 & \text{If } x \notin A \end{cases} \qquad (1)$$

Definition 2: *Fuzzy Set*. Let X be the universe of discourse whose elements are denoted by x. Then, the grade of membership of x in a fuzzy set A is be defined as $\mu_A(x) \in [0,1]$, where $\mu_A(x)$ is the membership function of x in A, which maps each element of X to a membership value in [0,1]. The fuzzy set A in X is a set of ordered pairs;

$$A = \{x, \mu_A(x) \mid x \in X\} \qquad (2)$$

By the above definition, the closer the value of $\mu_A(x)$ is to 1.0, the more x belongs to A, and vice versa. The elements of a fuzzy set indicate the value of each element in the set and its grade of membership.

4 A FUZZY GROUP GENETIC ALGORITHM APPROACH

The FGGA approach is a development from group genetic algorithm proposed by Falkenauer [8] for addressing grouping problems [9]. The FGGA approach and its elements, including chromosome coding, initialization, and genetic operators, are presented in this section.

4.1 FGGA coding scheme

To enhance the performance of FGGA, we develop a unique coding scheme which exploits the group structure of the problem [10]. Let A = [1, 2, 3,…,n] be a chromosome representing a set of n tasks to performed by p care givers. The evaluation of C involves partitioning clients along C into m groups such that the workload is balanced, or the workload variation between the care givers is minimized, and the cumulative load for each group does not exceed the care giver working time limit.

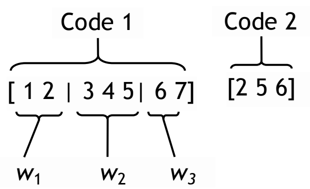

Figure 1: FGGA chromosome coding scheme

Figure 1 provides an illustration of the group structure of the chromosome code consisting of two codes: code 1 represents the assignment of care workers w_1, w_2, and w_3, to groups of clients or tasks {1,2}, {3,4,5}, and {6,7}, respectively. Code 1 is the actual group structure upon which the genetic operators act, while Code 2 denotes the last position of each client or task group, that is, it records the position of the delimiter or frontier "|" which separates client groups.

4.2 Initialization

An initial population of size p is created by random assignments of tasks to care givers. First, the care tasks are arranged in ascending order of their start times. In case of a tie, rank the duties according to their activity duration. For each care giver, assign a duty at a probability *b*, starting from the earliest. From the unassigned set of duties, assign duties beginning from the earliest. This procedure increases the likelihood of the initialization process to generate initial feasible solutions.

4.3 Fitness evaluation

We use a fuzzy evaluation technique to evaluate the fitness of each chromosome. In this regard, we let A represent a feasible task assignment, and x_{ij} a binary variable that defines whether a task i is assigned to care giver j with rank k, or not. It follows that the average workload for the assignment can be expressed in the form,

$$a = \frac{\sum_i \sum_j p_i x_{ij}}{\sum_i \sum_j x_{ij}} \tag{3}$$

The main aim is to minimize a function f_j, defining the variation of each care giver's total workload from the average workload a. The function f_j is given by the expression;

$$f_j = \left| \sum_i p_{ij} x_{ij} - a \right| \qquad \text{for all } j \tag{4}$$

Nevertheless, since the workload f_j should be within acceptable limits, we use a fuzzy function evaluation. Triangular functions have widely been used as membership functions, with appreciable success [11]. Figure 2 illustrates the triangular membership function, where a fuzzy number A is a triangular fuzzy number with a membership function of the form $\mu_j : X \to [0,1]$. It is important to note that μ_A is a normalized function that shows the desirability of the task assignment relative to the most preferred (average) workload, f_0.

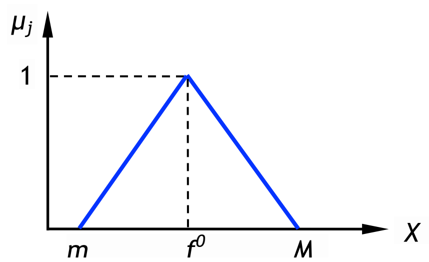

Figure 2: Preferred error as a triangular fuzzy number

Since the care givers' workloads should be as close as possible to f_0, we define the following membership function for every care worker j;

$$\mu_j(x) = \begin{cases} (f_j - m)/(f^0 - m) & \text{if } m \le x \le a \\ (f_j - M)/(f^0 - M) & \text{if } a \le x \le M \\ 0 & \text{if otherwise} \end{cases} \tag{5}$$

As a result, the final objective function can be formulated as a function of the normalized functions (membership functions) as follows;

$$z = \left(\frac{\mu_1(x)}{\omega_1} \wedge 1 \right) \wedge \left(\frac{\mu_2(x)}{\omega_2} \wedge 1 \right) \wedge \ldots \wedge \left(\frac{\mu_W(x)}{\omega_W} \wedge 1 \right) \tag{6}$$

where, ω_j denotes the weight behind task assignment of care worker j.

The weight ω_j offers the modeller an opportunity to model his/her choices or preferences to reflect management and/or care givers' preferences. This provides the FGGA an advantage over other metaheuristic approaches.

To compute fitness of each chromosome, FGGA maps the function z to a fitness function F_k,

$$F_k(t) = \max\left[0, z^m(t) - z_k(t)\right] \tag{7}$$

where, $z_k(t)$ is the objective function of chromosome k at iteration t; and z^m is the maximum objective function in the current population.

4.4 Selection

The selection operator selects the best performing chromosomes into a mating pool, *tempp*. The remainder stochastic sampling without replacement method was adopted in this study [12] [13]. Each chromosome k is selected and stored in the mating pool according to its expected count e_k,

$$e_k = \frac{F_k}{(1/p)\sum_{k=1}^{p} F_k} \tag{8}$$

where, F_k is the fitness function of the k^{th} chromosome.

In this strategy, each chromosome receives copies equal to the integer part of e_k, plus additional copies obtained by using the fractional part of e_k as a success probability of getting an additional copy of chromosome k into *tempp*. As such, the best performing candidates are selected with higher probability into the mating pool.

4.5 Crossover

Crossover is a mechanism by which selected chromosomes mate to produce new offspring, called selection pool [9]. The mechanism enables FGGA to explore unvisited regions in the solution space. Groups of genes in the selected chromosomes are exchanged at a probability *pcross*. First, a crossover point between 1 and g is randomly generated, where g is the number of groups. Second, the groups on the right of the crossover point are swapped. Third, the offspring are repaired as necessary. The process is repeated till the desired pool size, *poolsize*, is achieved. Figure 3 demonstrates the crossover mechanism using parent chromosomes P_2 and P_2. The offspring O_1 and O_2 are repaired to produce O_1' and O_2'.

Parents:	Offspring:	Repaired:
P_1: [5 2 | 4 3 1 | 6]	O_1: [5 2 | 3 1 | 6]	O_1': [5 2 | 3 1 | 4 6]
P_2: [6 5 | 3 1 | 4 2]	O_2: [6 5 | 4 3 1 | 4 2]	O_2': [6 5 | 4 3 1 | 2]

Figure 3: An example of crossover and repair mechanisms

After crossover, some genes may appear in more than one group, while others may be missing. Such offspring are repaired by eliminating duplicated genes on either side of the crossover point, and then inserting missing genes into those groups with the least loading. Thus, group coding takes advantage of the group structure to generate new offspring. Mutation follows the crossover operator.

4.6 Mutation

Mutation is applied to every new chromosome using two mutation operators: swap mutation and shift mutation [9]. Swap mutation exchanges genes between two groups in an individual chromosome, while shift mutation moves a randomly chosen frontier between two adjacent groups by one step to the right or to the left. Thus, the mutation operator provides FGGA with local search capability, a phenomenon called intensification. Figure 4 (a) and (b) provides an illustration of swap and shift mutation mechanisms, respectively.

	(a)	(b)
Before mutation :	[5 2 | **4** 3 1 | **6**]	[5 2 | 4 3 1 **|** 6]
After mutation :	[5 2 | **6** 3 1 | **4**]	[5 2 | 4 3 **|** 1 6]

Figure 4: An illustration of swap and shift mutation

4.7 Inversion and diversification

As iterations proceed, the population may prematurely converge to a particular solution, hence, it is crucial to control the population diversity [10]. Inversion is a mechanism that probabilistically rearranges the genes of a chromosome in the reverse order. Simply put, the inversion operator transforms a chromosome [1 2 | 4 | 3 5 6] to [6 5 3 | 4 | 2 1]. To check diversity, we first define an entropic measure H_i for each client i;

$$h_i = \sum_{j=1}^{n} \frac{(x_{ij}/p)\cdot \ln(x_{ij}/p)}{\ln(n)} \tag{9}$$

where, x_{ij} is the number of chromosomes in which client i is assigned position j in the current population; n is the number of clients. Then, diversity H becomes,

$$h = \sum_{i=1}^{n} h_i/n \tag{10}$$

Inversion is applied whenever diversity falls below a threshold value, h_d. However, the best performing candidates are preserved (3 in this application).

4.8 Overall FGGA algorithm

The overall algorithm incorporates the above operators, beginning with the selection of suitable input parameters. The selected input parameters were: crossover probability (0.35), mutation probability (0.01), and inversion probability (0.04). An initial population, $P(0)$, is generated randomly by random assignments of clients to care givers. The algorithm then proceeds into an iterative loop involving selection, crossover, mutation, inversion, and until termination condition is reached (maximum number of pre-specified T). Figure 5 presents the overall structure of the proposed FGGA.

```
Algorithm 1. Fuzzy group genetic algorithm
BEGIN
    1. Input: parameters; t = 0;
    2. Initialize population, P(0);
 REPEAT
    4. Selection:
         Evaluate P(t);
         Create temporal population, tempp(t);
    5. Group crossover:
         Select 2 chromosomes from tempp(t);
         Apply crossover operator and repair as necessary;
    6. Mutation:
         Mutate P(t);
         Add offspring to newpop(t);
    7. Replacement strategy:
         Compare successively, spool(t) and oldpop(t) strings;
         Take the ones that fare better;
         Select the rest of the strings with probability 0.55;
    8. Inversion and diversification:
           Compute diversity H;
           IF (H < h_d) THEN diversify till H ≥ h_d;
           Re-evaluate P(t);
    9. New population:
           oldpop(t) = newpop(t);
           Advance population, t = t + 1
 UNTIL (t ≥ T)
END
```

Figure 5: Overall FGGA pseudo-code

We present illustrative examples, computational results, and relevant discussions in the next section.

5 COMPUTATIONAL EXPERIMENTS, RESULTS AND DISCUSSIONS

5.1 Computational experiments

We adopt an illustrative example from Bachouch et al. (2010) as in Table 1 and 2. The data consists of task and care worker information. Task information comprises task duration, time window and the competence requirement. The care giver information comprises working time and qualification ranking.

Table 1: Task information [1]

Task	Duration	e_i	l_i	c_i
1	19	0	60	1
2	24	0	60	2
3	29	60	120	3
4	34	60	120	4
5	39	120	180	5
6	56	120	180	1
7	61	180	240	2
8	66	240	300	3
9	71	360	400	3
10	76	540	600	5

Table 2: Care worker information [1]

Care worker	e_j	l_j	q_j
1	19	0	60
2	24	0	60
3	29	60	120
4	34	60	120
5	39	120	180
6	56	120	180
7	61	180	240
8	66	240	300
9	71	360	400
10	76	540	600

In addition to the example given, further problem examples of sizes ranging from 10, 15, 20, and 25 tasks, with 3 to 15 care givers were generated randomly and tested using the FGGA approach. We provide the results and discussion in the next section.

5.2 Results and discussions

Table 3 provides the obtained optimal solution of the problem that is presented in [1]. The task assignment solution shows the start time of each task as well as the care giver assigned to each task. Here it can be seen from the given solution that care give 2 is not assigned.

Further experimentations with large numbers of tasks and care givers demonstrated that the FGGA can perform large scale task assignment problems within a reasonable computation time of a few seconds or minutes, while respecting all the competence and time window constraints.

Table 3: FGGA computational results

Task	Care worker	a_i	b_i
1	3	0	19
2	1	0	24
3	1	60	89
4	1	120	154
5	3	120	159
6	3	180	236
7	1	180	241
8	1	300	366
9	3	400	471
10	3	540	616

6 CONCLUSION

Designing decision support tools that can address the homecare task assignment problem in which workload must be balanced is a cause for concern. Task assignment or schedule quality is necessary to maintain or improve worker moral and avoid absenteeism and attrition. In an environment where the preference on workload is ill-defined or imprecise, the use of fuzzy set theory concepts is beneficial. This paper proposed a fuzzy group genetic algorithm that to solve task assignment problems in a homecare environment, given a set of tasks and a set of available care workers to perform the tasks. An illustrative example was adopted from the literature, demonstrating the effectiveness of the algorithm. The suggested approach provides useful contributions to researchers and academicians as well as practitioners in the health service sector.

6.1 Contributions to theory

The proposed algorithm is a contribution to the Industrial engineering community as it provides an approach to solve task assignment problems when the desired management goals and worker preferences are imprecise or ill-structured. Unlike other metaheuristic approaches such as genetic algorithms and simulated annealing, this approach provides more realism to the solution approach. Contrary to conventional linear programming methods, the algorithm is capable of handling large-scale problems, while providing useful solutions in a reasonable computation time. Therefore the proposed approach is an invaluable solution approach for further development of decision support systems for the home healthcare institutions. The method also provides useful contributions to the practicing decision maker.

6.2 Contributions to practice

The proposed fuzzy group genetic algorithm provides an opportunity to use weights, which gives a way of incorporating the decision maker's preferences and choices in an interactive manner. For the practicing Industrial Engineer (IE), it is important to appreciate the use of interactive decision support that do not prescribe the solution, but rather provide a listing of good alternative solutions, upon which the IE can make the most appropriate decision. Thus, the decision maker uses information from care givers and the management to make adjustments to the solution process in terms of weights. Overall, the fuzzy group genetic algorithm proposed in this paper is an effective and efficient approach that provides a viable platform for developing decision support tools for solving task assignment problems for the home healthcare service providers.

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A HOME HEALTHCARE MULTI-AGENT SYSTEM IN A MULTI-OBJECTIVE ENVIRONMENT

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ABSTRACT

Decision making in home care service is complex due to the need to satisfice multi-objective goals such as maximizing customer service quality, minimizing service cost, and maximizing employee satisfaction. With the increasing world-wide need for efficient and effective home healthcare, the increasing elderly population, and the increasing pressure from governments and other stakeholders in various societies, the development of effective novel approaches for home care decisions is imperative. In this paper, we present a multi-agent architecture that facilitates decision making characterised with multiple objectives. The approach integrates the capabilities of a multi-agent system and Web services so as to facilitate effective decisions for home healthcare services. The aim is to provide a multi-agent system based on genetic algorithm, where decisions are based on intelligent agents that provide intelligent alternative decisions in a multiple-objective environment.

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1 INTRODUCTION

The provision of health care and assistance to patients in their own homes often occurs in an uncertain environment [1]. Healthcare worker schedules in general and homecare worker schedules in particular, are constructed under uncertain, imprecise, and often conflicting goals and restrictions. Some critical examples of the conflicting management goals include the minimization of schedule cost [1] [2], the maximization of healthcare service quality, and the maximization of healthcare worker satisfaction [2]. Satisfying all these goals simultaneously is almost impossible due to their conflicting behaviour. Common restrictions encountered while constructing homecare worker schedules include the need to satisfy all the health care requirements of the patients (clients), the need to provide service to every patient within a given time window at a specific location, and the limitation on the maximum working hours that can be assigned to each worker per day. These restrictions fall into two main categories, that is, demand constraints and time constraints.

While demand constraints seek to satisfy all the healthcare requirements by clients, time constraints are concerned with time window restrictions, total work hours per day per worker, and other specific work time restrictions as stipulated by specific organizations and legislations. In the presence of all these constraints, the decision maker needs a robust decision support tool so that schedule cost, healthcare service quality, and worker schedule quality goals are met. As these goals involve humanistic perceptions and judgments from three players, i.e., the management, the clients, and the healthcare workers, the development of a more judicious approach to home healthcare scheduling is imperative. As such, the concept of satisficing is appropriate.

Satisficing is a flexible and adaptable alternative to optimization for multiple objective problems, where the decision maker gives up the idea of obtaining the “best” solution and seeks a solution that is “good enough” to exceed the preset lower bounds. The “satisficer” believes that, in practice, there are too many uncertainties and conflicts in values for true optimization, such that it is more reasonable to do “well enough”. The provision of home healthcare services takes place in a particularly mobile, dynamic, and imprecise environment. The healthcare system evolves constantly over time due to one or more of the following:

1. Handling of heterogeneous information;
2. Complexity of home healthcare tasks;
3. Dynamic preferences and goals of care givers, management and patients; and,
4. Imprecision of goals and preferences.

The real issue in a homecare system is that of efficient and effective coordination of players in the system. Multi-agent systems have been recognized as one of the technologies that would meet decision making needs in an agile and fast-changing environment [3] [4]. Monostori et al [5] [6] define an agent as a software object that mimics the role of a competent personal assistant to perform a specific task on behalf of the user, intelligently or not, independently of with little guidance. The authors also state that an agent is a computational system that is situated in a dynamic environment and is capable of exhibiting autonomous and intelligent behaviour.

The purpose of this work is to propose a framework for developing multi-agent systems for home healthcare systems in a multi-objective environment. As such, the objectives of this research are as follows:

1. Identify common operational problems associated with home health care services in a multi-objective environment;
2. Propose a homecare multi-agent system framework, highlighting agent functionalities, and the overall system services; and,
3. Apply the framework to homecare task allocation in a dynamic multi-objective environment.

The rest of paper is organized as follows. The next section presents a general description of the problem. Section 3 provides the proposed framework for developing a homecare multi-agent system. Section 4 presents an application of the framework to homecare task allocation in a dynamic multi-objective environment. Conclusions and further work prospects are provided in Section 5.

2 PROBLEM DESCRIPTION

Home healthcare service providers are faced with dynamically changing staff schedules due to evolving homecare systems. Staff preferences and patient preferences change over time. In addition, management targets are often adjusted according to internal and external changes. Oftentimes, preferences and management goals are expressed without measurable precision, but rather, in linguistic expressions such as "about 8 hours", "preferably 30 hours per week", and "preferably morning shifts" and other forms. Moreover, the interaction of the three players, the management, staff, and patients, is complex and difficult to model using closed form methods. Managers need intelligent interactive decision support tools in such complex, dynamic and multi-objective homecare environments. Decisions need to be made as regards to scheduling of tasks for nursing staff and assignment of homecare tasks that are to be performed at preferred time windows specified by the patients. The use of intelligent agents for decision making is the most viable option.

2.1 Nature of Homecare Services

The homecare environment is concerned with constructing work schedules and assigning tasks to care givers over the course of day. Care workers visit patients are their homes at specific time windows, defined by earliest start time and latest start time. In the process, the staff, patients, and management communicate through mobile and other network channels to update information and to revise staff schedules as needed. Meanwhile, a number of objectives have to be considered simultaneously when updating the staff schedules and task assignments.

2.2 Complicating Characteristics

Due to the presence of multiple conflicting objectives in homecare decisions, multiple goals are considered when developing suitable solution to homecare staff scheduling and task assignment. Three goals are considered simultaneously: (i) minimizing the schedule cost, (ii) maximizing client satisfaction, and (iii) maximizing worker satisfaction. This essentially involves finding a judicious trade-off between the goals, considering preferences and choices of the decision maker. In a typical homecare environment, the decision maker needs to consider a number of objectives, including the following:

1. *Schedule cost*. This is a management objective concerned with minimizing the cost associated with the trips followed by healthcare givers. The cost of each trip is estimated in terms of the total distance from the care giver's point of origin to the first client, the distances between successive clients, and from the last client back to the care giver's point of origin.
2. *Patient satisfaction*. This objective concerns the maximization of client satisfaction or service quality which can be expressed as a function of the violations of time windows preferred by the clients. A penalty pseudo-cost is often imposed when a care giver reaches a patient's home too early (earliness) or too late (lateness) in comparison to the preferred *time window of the patient*.
3. *Worker satisfaction*. In practice, it is essential to consider healthcare worker satisfaction, which entails meeting the worker preferences to the highest degree possible. Each worker indicates specific preferences in terms of individual working hours, work starting time, work finishing time, among others. The most common

specification is the total individual working hours. The overall worker satisfaction should be maximized.

In practice, the decision maker seeks to consider a trade-off between client satisfaction, worker satisfaction and cost minimization. This can be achieved by developing a multi-agent system.

3 PROPOSED MULTI-AGENT SYSTEM FRAMEWORK

In this section, we briefly describe the overall system structure, its goals, and the individual agent functionalities.

3.1 Overall System Structure and Goals

The suggested system framework incorporates intelligent agents, internet services, wireless networks, and mobile devices. The framework consists of a number of functional agents that are supervised by a supervisor agent, and managed by a manager agent through available communication channels. The system consists of Manager Agent, Supervisor Agent, Resource Agent, Scheduler Agent, Nurse Agent, and Patient Agent. The overall goal of the multi-agent system is to provide intelligent and robust decisions in a fast evolving homecare environment. Quick and robust decisions are especially needed in regards to homecare staff scheduling and task allocation where task loading is dynamic over the course of day, staff capability and availability change over time due to unforeseen circumstances, and patients' requests are updated over the course of day.

Figure 2 shows the proposed framework for developing a home healthcare multi-agent system. The descriptions of the functionalities of the agents follow.

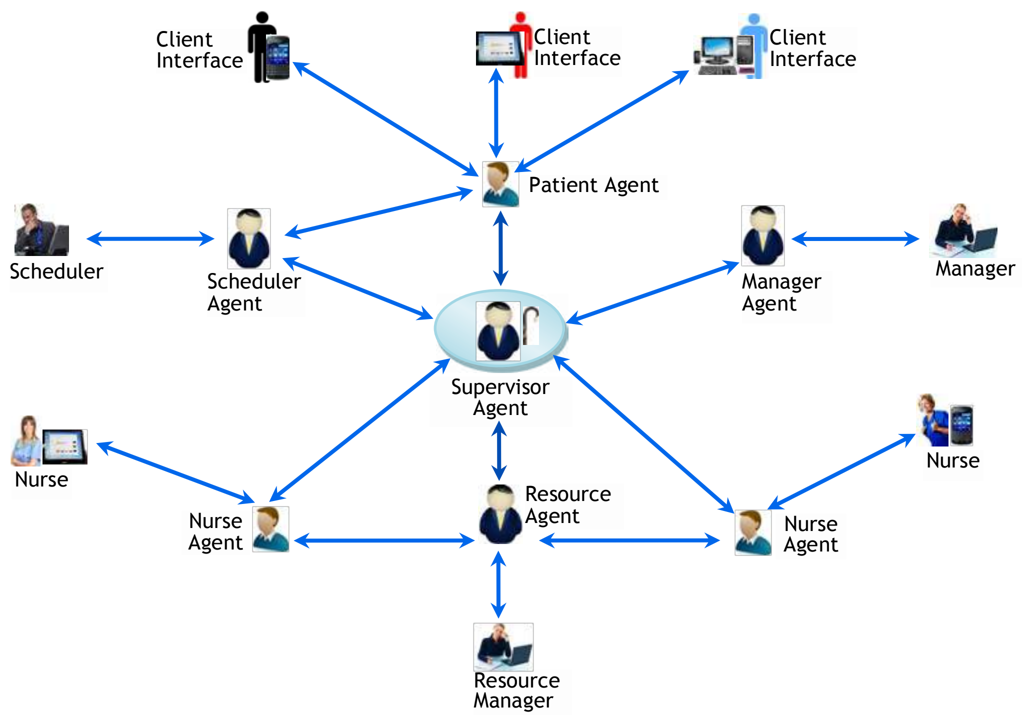

Figure 2: A Framework for a Homecare Multi-agent System

3.2 Agents and Functionalities

The agent platform forms the heart of the multi-agent system. These agents communicate and collaborate together through reliable communication channels to achieve a common goal. Each agent should have specific functionalities, capabilities and characteristics. This enhances system flexibility to add in new agents, as necessary. The major agents and their functionalities are described:

3.2.1 Manager Agent

The manager agent has the overall responsibility of managing resolving conflicts between functional agents, as communicated by the supervisor agent. It holds and keeps track of the quality of service, the nurse preferences, and the management requirements. This information is necessary for task scheduling and assignment decisions. In this respect, it sends requests for information updates from the supervisor agents. Overall, the manager agent is responsible for,

1. setting and updating the overall management goals;
2. regularizing patient and staff preferences; and,
3. finalizing staff planning and scheduling decisions originally prepared by the supervisor agent.

3.2.2 Supervisor Agent

The supervisor agent ensures that all the agents function correctly in the system. The agent periodically sends diagnostic messages to verify the status of all the agents. In the case that an agent malfunctions, another instance of the agent should be created. The supervisor agent is also responsible for conflict resolutions among other agents, as directed by the manager agent. In summary, the supervisor agent is responsible for;

4. correct functioning of other agents in the system;
5. conflict resolution between agents;
6. status updates from agents in the system; and,
7. updating information on management goals, staff preferences, and patient preferences.

3.2.3 Resource Agent

The resource agent keeps track of the information on capabilities and availabilities of staff resources in the system; compares the capabilities of staff with the workload, as advised by the supervisor agent and the nurse agents. It informs the supervisor agent on the times the nurse staff are available according to their current schedules. If there are any tasks that can be completed by the available staff, the information is relayed to the scheduler agent through the supervisor agent. Therefore, the resource agent is responsible for,

8. maintaining updates on staff availabilities and capabilities;
9. keeping track of task requirements and task loading; and,
10. comparing current loading and resource availabilities, and updates the supervisor agent.

The resource agent closely interacts with the nurse agents, obtaining resource information updates periodically.

3.2.4 Nurse Agent

The nurse agent schedules the nurse's working day and manages profiles, tasks, available time, and the resources. The agent must generate the plan considering the nurse's preferences such that all that all the patients assigned to the nurse receive care according to their time preferences. In addition the schedule must ensure that the nurse's working hours do not exceed the present maximum hours. Thus, the every nurse agent generates personalized plans based on the nurse's profile and working habits, as well as patient preferences. In summary, the nurse agent is responsible for,

11. managing nurse's profile, tasks, availability, and resources;
12. keeping track of the nurse preferences and working habits;
13. generating primary schedule plan, considering nurse preference, patient preferences and management goals.

3.2.5 Patient Agent

The patient agent manages patients' personal data and behaviour, that is, monitoring location, daily tasks, and reporting anomalies, if any. The patient agent is the most sensitive agent and it must frequently update information regarding the beliefs, preferences, and expectations of patients. Requests from the patients are recorded and considered. Precisely, the patient agent is responsible for,

14. updating information on patients' behaviour and healthcare preferences;
15. updating task requirements; and,
16. reporting patient anomalies.

Thus, the patient agent frequently updates the supervisor agent as well as the scheduler agent concerning the patients' requested tasks so as to maintain or improve the quality of service.

3.2.6 Scheduler Agent

The scheduler agent integrates management target, resource, and task information from the manager agent, the resource agent, and patient agent, respectively. The aim is to generate the ultimate schedule, subject to management goals, staff preferences, patients' preferences, and other constraints. Thus, in the presence of imprecise or uncertain goals and preferences, the scheduler agent generates an overall satisficing schedule that seeks to suffice and satisfy the overall expectations of the three players in the actual system: the management, the staff, and the patients. In short, the scheduler agent,

17. integrates the evolving target, resource and task information from other agents;
18. generates a satisficing solution for the ultimate staff schedules;
19. updates the scheduler's choices and preferences.

Therefore, the scheduler provides a satisficing solution, considering management targets, nurse preferences, and patient preferences that often evolve with time. This enables the healthcare system to provide improved quality of service.

4 APPLICATION IN A DYNAMIC MULTI-OBJECTIVE ENVIRONMENT

It is noted in this study that a dynamic multi-objective homecare environment is characterised by (i) goals, expectations, and preferences that evolve over time, (ii) multiple conflicting objectives, and (iii) imprecise or uncertain information. In the presence of fuzzy and dynamic data, coupled with conflicting objectives, the most appropriate decision is the one that seeks to satisfice the players in the system. Therefore, we propose a satisficing procedure that judiciously selects from a generated solution space at a given point in time, and then updates the solution space in accordance with the evolving information.

Figure 2 shows the proposed satisficing heuristic for interactive homecare staff scheduling decisions. Formally, the heuristic begins by searching from the solution space S_j, an untested solution $X_i \subseteq S_j$, and testing whether or not it is satisficing. If X_i is not satisficing, the search process continues, otherwise the solution is selected and implemented. After the implementation of the schedule, the perceptions of the three players - employee, client, management - will change over time, such that the decision maker needs to acquire and assess new information on their satisfaction or preferences and goals. If the new preferences reach the pre-specified thresholds, then the solution space S_j should be updated accordingly. The decision maker updates his preferences according to the new information obtained. The search for a satisficing solution starts again with the update information. The heuristic makes the approach more applicable and adaptable to the real life human decision process. However, the information pertaining to constraints and preferences is usually imprecise or uncertain.

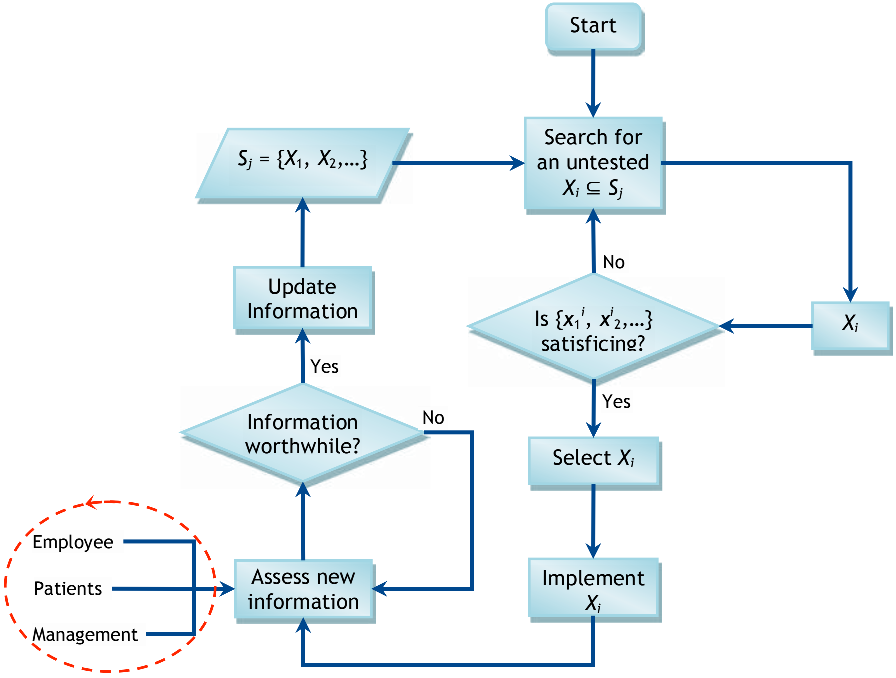

Figure 2: A satisficing approach to homecare decision making

5 CONCLUSION

Due to the ever-growing need to provide satisfactory care and support to patients at their homes and the widespread drive to offer such care services, novel and effective solutions to homecare decisions are essential. Developing robust decision making systems for homecare staff scheduling and task assignment is urgently necessary. This paper proposed a framework for developing multi-agent systems for homecare staff scheduling and task assignment decisions when the management goals, the staff preferences, and the patients' preferences are dynamic and conflicting. Considering that the information so provided is often imprecise in practice, the paper proposes a satisficing algorithm based on a dynamic solution space generated at a specific time subject to evolving preferences of the staff, the patients and the management. The proposed framework consists of a number of collaborating agents that communicate and are coordinated through efficient communication channels so as to achieve a satisficing solution at any point in time. It is anticipated that the framework forms a platform for robust decision making in homecare environments where information is imprecise and dynamic.

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THE EFFECT OF DOWNSTREAM QUALITY INSPECTIONS ON OVERALL SYSTEM PERFORMANCE: A CASE STUDY AT A FORGING COMPANY

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ABSTRACT

A strategic Original Equipment Manufacturer in the automotive sector delivers forged suspension components to the South African and International markets. Issues related to quality were identified, and to address these, the old batched quality inspection process was improved by creating an in-line quality testing station. The objectives of the inline quality inspection were to eliminate batching of items, including unnecessary movement of items, to increase the productivity of inspectors and to clear factory floor space taken up by the inventory and process space for batched inspection, eliminate the inherent risk of delayed identification of systematic production defects, reduce opportunities for re-handling, introduce a standardised inspection methodology, and ensure equitable inspector utilisation.

These objectives were met. The innovation also reduced quality errors, coming from upstream processes, which was unexpected.

This paper will explore how this quality improvement was achieved considering that the inspection stage itself had no operational function. Thanks to unexpected gains in quality, the break-even point for this innovation was remarkably short.

1 INTRODUCTION

Foxtec-Ikhwezi is a local manufacturer of original equipment (OEM) from non-ferrous metals. The company is located in the Eastern Cape city of East London (Industrial Development Zone, IDZ 1F) and is a joint venture entered into by Otto Fuchs AG and Ikhwezi Investment Holdings.

Foxtec-Ikhwezi produces forged aluminium suspension components for use in locally manufactured vehicles as well as for the export market. Due to several reasons, the process is a hybrid process of batched manufacturing and single piece flow. The quality inspection is currently a batched off-line process and features significant waste due to re-handling, transportation, and work duplication. It has been proposed that the quality inspection should be transformed into an in-line function, with less handling and transportation.

This study required the evaluation of repositioning the quality inspection from a batched into an in-line process by the use of innovative inspection workstations, and showing the advantages of such a move.

1.1 The product

Foxtec predominantly manufactures products vehicle suspension struts as shown in Figure 1. Foxtec exports between 85-90% of their product and the remainder is used locally. The material used is an alloy of aluminium which presents a significant weight to strength ratio for this product's particular application. The typical material properties can be summarised as being "artificially ageable with medium mechanical strength, weldability, and good corrosion resistance." (1) This product is a safety critical feature of a vehicle and thus its functional quality is a strict requirement.

Figure 1: The different product types

Despite the different product types the manufacturing process is generally the same for all of them, the fundamental variant being the forging dies used in the forge press for each product. The dies determine the geometry and dimensions of the product.

1.2 The process

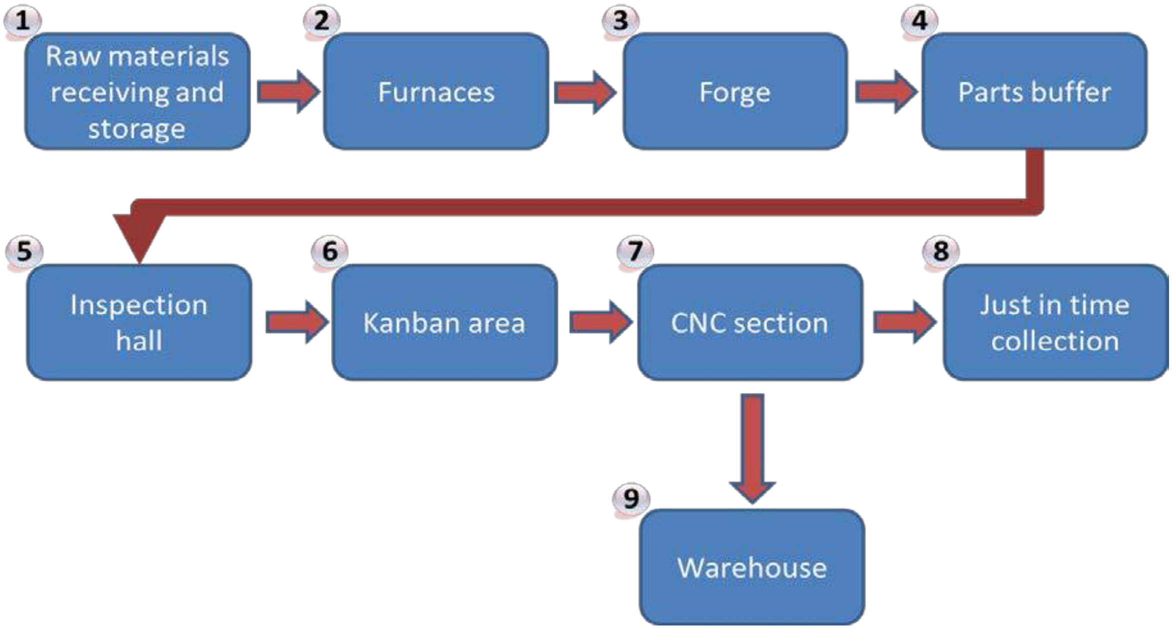

Figure 2: Process flow at Foxtec

Step one: Pellets with aluminium rods (raw material) forklifted out of the transportation truck and placed in the furnaces receiving bay.

Step two: A series of furnaces and quench tanks prepare the raw parts for forging and heat-treatment as required.

Step three: The main forge has a capacity of 2 100 parts in 24 hours. This forge allows for multiple dies to be used based on the required product.

Step four: The parts buffer section hold a significant number of uninspected parts

Step five: The inspection hall has 6 inspectors sitting in pairs in on three inspection tables. They inspect each and every forged part coming from the parts buffer.

Step six: The Kanban area stores the inspected parts in predetermined rows as directed by the pull from the Just in time orders and the scheduled parts to be produced.

Step seven: The parts are machined by CNC machines which also insert rubber bushes.

Step eight: The just in time collection bay has the parts packaged in readiness for collection by the just in time truck from the Mercedes Benz plant down the road from Foxtec.

Step nine: Parts that are destined for export to international markets are packaged and stored in the warehouse for export.

1.3 Current State summary

The inspection department consist of three work stations that have two inspectors per station. The inspectors carry out quality checks on all products leaving the forging department by performing a 360^0 visual inspection on the parts.

The inspection department is located after the forge and it is configured as a section on its own. The rate at which the inspection is done per part is undetermined yet accumulation of work shows that it is slower than the output of the forge. A knock-on effect is that parts required by the CNC section risk not being at the Kanban section as and when required. To overcome this, extra inventory is held to offset CNC demand.

The scenario described above alludes to a three pronged problem where Foxtec has to; firstly contend with the risk of unknown quality of thousands of products in buffer between the forge and the inspection station, secondly bear the cost of the waste inextricable to overproduction, and thirdly waste further resources trying to manage the excessive inventories before and after the inspection section.

Moving the inspection section in line with the forge such that they function in tandem rate will ensure that there is no build-up of inventory or backlog and possibly reduces the excessive size (from an inventory perspective) of the Kanban area.

2 LITERATURE REVIEW

2.1 Forging defects

Forging is a plastic forming process in which heated or cool metals are exposed to very high pressures which allow the material to assume the shape of negative tooling. Having an understanding of this process is critical in this study as this is the primary process of manufacturing at Foxtec.

Forging as a metal forming process produces metal products requiring little or no finishing when compared to casting and machining. Defects do occur during the forging process but it should be appreciated that fundamentally these defects are not inherent to the process itself. To elaborate, if a forging concern experiences a particular type of defect the cause of the defects should be identified and fixed, this will prevent recurrence of the defect, as long as the process parameters are properly configured the process will yield good quality products. (12)

Poor process and preform design are the main causes of most geometrical defects on forged parts. The following geometrical defects can occur during forging: laps, folds, under-fills, eccentricity and piping. Folds are the most common geometrical defect. The inspectors identify such defects.

2.2 Work study

“The term work study is defined in the British Standards as ‘A management service based on those techniques, particularly Method study and Work measurement, which are used in the examination of human work in all its contexts, and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed in order to effect improvement’ (4) .”

The fundamental objectives of work study can thus be thought of in the following way;

- Determining the most effective use of plant equipment
- Determining the effective use of human effort while working
- The evaluation of human work. (4)

In this study, the primary focus of work studies would be determining the effective use of the inspector’s effort while executing their duties and evaluating the activities involved in the inspection process. This is hoped to be accomplished specifically through time and method studies, two major constituents of work study.

2.3 Root cause analysis

This is a tool designed to assist in the identification of what, how, and why a problem occurred. Only when analysts are able to determine what, how, and why a problem occurred will they be able to specify workable remedial measures that prevent re-occurrence of the problem in question. (5) This may seem elementary but in complex processes, identification of the exact problem may not be clear. For instance, many processes have a lot of “fat” built in to them, evidenced by say over production; problems that do surface are masked in terms of their root cause since the process is still able to continue operating from the buffer built up by over production. An exact definition of root causes is difficult to establish from general literature but the following points are a succinct attempt:

Root causes are:

- specific underlying causes
- causes that can be reasonably identified
- those management has control to fix

those for which effective recommendations for preventing re-occurrences can be generated (5)

These literature definitions provide guiding principles that will be utilised in this study when identifying the root causes of identified challenges.

2.4 In-line design

Moving to one piece flow presents significant advantages, including:

- Reduced lead times
- Dramatic changes in transport
- Improved space utilisation
- Early detection of production problems

In this study it is anticipated that the moving of the inspection process into an in-line process will confer the above advantages

2.5 Automation

By replacing manual work with an automated process, error rates can be reduced significantly. Despite automation being viewed as an avenue by which to minimise human error in a system, increasing the degree and complexity of the automated process exasperates the consequence of an error becoming catastrophic, “*This high degree of process automation requires a high degree of monitoring and control of process and product quality*.” (6)

To contextualise the above paragraph, the process at Foxtec is such that the forging process is extensively automated and from the time the raw metal bar stock is loaded onto the furnace to when it leaves the tail end shot blast machine it is only handled once (a process which in itself is being considered for automation). Despite the automation, defects do occur for a myriad of reasons thus necessitating the inspection of each part at the end of this process. The disconnection at Foxtec comes in the form of a manual inspection process for parts that are made by an automated process. This disconnect could be the genesis of the problems currently being experienced in the inspection department. Granted, the inspection of each part requires many steps and the reworking of the parts (grinding) would be a challenge to automate but the manual process has to keep up with the automated process it is monitoring. The goal implicitly therefore, would be to get the inspection process as close as possible to automation and those aspects that prove to be challenging in terms of automation left manual.

3 DESIGN METHODOLOGY

The envisioned in-line design will comprise of three sub systems, which are standardised inspection procedures, workstation configurations and procedures and work table ergonomic design.

3.1 Standardised inspection procedure

The design of the standardised inspection procedure was done in consultation with the quality manager and the inspectors. It was structured such that is could be used for any type of product. It was also structured so that the inspectors have to fully inspect the part before performing any grinding procedures, this way they will avoid wasting time grinding parts that will eventually be scrapped or sent for re-work at shot blasting.

The quality manager advised that inspectors should run their eyes from right to left while inspecting a part because the process of analysing from right to left goes against the natural left to right process taught when reading or writing. By doing this the inspectors are likely to be more meticulous while inspecting.

Work study principles of time studies and method studies (work measurement and human movement) analysed in the literature review were instrumental in the standardisation of the inspection process.

3.2 Work station configuration

Three locations were identified as shown in the following schematic

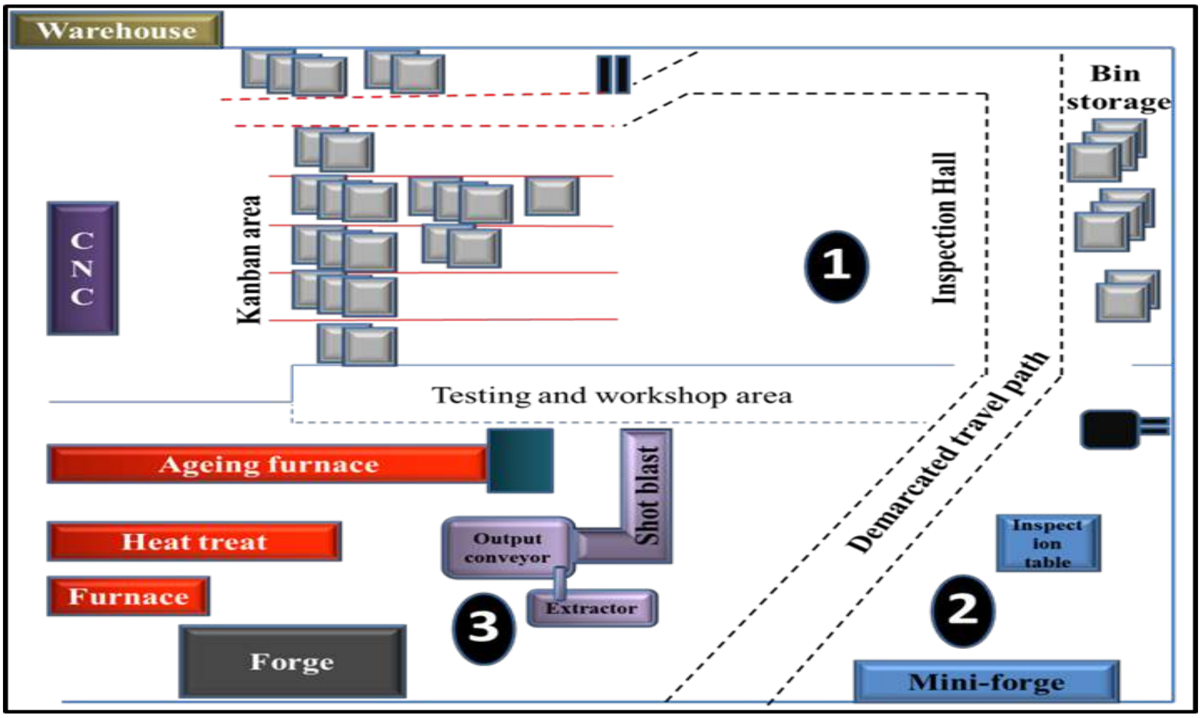

Figure 3: Potential workstation locations

The locations identified are shown by numbers 1, 2, and 3.

Location 3 was selected as it is close to the shot blast machine, though it presents significant floor space constraints. To avail more space next to the shot blast conveyor, the general manager says the extractor can be repositioned at the back of the shot blast machine. This location is the most ideal with regards to ensuring the in-line design results in the advantages highlighted from the literature analysis.

A configuration was selected where all the inspectors are on the same work station with their own work tables. The following schematic shows a proposed design layout, it shows the top and side views respectively.

This design allows for one piece flow alluded to in-line design literature with the accruing advantages of: reduced lead times, dramatic changes in transport, improved space utilisation and early detection of production problems.

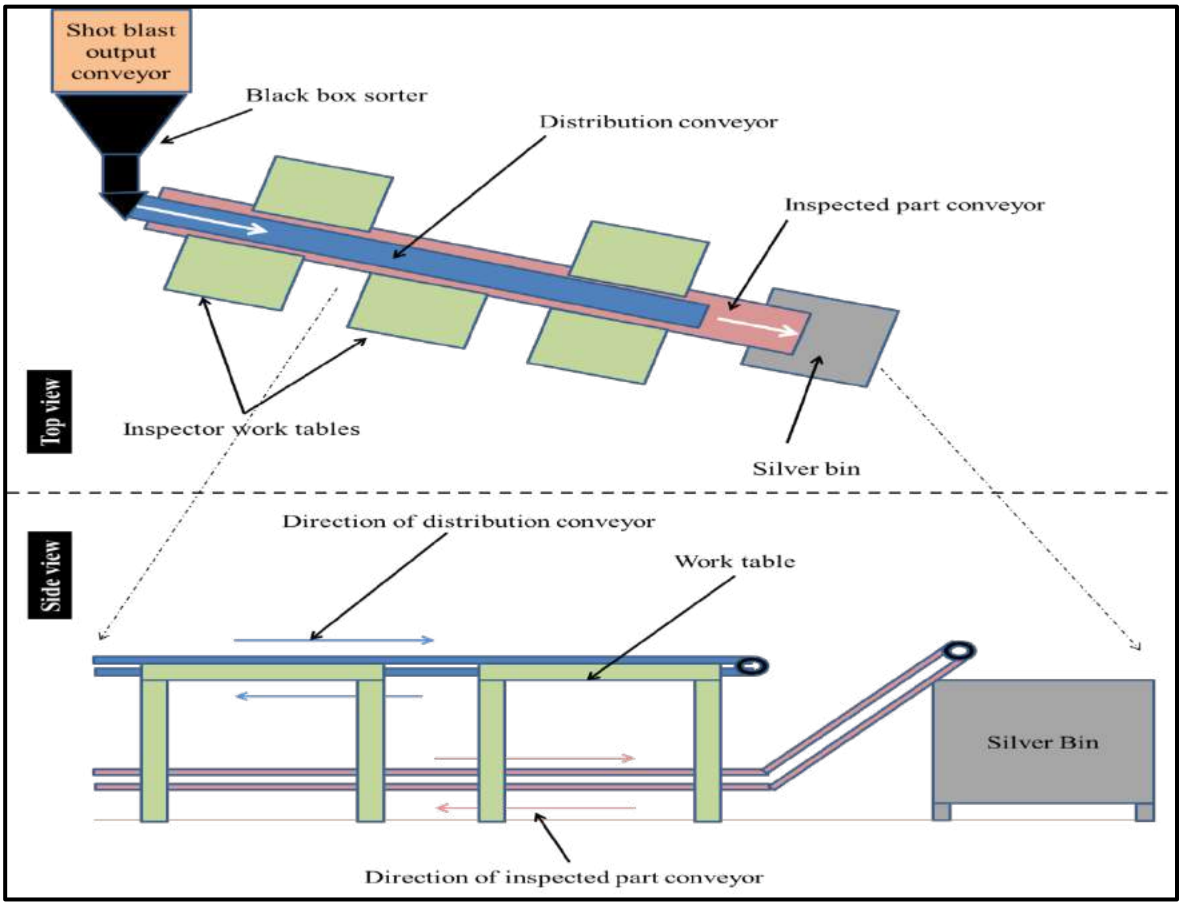

Figure 4: Proposed layout of new in line inspection system

3.3 Work table ergonomic design

The inspectors work table is a constituent component of the inspection workstation. This section looks at the ergonomic design of this component as a part of the workstation, based on the work study literature that elaborated on evaluation of human work.

The following is a schematic of the work table proposed design, it shows the front and top views respectively.

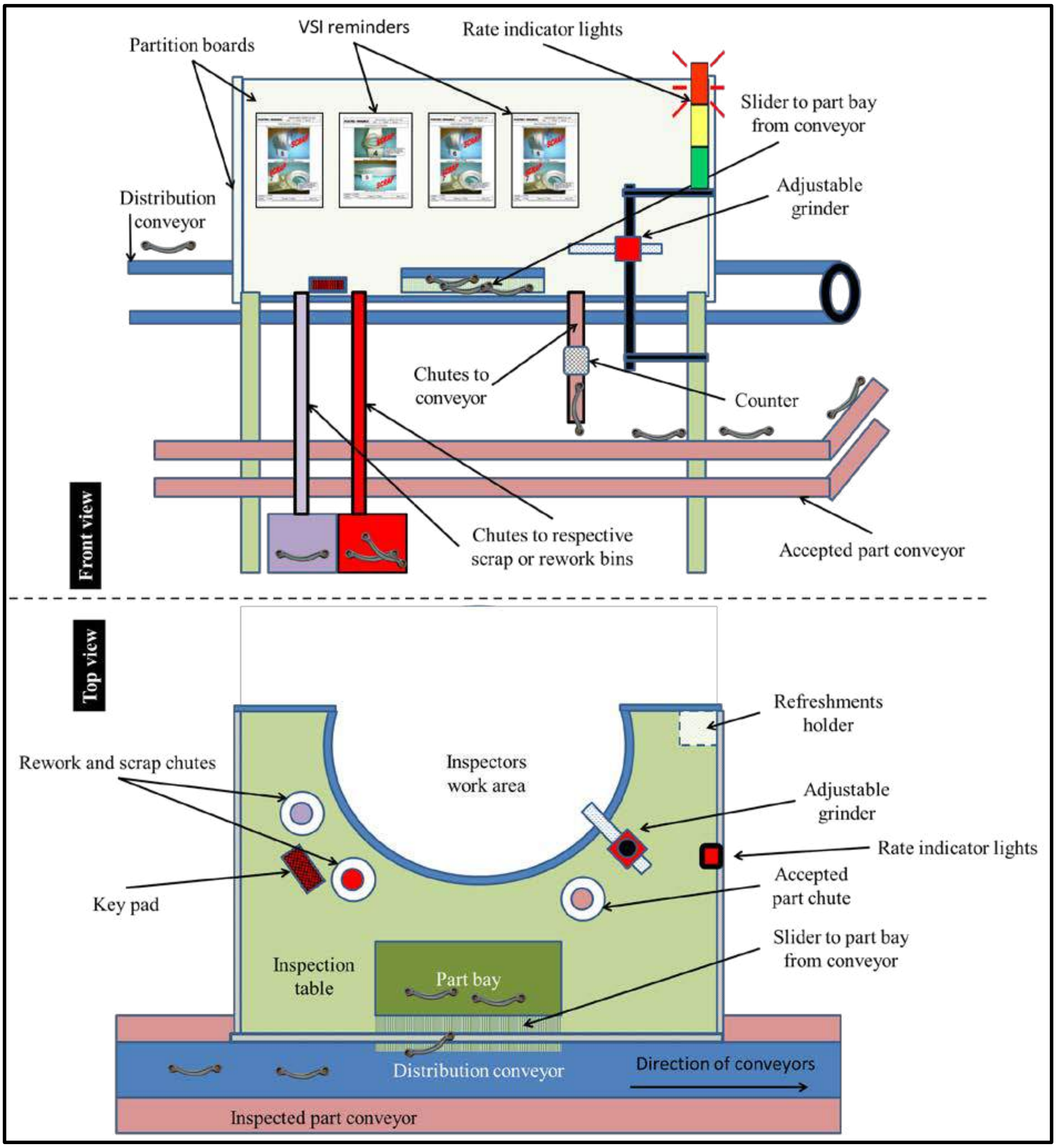

Figure 5: Inspector work table design

4 RESULTS ANALYSIS

4.1 Layout

The current floor space used by the inspection hall, inclusive of the bin storage area is 102m^2. The proposed new system will free up this space. The proposed inspection work station will at most cover 60m^2.

Currently every inspector travels an average of 1256 km per annum to retrieve and deliver material. The proposed system would eliminate this distance travelled entirely.

The physical location of the inspection bay next to the forge area will allow for better oversight from team leaders and management and allows for improved communication between the various functions within the plant.

The waste resulting from re-handling and batching will be eliminated.

4.2 Cycle time

The resulting cycle time for a part through the inspection system will be 8 seconds. This is because the non-value adding activities will be eliminated and the inspection time becomes the process time. Based on this the new cycle time is a 43% improvement from the current cycle time of 14.6 seconds.

4.3 People and process

From a people perspective the following benefits are accruing to the proposed design.

- Ergonomically:
    - The new work table eliminates the risk of injury
    - The work area is designed to allow the inspectors access to all areas of the table without over stretching and twisting
    - Adjustable grinders will ensure good posture regardless of the workers physique
    - Motion fatigue is reduced as all the chutes for the parts do not require any extra lifting by the worker
    - Quicker and easier access to the VIS (Visual Inspection Sheet) through the visual reminders on the partitions
    - Quicker and easier logging of defects
    - Improved flow reduces transportation distances by over 1200 km per year including associated productivity and wellness gains.
- Innovation with respect to the inspection methodology can be achieved from the set standardised method
- Equal work loading will be achieved
- Job enrichment will be enhanced by making the inspectors play a more active role in the structuring of their work in terms of scheduling and determining reward measures. This will be done primarily through the shift head inspectors.

From a process perspective, the elimination of non-value adding activities as alluded to throughout this section is critical. Another big benefit is the real time SPC charts tracking the different defect types that the inspectors are picking up. These charts on the work station computers will allow the immediate pick up of defects allowing for prompt process corrections from the forging department.

4.4 Cost benefit

The benefit that stands to be gained from the proposed inspection system is greater than financial savings but such an analysis is required to justify funding this implementation.

The floor space availed by implementing the new system is 102 m^2. This space will be utilised for other production activities within the factory. The cost of expanding the factory floor space at Foxtec is estimated at R 5,000 per m^2. This means that a potential saving of R 500,000 is realised just by making available the extra floor space.

Based purely on salaries, the annual opportunity cost due to poor utilisation is R 344,000 per annum. Additionally, the current inspectors structure takes inefficient practices into account, meaning that 25% of inspectors can now be redeployed elsewhere in the factory.

There is a potential cost saving associated with eliminating the risk of having inventories of parts yet to be inspected. This benefit should be appreciated but analysis of it was not done due to limited access to information on the number of parts re-worked and scrapped yearly.

5 SHORT FEEDBACK LOOPS

Prior to the introduction of the inline quality inspection station, the average rejection rate of components was 4.2%. This was reduced by over 50% to 1.6% on average. This is unexpected, as both quality inspections take place downstream from the forge, and should therefore not be able to affect the quality of products produced there. It is however a recorded fact that this did occur, and it is our contention that the immediacy of the in line quality inspection station allows inspectors to feed quality issues back to the forge immediately, meaning that an incorrect setup does not go unnoticed until the batch produced on a particular run is finally inspected. This short feedback loop is a driver of quality change upstream and paid for the significant cost of purchase, design and installation of the inspection station within a period of less than a year.

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COMPARING THEORY OF CONSTRAINTS (TOC) WITH TRIZ IN SOLVING A PRODUCTION PROBLEM IN SOUTH AFRICA – A CASE STUDY

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ABSTRACT

This research investigates the usability of TRIZ in a non- traditional area namely non-technical environment and compares results to that of TOC. The applicability in a non-technical environment is tested using a single case study in a production environment of a coal mine in South Africa. The task selected was improving the efficiency of a colliery by increasing the amount of coal conveyed by the conveyer belts. With constraints being the systems of scales and chutes which directly deposited coal onto the conveyer belt, solutions were generated for this system using the two tools and compared for strengths and weaknesses.

TRIZ was found to be applicable to this production environment and able to solve the problem that TOC traditionally did. In this respect it provided an alternative tool to TOC for the particular constraint considered. In addition TRIZ provided more options for solutions than TOC, although not all could be completed within the time constraints of the research. Further, TRIZ seemed to provide a stronger solution compared to TOC. Within limitations, overall TRIZ seems to be a more powerful tool for the selected production problem.

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1 INTRODUCTION

Organisations are being impacted by a multitude of challenges, such as accelerating rate of change, dramatic increase in competition, advancements in new technologies, and an increasingly complex information oriented world among others contributing to increased difficulty in finding solutions to problems [1]. Organisations need to find creative solutions to an array of organizational problems, in a multitude of organizational environments, with people of diverse backgrounds, knowledge bases and skill sets in order to solve these problems [1]. Higgins [2] suggests that the best way to savage such a situation is for organisations to embrace the use of creativity and innovation tools to enhance their employees' creative ability. One such tool that is able to enhance the creative skills of people is TRIZ [3].

TRIZ is a toolbox of techniques used to solve problems creatively which was developed by Genrich Altshuller and his colleagues in Russia in 1946 [4]. TRIZ was ultimately created as a pure engineering science, based on the statistical research of patents and other sources of technical information [5] to solve technical problems. TRIZ has been used successfully to solve a multitude of technical problems (i.e. design). The success of TRIZ led researchers to investigate its applicability in other fields which are fundamentally non-technical. Owing to this need, several TRIZ specialists in as early as 1970s and 1980s, started to attempt to apply TRIZ to management and administration problems, primarily for the purpose of enhancing various manufacturing processes [5].Notwithstanding these efforts the applicability of TRIZ in non-technical environments has not been tested to a satisfactory point [1]. Many researchers still believe the tool is only effective in the technical environment while others claim TRIZ is just as effective in non-technical environments as it is technical environments [6]. Nonetheless the evidence of the applicability of TRIZ in non-technical environments is scarce [6] in general and there is no indication that it has been attempted in South Africa in particular. This research seeks to investigate and contribute evidence on the applicability of TRIZ to solve problems in a non-technical environment, namely production, in a South African setting.

To test the applicability of TRIZ in a production environment it is compared against a well-known tool, Theory of constraints (TOC) in solving a typical production problem. Both tools were used to solve the problem and their results compared first to establish whether TRIZ was able to provide a solution to the problem and then evaluate the solution to determine the strengths and weakness between the two.

2 LITERATURE REVIEW

2.1 Defining TRIZ

TRIZ, ("*Teoriya Resheniya Izobretatelskikh Zadatch")* [8], pronounced "*treez*" [9] is a Russian acronym directly translated to mean *Theory of Inventive Problem Solving* [7]. A few definitions of TRIZ exist; [9] [10] [11] [12]. For the purpose of this research the definition of TRIZ that will be recognised is that of "*an empirical, constructive, qualitative and universal methodology [used] to generate ideas and to solve problems especially in the development of technical systems that is based on models of contradictions in technical systems and methods for their solutions that were derived from known inventions*" [13]. The definition of TRIZ is often simplified by the use of a diagram similar to the one shown below in Figure 1. The diagram defines TRIZ through an illustration of a system where a specific problem is converted into an abstract problem for which an abstract solution is formulated through TRIZ tools. The abstract problem is then translated into a specific solution. The process of TRIZ is a structured method of achieving the same results as that of a trial-and-error process in a shorter time and in a more predictable manner.

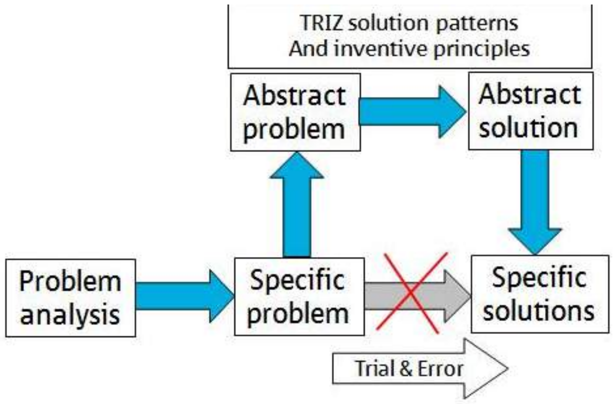

Figure 1: Defining TRIZ through a sketch [14]

2.1.1 TRIZ approach

TRIZ takes a systems approach [15] to creative problem solving [1]. Bowyer [1] categorizes the use of TRIZ systems thinking in the following ways; first, TRIZ systematically investigates the parts of the system which includes the location of the problem and when the problem occurs [16]. Secondly, TRIZ uses systems thinking to employ available resources within the whole system to solve the problem or resolve the contradictions. Thirdly, TRIZ looks at the systems from several other perspectives (i.e. past, present, future) including super-systems and the subsystem of the system.

2.1.2 TRIZ pillars

Mann [17] highlights five pillars of TRIZ which together play a critical role in defining and solving problems through the TRIZ methodology [17].

Contradictions

Contradictions are the conventional trade-offs that most designers take for granted [17] [18]. There are two kinds of contradictions that TRIZ recognizes; technical contradictions and physical contradictions [6]. Technical contradictions are those that are between two different parameters that are in conflict (for example; wanting a high strength with low weight). Physical contradictions are those that seek different values of the same parameter, i.e. wanting high weight and low weight.

Ideality

Ideality is typically defined as the sum of the positive functional benefits delivered by a system divided by the sum of all the negative aspects [17]. The motivation behind this pillar of TRIZ is the idea that as a system evolves, it delivers more of the benefits and less of the harmful stuff. If a system is fully evolved, then it will deliver all the benefits and none of the harmful elements, and that is what is ultimately required; the Ideal Final Result (IFR). The tool suggests that the problem solver starts solving the problem from the IFR and not from the current state as conventional methods would have it. That is, the problem solver moves from a single IFR and expands towards the current solution in small incremental steps that allows the problem solver to add adjustments to the IFR to bring it closer to reality, providing a structured, more effective design method to generate solutions [17].

Function and Functionality

In TRIZ, function and functionality are examined through the use of the Functional Attribute Analysis (FAA) tool. FAA is an extension of the work of Larry Miles [19]. In the TRIZ version of FAA, not only is the user advised to identify the function of the components in the system but rather they are also encouraged to identify the harmful, ineffective and excessive functional relationships as well [19]. FAA is useful for expanding ones knowledge and understanding the functions of the object of interest.

Use of resources

The investigation into the maximisation of the use of resources within systems uncovers a number of highly predictable, discontinuous trends of evolution, [17] [19] [20]. One of the great advantages of using the trends pillar is that it allows users to identify trend jumps that have been used in other industries that have not yet taken place in the industry under consideration [17].

Shifting perspective

This is the concept of re-framing strategies to help solve the problem fostered by psychological inertia [17]. This pillar recognises the importance of not only thinking in the here and now realm, but rather encourages problem solvers to think of the past and future in pursuit of solutions. The use of this pillar is used with the aid of a tool called the 9 Window approach [19]. The 9 Window tool is one that comprises of a tabular looking structure which consists of 9 windows which allows the user to explore the problems in the super-system, the system, and the subsystem considering the past, the present, and the future tenses.

2.1.3 TRIZ applications

TRIZ tools were originally formulated to provide innovative solutions to technical problems. However, over the years the tools have been adjusted to assist the generation of innovative solutions in other environments. TRIZ tool are not only useful to engineers and scientists seeking to enhance technical systems but may be used by anyone to enhance their creativity in any environment [10].

2.1.4 Challenges of TRIZ

TRIZ has a number of limitations. Some of these limitations are highlighted below;

- TRIZ problem solvers seldom know which of the TRIZ tools to use when. This challenge can only be combated by practice and familiarity [21].
- The TRIZ principles and processes that are meant to resolve nontechnical problems have not yet been thoroughly defined [1] [22].
- There is no precise recommendation on how to formulate contradictions which leads to ad hoc formulation of contradictions [6].
- The design parameters provided in the contradiction matrix are highly generic and limited, forcing the problem solver to converge to one of the contradictions when the problem is not that straight forward. The way to execute the solution is not guided leaving the interpretation of the contradiction to the problem solver [6].
- The TRIZ methodology is complicated and time consuming. It is recommended that people spend a minimum of 80 hours of training in TRIZ before they attempt to use it to solve a real world problem [1] [16].
- The translation of some of the TRIZ concepts from Russian to English use terminology that has proven to be difficult for some people to understand [1].
- TRIZ uses "*deductive reasoning*" which is taught extensively in Russia but not so much in other educational systems [1].
- TRIZ has been extensively applied by consultants and not by managers, supervisors or project managers who have not been intensively trained [1] [22]. Elaborating, Bowyer [1] adds that TRIZs' applicability in organisational problems by organizational development practitioners in the western world has not been substantially developed or tested.

2.2 TOC as a problem solving tool in production

TOC developed by Eliyahu Goldratt [7] is used extensively in production to identify constraints in a system and thereby improve the system through eradicating the constraints.

2.2.1 Defining the Theory Of Constraints (TOC)

TOC can be defined as "*a set of holistic processes and rules, all based on a systems approach, that exploits the inherent simplicity within complex systems by focusing on the few "leverage points" as a way to synchronize the parts to achieve on-going improvement in the performance of the system as a whole*" [23]. Other similar definitions of TOC exist [24] [25] [26] [27]. Similar to TRIZ, TOC takes the systems approach to problem solving [23].

2.2.2 TOC tools

Goldratt developed five tools which have been used effectively in problem solving situations. They are five distinct logic trees namely; Current Reality Tree, Evaporating Cloud, Future reality tree, Prerequisite Tree and the Transition Tree [24]. The trees are each briefly explained below;

Current reality Tree (CRT)

A Current Reality Tree (CRT) is a logical structure which has been designed to depict the state of reality as it currently exists in a given system [24]. The CRT constructs a chain of cause-and-effects of the circumstances of a system. The tree is drawn starting with the observed undesirable effects (UDEs), postulating likely causes for those effects. This is done by using the symptoms observed to work back to the core problem which is often the constraint that is being sought through stages. The purpose of the CRT tool is to highlight what to change [24].

Evaporation Cloud (EC)

Also known as the Conflict Resolution Diagram (CRD), the Evaporation Cloud (EC) solves problems that perpetuate chronic problems. This implies that the problems that cause the main problem present some difficulty and hence this difficulty needs to be removed. The problem solver identifies two opposing wants, that represent the conflict, the need that each want is trying to satisfy, and a common objective or goal that both needs are trying to fulfil. The tool will then resolve conflict altogether without resorting to compromise [24].

Future Reality Tree (FRT)

The FRT has two purposes; first it verifies if the problem to be solved will indeed reap the benefit deemed and secondly, it helps to identify any new problems that may arise and to eradicate them before they manifest. This helps to provide a test prior to making an investment into the solution and to ensure that the system is indeed getting better and not worse. The FRT identifies what to change with particular consideration of the impact on the future of the organisation. Each step of the FRT group is scrutinised to ensure no problems are overlooked [24].

The prerequisite tree (PRT)

The prerequisite tree helps to implement decisions that have been derived from the other trees. It also identifies obstacles to the goal and provides a sequence of how to tackle the problems. Once problem solvers have identified what to change to, they need to then implement the solution. The purpose of the PRT is to identify the critical elements, or obstacles that are preventing the problem solver from reaching the objective [24].

Transition Tree (TT)

The TT is an operational or tactical tool that gives a step-by-step process of how to implement the cause of action. It dictates what steps to take and the rationale of the steps.

Problem solvers construct and scrutinise the details of the action plan through the use of the effect-cause-effect method. Each step is scrutinized with each succeeding level of the tree being built upon the previous level, building progressively upward to an overall objective or desired effect [24].

2.3 TRIZ compared to TOC

A few authors have studied the relationship between TRIZ and TOC. The following gives a comparison of the two tools based on literature.

2.3.1 Similarities

- TOC talks about the weak link (trade-offs) which in TRIZ language is contradictions. Both tools maintain that unless you remove these, the system will not really improve [28].
- In TOC the major tool for innovation is referred to as the Conflict Resolution Diagram (CRD) or Evaporation Cloud (EC). The tool is similar to (Functional Attribute Analysis) FAA in TRIZ [26].
- To accommodate the future, TRIZ uses its patterns of evolution while TOC uses a Future Reality Tree (FRT). Patterns of evolution give suggestions as to what the future is likely to be while Future Reality Tree (FRT) presents the user with what he/she wants it to be [29].
- Both tools subordinate the importance of reducing cost in improving 'Ideality' and 'Value added productivity' [26].

2.3.2 TRIZ stronger

- TRIZ offers a better structured approach for the generation of ideas [30]. The Conflict Resolution Diagram (CRD) or Evaporation Cloud (EC) of TOC helps find contradictions and conflicts and helps clarify the reasons for conflict whereas TRIZ removes the conflict [25] [30].
- The 9 window tool of TRIZ offers an effective change in perspective. TOC does not have a tool to match this [29].
- TRIZ is more knowledge based in that achieving the paradigm shift associated with finding solutions to complex problems often requires knowledge of existing technology external to the field and knowledge of scientific effects [26].

2.3.3 TRIZ weaker

- Conflict Resolution Diagram (CRD) or Evaporation Cloud (EC) of TOC helps find contradictions and conflicts and helps clarify the reasons for conflict whereas TRIZ removes the conflict [30].
- Asthana [29] suggests that for systematically analysing the current state, TOC offers a better tool through its Current Reality Tree (CRT).
- To design a roadmap to predict and prevent future possible roadblocks, the best options are those presented by the Prerequisite Tree (PRT) and Transistion Tree (TT) offered by the TOC [29].
- In defining the contradiction, the TRIZ concept of physical contradictions and the TOC Conflict Resolution Diagram (CRD) or Evaporation Cloud (EC) has been shown to have a common basis. However, EC offers a better tool in breaking the physical contradiction [28].

3 METHODOLOGY

A case study was used to test the applicability of TRIZ in comparison to TOC. The case study was selected to ensure that it is one where traditional TOC methodologies could be effectively applied, namely production. TRIZ and TOC were both used to try and solve the same case study. This was to ensure that the solutions could be comparable.

The case study that was used was that of improving the throughput in tonnage of coal in a colliery in one of South Africa's leading mines. The mine produces coal almost continuously. This means that whether the colliery is able to transfer the coal or not, the mine still supplies coal to the colliery. The ideal state is that the bunker (coal buffer) should be emptied continuously to ensure that it is never full. If the bunker gets full, the coal in the bunker needs to be manually thrown out into a pile next to the bunker until there is enough space to (manually) load it back into the bunker. The value of this unnecessary exercise is a loss in monetary terms including material and production time lost and a decline in the quality of the coal eventually sent for processing. The burning platform was therefore to optimize the throughput of the colliery to ensure that there is never a need to throw out any coal. This limited the case study objective to;

- Reduce throw-outs
- Improve throughput of coal transferred

To ensure that TRIZ could be directly compared with TOC the following precautions were taken. The same problem was to be solved using the two tools within the same time frame. Only one problem solver was to apply both tools. The problem solver had to learn both tools at the same time to the level of being able to use the tools to derive solutions to a given problem. The problem solver therefore needed to acquire a minimum level of proficiency in using both tools, a level that enabled the problem solver recognise the array of techniques in each tool and identify which of these were similar to both tools, and therefore which of these were comparable from both tools that could be applied to the same problem, and which one gave a more satisfactory solution according to how wholesome and how feasible the solution was. In addition, the problem solver was not allowed to seek assistance from any source other than relying on the guidance of learned literature to solve the problem at hand, as other sources may be inclined to the use of one tool over the other.

To determine the strengths and weaknesses of the solutions the following criteria were used. The solution was examined according to the extent to which it was conclusive, primarily how wholesome and in-depth it was. In particular, a solution that outlined both what to do and how to do it was considered stronger than a solution that only indicated what to do. In addition, feasibility of the solution was taken into account by comparing the relative ease of implementation of the solution and its cost effectiveness.

3.1.1 TRIZ methodology overview

The TRIZ methodology used was that described by Darrell Mann [19]. An illustration of the overall process is shown in Figure 2.

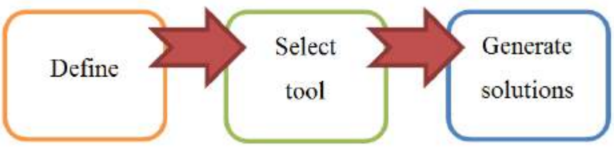

Figure 2: TRIZ methodology overview

3.1.1.1 Define

Mann [19] suggests that 90% of the time should be spent defining what the problem is. There are four steps that were used to enhance the ability to define the problem well and they are; (a) problem explorer, (b) function and attribute analysis, (c) s-curve analysis and, (d) ideality / ideal final result. The process followed for each step is shown in

Figure 3.

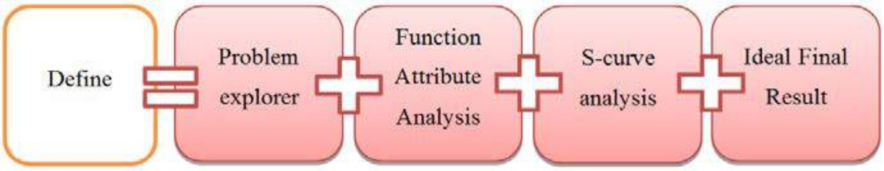

Figure 3: TRIZ methodology - define

3.1.1.2 Select tool

It is rarely the case that there is only one tool that is used to solve problems. However, most people do not know all the tools involved in the TRIZ toolkit. An overview of the tools to select from is given below in Figure 4.

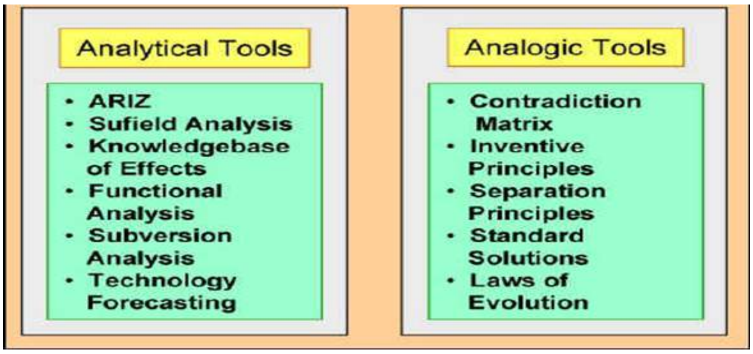

Figure 4: TRIZ methodology - tools [31]

Mann [19] provides a route map that suggests the most appropriate tools to use in a given situation. A summary of the table is shown below (Table 1). The table is structured such that the areas with the highest priority are highlighted first. On the vertical axis, the focus areas are tabulated in descending order of priority. The horizontal first row gives the options of tools to use starting with the best option going down to the fourth option.

Table 1: TRIZ methodology - Solution selecting tool

	1st Option	2nd Option	3rd Option	4th Option
Contradictions	Physical contradictions	Technical contradiction	Trends	Knowledge / Effect
Insufficient action	Knowledge / Effect	Trends	S-fields	Technical contradiction
Excessive Action	Trends	Knowledge /Effect	S-fields	Technical contradiction
Missing Action	S-fields	Resources	IFR	
System Doesn't Exist	IFR	Knowledge /Effect	S-fields	
System Improvement / No problem	IFR	Trimming	Technical contradiction	
Measurement problem	S-fields	IFR	Knowledge /Effect	Technical contradiction
Cost reduction	Trimming	IFR	Technical	

	1st Option	2nd Option	3rd Option	4th Option
			contradiction	
Optimization	Optimization methods			
Don't know	ARIZ			

3.1.1.3 Generate solution

Solution generation is highly dependent on the tool which was suggested from Table 1. The procedure for the top three tools is provided below;

Technical contradictions

Contradictions are solved by using the 39 by 39 contradiction matrix to find conflicting contradictions and then using the appropriate manner to reduce or remove them.

Trends

Mann [19] refers to 30 trends (interpretable in 35 different ways), that have been brought forth by various researchers [19]. In the 35 trends, researchers highlight the basic trend followed by others in the evolution of a component or system, paying special attention to the sequence of events that occur in the trend. Trends may be used to help find new s-curves, improve insufficient or excessive actions, or simply to improve attributes of a component or process [19].

Knowledge effects

Knowledge/effects direct problem solvers to look beyond the current state horizon to see if anyone else has been able to solve this problem. The tool offers three options of resource types, resources that assist if one is: looking to deliver a function more efficiently, looking to improve the delivery of an attribute associated with a part of a system, and resources that allow the team to see how closely someone else might have already solved the same kind of problem. Mann [19] suggests that this tool may not necessarily solve the problem but it would give the problem solver the knowledge that the problem can be solved which is often enough to catapult the problem solver to the ideal feasible solution.

3.2 TOC problem solving methodology

Solving problems with TOC involved using the different trees to identify the problem, prioritize the most important issues and find solutions for the most prevalent issues. The order in which the trees should be used is provided in Figure 5 below [32].

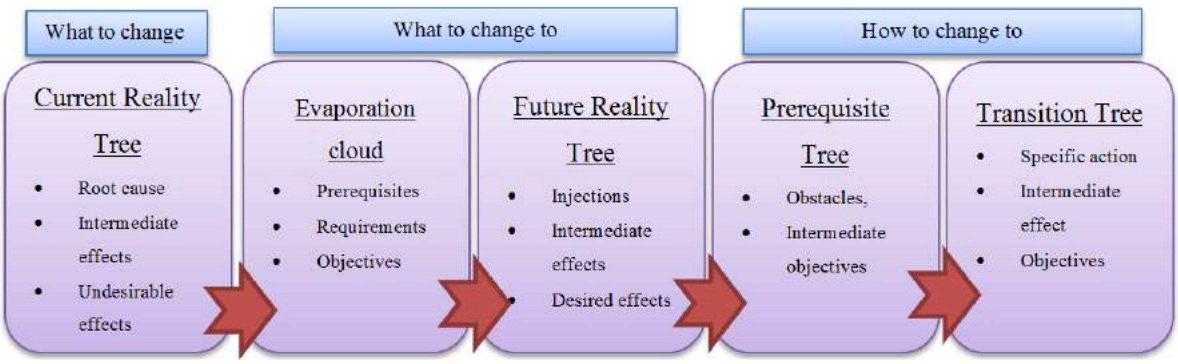

Figure 5: TOC methodology - Overview

4 Results: Comparing TRIZ and TOC

4.1 Learning the tool

Both tools had to be learned in order to generate solutions. The time it took to learn TRIZ compared to TOC was significantly longer, ranging in a number of days. The time required to learn TOC was significantly shorter as it took a number of hours. This was because the TRIZ tool is still in its early ages of development and so finding reliable information on how to use the tool was difficult compared to TOC. The information required on how to apply TOC was readily available including many step-by-step procedures on how to build the different trees. The difficulty presented in the length of time to learn TRIZ resonates with the research conducted by Bowyer [1] and others [16]. Bowyer [1] highlighted that it takes about 80hours [ten days, 8 hours a day] to learn TRIZ to a point where it can be used. This is a weakness for TRIZ as it means people will probably need to go for training to learn such a tool, limiting the number of people who can successfully embrace the tool and incorporate it into their work.

4.2 Using the tool to define the problem

TRIZ had a large number of tools, seven to be exact, which were used to define the problem. The tools generated information to expand the problem space. Some of the tools were simple to use because they required information that was immediately available regarding the case study. Some tools were not so simple to use because they required the problem solver to know more information than was immediately available. The TRIZ tools used to define the problem had the set back of not being able to build into each other. Each tool generated information in a different direction making it difficult to know which tool to use when or to identify which of the generated information was more important than the other.

TOC on the other hand was much simpler to use than TRIZ. The arrows provided in most of the TOC trees immediately showed which direction the tree should be read in (i.e. top to bottom or bottom up). The trees were very simple and straight forward to construct because they required little information and they did not include many levels. Using TOC was also simpler because it provided hierarchy in the way the trees were constructed. It allowed for the trees to build into each other, allowing the information being generated to be used to construct the next tree.

4.3 Using the tool to generate solutions

Three TRIZ tools were used to generate solutions. The tools were; the contradiction matrix, knowledge/effects and trends. This can be highlighted as a strength as multiple solution generating tools were available, not just one. The contradiction matrix was simple to use, well-structured and straight forward. The solution generated was complete and satisfactory to a high degree as it gave the problem solver guidance on how to implement change. This was not the view of Cavallucci [6] who argues that the formulation of contradictions is ad hoc due to a lack of structure, and that the limit imposed on the user to select from only a limited number of options is impractical. The tools knowledge/effects and trends were also used but no satisfactory solution was derived from them. The disadvantage experienced with this tool was that they required extra knowledge and resources and training in order to bring the solutions to a satisfactorily conclusion.

Using TOC to generate a solution was straight forward. The trees were structured such that the information generated from them led to a solution. The solution provided was complete and satisfactory. Comparing the ability to generate solutions using TRIZ and TOC, one can conclude that TRIZ and TOC proved to be equally strong. TRIZ had the advantage of having more than one solution generating option to choose from whereas TOC had only one. However, the structure provided by TOC in generating solutions was better appreciated than TRIZ that lacked structure.

4.4 Quality of the solutions generated

Three solutions were generated using three different tools of TRIZ. The quality of the solutions differed according to the different tool. The solution generated from the contradiction matrix was seen as a strong, sufficient and feasible solution. The solution generated using the contradiction matrix tool provided the problem solver with clear direction on how to remove a contradiction in the system. The other two tools (the knowledge/effects and trends) guided the problem solver only to a certain extent, providing solutions that were considered incomplete and insufficient.

The TRIZ solution generated from the contradiction matrix was the only one considered feasible from TRIZ. Using TOC to generate solution gave a solution that required a number of components to be adjusted in the system to bring it closer to perfection. The solution was satisfactory and conclusive as it provided the problem solver with direction on how to remove contradictions in the system. Comparing the final solution presented by TRIZ to that by TOC, the solution presented by TRIZ was considered to be stronger. This is because the solution offered by TRIZ highlighted the main contradiction that was preventing the system from being efficient and provided solutions that were appropriate and more satisfactory than that which was provided by TOC. This finding resonates with the research conducted by Rantanen and Domb [30] who claimed that TRIZ is stronger than TOC in removing constraints.

5 Conclusions

The following can be concluded from the research;

TRIZ is applicable in non-technical environments as shown in this research and as evidenced by the solution generated from the case study.

TRIZ has the following strengths compared to TOC;

- It provides a resource of 40 inventive principles that can be used as a starting base to find solutions to complex problems. TOC has no such resource.
- TRIZ provides stronger solutions.
- TRIZ removes contradiction completely.
- The TRIZ 9 window tool encourages the problem solver to think beyond the current state.
- TRIZ offers a wider range of solution generating tools.
- TRIZ provides a database with suggestions on how to solve complicated problems.

TRIZ has the following weaknesses compared to TOC

- TRIZ takes longer [days] to learn.
- TRIZ is more difficult to use.
- TRIZ doesn't have a strong tool for finding contradictions.
- TRIZ does not have good solution generating structure.

TRIZ was successfully applied in the production problem presented by the case study.

The results of this study are encouraging in showing that TRIZ can successfully be applied to a non-technical problem. The study could be extended to consider the applicability of TRIZ in various other non-technical situations such as other production situations and management issues.

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A CONCEPTUAL FRAMEWORK FOR THE ANALYSIS OF SUPPLY CHAIN RISK MANAGEMENT IN SMALL AND MEDIUM MANUFACTURING ENTERPRISES IN SOUTH AFRICA

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ABSTRACT

Theory, frameworks, tools and techniques used to analyse Small and Medium Manufacturing Enterprises (SME) have often been designed for application in Large Enterprises. This is predominantly the case when it comes to Supply Chain Management (SCM) and Supply Chain Risk Management (SCRM). SMEs, however, particularly in South Africa, have unique characteristics and challenges, often vastly different from those of large enterprises. This provides the impetus for the development of SME specific frameworks that take these differences into consideration. This paper presents an initial attempt to bridge this theoretical gap through the development of a conceptual framework for the analysis of Supply Chain Risk Management in Small and Medium Manufacturing Enterprises in South Africa.

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1 INTRODUCTION

Supply Chain Risk Management (SCRM) is a relatively recent area of research within the broader field of Supply Chain Management and consequently has deficiencies [10], [20], [17], [7] particularly in the context of small and medium enterprises (SME's) [2], [3], [4]. Theoretical and Conceptual frameworks and models for the analysis of Supply Chain Risk Management have predominantly been developed within the context of the Large Enterprise and/or the Supply Chain network as a whole [17], [23], [16], [22], [11]. Limited literature on studies on SCRM in the context of Small Enterprises could be located [2], [3], [4], [24]. Similarly, literature on Risk Management in Small Business seems to be limited [25], [26], [27].

Small and large firms are fundamentally different, and small firms may share common characteristics, such as resource scarcity, which set them apart from larger organisations [28]. But, in today's increasingly globalized economy, small and medium enterprises (SMEs) are now considered to be the major source of dynamism, innovation and flexibility in emerging and developing countries, as well as to the economies of most industrialized nations [29].

Thus, in the context of limited SCRM research in small enterprises and their unique features, the key question is: How do Small Manufacturing Enterprises Manage Risk within their Supply Chains?

Khan and Burnes [10] propose that research in SCRM needs to be grounded in broader risk theory. With this premise in mind, this paper seeks **to propose a particular risk theory perspective** in which a conceptual framework for the analysis of Supply Chain Risk Management in Small and Medium Manufacturing Enterprises in South Africa may be grounded.

The paper is structured as follows: a review of studies in SCRM in small enterprises is followed by a précis of the extant theories, practices and research concerning risk in a general business environment and then, in small enterprises; a synopsis of the National Small Business Act of South Africa (and amendments) is used to identify key qualitative criteria of particular interest to the development of a conceptual framework for SCRM in Small Manufacturing Enterprises in South Africa; these criteria are then further explored in Risk literature and distilled to **provide a grounding for the framework**.

2 SCRM AND SMALL ENTERPRISES

Karantana *et al* [9] define supply chains as "interlinked networks of suppliers, manufacturers, distributors and customers that have been set up to provide a product or service to customers". Supply Chain Management involves and has evolved from fields such as purchasing and supply, logistics and transportation, operations management, marketing, organizational theory, management information systems, and strategic management [9].

Rao and Goldsby [17] identify a number of different definitions of SCRM in the extant literature, most notably those provided by Christopher and Peck [30], Norman and Lindroth [15], Juttner *et al* [7], Tang [31] and Manuj and Mentzer [32]. From these definitions, Rao and Goldsby [17] observe that "SCRM is an extension of the within-firm risk management ideology". Despite small differences in the definitions, what generally emerges is that any approach to SCRM should encompass "understanding and reducing vulnerability to the supply chain as a whole" [17] as opposed to merely at a firm level.

A few studies examining supply chain risk management in SMEs could be located:

Finch [4] uses the information system environment and risk identification framework developed by Bandyopadhyay *et al* [33] to structure the literature and case study review. He finds that the risk exposure of large companies appears to increase when partnering with SMEs in business critical positions in the supply chain. SMEs also experience elevated exposure to risk by partnering in a supply chain. The research, thus, adds to the evidence of the need to identify and understand the impact of risk in the supply chain as a whole and on SMEs in particular?

Faisal *et al.* [3] provide a conceptual framework for quantification and mitigation of information risks. Graph theory is applied for the quantification of the risks. Interpretive structural modeling (ISM) is utilized to gain insight into the interrelationships between information risk mitigation enablers. They identify eleven variables that can impact information risk in the supply chain from a literature review and through discussion with supply chain experts involved with SMEs. Some of these are: a lack of co-ordination across the supply chain, the inability to adjust in a continuously changing, unpredictable business environment [34], a lack of identification and development of contingency plans for the various risks that exist internally and externally to the organization, a lack of sharing of both risks and rewards between the members of the supply chain and a lack of continuous risk assessment.

Ellegard [2] discovers, using an interpretive case study based methodology, that small manufacturing companies predominantly apply similar risk management practices that are defensive. This generally encompasses risk elimination practices, including knowledge protection and local sourcing, in combination with relational practices such as fairness, loyalty, and the seeking of responsive, dependable and like-minded suppliers. The approach is, thus, optimized to simultaneously reduce supply risks, resources and time consumption.

Thun *et al* [24] examine the differences between SMEs and large-scale companies regarding SCRM through a survey based empirical study of SMEs in the automotive industry in Germany. They find that SMEs regard themselves as slightly more vulnerable to supply chain risk in comparison to larger organisations. They attribute this marginal difference to the high dependence of SMEs on large OEMs leading to higher risk exposure. There is no significant difference between SMEs and large organisations regarding the evaluation of key drivers of supply chain risks where key drivers were identified as developments towards globalisation and lean supply chains. There was a significant difference concerning the suitability of SCRM instruments. They found that SMEs focus on reactive instruments such as safety stocks and overcapacities (redundancies) whereas large enterprises tend to use preventative instruments that decrease the likelihood of incident occurrences such as high quality suppliers or on-time deliveries.

Sunjka and Sklar-Chik [35] found, through an empirical pilot study, that manufacturing SMEs are affected by similar risk issues but that there are indications of industry specific risks emanating from the supply side markets and the demand side markets. The majority of risk sources were of a macro-economic and socio-political nature. SMEs do not exhibit explicit or formalised supply chain risk management practices, but are conversant with the risks throughout their supply chain and manage these within their capability. Corroborating Thun *et al* [24] it was found that SMEs focussed less on reducing the root cause of events and approaches could be characterised as defensive.

Thus, seminal work with regard to SCRM in SMEs is needed [24]. Khan and Burnes [10] suggest that broader risk theory should provide the fundamental foundation.

3 RISK MANAGEMENT

As proposed by Khan and Burnes [10], future research in SCRM needs to be grounded in broader risk theory. The purpose of this section, therefore, is to gain an understanding of the extant theories, practices and research concerning risk in a business environment.

Rao and Goldsby [17] discover that there are “few clear and concise” definitions of risk. They argue that this is the result of “tension in the academic literature on the nature of risk itself”, that is, risk may have a downside possibility or outcome as well as an upside possibility where “performance may be higher than expected” [17]. They, however, note that most researchers in business studies seem to “use the term risk to refer to some form of negative change with respect to performance" [17]. They ultimately prefer the Holton (2004) definition that refers to a risk situation as one that "entails exposure to two essential components: exposure to an event and the uncertainty of possible outcome" [17] of that event.

Risk Theory has its origins in the insurance industry. Almer [36] points out that in practice, risk theory can be identified with insurance risk theory or with probability theory applied to insurance risk problems. He concludes that probability theory, thus, provided insurance theory with a powerful instrument for "exact definitions and for risk analysis". Considerable developments in the use of probability theory for the prediction of expected loss and pure (event) risk in insurance theory have been made by actuaries and insurance theoreticians, mainly in the life insurance industry [18]. According to Valsamakis [18] risk may be defined as the "uncertainty surrounding an event and outcome in a specific situation".

Lewis [13] indicates that, emerging from a regulatory focus on operational risk management to ensure the sustainability of companies, greater attention has been paid to operational risk quantification, a wide range of statistical methods for measuring, modeling and monitoring operational risk have surfaced that have "proven their worth in real-world business situations".

Risk management has classically fallen within the ambit of financial management and has been described in financial literature as "being concerned with identifying and managing a firm's exposure to financial risk where financial risk is defined as the variability in cash flows and market values caused by unpredictable changes in commodity prices, interest rates and exchange rates" [8]. J.P.Morgan *et al* [6], however, propose that the principles of risk management of derivatives are equally applicable to the management of "other risks". It is, however, the responsibility of the management of each organization "to develop a risk management process that is appropriate to its specific business".

Valsamakis *et al* [18] perceive risk management, in its modern conception, to be a "systematic and holistic business discipline". They identify risk control and risk financing as two principle techniques, whose relationship modern risk management seeks to optimize. Valsamakis *et al* [18] stress that there is a "lack of an integrated approach to risk management", that is, risk management needs to be assimilated with the other managerial activities while the risk financing and risk control functions should be amalgamated. These deficiencies seem to be the result of a discrete, piecemeal approach to risk management which has been embedded in the insurance industry, where the issues of risk identification and quantification have been ignored. While there has been development of risk management models, Valsamakis *et al* [18], state that these concentrate on "specific interests rather than the more fundamental issues" as outlined above.

Klimczak [12] conducted an empirical investigation into major corporate risk management theories, namely, financial theory, agency theory, stakeholder theory and new institutional economics, with the aim of verifying the theories in practice. The results of the research indicate that there is little supporting evidence for financial economics and agency theory hypotheses, while stakeholder and new institutional economics may offer new insights into the determinants of risk management.

The rise in prominence of Corporate Governance and Risk Management over the last three decades can be attributed to some extent to the publication of the Cadbury Report (1992), the Turnbull Report (1999) in the United Kingdom and the King Reports (1994, 2002, 2009) in South Africa [37]. Although, voluntary, these corporate governance codes have emphasized that "boards of directors have an explicit responsibility to ensure that all potential threats to the business enterprise have been systematically identified, carefully evaluated and effectively controlled" [37]. This, New Institutional Economics provides a different perspective on risk management in that the focus is shifted to governance processes and socio-economic institutions that guide these processes [12]. No empirical studies on this risk management approach had been carried out at the time of the research.

Hutter and Power [5] point out that the ‘risk society’ thesis proposed by Beck (1992) encapsulates a paradox where “the risks we face today are largely ‘manufactured’, potentially fatal by-products of an industrial machine which demands a new politics to control it” [5]. Organizations are thus, “critical agents of any … risk society” because “organizations are both centres for processing and handling risks and potential producers and exporters of risk” [5]. The “organizational networks” created to manage risks, themselves promote new consequences and risk, that is, “the risk of risk management” or “disasters and accidents are in a very important sense *organized*” [5].

Nocco and Stulz [14] explain that over the last decade corporate risk management has developed beyond the insurance and financial exposures hedging to comprise many other categories of risk, most prominently, operational risk, reputational risk and strategic risk. The function of risk management within companies has risen in prominence to a senior executive level in the form of a chief risk officer and the board of directors has the responsibility of monitoring and controlling risk indicators. There are essentially two approaches to risk management. Firstly, the traditional approach is siloed in nature, that is, different risks are delegated to various specialized people in the organization who use different instruments to manage the designated risks. Integrated Risk Management (IRM) or Enterprise Risk Management (ERM), however, calls for a co-ordinated, strategic framework or a “portfolio view” in the management of risk.

Nocco and Stultz ([14] propose that companies apply the ERM approach gain “long-run competitive advantage” over those using “the one risk at a time” approaches. They believe that although the principles underlying the ERM theory are well-founded, the implementation of ERM lends scope for further research. In particular, “a more complete understanding of firm value is required”; further assistance is required in the estimation of correlation between the various risk types that is critical to the measurement of risk across the whole firm; and, more research is required on the quantification, assessment and understanding of reputational and strategic risks.

More recent research by Voinea and Anton [19] spurred by the recent global financial crisis suggests that certain weaknesses in risk management. They point to a number of studies that stress the requirement for improved Integrated Risk Management or ERM.

Finally, Corvellec [1] in contrast, claims that the practice of risk management should be disengaged from the risk management theories and that “risk management practices do not need to be explicit but can be embedded in the management tactics that characterise the organizations operational mode” [1].He continues to suggest that formal established risk management models present a “very specific view about uncertainty and how it should be dealt with …[They] are “likely to destabilize and disrupt existing practices of risk management …[and] may even increase the risks that the organization is exposed to” [1]. Consequently, “redefinition of the boundaries and nature of risk management theory and practice” [1] is required. This may be particularly relevant to Small Business Enterprises where a lack of resources, among other things, could preclude formal risk management practices.

Thus, there are a number of different notions and theories on risk, risk management and its practice. What emerges most significantly, however, is that there is a need for more research in the field of modern risk management to enhance understanding of the expanding scope and provide guidance for its practice.

4 RISK MANAGEMENT IN SMALL ENTERPRISES

The following studies on risk management in small enterprises could be located.

Leopoulos *et al* [25] examine the possibilities of computer-aided quantitative risk analysis tools in a project environment and suggest that these would benefit SMEs “since due to their size they cannot afford project cost overruns”. They primarily focus on an analysis of the analytical tools and suggest that “research efforts … should be put towards the implementation of risk management techniques in SMEs”.

Blanc Alquier and Lagasse Tignol [26] present the PRIMA (Project Risk Management) method and tools. The method is based on a decision support system for the bidding process, “considered in project management as the most important phase in terms of rewards”. The benefits to SMEs of this method are the rapid building of more accurate and competitive bids, and the identification of the most opportune bids.

These two studies provide little or no insight in terms of understanding the “how” of risk management in small business, focusing more on possible tools to assist SMEs manage risk in a project environment.

Gilmore *et al* [27] investigate the risk perceptions and risk management approaches, based on the cognitive-orientated approach to entrepreneurial risk, of 40 entrepreneur/owner-managers of small firms (more than 10 and less than 250 employees) across a number of different industries (including manufacturing) in a regional economy in the United Kingdom. They showed that the dominant areas in which risk was experienced were in activities and decisions relating to cash flow, company size i.e. growth, entering a new market or new business area, and delegation of responsibilities to staff. Their study further revealed that the owner managers employed various strategies to manage and minimize the risk associated with these activities. The two key risk management strategies were the use of networking (with contacts to elicit their advice and/or information) and the drawing on their managerial competencies (experiential knowledge built over time).

The Gilmore *et al* [27] study provides relevant insights into the way in which the investigation of how risk is managed in small enterprises can be approached. Because the owner-manager is the primary decision-maker within the small business, it is important to understand his personal perceptions of risk and how he/she decides to manage these risks. The study does not address the supply chain in particular, nor does it uncover anything explicitly relevant to risk in the supply chain. As the owner-manager and entrepreneur are in many instances synonymous [38] more insight on the profile of the owner-manager is sought from the theory of entrepreneurship [39], [40], [41].

5 SMALL ENTERPRISE AND ENTRPRENEURSHIP

Small enterprise and entrepreneurship have often been perceived as synonymous [38]. While the Theory of Entrepreneurship provides a number of different conceptions of the entrepreneur and entrepreneurship, what emerge are the following important aspects [45]: the entrepreneur and entrepreneurship are involved with,

- Identifying real business opportunities,
- Innovation and creativity in discovering something new and different,
- Obtaining resources in the form of capital, labour and operating equipment,
- Creating or growing a new or existing business,
- Taking on risk of a personal and financial nature,
- Receiving reward in the form of profit and/or an increase in business value,
- Business management in the form of planning, organising, leading and controlling business functions.

These features may relate to an independent business owner or to someone within a large corporation who has the freedom to build a business area in their own way with profit motives [38]. Because of the heterogeneous nature of small business [39], [42], this paper postulates that the likelihood of all these aspects or only some relating to all small business owners will depend on the inherent characteristics and behaviour of the entrepreneur or owner/manager; and these may be determined by the inherent size and stage of development of the enterprise [43]. This may be evidenced by certain well-documented characteristics of small businesses that include limited resources (such as finance, time, marketing knowledge); lack of specialist expertise (owner-managers tend to be generalists rather than specialists); and limited impact in the marketplace [43].

6 SMALL ENTERPRISE IN SOUTH AFRICA

There is no universally accepted definition for a Small Enterprise [21], but consensus in the literature reveals the following common criteria ([21], [46] as cited by Niemen [38]): a small business is

- Independently owned, operated and financed, where one or very few people manage the business without a formalised management structure, and does not form part of a large enterprise,
- Has a relatively small share of the marketplace or relatively little impact on the sector/industry in which it operates.

The National Small Business Amendment Act [44] aligns with these criteria by providing both qualitative and quantitative criteria in defining a ‘small enterprise’. This definition is of particular importance as it is the one used by policy makers to identify this form of business entity. Key qualitative criteria are:

“’small enterprise’ means a separate and distinct business entity, together with its branches or subsidiaries, if any, including co-operative enterprises, managed by one owner or more predominantly carried on in any sector or subsector of the economy mentioned in column 1 of the Schedule and classified as a micro-, a very small, a small or a medium enterprise by satisfying the criteria mentioned in columns 3, 4 and *5* of the Schedule” [44]

The Schedule provides the quantitative criteria. An extract for the sector of interest for this paper i.e. manufacturing is shown below:

Table 1: Extract from Schedule [47]

Column 1	**Column 2**	**Column 3**	**Column 4**	**Column 5**
Sector or sub-sector in accordance with the Standard Industrial Classification	**Size of Class**	**Total Full-time Equivalent (FTE) of paid employees** *Less than*	**Total Turnover** *Less than*	**Total Gross Asset Value (fixed property excluded)** *Less than*
Manufacturing	Medium	200	R51 mill	R19 mill
	Small	50	R13 mill	R5 mill
	Very Small	20	R5 mill	R2 mill
	Micro-	5	R0.2 mill	R0.1 mill

Niemen [38] points out that these quantitative criteria have been subject to criticism for a number of reasons. Firstly, there is no single criterion specifying “smallness”, but three different specifiers (Columns 1, 2 and 3) where the Act does not clarify whether only one or all criteria need to be fulfilled to classify class. Secondly, comparative analysis over time is difficult based on the monetary criteria, as indices need to be developed to account for price changes (inflation).

For the purpose of this paper Small Enterprise will incorporate the Medium and Small Classes in the manufacturing sector in the Schedule. Of particular interest for this paper is the notion of a single (or very few people) manager/owner where the business is without a formalised management structure.

7 CONCLUSION

The preceding discourse, thus, presents the following arguments:

- Small Enterprises are fundamentally differently from Large Organisations, and this should be recognised in the formulation of theory, tools and techniques for SMEs.
- There are limited studies on SCRM and RM in Small and Medium Enterprises, thus more research in this area is required.
- “risk management practices do not need to be explicit but can be embedded in the management tactics that characterise the organizations operational mode” [1] which may be particularly relevant to SMEs.
- The owner-manager is the primary decision-maker within the small business, hence it is important to understand his/her personal perceptions of risk and how he/she decides to manage these risks i.e. his/her risk behaviour/profile.
- The Theory of Entrepreneurship may provide some insights into the profile of the owner/manager.

8 THE BASIS FOR THE FRAMEWORK

Therefore, to understand how small enterprises manage risk in their supply chains, it is pertinent to appreciate that within the context of the small business that risk management practices may not be explicit and may well be embedded within the management tactics that are inherent to the operational mode of the firm, as suggested by Corvellec [1]. Additionally, because small businesses are owner managed without formalised management structures [38], it would seem that the operational mode of the firm would be highly dependent on the decision-making behaviour of the owner/manager. Hence, developing the risk profile of the owner/manager i.e. the individual decision-maker would provide a basis for understanding how risk would be managed within the supply chain of the SME.

A risk profile may be constructed using behavioural interviewing techniques where the interviewee is asked to recount a series of specific Supply Chain relevant risk situations, then describe his/her personal actions taken in these situations, and the perceived success of the result of his/her actions on the situations [48],[49]. The risk behaviour of the owner/manager, and consequently the small business, in particular supply chain risk situations, may then be classified more formally as follows [50],

- Risk Avoidance - Do something to remove it. Use another supplier for example.
- Risk Transference - Make someone else responsible. Perhaps a Vendor can be made responsible for a particularly risky part of the project.
- Risk Mitigation - Take actions to lessen the impact or chance of the risk occurring. If the risk relates to availability of resources, draw up an agreement and get sign-off for the resource to be available.
- Risk Acceptance - The risk might be so small the effort to do anything is not worthwhile.

The theoretical and conceptual basis for this premise and, hence, for the framework, is illustrated in Figure 1 below. All of the concepts in the framework require further research and development, as pointed out in the literature.

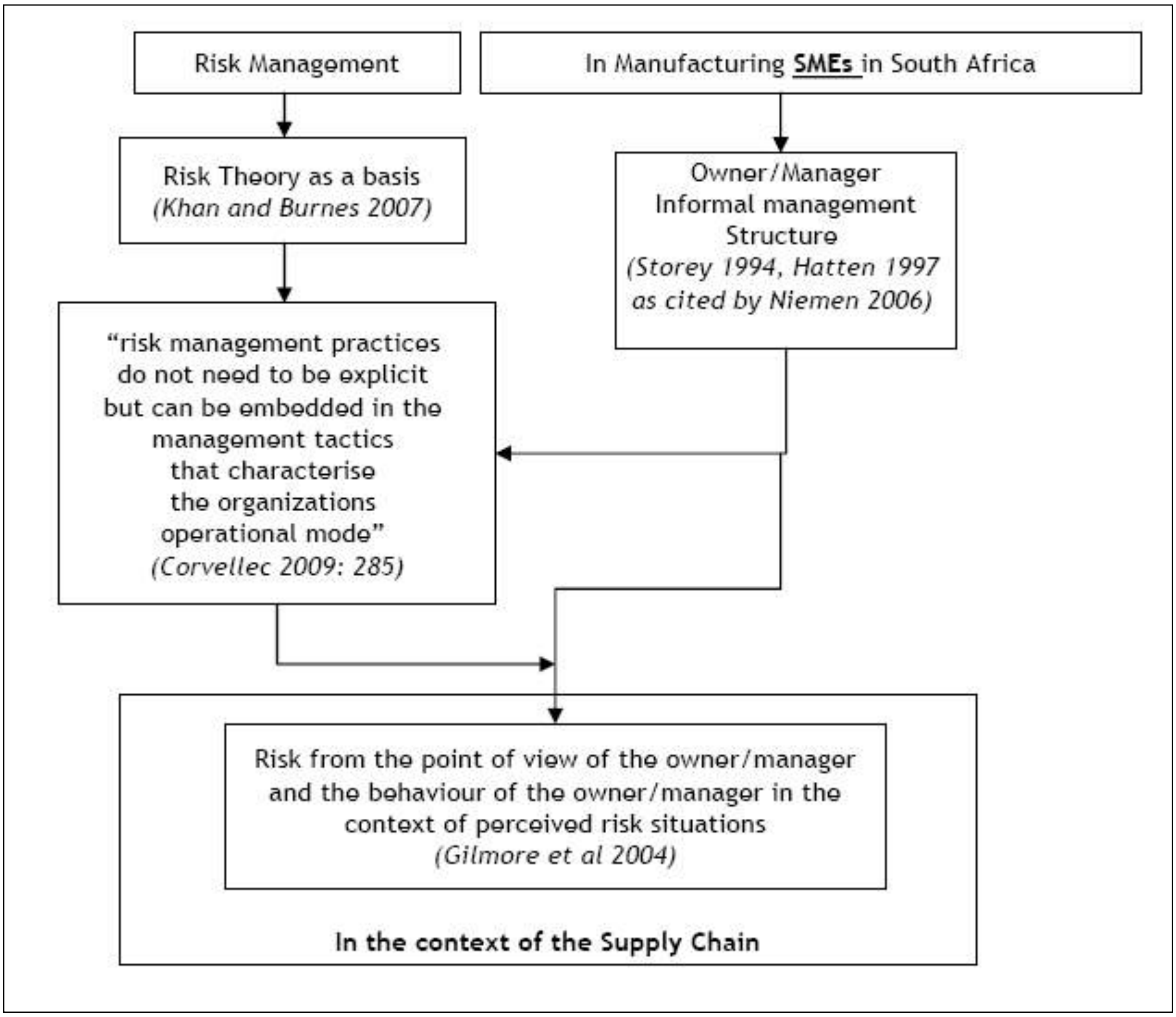

Figure 1: Basis for the Framework

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SIGNIFICANT CAUSES AND EFFECTS OF PROJECT DELAYS IN THE NIGER DELTA REGION, NIGERIA

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ABSTRACT

Social infrastructure and amenities are crucial to creating sustainable communities. The Niger Delta region has been severely deprived by a lack of basic social amenities. In 2009, the Niger Delta Regional Development Master Plan (NDRDMP) was launched to ensure well-coordinated developmental programmes. Implementation of the master plan is expected to be completed within fifteen years at a cost of over USD 36,000,000. The continuous rise in the inflation rate in Nigeria would increase the cost of implementing the master plan, if the projects are not completed on scheduled time. Although most of these social amenities projects' construction works began over the past years, their completion times have, however, been pushed back beyond the stipulated completion durations. Additionally, delays in infrastructural projects could impede oil exploration and cause negative impacts on the socio-economic activities of the Nigerian state. This, therefore, poses serious concern to the developmental partners in the region.

This study investigates the major causes and effects of construction project delays in the Niger Delta Region.

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1 INTRODUCTION

In 2009, the Niger Delta Regional Development Master Plan (NDRDMP) was launched to ensure well-coordinated developmental programmes by the developmental partners. The master plan contains a detailed framework on how the developmental activities are to be carried out in the Niger Delta region. Implementation of the master plan was initially expected to be completed within fifteen years at a cost of over six trillion Naira or over thirty-six million US Dollars (N160 = 1 USD) [17].The continuous rise in the inflation rate in Nigeria will increase the cost of implementing the master plan, if the projects are not completed on scheduled time. Delays in the execution of infrastructural projects in the Niger Delta could also impede oil exploration and cause negative impacts on the socio-economic activities of the Nigerian state. This, therefore, poses a serious concern to the developmental partners in the Niger Delta region.

Recently, there have been indications that the master plan implementation is behind schedule. The Minister of Niger Delta Affairs has claimed that, developmental programmes in the Niger Delta region have been challenged by delays in execution of construction projects [29]. Also, despite, the Niger Delta region being severely deprived by a lack of basic social amenities Ojo [20],most of the social amenities projects where construction works began over the past years have had their completion time pushed back beyond the stipulated completion durations [17].

Several attempts by Project Professionals and Researchers to tackle the causes and effects of project delays have not yielded sufficient positive results [24]. "Even with today's technology, and management's understanding of project management techniques, construction projects continue to suffer delay and project completion dates still get pushed back" [3]. These delays are experienced both in the public and private sector projects [30].

Thus, this problem of delays in the completion of construction projects in the Niger Delta Region raises the central question of this research study: What is the nature and significance of construction project delays experienced in the Niger Delta Region?

The primary objectives of the study were to:

1.1 Identify causes of project delays and determine the most important ones in the Niger Delta region, Nigeria.
1.2 Identify effects of project delays and determine the most important ones in the Niger Delta region, Nigeria.
1.3 Propose solutions to project delays in the Niger Delta region by ranking their impacts and investigating how they could be eliminated or minimized.

2 CONSTRUCTION PROJECTS

Construction is an industry that involves complex and dynamic processes. It consists of successful coordination of multiple discrete business entities such as professionals, tradesmen, manufacturers, trade unions, investors, local authorities, specialists, trade contractors and others [14]. Construction projects impact on a nation's economy. Successful completion of construction projects leads to wealth creation; socio-economic growth and improved standards of living [16],[25]. Nations are evaluated as "developed", "developing" and "underdeveloped" based on the quantity and quality of completed construction projects in their domain [1], [13]. Delays in construction projects therefore impact on the economic projections of a nation. Dlakwa and Culpin [9] found that, in Nigeria 60% of the total national investment goes into construction projects.

Delays in the completion of construction projects is one of the most recurring problems in the construction industry [12] and it is a common global phenomenon [11], [15]. Delays have costly, risky and undesirable consequences on project success in terms of time, cost, quality and safety. These impacts are not only confined to the construction industry but they influence the overall economy of a country [23], [6], [21].

2.1 Construction projects in the Niger Delta region

Nigeria is the tenth largest contributor to the World's crude oil supply [27]. Ninety percent (90%) of its foreign exchange earnings come from sales of crude oil. Oil exploration in Nigeria is carried-out in the Niger Delta region [10]. The Niger Delta comprises of nine states of the federation: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers states [17]. In the last ten years, oil production in Nigeria has been intermittently disrupted by protests of the Niger Delta indigenes [10],[27]. They claim that, their environment has been degraded through oil exploration without meaningful efforts by the oil and gas operators to develop the region. Ejibunu [10] and Ojo [20] assert that, the Niger Delta region is grossly under-developed. Despite successful exploration of oil and gas over the past fifty years, there are inadequate infrastructural projects such as roads, hospitals and, school buildings. This underdevelopment has led to youth unrest, militancy and consequently, hindered oil and gas exploration. Therefore, Nigeria's oil and gas supply in the world oil market has dropped [10].

Construction projects in the Niger Delta region include infrastructural and utilities projects such as buildings (hospitals, school blocks, skill acquisition centres), electrification, jetties/shore protection, channelization, roads/ bridges and water works. Presently, on-going infrastructural construction projects consume 60%-70% of annual capital budgetary expenditure in the region [17].These projects are out-sourced to contractors and consultants for execution [17]. Successful completion of construction projects in the Niger Delta region is a key determinant to successful explorations of petroleum oil, as well as, socio-economic upliftment. Additionally, completion of the infrastructural projects is expected to minimise agitation for development, militancy and youth unrests in the region

Donor agencies, such as the European Union and NGO's, partner with some benefitting communities to execute infrastructural projects in the region. These agencies implement the projects according to terms and conditions stipulated on a memorandum of understanding (MOU) agreed between them and the beneficiary communities.

3 DEFINITIONS

3.1 Project delays

Projects are considered delayed when their stipulated completion durations have not been achieved [15]. Delays are frequent occurrences in developing countries such as Thailand, Pakistan, Saudi Arabia, Nigeria and Vietnam respectively [26]. Pourrostam, *et al* [23], remark that, project delays are the biggest challenges for the construction industry in developing countries. Delays are, however, not only experienced in the developing countries, they are global phenomena [11], [15].

3.2 Classification of delays

Delays are categorised as follows: excusable non-compensable delays, Non- excusable delays, excusable compensable delays and concurrent delays [34].

Excusable non-compensable delays are those which are beyond the control of both the owner and the contractor. Non-excusable delays are those which are the responsibility of the contractor. Excusable compensable delays are delays caused by the project owner (client). Concurrent delays are those caused by both the owner and the contractor. There are a few tests which must be satisfied for a delay to be considered excusable and compensable. The starting point of satisfying these tests is establishing a basis for measuring delay, and identifying relevant events that lead to such delays [14].

3.3 Effects of project delays:

The impact or consequences of delay in project completion is termed the effect of project delay. Memon, *et al* [16], state that effect of delay is a change or impact due to delay

4 CAUSES AND EFFECTS OF PROJECT DELAYS IDENTIFIED FOR INVESTIGATION

Thirty-eight (38) causes of construction project delays were identified from the literature [26], [24], [2], [18]. These were categorised and used for investigation in this study as follows in Table 1 and Table 2.

Table 1: Causes of project delays

4.1 Clients' related issues	**Description**
Insufficient funding	Funds are not adequately released during relevant phases of projects' execution. Milestones payments are not made on time due to organizational lapses or bureaucracy. Inadequate cash flow leads to delay in delivery of materials and equipment to the site and delay in payment of workers' salaries.
Interference with project performance	Top management staff of the Client's establishment could interfere in project execution because of vested interest. For instance, some scope could be introduced without due authorization. This happens mostly, if the management staff were instrumental in the appointment of the vendor.
Delay or non-payment for Completed works	This happens when agreed milestones for payment are not followed or when there is no cash flow projection in the project implementation plan. For Public sector projects, a delay in passage of the year's appropriation bill by the National Assembly could lead to delay in payment to Contractors and Consultants.
Impractical allocation of resources	Funds, manpower, materials, equipment are inadequate to complete the project because project owners or clients have not properly assessed whether they have the required resources to complete such projects.
Unrealistic contract duration	This could be caused by wrong packaging of the contract document, political interference or unprofessional/inexperienced client's staff. Where the stated completion duration is impracticable, the onus lies on the stakeholders to review the initial expected completion time and make amends where necessary.
Wrong choice of Consultants & contractors	Clients select Consultants and Contractors as their vendors. If the selection process is faulty, unqualified vendors will be engaged. This could lead to faulty works and frequent rework and delay in project completion
Slow decision making	Clients are the project Owners. When they do not make decisions on time regarding project matters, they slow down activities at the project sites. Slow decision making could be caused by an organization's internal bureaucracy or wrong channels of communication.
Design alterations & change orders	Change in specifications and scope which were not considered originally or changes of design to address some omissions that were vital to project functionality. Alterations may require temporary stoppages that delay overall project completion.
4.2 Contractor-related issues	**Description**
Poor coordination of subcontractors	Some aspects of construction works are subcontracted to nominated specialised subcontractors. These subcontractors must be properly coordinated by the Prime contractor to ensure timely delivery of assigned aspects of works. Contractors must therefore ensure that each subcontractor delivers at the stipulated time expected and to specifications.

Inappropriate construction methods	Construction activities are required to be carried out using best practices and tools. When the procedures are not followed, errors occur, leading to rework and delays.
Inadequate planning	Contractors appoint Project Managers who are expected to draw up workable project plans and modalities for their implementation. A faulty plan will lead to delay in project completion. Most Local Contractors rarely have practicable work programs at the initial stage of project planning. Lack of appropriate work programs impairs monitoring of project progress against the stipulated time.
Inadequate experience	A contractor who does not possess requisite experience usually makes construction errors. These errors lead to rework and delays in activities.
Mistakes during construction stage	Inexperienced contractors usually make errors during construction. Sometimes contractors employ low skilled staff in order to make more profit by paying them lower salaries. Tendencies of errors are, thus, higher. Rework of an already executed aspect of a scope slows down project progress. This has serious impact if it involves execution of critical tasks.
Incompetent site management	Contractor's employees that are not skilled in project management are not able to manage their project site appropriately, thus, culminating in faulty work, reworks and delay in completion of tasks.
Wrong choice of Bankers	Banks provide funds for most projects. Their actions and inactions directly impact on a contractor's ability to execute the project as scheduled. Some Banks' internal processes could hinder timely release of funds. This happens especially when a contractor requires facilities such as loans to finance the project. It is a major challenge in Nigeria where the banking industry is in a developing stage.
4.3 Labour and equipment related issues	**Description**
Unskilled site manpower	Employment of unskilled personnel at the project sites impedes execution of work to specification and leads to error or mistakes during construction. Time is then spent on alterations and corrections.
Improper equipment selection & Faulty equipment	The use of the incorrect equipment extends tasks while faulty equipment leads to delay due to the time spent to repair.
Labour disputes	Labour disputes such as strikes slow down construction as time is spent on negotiation and settlement of grievances.
4.4 Materials-related issues	**Description**
Poor quality materials	Poor quality materials lead to poor quality workmanship, thus an unacceptable product. Most often, the project owners insist that correction be made or that parts of work be completely redone.
Material shortages	This results in slowed activities and sometimes temporary abandonment of sites.
4.5 Consultant-related issues	**Description**
Inappropriate design	Improper design stalls project execution because of the time it takes for such design to be reviewed, amended and accepted for construction works. When errors are observed in the design, works are temporary suspended until such errors are removed. This is predominant in organisations where selection processes of vendors are compromised.
Poor contract management	Most projects have consultants as the contract managers. They liaise between the client and the contractor. Projects get delayed when the required management principles are not utilised during projects' execution.

Late identification & resolution of drawings & specification errors & omissions	Projects are required to be completed on schedule, within budget and according to specification. If consultants do not identify errors and omissions in the working drawings early enough, already completed activities may require alterations when such errors and omissions are discovered after project commencement.
Late preparation of drawings and other contract documents	Drawings and other contract documents such as Bill of Engineering Measurement and Evaluation (BEME) are required for a smooth execution of any project. Therefore, delay in their release stalls project activities.
Improper contract packaging/delivery strategy	Clients usually outsource packaging/delivery of contracts to the consultants who are professionals. Errors in this task hinder the overall project performance because issues not properly captured must be addressed before project activities can progress otherwise, issue may arise that lead to legal redress.
Over inspection	Inspectors are required to track performance of the project through periodical monitoring. Too frequent inspection becomes a distraction to the contractors, and hence could impede contractors' progress.
Long waiting time for inspection & testing	Certain aspects of projects require inspection and testing before further activities could be carried out. Usually, Consultants and Clients' staff are tasked with the responsibility of coordinating such exercises. Delays in these impede project progress.
Inappropriate coordination of information	If projects issues or contractor's requests are not addressed timeously and information is not effectively managed, project activities can be negatively affected. There must be a good communication management plan in place so that site information is properly channelled and coordinated. Lack of coordination of information fosters misunderstanding, potentially causing conflicts that require resolution time.
4.6 Community related issues	**Description**
Lack of community buy-in	Local communities are stakeholders in public sector projects that are carried out to improve socio-economic conditions. Proper needs assessments are important as communities usually partner with projects they know will address their needs. It is therefore appropriate to ensure a buy-in from expected beneficiaries of projects so that they could cooperate with the Construction Companies during execution.
Delay or Non-payment of Compensation	At times people in the community are required to relinquish their properties for demolition to achieve project objectives. In contracts, provisions are made for payment of compensation. Delay in making these payments or non-payments may stall project execution because, the affected owners of such properties resist attempts for their properties to be demolished without provision for replacement.
Youth unrest, Militancy & communal crises	These issues are peculiar to the Niger Delta region. They were included by the researcher, Unwana Jacob, in view of his experience in project delivery in the region. Recently, there has been frequent unrest in the region due to agitation by the youth protesting that their region has been deprived of basic socio-economic amenities despite huge oil and gas explorations. They have threatened to take oil and other construction workers hostage as well as some elites in the region to express their grievances. This poses a major challenge in projects execution in the region. Community unrest results in a non- conducive environment for project execution, resulting in a slower pace of project work and sometimes total abandonment of project sites.
4.7 Contractual relationship related issues	**Description**

Lack of adequate communication between the parties	Poor or inadequate communication between parties leads to misunderstanding and misrepresentation of facts. This could breed conflicts and consequently hinders smooth progress of activities.
Major disputes & negotiations	Major disputes and negotiations between parties in project impede progress of work as aggrieved parties wait until grievances are resolved before they continue.
Wrong organizational structure linking to the project	Organisational structures affect project performance [8].There are certain projects that cannot be managed by certain types of organisational structures. For instance, it is difficult to execute quick impact projects in a functional organisational structure because of the slow decision making processes and bureaucracies associated with such a structure.
4.8 External issues	**Description**
Weather conditions	In areas where there is frequent rainfall, inexperienced contractor/consultants do not account for weather projections in their project implementation plan.
Change in government's leadership & policies	Certain projects are stalled and abandoned when political leadership that initiated them change. Sometimes, change in government policies such as monetary and fiscal policies could lead to an increase in the cost of construction materials and equipment. Contractors will not be able to continue with the project as scheduled because of the time they need to spend on approvals for price fluctuations and contract revision.
Natural disasters (e.g. floods, lightning strikes)	There are areas that usually experience natural disasters such as floods. These disasters are generally unpredictable. However, well established project management organisations possess requisite skills to manage natural disasters.
Interference by political leaders	This is usually experienced in Public sector projects. Some political leaders have vested interest in particular projects. They interfere by requesting additional scope requirements not captured in the original design or by imposing unqualified contractors/ subcontractors on the client. The above action leads to poor project performance especially in terms of time.

Table 2 Effects of project delays identified for investigation

Effect	Description
Time overrun	When the stipulated completion time is pushed forward, the project is said to have experienced time overrun.
Budget overrun	When a project is completed at a cost higher than what was budgeted, it is said to experience a budget overrun.
Poor quality completed project	As highlighted in the previous section inferior workmanship and/or inferior quality materials, can lead to issues of project quality
Bad Public Relations	When projects are delayed, contractors, consultants and clients could put their public reputations at risk
Litigation	Disputes can lead to court cases for resolution especially when large penalties are at stake
Arbitration	The cost and time related to the engagement of professional arbitrators
Disputes and claims	Disputes and claims arise against for the losses incurred through delays
Total abandonment	Delays in project execution could lead to total abandonment if issues leading to the delays are not resolved timeously

5 RESEARCH METHOD

To investigate the central hypothesis: "There is no cause/effect of project delays in the Niger Delta region that is most important", a questionnaire survey was considered appropriate. This was because surveys can reach larger numbers of participants as opposed to face-to-face interviews and because of community and militant related unrest in the Niger Delta region collection of data at projects sites was not feasible. The questionnaire was constructed based on the groupings in section 4 above of the 38 causes of project delays, and the 8 effects of delays. A five point Likert scale was adopted, and option boxes and open-ended questions were used, where the scale was not appropriate.

Participants fell into three broad categories, namely, Public sector, Multinational Companies and Private Companies which included consultants, clients and contractors. They understand and communicate in the English language and hold at least a first degree in a relevant engineering, project management and/ or related disciplines. The sample was selected conveniently and judgementally to capture the required subgroups in the population. Port Harcourt city in Nigeria is situated in the Niger Delta region. It is the most industrialised city in the Niger Delta region, thus most construction and consulting companies locate their administrative offices in this city but their operations reach the nine States of the Niger Delta region.The city also hosts regional offices of most developmental organisations. Port Harcourt was therefore considered representative of the entire population of Project management practitioners in the Niger Delta region.

Quantitatively, sample size could be determined using the Cochran's [7] formulas for sample size calculation [32].The required minimum returned sample size needed to be 220. However, it is difficult and practically impossible to record a response rate of 100% in a survey. Secondly, budget, time and other constraints could make it practically impossible to achieve the required response in a survey [5]. In this research study, returned questionnaires used in the analysis were eighty-three (83). This is about 38% of the required sample size (83/220 = 37.7%). However, the responses in this study spread across all categories of the participants required in the demographic information. Ultimately, one hundred and eighty-eight (188) questionnaires were served. This gave a response rate of 44%. Burgess [5] recommends that, in a questionnaire survey research, a responses rate of 30% -40% is acceptable for data analysis. The shortfall in the required sample size implies that, conclusions in this study may be considered as perception of the respondents only.

6 RESULTS AND DISCUSSION

Summated scores from responses in the survey were analysed using inferential statistics i.e. factor analysis, analysis of variance (ANOVA) and t-test, to reflect the actual support for the research focus.

6.1 Validity and reliability of the research instrument

Results of reliability analyses for the following items: All Causes of delays, Clients'-, Contractor-, Labour and equipment-, Material-, Consultant-, Community-, Contractual relationship-related issues and External causes, using measurement of internal consistencies' approach showed that seven (7) out of the eight (8) Cronbach's Alpha coefficients for all factors were greater than 0.5. These fall within the acceptable value considered for a research instrument's reliability [4]. Only Materials' related issues fell below 0.5.

6.2 Most important (significant) causes of project delays

The five point Likert scale data could be reduced to three- positive, neutral and negative.. From the interpretation of responses on Likert scale data, a mean score of 3.5 was chosen as cut-off point for significant (most important) factors. It is equivalent to 70% which implies strong support/high opinion. Factors on causes and effects of delays with a mean score greater than or equal to 3.5 were used to frame sub-hypotheses from the main hypothesis.

Results from mean score analyses using 3.5 as a cut-off point for significant factors and the sub-hypotheses' testing showed that the respondents perceived that the eleven factors listed below were most important causes of project delays in the Niger Delta region:

1 Youth unrest, militancy and communal crises
2 Inadequate planning by the contractors
3 Delay or non-payment of compensation to the communities
4 Wrong choice of consultants and contractors by the clients
5 Weather condition; poor contract management by the consultants
6 Late identification and resolution of drawings and specification errors and omissions by the consultants
7 Lack of community buy-in
8 Poor contract management by the consultants
9 Inappropriate design by the consultants
10 Unrealistic contract duration by the clients
11 Poor coordination of subcontractors by the contractors

6.3 Most important effects of delays

The analyses of the respondents' mean scores and results of sub-hypotheses' testing indicated that there were three most important effects of project delays in the Niger Delta region, namely:

1 Time overrun: Overall respondents ranked time overrun as the first most important effect of project delays (mean score = 4.03). The t-test results indicates that, this is significant in the Niger Delta region (p-value=0 at 5% significance level).
2 Budget (Cost) overrun: Overall respondents ranked budget overrun as the second most important effect of construction project delays (mean score=3.90). The t-test of mean score at 5% significance level gave a "p-value" = 0.
3 Disputes and claims: Overall respondents ranked disputes and claims as third most important effects of project delays (mean score= 3.53). Results of the t-test on the mean score at 5% significance gave a p-value of "0" which implies that this is one of the significant effects of project delays in the Niger Delta region. Delays in construction projects generate grievances among the stakeholders. Therefore, aggrieved parties could make claims to remedy damages that they incurred.

Most respondents (84.7%) perceived delays to be unbeneficial, while a few respondents (12.5%) perceived that there were some benefits of delays, and 2.80% of respondents were not sure.

6.4 Beneficiaries of project delays

48.2% of the overall respondents perceived contractors as beneficiaries of delays. They expressed their opinion that when projects are delayed, contractors ask for upward review of their contract sum, and they could thus make more profit as a result of the revised contract price.

28.9% of the overall respondents perceived consultants as beneficiaries of delays. They expressed the opinion that, when projects are delayed supervising consultants request for extension of their contract duration with the clients. This gives them the opportunity to make more income. Delays in completing a particular project by a consultant could hinder future offer of new jobs opportunities to such firms.

20.5% of respondents perceived projects' host communities as beneficiaries of delays. Most unskilled workers are usually sourced from host communities to encourage community-contractor cooperation. Some respondents commented that when projects are delayed, workers who are indigenes of the host community continue to stay on employment until such projects are completed. Secondly, they remarked that, delays in project execution could reveal poor quality workmanship which could have not been noticed until after defect liability period. If poor quality executed works are noticed early, there would be call for rework before final project completion.

9.6% of respondents perceived sponsors/clients as beneficiaries of delays. These categories of respondents believed that, sponsors/clients could make claims from the contractors for delays caused by them. The researcher is of the opinion that, demand for claims could not be compared to actualisation of the project objectives. Therefore, sponsors/clients do not derive any benefit from project delays.

6.5 Extent of project delays

Respondents perceived that, project delays mostly occur in roads/bridges, and shore protection/channelization projects. Construction works in the Niger Delta is challenged by weather. Roads/bridges constructions involve a lot of earth works while shore protection/channelization involves dredging and sand filling works, and the use of imported construction materials such as Reno mattresses, steel sheet piles and others. All these are weather-dependent activities, thus strict planning is required to meet project timelines. Construction works in these categories of projects require more specialised equipment and manpower than other types of infrastructures. The use of inexperienced vendors as contractors and consultants could therefore, negatively impact on the smooth execution of the project.

7 RECOMMENDATIONS

Recommendations are made for some of the major causes of project delays determined from the study; these recommendations are considered as solutions to construction project delays in the Niger Delta region.

7.1 Solutions to youth unrest, militancy and communal crises

The Amnesty and ex-militants' rehabilitation programme of the Federal Government of Nigeria should be sustained. Stakeholders in the Niger Delta region should intensify efforts in social re-orientation programme against violence and violent related behaviours. Youths should be encouraged to participate in project conceptualisation and execution. Negative impacts of youth unrest, militancy and communal crises should be incorporated into school's curricula at all levels. Provisions for security should be made during project design. Youths of the project communities should be engaged and trained as project's police. There should be a systematic and careful management of communal crises in the region through the adoption of modern conflict resolution strategies such as non-violent communication (NCV) and dialogue. The Federal Government should proactively tackle the concerns of the Niger Delta youths rather than being reactionary. The Government should promote peace agenda in the region such as through education on importance of peace to socio-economic development, access to justice and more equitable distribution of resources [33]. There must be concerted efforts by the Niger Delta stakeholders towards full implementation of the Niger Delta regional Master Plan. Ejibunu [10] states that full implementation of the Niger Delta Master Plan could end agitation by its People. Dialogue must be adapted to resolve communal crises. Niger Delta stakeholders should collaborate among themselves to execute corporate social responsibility projects. Ejibunu [10] observes that, this approach could reduce agitations by aggrieved youths in the Niger Delta region.

7.2 Solutions to inadequate planning by the contractors

Risk management planning must be done at the early stage of a project, communication management planning, All assumptions on the project must be carried out at the planning stage; All relevant stakeholders must be involved at the planning stage of the project. Contractors must set up framework for cash management at the planning stage, identify quality standards and work out modalities on how to satisfy them [22].

7.3 Solution to delay or non-payment of compensation to the community

It is established that the Niger Delta region is volatile [31]. Payment of compensation funds should be made early enough so that the demolitions of structures on the project are right of way. There must adequate budgetary provisions for settlement of compensations claims.

7.4 Solution to wrong choice of consultants and contractors by the clients

Clients should properly pre-qualify contractors and consultants before engaging them. The procurement laws of the Federal Government must be strictly followed. Toor and Ogunlana [26] recommend reforms in procurement systems, value chain management and stakeholders' management as strategies to curtail construction delays.

7.5 Solutions to lack of community buy-in

Project sponsors/clients should adequately consult with the expected beneficiaries of developmental projects so as to enhance their buy-ins. This should be undertaken during needs assessment and conceptualisation phase of every project.

UNDP [33] recommends that, there should be a participatory planning and people-centred development agenda as a remedy to lack of community buy-in in socio-economic intervention programmes.

8 CONCLUSIONS

This study was limited in that it was only carried out on developmental projects in the Niger Delta region; and by the activities of militants in the Niger Delta region which hindered collection of data at the various project sites.

The study, however,contributes to the existing body of knowledge through:

- The design and construction of a questionnaire that could be adapted for the collection of multivariate data from project practitioners in the Niger Delta region.
- The determination of most important causes of project delays in the Niger Delta region.
- The determination of most important effects of construction project delays in the Niger Delta region.
- Establishing that there were no tangible benefits of construction project delays.

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OPIMISATION OF EMPTY RAIL WAGON RE-DISTRIBUTION

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ABSTRACT

Rail freight network service design is characterized by asymmetrical demand by volume. The loaded wagon in-flow to a specific region is generally unequal to the out-flow from that region. Over time, an imbalance in wagon resource and capacity is realized in the network. The periodic re-distribution of empty wagons is necessary. Re-distribution is non-revenue earning and a cost. To minimize cost and improve efficiency, the empty wagon mileage should be optimized (minimized). Traditionally, operational planning was effected through reasoning and head knowledge of operating staff. The human element renders the resulting system behaviour inherently inconsistent and sub-optimal, particularly with increasing network size. A need arises for a management decision support system that consistently guarantees optimized aggregate empty mileage and associated costs. This paper formulates and applies a linear programming (LP) based mathematical model as a Decision Support System (DSS) to the empty wagon re-distribution management problem. Network capacity and resource constraints are considered. The model is applied to a medium sized African rail freight operator with encouraging results.

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1 INTRODUCTION

The Southern Africa regional economies are increasingly reliant upon export of primary commodities [4]. Freight transportation service arises from the spatial distribution of resources and customers, and is a key economic activity in this respect [5]. Freight transport consequently constitutes a significant cost element in the value chain for most products [6]. Transport and communication services are pre-requisites for economic development and global competitiveness and efficient economies seek to minimise total logistics costs [19].

The Rail freight mode of transport affords significant advantages to an economy over road freight particularly for bulk commodities. The advantages include among others, reduced carbon emissions, cost competitiveness, superior safety and reduced road congestion [7].

A rail freight transport system constitutes several resource classes namely wagons, locomotives, personnel, infrastructure, and management systems to name but the more significant [8]. The overall system operational efficiency is a function of the utilization efficiencies and productivity levels of these resources.

The wagon fleet constitutes approximately 40% of the total asset value of the average rail road operator, arguably the most significant resource class. It is estimated that the average wagon in a typical rail network moves 45% of its gross mileage empty [9]. Additional waste in the form of wagon dwell time, load/unload time, maintenance imperatives, and operational inefficiencies further reduces fleet utilization. Key efficiency metrics applicable to the transport industry include, route efficiency, utilisation efficiency (empty mileage), and load factor [10].

Rail network operations are characterized by asymmetrical demand by volume. The loaded wagon inflow to a specific region is unequal to the loaded outflow from that region. Consequently, over time, an imbalance in empty wagon resource and capacity manifests in the network. This imbalance necessitates the periodic re-distribution of empty wagons from surplus points to economically convenient loading points [11].

Empty wagon re-distribution is non-revenue earning. The aggregate empty wagon mileage should be optimized (minimized) in order to improve operational efficiency [20]. Improved resource utilization contributes towards optimal fleet sizing, positively impacting return on capital, maintenance and ownership costs.

Sayarashad et al. [1] formulated and provided a solution procedure for optimal fleet sizing and empty wagon allocation assuming deterministic transit times and demand. The reduction of empty movements in transportation reduces logistics costs, improves economic performance and decreases operational problems and environmental impact [3]. Empty repositioning management can benefit from advances in information and communication systems and their integration with optimization modelling [3].

The case of a southern Africa based freight rail operator is considered, with special emphasis on empty wagon re-distribution management. For the operator under study, tactical day-to-day planning of empty wagon re-distribution is largely effected by a centralized group of operational staff, employing collective reasoning and head knowledge. The decisions arising are subject to human proficiency levels and cyclical human behavioural patterns. The hypothesis held is that the behaviour of the operational system arising is inherently inconsistent and sub-optimal, particularly with increasing network size and traffic volumes. The critical need for a management DSS to complement human effort and guarantee optimized tactical planning arises.

Complex resource layering arrangements precede any train movement. The resources include locomotives, operating crew, loaded wagons and infrastructure, to mention the more significant ones. Availability and reliability of each of these resources constitute a significant constraint in empty wagon distribution.

Leddon [12] considered the empty rail wagon allocation problem, applying the transportation model as solution methodology, using estimated wagon supply and demand as well as time invariant events. In spite of the assumptions, the model provided promising results.

Turnquist [13] presented more realistic integer flow formulations again assuming deterministic wagon demand and flow patterns, yielding improved operating results. Powel [14] added realism to the formulations and developed dynamic stochastic models for the empty wagon distribution (EWD) problem, accommodating the stochastic nature of demand and flow patterns. Powel [8] notes that the demand for services in freight rail transport over time and space is typically random. Arvidsson [10] emphasizes the need for expeditious servicing of demand to minimize opportunity costs in freight business.

Beurrier [15] integrates mathematical optimization modelling and expert systems in order to accommodate business strategic objectives. Zhang [17] presents an ICS based intelligent DSS for EWD management and Giannetoni [7] incorporates cloud computing and GPS technologies in an ICS based optimization model with promising results.

Ferreira [16] notes that the practical implementation of EWD by rail operators remains unsatisfactory. Powel [18] suggests that the unsatisfactory implementation levels is because much current research focuses upon myopic heuristics, with minimal realism. He further notes that solutions to railway optimization models are complex and this has resulted in over simplification of most formulations, in turn imposing limitations on practical relevance and implementation aspects of the models.

This research effort aims to determine the impact of LP based mathematical modelling to the empty rail wagon re-distribution problem in a medium sized African freight rail operator in order to contribute towards development of effective and applicable DSS in the freight rail industry on the African continent. The model emphasis is on realism and practicality.

2 PROBLEM DESCRIPTION

Rail freight networks are typically unbalanced across space and time, characterized by increasing wagon inventories at some nodes and deficit levels at some. The imbalance necessitates periodic empty wagon re-distribution. The need arises for a tactical day-to-day strategy for the re-positioning of the empties, with the objective to minimize aggregate empty mileage and improve operational efficiency. For the case under study:

- Wagon re-positioning day-to-day tactical planning is manual, time consuming and characterized by priority conflicts.
- The rail operator consistently fails to achieve planned empty wagon placement targets.
- Resource layering constraints are not systematically integrated into the tactical planning and execution systems.
- The operator under study applies a 24 hour planning and execution window.
- Wagon supply lags demand.
- The problem is to determine how many empty wagons to send empty from node i to node j.

3 METHODOLOGY

In order to develop a feasible management DSS applicable to the Empty wagon distribution (EWD) for the rail operator under study, the methodology adopted integrates statistical analysis, mathematical programming and ICS. The main steps of the methodology are as follows:

(i) The daily empty wagon demand and supply statistics for a 90 day sample period covering july – September, were collated from operator record sheets. The 10 most significant hubs (nodes) by demand/supply were identified. The rail network was simplified to reflect only the ten nodes.

(ii) The aggregate empty mileage to satisfy the empty wagon demands for the simplified network using the baseline operating model was determined for the sample period.

(iii) An LP based mathematical optimization model, incorporating constraints arising from resource layering imperatives was formulated. The baseline demand and supply variables for the 90 day simulation period were applied as the input variables.

(iv) The response variable, the aggregate empty mileage (cost), of the baseline model was evaluated relative to the response variable output of the simulated mathematical model.

(v) The mathprog software was used.

4 SYSTEM MODELLING AND FORMULATION

In line with the above stated current work objectives, we consider the problem of managing the re-distribution of railway empty wagons over space and time in an environment where capacity lags demand. In such a network, a node represents a city (wagon demand/ generation point) and an arc represents the link between any pair of nodes. The primary objective is to minimise aggregate empty wagon distance hence total transportation cost.

It is assumed planned wagon re-positioning is achieved within 24hrs and demand not satisfied in that period is lost. The succeeding planning window is considered independently.

4.1 Nodal allocation

When capacity lags demand, it is necessary to put in place a sustainable allocation system to allocate the limited resources. Pertinent determinants of nodal allocations include:

Nodal demand = r_i

Nodal empties generation = g_i

Global demand = r_g

Global supply = S_g

The global supply ratio, d_{ni} = $\frac{S_g}{d_g}$

Periodic nodal allocations = A_i

= f(r_i, d_{ni})

= $d_{ni} * r_i$

A_i, guarantees equitable resource allocation when supply lags demand.

Wagon surplus at node N_i, = S_i

S_i = g_i - ($r_i * d_{ni}$)

4.2 Transportation model

4.2.1 Notations and formulation

Having determined the nodal empty wagon allocations per time window, the next problem is to determine optimal distribution pattern. To formulate this problem the following assumptions (in line with current operational norms) are made: -

- There is only one type of capacity. Any unit of capacity is compatible with any demand
- Shipments from one terminal to another are transported directly. Intermediate steps are not possible.
- Travel times are equal to one time period (24hrs).
- Shipment costs are independent of direction on the same arc.
- Wagon demand and transit times are assumed deterministic

The following decision variables are defined:

N_i = Wagon supply node

N_j = wagon demand/ destination node

X_{ij} = number of empty wagon from node *i* destined for node *j*

d_{ij} = kilometre distance between nodes *i* and *j*

C_w = incurred cost per wagon per unit distance (km) traversed

C_{st} = inventory costs per wagon at node *j*

= $C_{w*}\, d_{ij}$

C_m = marketing cost

C_O = overheads costs

C_r = Maintenance and repair cost

g_i = empty wagon generation at node i

r_i = empty wagon demand in node i

l_t = long haul locomotive availability (numbers) in time period t

C_{rt} = Train operating crew availability (numbers) in period t

Z = is the set of nodes/terminals in the network

A_i = Nodal empty wagon allocation as determined by allocation formula

S_i = wagon surplus at node N_i

It is further assumed the cost per unit distance of each wagon is constant irrespective of load status.

The mathematical formulation of the empty wagon fleet management problem as given by:

Minimize,

$$\square = \sum_{ij \in N} X_{ij}\, d_{ij} C_w + \sum_{j \in N} C_{st}\, (g_i - r_i - X_{ij}) + C_o + C_i + C_m$$

Where, $C_o + C_i + C_{m,}$ are constants,

The function, $\sum_{j \in N} C_{st}\, (g_i - r_i - X_{ij})$

Constitute wagon storage costs i.e marshalling yard operational costs. For computational ease, yard operational costs are readily absorbable into the general transportation costs.

The final simplified formulation,

Minimise,

$$Z = \sum_{ij \in N} X_{ij}\, d_{ij} C_{tw}$$

Where:

C_{tw} = aggregated unit wagon shipment cost.

4.3 Constraints

In the system under study, three critical constraints have been identified. These are, train crew, locomotives and infrastructure.

4.3.1 Train crew constraints

The availability of operating train crew presents a constraint on system's ability to effect planned wagon distribution. The respective inequality constraint has been derived as:

$$0.03 \sum X_{ij} \geq \frac{1}{d_P} * (1 + U_s) \sum \frac{S_i}{33}$$

4.3.2 Infrastructure constraints

The wagon handling capacity per arc, in unit time, is a complex function of the under listed variables:

a) Temporary bottlenecks - arising from accidents and recovery work, environmental and weather elements etc.
b) Infrastructure condition - a function of maintenance and general upkeep of signalling and permanent way facilities
c) Design limitations

For simulation purposes, surveys backed by the minimal statistical data available, were employed to determine current realisable wagon clearance capacity for each arc. These arc clearance capacities were then adopted as the respective arc constraints. Table 1 below illustrates these constraints.

Table 1:Arc wagon clearance Capacity per day

ARC	DESIGN CAPACITY	CURRENT REALISABLE
X_{910}	14 Trains	4
	462 Wagons	132
X_{89}	19Trains	6
	627 wagons	198
X_{78}	26 trains	8
	858 wagons	264
X_{27}	21 trains	4
	693 wagons	132
X_{47}	19 trains	4
	627 wagons	132
X_{46}	14 trains	2
	462 wagons	66
X_{45}	17 trains	2
	561 wagons	66
X_{34}	16 trains	3
	528 wagons	99
X_{21}	19 trains	5
	627 wagons	165
X_{211}	12 trains	1
	396 wagons	33

4.3.3 Motive power constraints

Motive power (locomotives) is necessary for hauling trains. The defining inequality constraint for locomotives is derived:

$0.05 \sum X_i \quad \geq \quad 512$, based on current locomotive availability and reliability indicators.

Locomotive failures at origin nodes result in train cancellations, whilst failure in transit causes premature train termination. In both cases, additional motive power capacity is necessary to achieve planned wagon redistribution target.

4.4 Generalised formulation

From section 4.2, we present the generalised formulation:

Minimise,

$$Z = \sum_{ij \in N} X_{ij}\, d_{ij} C_{tw}$$

Subject to constraints:

$$\sum_{ij \in N} X_{ij} \quad \geq \quad 1.67 \sum_{i \in N} S_i$$

$$\sum X_{ij} \quad \geq \quad \frac{1}{d_P} * \; (1 + U_s) \sum S_i * \frac{1}{0.03}$$

$$X_{9,10} \leq 11880$$

$$X_{8,9} \leq 17820$$

$$X_{7,8} \leq 23760$$

$$X_{2,7} \leq 11880$$

$$X_{4,7} \leq 11880$$

$$X_{4,6} \leq 5940$$

$$X_{4,5} \leq 5940$$

$$X_{3,4} \leq 8910$$

$$X_{2,1} \leq 14850$$

$$X_{2,11} \leq 2970$$

5 DATA PREPARATION

Considering the 90 day simulation period, aggregate demand per node is tabulated below:

Table 2: Aggregate Nodal Demand

NODE	DEMAND	SUPPLY	S_i	g_i
1	8603	7133	-6108	0
2	12109	10000	3402	12000
3	0	0	0	0
4	940	632	-688	0
5	4901	2033	-3480	0
6	2643	2438	1624	3500
7	6500	3187	1385	6000
8	14353	9760	3710	13900
9	2198	1696	136	1679
10	0	0	0	0
Total	52247	37079	0	37079

Global satisfaction ratio, $d_{ni} = \frac{S_g}{d_g}$

$= \frac{37079}{52247}$

= 71%

Due to the absence of reliable and accurate data on nodal generations, most g_i values are estimates based on surveys and scanty data available.

6 NUMERICAL RESULTS AND DISCUSSION

An attempt is made to establish in numerical terms relative performance of current against proposed operational models. Two measures of performance are put to use:

a) Redistribution cost
b) Empty wagon mileage index

From the operator's database, wagon conveyance costs per unit distance, has been calculated to be:

= $ 65,036 per /km

Aggregate empty wagon mileage (for 90 day simulation period)

= 11065000km

Total distribution costs incurred = 11065000 * 65,036

TC_1 = $719623340

The baseline supply and demand input variables as shown in table 2, were applied to the model formulated in section 4.4. The Mathprog optimisation software was employed to solve the problem.

The response variable (aggregate empty wagon mileage) output at 71% demand satisfaction level:

= 5 202 263.5km

The total re-distribution costs at 71% demand satisfaction level:

TC_2 = $338 334 407

Direct costs savings: = $TC_1 - TC_2$

= $ 381288933

Percentage saving = $\frac{381288933}{719623340}$

= 53%

7 CONCLUSION

The linear programming based empty wagon re-distribution model shows encouraging results. Relative to current operational systems with all other operational parameters fixed, a 53% reduction in empty wagon mileage and associated costs is recorded

The hypothesis is proved correct, the current operations model is sub optimal. Mathematical programming can be integrated into management DSS for the EWD problem in the context of African railroad operations with considerable success.

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NURSE SCHEDULING DECISION SUPPORT SYSTEMS AS A WORKFORCE MANAGEMENT TECHNOLOGY SOLUTION IN PUBLIC HEALTHCARE

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ABSTRACT

Although many academic studies report on the development of Decision Support Systems (DSSs) for nurse scheduling and related mathematical models, few of these systems and models are actually used. The purpose of this paper is to contribute to the adoption of these solutions, specifically in the public healthcare system of South Africa. Factors that influence the uptake of nurse scheduling DSSs are identified by means of a study of state of the art, interviews with various role players. A root cause analysis is conducted accordingly in order to identify issues that need to be considered for sustainable facilitation of nurse scheduling DSS, and so contributing toward future development of workforce management solutions for nursing in public healthcare.

1 INTRODUCTION

1.1 Background

1.1.1 Nursing in South Africa

Nursing staff constitute the largest component of hospital's workforce. Within South Africa's (SA's) healthcare system, the nursing profession represents more than 50% of the total professional human resources [**1**]. The South African Nursing Council has identified a shortage of nurses in SA. In an era where SA's HIV/AIDS epidemic is booming, nursing staff have periodically represented the biggest required increase across all professional healthcare staff [**2**]. There is thus a need to manage and support nursing staff in more reasonable and efficient ways.

Strategic support for nurses is envisioned by some Provincial Nursing Strategy (PNS) documents. A particular PNS document addresses operational burdens that nurses are faced with and current provincial and global scaled challenges. These challenges include; a shortage of professional nurses, high attrition rates and migration of skilled nurses. A strategic objective in the PNS document is to enhance nursing management capacity by improving efficiency in decision making in nurse management. [**3**]

1.1.2 Nurse Scheduling Problem

It is anticipated that scheduling that addresses nursing constraints and preferences whilst aiding hospital objectives will result in high operational merit and better quality work environments.

Recent research and development on mathematical models and integrated scheduling systems that address nurse scheduling is plentiful. The Nurse Rostering Problem (NRP) is universally known for two extreme difficulties: its complex combinatorial optimization modelling and its difficult practical matching and implementation.

In 2007, D L Kellogg and S Walczak reviewed 72 cited articles on nurse scheduling models. Of the 72 articles, 50 developed nurse scheduling models; 34 of those models were conceptualized on a computer; 15 were implemented and only 8 are still in use at present. The ANSOS system is an example of a published academic nurse scheduling model that became a commercial success, because of its ability to evolve and solve more than just scheduling problems. [**4**]

Three recent studies, which were executed within context of the South African public health sector focused on mathematical modelling rather than sustainable facilitation [**5,6,7**].

The *Integrated Staffing Model (ISM)* is an example of an integrated solution aiding nurse scheduling decision making in private healthcare in SA. Mediclinic have worked for two years on their ISM. The ISM embraces scientific standardisation to promote fairness and efficiency within Mediclinic's healthcare provision strategies. [**8**]

1.1.3 Health Decision Support- and Workforce Management Systems

The purpose of HDSSs are to improve the efficiency and effectiveness with which health service administrators or clinicians make decisions to optimise personal and organizational performance outcomes. [**10**]

Nurse scheduling solutions form part of typical workforce management tools, such as time and attendance, workforce payroll, workforce planning and profiling.

1.2 Problem Statement

The problem is that amidst literature confirmed- and commercially advertised nurse scheduling DSSs potential and benefits, there is still little support toward development of such a workforce management tool in South African government-facilitated hospitals.

1.3 Objectives

The first objective of this paper is to identify factors that need to be considered for sustainable facilitation of Nurse Scheduling DSSs. Secondly, the paper aims to contribute towards future development of nurse scheduling DSSs in South African public healthcare by proposing solutions that would increase project facilitation success rates.

1.4 Methodology

Firstly, factors that influence the uptake of nurse scheduling DSSs are identified by means of a study of state of the art, interviews with developers of nurse scheduling DSSs, academic researchers, technology research personal at Medical Research Council SA, hospital managers, nursing managers and supervisors, a private healthcare nursing productivity project manager, commercial workforce management technology group managers. These factors were then brought together in a Root Cause Analysis (RCA) and mapped on a Cause-and-Effect Diagram (CED). The CED translates the factors into barriers that hinder sustainable facilitation of nurse scheduling DSS on condition that they are not considered. Lastly, future development of nurse scheduling DSSs in public healthcare is probed.

2 BARRIERS TO SUSTAINABLE FACILITATION

The RCA is graphically mapped in the form of a CED is split up and displayed in **Error! Reference source not found.** and **Error! Reference source not found.** on the following two pages. The resultant RCA Barriers for Sustainable Facilitation are mapped in Figure 2 and Figure 3 and are discussed below in the light of consideration that is needed for sustainable facilitation of nurse scheduling DSSs.

2.1 Healthcare Method Barrier

2.1.1 Complex Healtcare Work Environment

Healthcare work environments are characterized by extensive personal and emotional interaction. For this reason, patient safety and -confidentiality foster strict healthcare policies. These strict policies ripple throughout the healthcare system and affect any intervention with healthcare personnel or resources utilized. Heavy- and critical workloads, anticipated to be more extreme in South African public than in private healthcare, permit limited attention and time for improvement interventions such as nurse scheduling DSSs. Strenuous work environments and strict healthcare policies need to be planned for when facilitating technology workforce management solutions such as nurse scheduling DSSs.

2.1.2 Scheduling Protocol

Integrated nurse scheduling success is dependent on certain workforce management support interactions such as: (1) accurate t**ime and attendance recordings**; (2) fair and concise absence management; (3) fair and simplistic leave management; (4) workforce analytics; and (5) human resource nurse profile management.

Above discussed support interactions are *administrative support services* to nursing staff that support the executive mission of a hospital by managing human resources and official procedures. Efficient administrative support services empower nurses to focus on the primary objective of their profession: providing patients with quality care. **[11]**

2.2 Healthcare Organizational Barrier

Figure 1 illustrates continuous quality improvement reasoning in healthcare. The private healthcare sector has strong market share components that fuel their improvement effort.

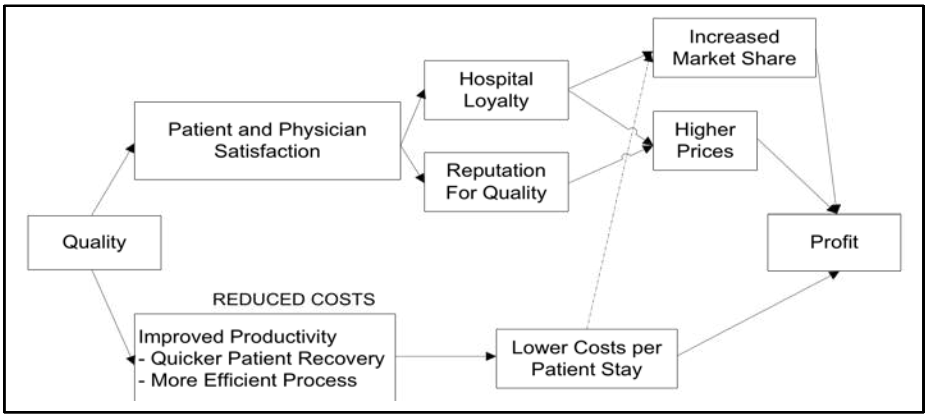

Figure 1: Relationship between Cost and Quality in Healthcare [12]

Abundant motivational theories are available to use for workforce quality improvement. One important aspect is evident in most of prevalent motivation theories: a human being is not only motivated by extrinsic factors, but equally so by intrinsic factors. **[13]**

2.2.1 Change Management

Organizations such as public and private healthcare constantly face pressure to change in order to adapt to dynamic environments with internal growth- and uncontrollable external factors. Organizations that appreciate and manage change well tend to be most effective. **[14]**

2.3 Support System Method Barrier

2.3.1 Focus on the end-user

Attention needs to be paid to different end-users of a support system solution. In broader scope appreciation of training, experiences and activities of nurses need to be considered. Various commercial nurse scheduling solutions include seniority, skills and certifications along with preferences in their availability formula for nursing staff on call **[15]**. Other supporting staff and departments also need to be considered when designing the system solution **[15,16,17]**.

2.3.2 Organizational Context

Public healthcare organizational context differs from private healthcare. The South African public health sector was restructured post-1994 to increase access and coverage of healthcare to all. In order to meet healthcare needs of 86% of South SA's population the DoH has established a hierarchy of health services which has rules and endeavours of its own **[20]**.

2.3.3 System Support

The perception of reliable customer support is important in the purchase and implementation of any information system **[21]**. Kellogg and Walczak **[4]** confirm this statement and weigh it as one of the major reason for failure of academic nurse scheduling solutions. Academics are not prepared to provide system-maintenance relationships for their solutions.

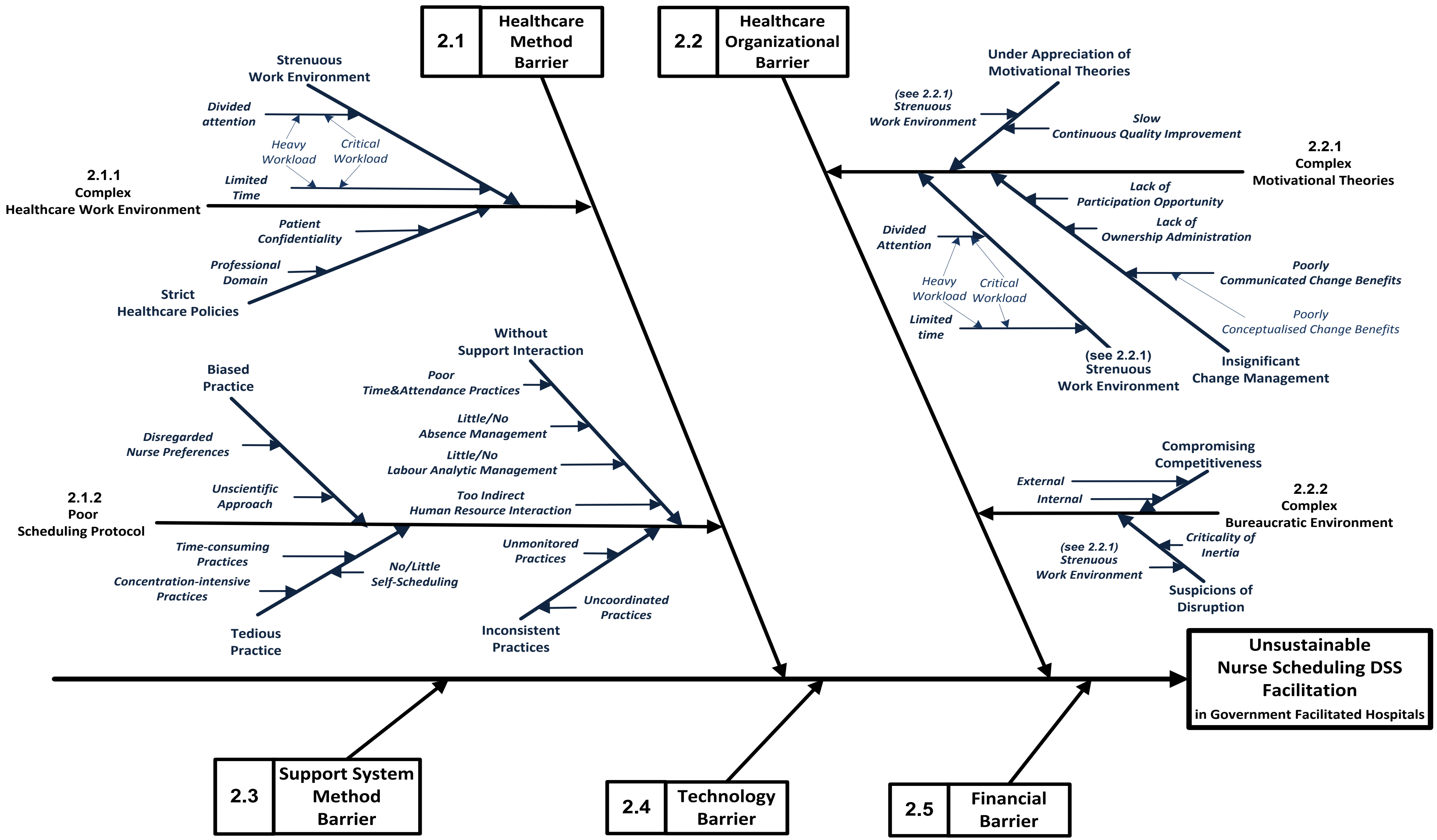

Figure 2: Expansion Segment 1 of CED for Unsustainable Nurse Scheduling DSS Facilitation

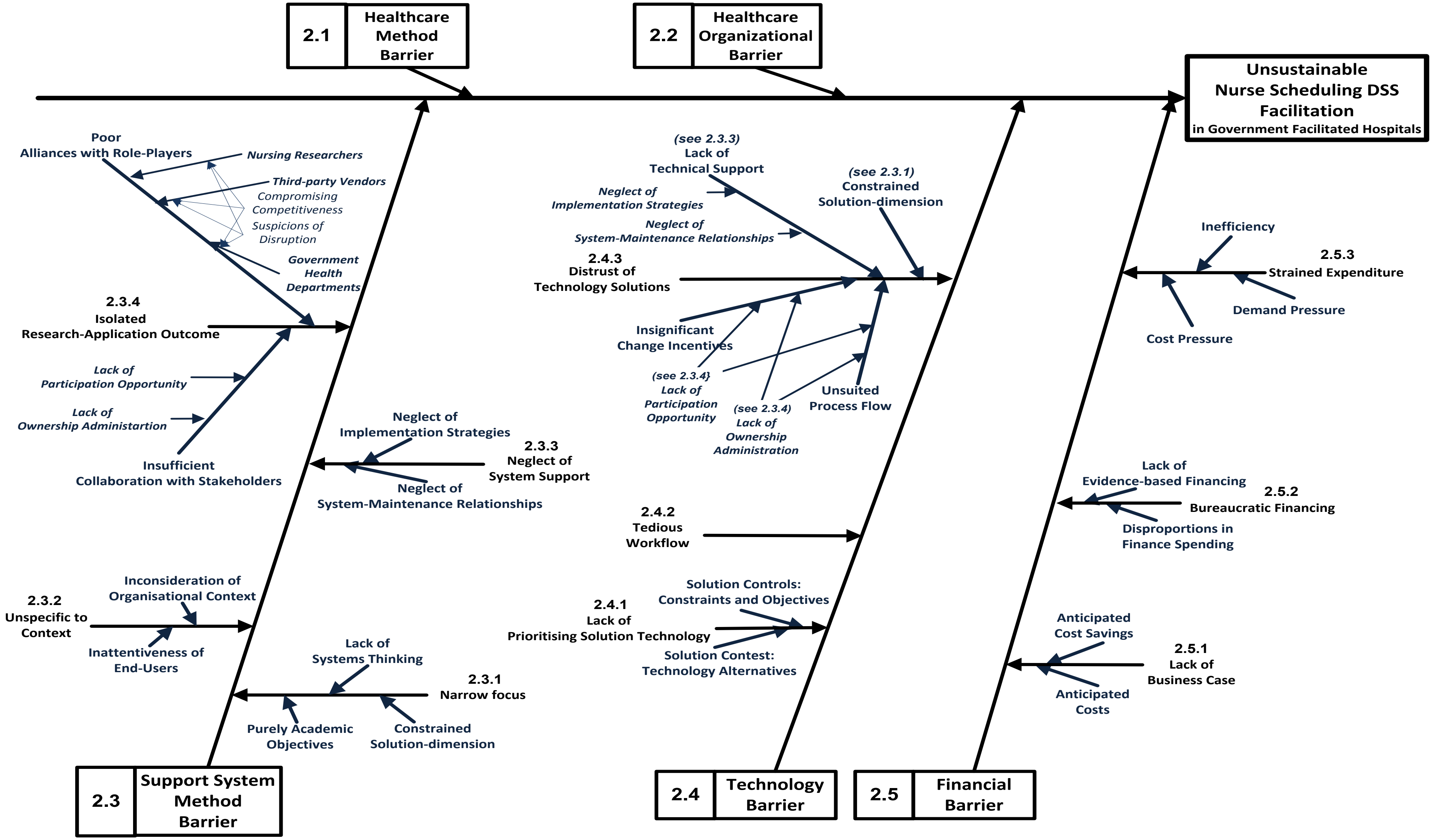

Figure 3: Expansion Segment 2 of CED for Unsustainable Nurse Scheduling DSS Facilitation

2.3.2 Stakeholders

Successful project facilitation usually imbeds *ownership administration* and *participation opportunity* by identify change stakeholders and communicating their responsibilities as such:

- A Champion is an individual whom is the driving force behind the change initiative.
- **The Initiating Sponsor** is a high-level management individual who lends support and prestige to the work of the champion.
- **The Steering Committee** is a group of stakeholders for whom the change process is being undertaken, they should lend direct management guidance and support to the change effort.
- **The Engineering Team** is a team that does the actual analysis and preparation of the master change plan, and help to guide and manage the deployment of the master plan.
- **The Design Team** is a team that does the detail design and development of refreezing concepts.
- **The Change Management Team** is a team that is responsible for the human relation issues that prepare and support employees for change, i.e. change communication, training etc. **[22]**

Alliance of nurse researchers, health departments, third-party vendors and the project initiator is highly recommended to help close the research-application gap **[4]**. Nurse scheduling DSS project initiators for public hospitals have mostly only been academic researchers in the field of Operations Research or Industrial Engineering. **[5,6,7]**

2.4 Technology Barrier

By addressing presented technology barriers discussed below, nurse scheduling DSSs can be proved feasible and indispensable as a technology solution improving nursing

2.4.1 Lack of Prioritising Solution Technology

Nurse scheduling DSS development is currently constrained by a shortage of nurses and poor nursing workforce management support interactions in public healthcare that involve: (1) records of scheduling drivers; (2) time and attendance input; and (3) absence and leave management. Prioritising solution technology according to constraints must be done. [8, 23]

2.4.2 Solution Controls: Constraints and Objectives

2.4.2.1 Constraints

- **Nurse Shortage:** A shortage of nurses makes it difficult to award present nurses with preferred and flexible schedules whilst satisfying patient care needs and hospital objectives. **[2]**
- **Records of Scheduling Drivers:** Scheduling driver input such as attendance and patient case-mixes records are not readily available to improve aligned decisions of predicted patient demand with nurses available. [8]
- **Time & Attendance Input:** Current *time & attendance* recording leaves room for unintentional- and intentional error, is a very tedious and an inaccurate source of information to nursing management. [19, 24, 25]
- **Absence & Leave Management:** Current *absence & leave systems* leave room for serial offenders to cheat the system while obedient nurses filling in don't receive the credit they deserve while helping out with crises. [19, 24, 25]

2.4.2.2 Objectives

Objectives were identified as: financial feasibility, easy implementation, easy maintenance, integrated interaction, value added to nurses and value added to hospital analytics. **[19, 24, 25]** These objectives were used and ranked accordingly in study performing a *technology prioritising exercise*. In this *technology prioritising exercise Time & Attendance-*, and *Absence & Leave Management systems* were ranked to be government-facilitated hospitals in SA's most imperative next-step in workforce management technology support. Many barriers and strategies identified for nurse scheduling DSSs as a technology workforce management solution in this paper can be extrapolated for facilitation of automated *Time & Attendance-*, and *Absence & Leave Management systems*. [**26**]

2.4.2 Tedious Workflow

Automating manual systems is not only based on cost-savings but also on the elimination of tedious processes that produce inaccurate, untimely and un-integrated outputs **[27]**.

Converting a manual system to an automated system will require a work team to conduct a *Situational Analysis*. A *Situational Analysis* will pinpoint problem areas automation can correct and identify risk opportunities and improvement of automation **[28]**. The work team must look for: (1) redundant data entry; (2) inefficiencies; (3) employee and employer dissatisfaction; (4) unacceptable error rates; and (5) administrative costs etc.

2.4.3 Technology Solutions

It is noted that nurses have little trust and acceptance of computerized DSSs **[4]**. Hsiao's **[29]** analysis of technology adopter's fears according to *reliability-related* and *value-oriented* distrust is embedded in the discussions below.

2.4.3.1 Technical Support

Reliability-related distrust occurs when nursing staff expectations of an ICT solution is reduced due to lack of technical support. This is true when a solution is presented without appropriate implementation strategies and system-maintenance relationships.

2.4.3.2 Change Incentives and Unsuited Process Flow

Value-oriented distrust arises when nurses' beliefs of a workforce management ICT solution differs gravely from *champion* and *initiating sponsor* beliefs. The change incentives are possibly poorly communicated and the change process flow unsuited. To correct the latter, *Participation Opportunity* and *Ownership Administration* is necessary.

2.5 Financial Barrier

A key barrier to facilitation of an ICT solution, nurse scheduling DSS parts, appears to be the anticipation of high costs and uncertainty of benefits.

2.5.1 Business Case

Anticipating and quantifying some of the cost-savings and costs of a workforce management ICT solution can be the key to gaining approval from higher-level role-players to assign resources to further development of workforce management parts **[30]**. The latter is the formation of a business case which is itemised and discussed below.

2.5.2 Anticipated Cost Savings

Benefits of workforce management are advertised by commercial vendors promising:

2.5.2.1 **Control workforce cost**

- Move nursing staff from time-consuming tasks to higher-value tasks.
- Increase ownership and flexibility of scheduling intrinsically motivating nurses.
- Increase visibility and control over workforce-related metrics.

2.5.2.2 Control workforce productivity

- Automate time-consuming manual processes.
- Ensure timely response to workforce demand and changes.

2.5.2.3 Control Compliance

- Centralize and align policy administration for consistency.
- Easily enforce company, local, industry, or government policy.
- Reduce compliance risk with detailed audit tracking. [8, 27, 31]

A work team can elapse or expand on these benefits in manifold matters by considering potential benefits to: efficiency, service delivery, decision making, staff development and financial management. **[8] Mercer (2010) conducted a study on the total financial impact of employee absenteeism and concluded that employee absence is equivalent to about 35% of base payroll. This 35% is made-up of: (1) direct cost such as benefit provided during off-time; and (2) indirect cost such as operational inefficiency impact.**

2.5.2.4 Anticipated Cost

Anticipated cost for typical ICT nursing workforce management solutions are:

- *Hardware costs*
- *Software costs*
- *Installation costs*
- *Training costs*
- *Recurring costs* [8, 27, 31]

The approval of a total cost ownership budget, that includes anticipated costs as set out above, would in public healthcare rely on financing in the form of a conditional grant. Depending on the scale of the workforce management solution the grant would be awarded on national- , regional- or at hospital level. This financing is elaborated on next.

2.5.3 Bureaucratic Financing

2.5.3.1 Cause-and-effect of South African Financing and Expenditure

The South African public health sector was restructured post-1994 to increase access and coverage of healthcare to all. Unfortunately together with restructuring overall quality faltering brought tr*oubling health trends. Economists warn that SA's current public-private healthcare mix is widening healthcare inequality. The p*ublic healthcare sector serves about 86% of SA's population with approximately a third less of health expenditure available to them than available to private healthcare [**20**].

2.5.3.2 Lack of Evidence-based Financing

Public healthcare financing is based on two mechanisms: (1) a geographic distribution formula that accounts for population weighed outside of medical schemes; and (2) a system of conditional grants for earmarked services in tertiary care and professional training. The planning of services rely thus on a bureaucratic system of control that lacks evidence-based knowledge of predicted workload or case-mix. New healthcare financing mechanisms being researched are duly in favour of IT integration that accurately and efficiently uses data in hospitals to determine funding in evidence-based manners. [**32**]

2.5.3.3 Disproportions in Finance Spending

Lowest per capita spending is reported in rural areas with *high rates of poverty* – these areas are considered *high-risk areas*. [**33**] The disproportions in spending are imperative when discussing funding for a workforce management initiative for nurses in SA. It seems rational to avoid *high-risk areas* for workforce management initiatives, but it must be viewed as a challenge to provide equitable healthcare support to all South African nursing staff so that they could better deliver equitable healthcare to all members of SA's society.

2.5.4 Strained Expenditure

Public hospital expenditure is further constrained by cost- and demand pressures and inefficiencies as per the discussions that follow in this subsection. [**32**]

2.5.4.1 Cost Pressure

Cost of medicines, equipment and staff have been rising faster than general inflation, reducing the volume of services that can be purchased for the same expenditure.

2.5.4.2 Demand Pressure

Healthcare services demand increase along with population growth, technological improvements and change in overall chronicle disease burdens.

2.5.4.3 Inefficiency

Excessively tedious and unsupported administration of services and tasks lead to delays and poor value for money. Where more efficiently managing the nursing workforce, which represent more than 50% of healthcare professionals, would definitely lead to more efficient and effective treatment of diseases.

Tertiary- and Regional hospitals inefficiencies should be addressed first with workforce management initiatives, as they are the most visible and costly operational unit of the SA's public health system absorbing about 38% of the healthcare budget, and represent an estimated 75% of all healthcare facilities [**32**].

3 CONCLUSION

Even though nurse scheduling DDSs have the confirmed potential to contribute to the utilization and effectiveness of the nursing workforce, there is still little support toward development of such a workforce management tool in South African government-facilitated hospitals. Methodological, organizational, system support, technological and financial dimensions need to be considered to successfully facilitate nurse scheduling DSSs.

This paper firstly identifies factors that need to be considered for sustainable facilitation of Nurse Scheduling DSSs, and categorised it in methodological, organizational, system support, technological and financial dimensions. Pragmatic research results were ensured by basing the RCA in Chapter 2 on comprehensive resources in the academic community, healthcare and nursing community as well as the workforce management industry that have experience with technical solutions for healthcare staff in both private and public hospitals.

Finally this paper aimed to contribute toward future development of nurse scheduling DSSs in South African public healthcare, and it did so by suggesting resolutions that would increase project facilitation success rates.

Skilled healthcare professionals such as RNs are already so scarce that public healthcare cannot afford not to pay attention to workforce management initiatives, as proposed by this project. If this study raises cognizance amongst important role-players, allied with nursing workforce management in public healthcare, of core concepts and strategies which public healthcare needs to recognize to facilitate sustainable nursing workforce management technology solutions, then it has already succeed in its core purpose.

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MANAGING BOTTLENECKS IN FAST AND RANDOMLY CHANGING PRODUCTION ENVIRONMENT

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ABSTRACT

Bottlenecks create unnecessary requirements for material handling within production settings. Several approaches have been developed and implemented to address bottlenecks such as line balancing, slowest workstation determining the paces at which other workstations operate, introduction of storage buffer, etc. Unfortunately, the existing models dwell on deterministic parameters such as fixed production rate, fixed demands, fixed production cycle time, fixed workstation cycle time, constant pace of the slowest workstation, etc. With the key word being fixed, this paper improves on existing approaches by randomising the fixed parameters that are all functions of time. This is achieved by establishing the time-increments of the production parameters and followed by making them stochastic by the addition of fluctuation terms. The theory of Ito's Stochastic Differential Rule is applied.

Results reveal that an increase in demands, at constant flow/production output rate, requires an increase in production resources, increase in storage buffer requirement and increase pressure on the production environment when the previous models are employed. The employment of the proposed improved approach shows consideration reduction in the amount of required resources and storage buffers. The effects of machine degradations are also revealed.

Keyword: random demand, random TAKT time, random cycle time, number of resources

1 INTRODUCTION

In most production environments, products have to go through many workstations before the end products are finally released to customers. This production layout is commonly known as flow line production, more suitable for mass production. Due to the fact that all the workstations along a flow line mass production may not always operate at the same pace, bottlenecks arise which call for (unnecessary) material handling. Several strategies have been devised to handle production bottlenecks [1,2,3,4,5] which include the application of the theory of line balancing, the slowest workstation determining the pace at which the other workstations works and inclusion of storage buffers between workstations. These theories all work best in environments where everything is supposed to go as planned, although with some shortcomings.

The introduction of storage buffers between workstations is aimed at holding extra “raw” materials in front of the receiving workstations if these workstations are operating at rates slower than the preceding ones. This approach works well if production is not continued for very long period of time or production is being interrupted by frequent short-downs of some (or all) of the workstations or when dealing with seasonal raw materials. If production goes on continuously with time without frequent short downs and the raw materials are readily available, then there will come a time when the buffers will get full thus necessitating an increase in the sizes or number of the storage buffers. This increase cannot continue indefinitely (i.e. for a long time) due to space requirements and monetary implications. One way to improve on these current approach and its shortcomings is to use a model where the slowest workstation determines the pace at which other workstations operate.

The approach that slowest workstation determining the pace of other workstations is common in most manufacturing flow line environments and it is, in fact, recommended in some production system textbooks, [1-3]. This approach is more effective where production is uninterrupted, but it cannot handle seasonal raw materials. It also has the limitation of resource idleness and, if not well managed, overstaffing of operators. The overstaffing of operators is common in production environments where there is job specializations i.e. where workers are more specialized to work on their own machines and they may not want themselves to be deplored to another workstations either through the use of job descriptions or unionisms, or simply because they do not have good knowledge of the operations at other workstations, [6]. Thus, the word “overstaffing” is used in this report to indicate the idleness of non-re-deplorable staff. This limitation, which is a clear indication of low productivity, will always be present in such type of production layout. To improve on this overstaffing or resource idleness, the theory of line balancing can be used, [2].

The theory of line balancing deals with the “appropriate” duplication of slower workstations so that there is no idleness of any resource along the production line. So, in this case the manufacturing plant is designed to release products at the rate of the fastest workstation, which is opposed to the design elaborated in the preceding paragraph where jobs are released at the rate of the slowest workstations. This design is an improvement of the previous two designs as no storage buffer is needed between workstation and no resource is idle. It disadvantages are that it is not designed to handle seasonal raw materials, more fund is initially needed to install the workstations’ equipment and it is not (cost) effective with seasonality or varying demands. The management of the varying (specifically increasing) demand will be dealt with in the rest of this paper.

To avoid the “recurring” issue about seasonal raw materials (“recurring issue” because seasonal raw materials seem to be an issue of the three design approaches), some manufacturing plants build warehouses in the plant or for the plant that hold and preserve sufficient raw materials that can be used throughout the production time until the next season where the raw materials are available. This may be dealt with through the inventory management department or inventory policies.

One can then see that there has been and there is still a constant need for continuous improvement of flows along production lines. This constant need for improvement in production environments, in general and not only limited to flow improvement, has led to the concept of Lean Manufacturing, [3]. Although this paper is not on the general application of Lean Concepts in flow line manufacturing, this paper focuses on the improvements on bottlenecks following randomly changing/increasing demands and machines (or workstations) degradations. With line balancing seeming to be the best of the of the three strategies, the rest of this report will dwell on how this model may be managed following random demand increase and machine breakdowns.

It should be acknowledged that the sole driving factor for production is demand: either current demand or forecasted (future) demand, [1-3]. In line balancing, knowing the demand needed over a period of time (e.g. hourly, daily, weekly or monthly, etc.) one can determine the TAKT time (i.e. the production time needed to be spent per unit to meet the demand, [1,2]). Further knowing the cycle time at each workstation (called standard time) one can determine the number of workstations or operators needed to meet the demand. So, the two major parameters of this report are the random variations in demand and standard time at workstations. If these two parameters vary randomly then the other production parameters are also bound to vary randomly i.e. the demand for the company's product may not always be constant and the operating machines might degrade with time and as such may operate at a different pace.

2 METHOD

When a machine does not operate as intended by its fabricator or designer then the machine can be considered to be faulty and has to be repaired, [3, 6]. These abnormal operations do not occur frequently: it is only probable that they would occur, [3,6,7,8]. The machine might operates faster or slower, which leads to "asynchronous" situation since the pace of this machine as prescribed by the machine designer traditionally should be or should have been used when deciding on the number of other machine(s) along the line during line balancing, [3]. In such a case, the line would not be balanced again. Examples of a situation where a machine might operate faster are when a wrong component is used in the assembly of the new machine or during maintenance, or when an electrical component is faulty. Although one may want to claim that if a production machine operates faster then it is an indication of improvement on product-release rate, it should be cautioned that machine components are not designed in isolation since the set of production conditions are interrelated, [3]. For example, if the feed rate (determined by the spindle rotational speed, [3]) of machine suddenly increases, then it can lead to, for example, tool breakage or damage of the work piece. The other situation where a machine may operate slower is more common with more common causes being the wear and tear, [6]. Since maintenance is the way forward to address both cases where a machine might operate faster or slower, the practical cycle time (also called standard time) per workstation along flow-line production that involves maintenance operation is given by, [3]

$$T_p = T_c + FT_d \qquad (1)$$

where T_p is the practical (or real) cycle time, T_c is the ideal cycle time, F is the probability of fault(s) and T_d is the downtime. Note that here one deals with "downtime" as opposed to "average downtime" because the exact value is needed during line balancing (i.e. one deals with the "average downtime" when the slowest workstation determines the pace at which other workstations operate). Note that since the objective of line balancing is to "duplicate' workstations along the productions line so that products are released at the rate of the fastest workstations, the failure of one workstation may not necessarily bring about work total stoppage at the entire plant. Such failure can be managed by introducing temporal storage buffer(s) and overtime(s). It is important to further recall that the downtimes due to probable or abrupt machine failure should be treated differently from those planned downtimes meant for, for example, meetings lunch, power outages like load scheduling, panned maintenance, etc.

A product's demand variation with time (e.g. daily, weekly, monthly, etc.) should lead to the variation of the "expected production rate" or TAKT time. The demand for a product may vary in several different ways: either increasing or decreasing or fluctuating or with periodic jumps, and so on and randomly most time. The exact nature of the variation of the demand should be obtained from the empirical data through, for example, curve fitting of scatter plots and then forecasting. A parabolic model for increase in random demand (i.e. increasing demand that slows down in a long run) is dealt with in this report. When the demand for a company's product varies in, for example, a parabolic manner, then TAKT time varies in a similar manner given by

$$T_k^2 = T_{k0}^2 + a.t \tag{2}$$

where T_{k0}^2 is the square of initial TAKT time or the square of the initial demand per given time, a is a constant called the parabolic rate constant, and t is time. The rate of variation of the TAKT time (otherwise called the time increment of the TAKT time) is given by

$$\frac{dT_k}{dt} = \frac{a}{T_K} \tag{3}$$

The stochastic counterpart of last expression is obtained by the addition of fluctuation terms to obtain, [7-11]

$$dT_k = \frac{a}{T_K}dt + f_c(T_k)dW(t) + f_p(T_k)dN(t) \tag{4}$$

where $f_c(T_k)dW(t)$ is the random fluctuation in demand due to continuous changes, $f_p(T_k)dN(t)$ is the random fluctuation in demand due to periodic changes, a/T_k is the drift term, $f_c(T_k)$ is the diffusion term, $f_p(T_k)$ is the jump term, $dW(t)$ is the increment of the Weiner's process and $dN(t)$ is the number of increment of stochastic counting process or, specifically, the number of demand increments within an infinitesimal time interval. Note that fluctuations in demand may be given as functions of demand or time or other variable(s). In this report, they are given as functions of demands.

During line balancing, dividing the TAKT time by the standard time, [1,2] gives the needed number of workstations W_{si} to meet the demand. Thus, the stochastic counterpart of W_s is obtained by the necessary integration of expression (4) followed by dividing the answer by expression (1). Note that expression (1) is already a random expression due to the inclusion of the probabilistic term, F. The result should normally be rounded up to avoid under capacity that creates further bottlenecks. Workers can then be added to workstations to improve on production while taking into consideration the cost implication of such addition. The effect of this possible workers addition to rounded-up workstations is deal with under the "cumulative effect of rounding-up workstations" section of the results.

3 RESULTS AND DISCUSSIONS

An exampled production situation that requires the application of the theory of line balancing is dealt with. For confidentiality reasons and for the sake of not advertising any particular company, the name of the company whose current data has been used will remain anonymous. Without loss of generality, assume that all the workstations operate scrap-free such that the TAKT time per workstation or demand per time per workstation type is the same for all the workstations along the line (normally the knowledge of scrap rates should be used in scrap estimation or backward analysis, [2], to obtain the TAKT time per preceding workstation). Note that this scrap free assumption would not significantly change the trend of the results per workstation: trends are important to the report.

The company operates three 8-hour shifts per day and experiences on average a routine 16 minutes downtime per shift due to breaks and meeting. The efficiency of the company is average 80% and a product goes through six workstations before it is completed. The sequence for processing jobs and the standard processing times at each workstation are as given in table 1. The company's current demand is 3600 units per day and the demand is projected to experience a parabolic increase per day with the parabolic rate *a* given as $1.5x10^{-3}$.The probability of fault or failure per workstation that necessitates (reactive) maintenance downtime is as given in Table 1. The company feels that the increase in demand might be effected continuously or periodically with randomly fluctuation terms given as $f_c(D)= f_c(T_k)=b(T_k)^{-1/3}$ and $f_p(D)= f_p(T_k)=c.T_k^{-1/2}$ respectively, where b=0.5 and c=1.5. The rate of increase in demand per given time caused by periodic fluctuation is given by $\lambda(T_K)=1/T_k^3$. The fluctuation in demand is expected to follow a lognormal distribution. Thus, expression (4) is simplified by applying the theory of Ito's Stochastic Differential Rule and Equations for Moments, followed by taking the expectation of the both sides of the resulting expressions using the properties of the lognormal distribution, [12]. The resulting differential equations are solved using Engineering Equation Solver software, EES, [F-Chart software, Madison, WI53744, USA].

Table1: Workstations operating characteristics or parameters

Operation	Time standard (minutes)	Downtime (minutes)	Probability of failure (F)
Loading	0.251	30	0.001
Mill flat surface	1.260	37	0.02
Mill oval edge	3.251	25	0.01
Drill a hole	0.258	44	0.04
Mill circular edge	2.521	18	0.01
Unloading/packaging	0.895	14	0.001

Note that the fluctuations in demand are chosen such that these fluctuations diminish as the product becomes famous or after a long period of time. Thus, both choices of parabolic increase in demand and the natures of the fluctuation terms are such that demand becomes stable in the long run. This model is, in general, more suitable for a new company or for the introduction of new product to the market, [1,2]. The results for a projected ten-year period are indicated in the plots below.

Observe from Figure 1 that the demand for the product increases in such a way that the TAKT time increases from 3.233 units per minute to 7.968 units per minute after 10 years, which is about 7.968/3.233= 2.465 three times increase. The increases in the number of required workstations in the order of flow through the flow line are as follows (Figure 2a and Figure 2b): (11.5=12) / <u>(28.36=29)</u> = ***<u>(2.466=2.417)</u>***; (1.616=2) / <u>(3.984=4)</u> = (***<u>2.466=2</u>***); (0.9234=1) / (<u>2.276=3</u>) = (***<u>2.465=3</u>***); (1.602=2) / (<u>3.949=4</u>) = (***<u>2.465=2</u>***); (1.197=2) / (<u>2.95=3</u>) = (***<u>2.464=1.5</u>***) and (3.556=4) / (<u>8.766=9</u>) = (***<u>2.465=2.25</u>***) where the set (actual=rounded) should be interpreted as the actual values against the rounded value. The first sets made up of normal characters are the initial values, the <u>underlined</u> sets are the final values, and the ***<u>bold-italic-underlined</u>*** sets are the number of times increase. It can be seen from these sets that if *fractions* of workstations could be bought then the rate of increase of the TAKT time will be the same as the rate of increase of the number of required workstations along the line (proportionate to 2.47 times). But since fractions of workstations cannot be bought, the effect of rounding-up shows a serious fluctuation in the number of workstations required: ranging from as low as 1.5 or 2 to 3 times the number of workstations required. This fluctuation in required number of workstations also indicates the challenge that should be faced during line balancing and possible addition of operators to less capacitated workstations. Thus, the percentage load that indicates the degree of balances line is also expected to fluctuate, Figure 4. Having the knowledge of “Excess resources” required should further help balancing the line or in capacitating the workstations.

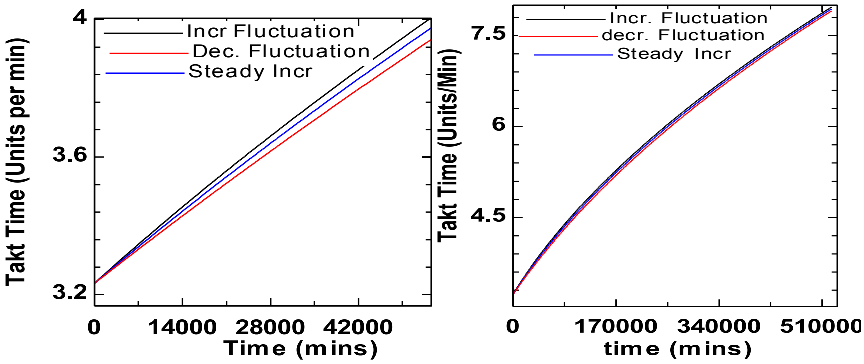

Figure1: Demand variations: deterministic (steady) and stochastic (fluctuating) increases.

Observe that due to random fluctuations, the evolution of the demand per day may be more or less than that of the steady demand increase without fluctuations. Observe also that the dispersion of the demand fluctuation is very low since the plots of Figure 1 are closer to each other. It can then be assumed all the curves span the range of a scatter plot of the projected demand and that the two extreme plots can be assumed to be the range of the results within which all other values fall.

Observe by comparing Figure 1, Figure 2a and Figure 2b that as demand increases, the number of required workstation increases too, which agrees with practical expectations. It can be observed from Figure 2c that the current proposed model reveals that as the fluctuation in demand increases the number of required workstations increases and as the fluctuation in demand decreases the required number of workstation is considerably reduced. But the use of a model that does not consider fluctuation reveals that the result does not vary with demand fluctuations. Thus, the use of the current model, and also taking into consideration the fact that the fluctuation in demand may decay in time and that each product has its life cycle, it can be claimed that the current approach shows an improvement in the results that best correlates with empirical data. Figure 2a reveals the parabolic relationship between the required number of workstations and time while the one (Figure 2b) between the required number of workstation and TAKT time is linear.

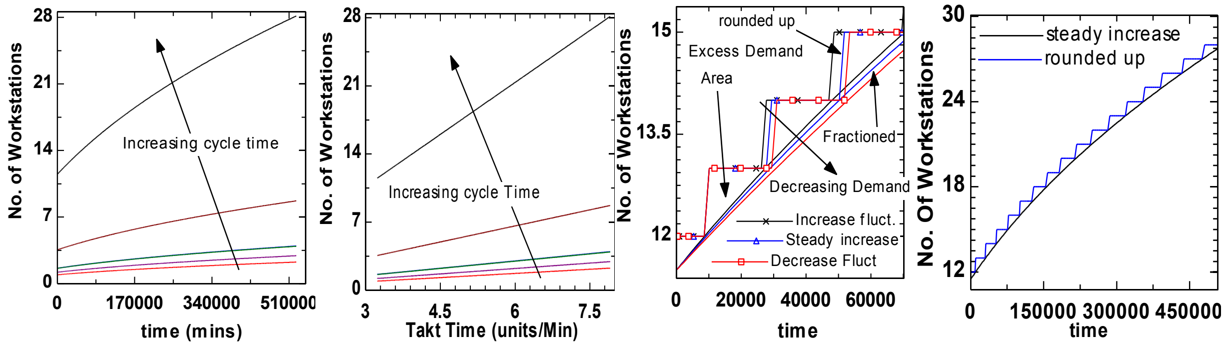

Figure 2: Variations in number of required workstations

The excess numbers of workstations, results found in Figure 3, are obtained as the differences between the rounded-up values and the actual fractioned values, (see Figure 2c and Figure 3a). This corresponds to the area under the "triangular region" between the curve in Figure 2c and figure 2d. An interesting observation that can be made from the present paper is that the amount of "excess" workstation required for fast changing demand is smaller than that of the slower changing demand in the long run, Figure 2c, Figure 3a, Figure 3b and Figure 3c. The number of excess workstation, obtained as a consequence of rounding-up calculated number of workstations since a fraction of machine cannot be purchased, should be used as an indication of the number of operators that may be added to the workstation to avoid resource wastage. The excess workstation is actually a resource wastage meant to avoid underproduction that should create backlogs. It should be stated that a decision to increase the number of workstation, as proposed by the results, is cost effective if the workstations are cheaper to buy while the model of having extra operators may work best if there is sufficient space within workstations for parallel operations.

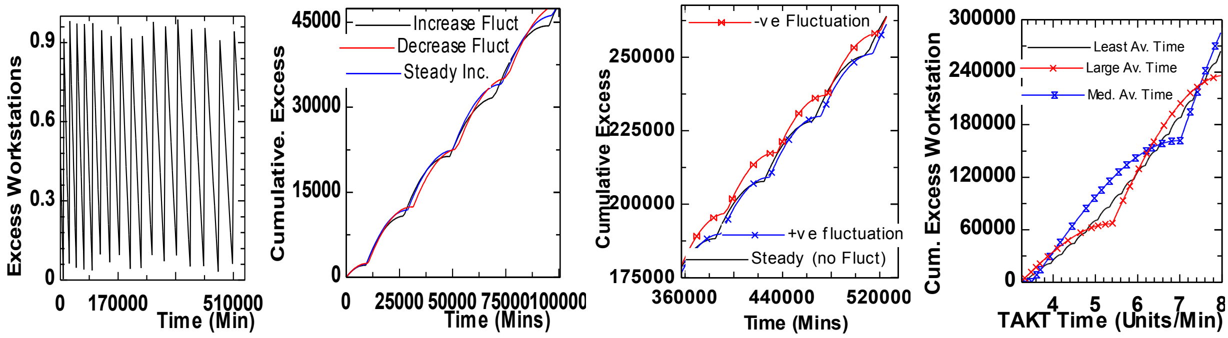

Figure 3: (a) Excess number of workstations due to rounding-up, (b) & (c) cumulative effects of rounding-up workstations (or waste amount of man-hour due to rounding-up); where fig.3c is meant to indicate long run behaviour.

The plots (Figure 3) of the "cumulative excess" number of workstation is an indication of the total amount of resources (such as man-hour) that should be expected to be wasted if extra operators are not added to workstations. Such significantly large value of "cumulative excess" points out the discomfort that managers usually have with idle facilities. As observed that the amount of excess resources (Figure 3b and Figure 3c) and the number of required workstation (Figure 2c) fluctuate tremendously, the ability of a manager to manage source fluctuations accurately with human judgment is very slim. So, instead of managers trying to respond to the fluctuations by adjusting the number of workstations or employing more operators to excess resource, some of them decide to introduce storage buffers between workstations and recommend overtime for operators. With such an over-time approach and also being informed by the trend that demand and number of workstations will take, they temporally use smaller size storage buffers while awaiting the purchase of new facilities. Of course, this might not be optimal, but taking into consideration the fact "each change" has its cost implications, those managers would not always be making the worst decisions.

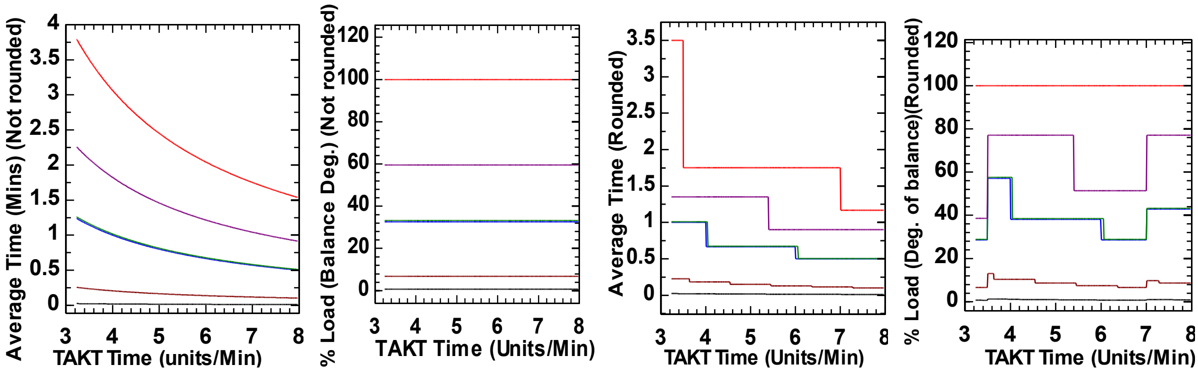

Figure 4: Effect of Average time and degree of balance

The principle of line balancing has been applied as stated in [2]. The TAKT time has been divided by the standard time and the answer rounded. This has been followed by dividing the "standard time" by the "rounded-up value" to obtain "average time". The average times has been divided by the smallest of them all to obtain the percentage load. Note that this percentage load indicates whether the line is balanced (i.e. fully capacitated) or not i.e. the degree of balance. Observe that if these values were obtained for fractionated workstations, then the average time will be seen to decrease steadily (Figure 4a) and the percentage load (Figure 4b) would be constant for all the workstations. But for practical situation, since fractions of workstations are not realistic, it can be observed that the average time can be seen to experience some jump-decreases followed by constant values for some time and the subsequent jump-decreases (Figure 4c), while the percentage load is seen to show some jump-increases, constant-ranges and jump-decreases (Figure 4d) with increase in TAKT time for some of the workstations. For all the cases, observe that the workstation with the largest average time (i.e. the slowest) is 100% balanced (i.e. 100% loaded) while the other workstations have poor balance. The less balanced workstations indicate that either operator(s) should be added to the workstations or that they should be outsourced. This also indicates the challenge that should be faced in managing the production line.

4 CONCLUSION

It can be concluded that model for predicting and controlling bottleneck in randomly increasing demand environment has been proposed and tested.

Results reveal that based on the constraint of not being able to purchase fractions of workstations, the rate at which the number of workstations should increase does not always follow from the rate of increase in demand. This rate shows random fluctuations that are difficult to manage from mere human judgment. But the use of the proposed model indicates when to react.

Results shows that in fast changing demand, a manager who follows the proposed model will have less excess resource or will waste little amount of resources.

Results reveal that while some of the stations will be fully loaded (up to 100% load) others will be poorly load (as smaller as 19% load).

It can also be concluded that a mixed employment of the idea derived from the proposed model and the use of some amount storage buffer would minimize the risk of underproductions or over capacity.

4.1 Acknowledgement

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AN OVERVIEW OF ADVANCED COOLING TECHNIQUES FOR TITANIUM ALLOY MACHINING IN AEROSPACE

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ABSTRACT

Titanium is classified as a difficult to machine superalloy. Its low thermal conductivity causes a concentration of heat in the tool. It causes cutting tools to overheat during machining, that leads to increased machining cost. However, recent advances in cooling technology in aerospace manufacturing, specifically the combination of through spindle cooling and split tools, is claimed to yield improved Ti-6AL-4V machining productivity. The development was led by a tool supplier placing a premium on confidentiality. The result is as this technology has only recently been released into the market, rather little if any performance studies have been published in scientific literature.

The paper investigates the potential machining benefits of through spindle cooled split tools for Ti-6AL-4V milling. The geometry, coolant flow and operational characteristics of the split tools are described. The performance of other more conventional cooling methods such as a nozzle directed high pressure coolant stream is presented from literature. The investigation includes test results of split tools. In conclusion an application domain is discussed where the technology offers improvements over existing technologies.

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1 INTRODUCTION

The price of titanium can be up to 9 times more than steel due to a considerably more demanding process from ore to component [1]. Melting is done in either a vacuum or an inert atmosphere at nominally 1600 degrees Celsius compared to steel melting at nominally 1500 degrees Celsius in a normal atmosphere environment [2] [3] [4]. Similarly machining properties are also challenging, classifying titanium as a difficult to machine super alloy [5]. The machining of titanium alloy generates a large amount of heat, close to the cutting zone. This heat is the primary cause of tool failure, be it directly or indirectly. A number of cooling strategies have therefore been investigated by researchers [6].

The most common and extensively studied cooling strategies are dry cutting, flood cooling, high pressure cooling and through spindle high pressure cooling. The strategy and technique used depends on the material and parameters surrounding the machining process.

Recent advances in cooling technology for aerospace manufacturing, specifically the combination of through spindle cooling and split tools, is claimed to yield improved machining productivity for difficult-to-machine materials.

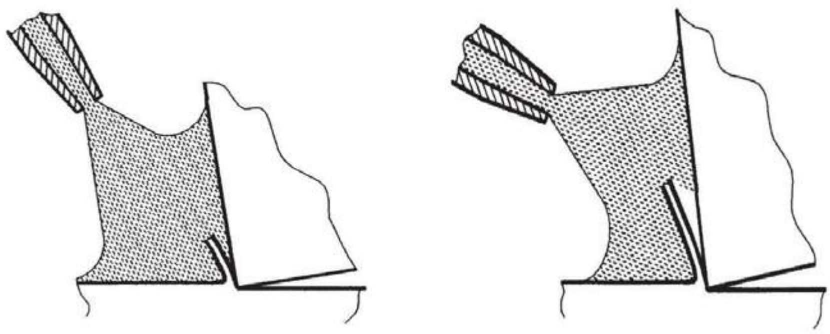
New advancements are highly specialized as they are usually made in-house by means of a partnership between the manufacturer and the tool supplier with a high premium on confidentiality. The cooling methods are designed for very specific applications within the production process and usually comprises a finely tuned hybrid between some of the aforementioned conventional cooling systems [7].

The result is that these technologies have only recently been released into the market, rather little if any performance studies have been published in scientific literature.

2 OVERVIEW OF CONVENTIONAL COOLING METHODS

2.1 Flood Cooling

Flood cooling using soluble oil is the most commonly used cooling method in industry. Flood cooling, best described as an uninterrupted flow of an abundant quantity of coolant, removes chips by a flushing action. With flood cooling, thermal shock on milling tools are minimized and the ignition of chips eliminated [8] [6].



(a) (b)

Figure 1: Extreme directional effects of flood cooling *[6]*.

This method is often a benchmark for experiments due to its extensive use in standard machining applications. Flood cooling is however insufficient in some cases, one of which is titanium machining.

Flood cooling is not based on the principle of precise directional application of the coolant stream. Two extreme cases are shown in Figure 1. In the most extreme case, where titanium's short contact area between chip and tool is approximated, the chip prevents the coolant from being applied to the tool chip interface (b). The cutting edge therefore experiences a large thermal load resulting in poor tool life [6].

2.2 High Pressure Cooling

High pressure cooling became the norm in industry as soon as flood cooling methods were found less effective for high speed machining of hard metals. During high speed machining the performance levels of modern machinery generate so much heat that normal flood cooling is unable to remove chips quick enough and pierce through the vapour barrier. As a result long, thick and unmanageable chips form [9].

The Leidenfrost phenomenon can be observed in cases where a vapour barrier is formed. In Figure 2, Bernardin and Mudawar's time based graph for initial vapour barrier formation versus time [10] is depicted. This initial barrier "film boiling regime" prohibits the flood coolant to come into contact with the hot tool-chip interface as the vapour barrier persists

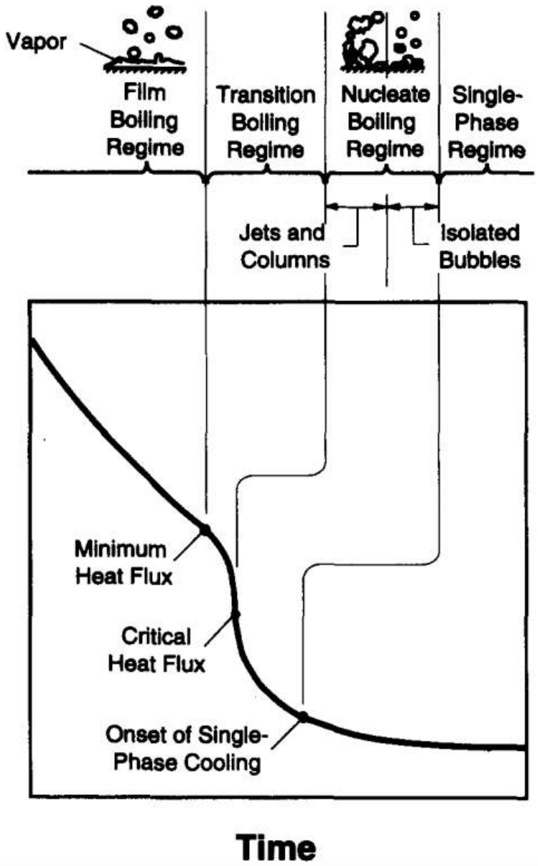


Figure 2: Boiling regimes associated with bath quenching a small metallic mass *[10]*.

[9] [10]. The only way in which to penetrate and remove the vapour barrier is to use high pressure (HP) nozzles to direct coolant at the hot surface. High pressure cooling also enables the formation of short chips. This prohibits the re-cutting of chips, increasing tool life [9].

Ezugwu et al. [11] found that high pressure cooling demonstrates the potential for improvements in tool life when machining Ti-6Al-4V with cemented carbide (coated and uncoated) tools at higher cutting speeds. Figure 3 illustrates notable tool life enhancement under high pressure, compared to flood cooling methods [11]. Particular attention to the greater potential of the high pressure over flood cooling should be noted, specifically at higher cutting speeds. Tool life usually increases with higher coolant pressures [11] as the cutting speed increases.

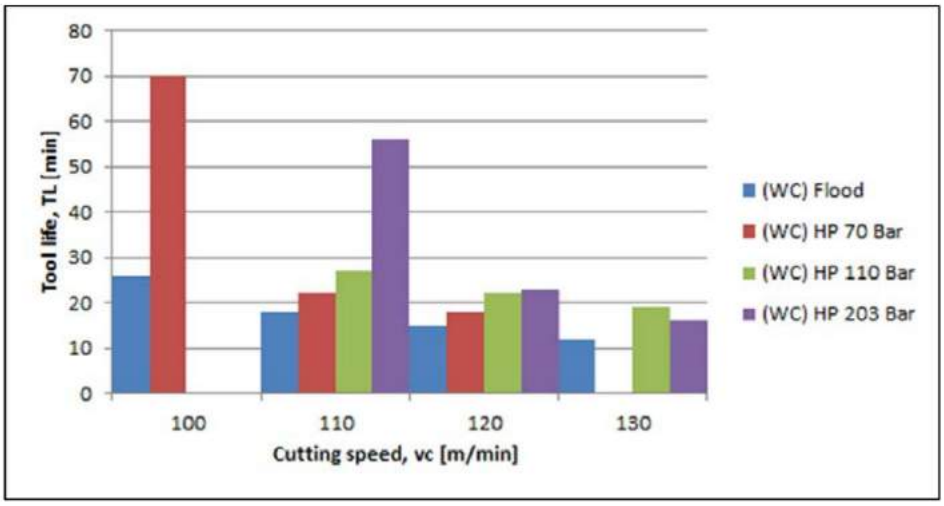


Figure 3: Tool life when machining titanium alloy with uncoated tungsten carbide under different cooling strategies *[12]*.

At a cutting speed of 110 m/min (Figure 3) the highest pressure of 203 bar yields approximately double the tool life compared to 110 bar pressure and an approximate three times increase in tool life compared to flood cooling. However, a cutting speed of 120m/min has a variance in tool life of less than 5% between 203 bar and 110 bar cooling pressure, compared to 110 m/min [12], therefore making the supposed direct relationship between pressures and cooling effectiveness questionable.

2.3 Near Dry Machining with Oil based Lubricants

As industry moves toward greener manufacturing processes, the minimal quantity of lubricant technique (MQL) is being implemented in cases where the waste oil by-product of machining is undesirable [13] [14] [15]. The minimal quantity of lubricant technique employs a pressured air nozzle to deliver a small amount of oil mist to the cutting surface thereby substantially reducing the amount of cutting fluid required for machining operations.

In an attempt to improve the current minimal quantity of lubricant technique, Aoyama et al. [16] argues that it has two major disadvantages for consideration: Due to the absence of the hydraulic pressure of pressurized coolant, the chip removal ability of the minimal quantity of lubricant technique is limited. Furthermore, the minimal quantity of lubricant technique results in the work area being covered in oil due to the fine oil mist. It causes machine problems, slippage on affected surfaces and inhalation of hazardous oil mist [16].

Aoyama et al. [16] proposes an improved system: "Direct Oil Drop Supply system (DOS)", to counteract the oil mist problem of the minimal quantity of lubricant technique. During the operation of this system, pressurized oil drops are supplied to the nozzle via a 0.4 MPa gear pump.

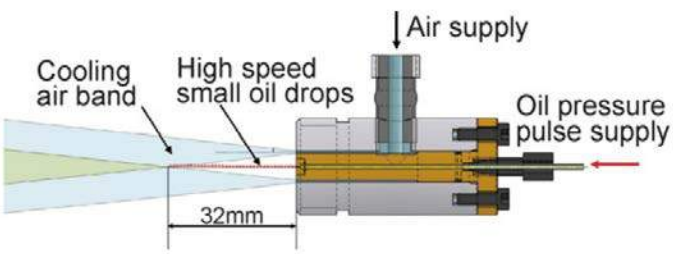


Figure 4: Structure of nozzle for DOS system *[16]*.

Compressed air is also exhausted from the circular slit surrounding the oil discharge hole in order to direct the oil mist to the cutting surface. The pressurized air serves both as chip removal mechanism and also contains the oil drops inside a high speed air barrier. During experimentation it was found that the nozzle in Figure 4 did not deliver oil to the entire cutting surface effectively and a second derivate nozzle was designed.

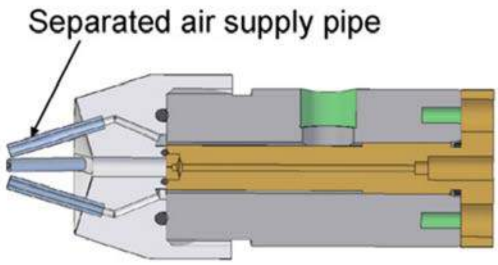


Figure 5: New DOS nozzle design ***[16]*****.**

The subsequent design (Figure 5) comprises four small air flow pipes to deliver air flow to the cutting point more directly while still separating the oil and air. The oil delivery nozzle is located in the centre of the four surrounding air supply nozzles.

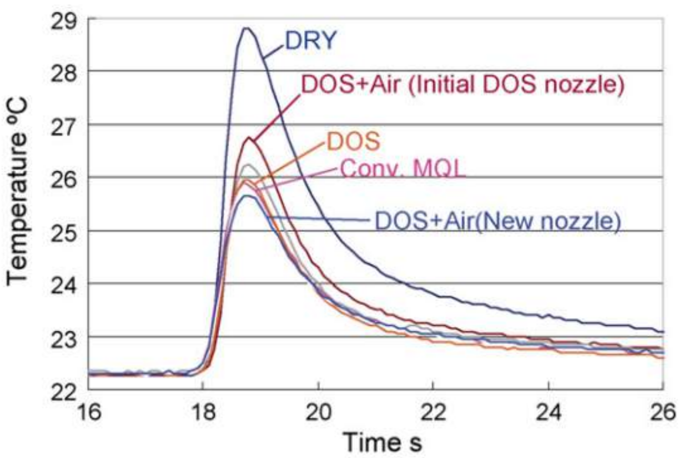


Figure 6: Behaviour of cutting temperature ***[16]*****.**

Figure 6 illustrates the measured temperatures at the cutting surface for Ti-6Al-4V with a 10mm Carbide square end mill. Cutting speed set at 150m/min, depth of cut 6mm and radial depth of cut at 0.5mm. Results indicate little difference in temperature between the minimal quantity of lubricant technique and the direct oil drop supply system. Aoyama et al. reported an 80% reduction in oil mist diffusion around the machine [16].

Yuan et al. [17] found that although the minimal quantity of lubricant technique significantly reduces cutting force, tool wear and surface roughness, it cannot produce evident effect on cutting performance. As a result flaking wear on the flank surface of the insert was found under certain experimental conditions.

Additionally, another major disadvantage of this experimental technology is the degree of customization that is required to install a minimal quantity of lubricant technique system or direct oil drop supply system. Machine modification setups can be complex and expensive.

2.4 Liquid Nitrogen Cooling

Liquid nitrogen (LN_2) as a coolant has been used in a number of studies. In certain cases, it has been conclusively proven that when utilized correctly; it improves tool life, surface finish and dimensional accuracy [18] [19].

Wang et al. [20] compared conventional cooling and LN_2 cooling during turning of Ti-6Al-4V for a cutting speed of 132m/min^{-1}, feed rate of 0.2 mm/rev^{-1} and depth of cut of 1 mm. Experiment results indicated that with conventional cooling, flank wear was increased 5 times as compared to LN_2 cooling.

In contrast to this, Nandy and Paul (2008) [21] found that high pressure cooling outperformed cryogenic cooling by two fold when comparing tool wear. Further experiments by Bermingham et al. (2011) [22] supports Nandy and Paul's finding.

Although both of the aforementioned papers found that high pressure cooling resulted in improved performance over cryogenic cooling, improvements are marginal. Turning of Ti-6Al-4V is used as comparison for all 3 experimental sets. The discrepancies between the respective findings can be attributed to differences in coolant delivery mechanisms.

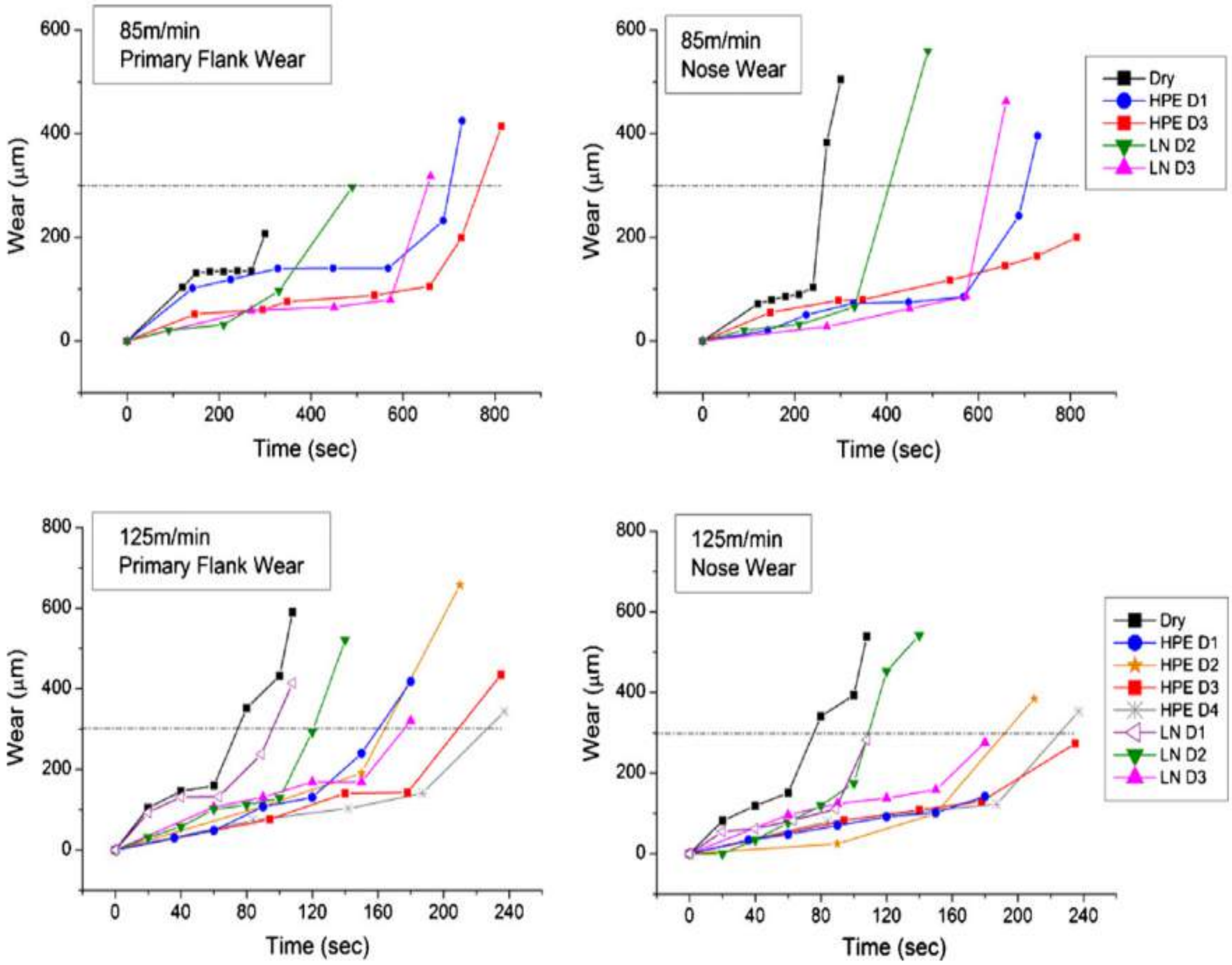


Figure 7: Flank and Nose wear during turning of Ti-6Al-4V ***[22].***

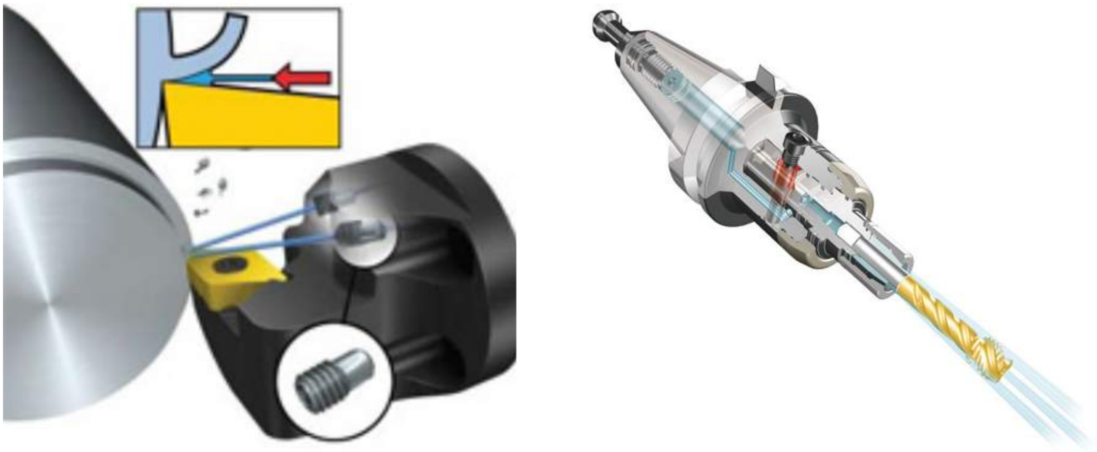
Birmingham et al. experimented with 4 different coolant delivery systems (Note D1-4 postfix for tests in Figure 7), that generated different results.

Cryogenic cooling reduces tool wear during higher speed turning operations (125m/min) while performing slightly inferior to high pressure cooling at lower machining speeds [20] [21] [22]. Evidence therefore suggests that there are high speed application possibilities for cryogenic cooling.

2.5 High Pressure through Spindle Cooling

High pressure through spindle cooling (HPTSC) has been a reality since 1994 when it was first patented by Du et al. [23]. This, nearly 20 year old technology has directly led to the removal of the external cooling pipe and nozzle in the design of modern high pressure cooling systems.

During high pressure through spindle cooling, coolant is delivered to the work surface by means of a channel inside the tool clamp and/or cutter body. The coolant is directed at the workpiece through tiny nozzles that are mounted close to the insert cutting edge [9].



(a) (b)

Figure 8: (a) CoroTurn HP - HPSTC system delivers coolant directly onto the cutting edge. (b) HPSTC application for Hyundai's WIA drilling tool body.

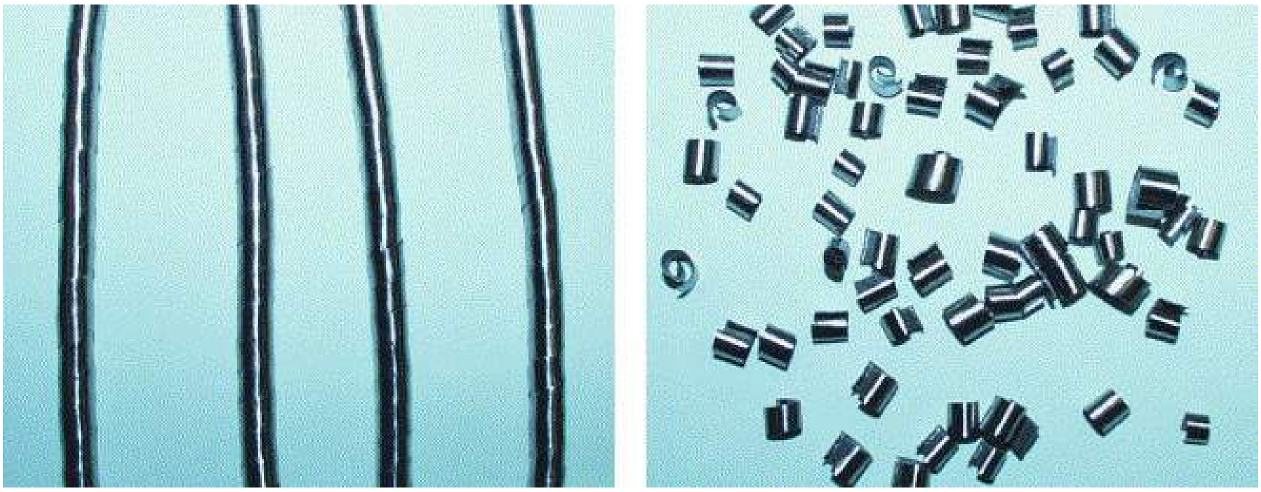
High pressure through spindle cooling seems complex and requiring high cost to implement. It is viewed superficially, but tool manufacturers maintain that it provides unrivalled advantages: Rapid tool changes, better chip control, increased tool life for difficult to machine materials, 50% increase in cutting capability at the same cutting parameters and 20% cutting speed increase for aerospace materials such as titanium and nickel alloys [9]. Although this method requires high pressure through spindle cooling capable machines, some tool manufacturers such as MAG provide through spindle cooling retrofit kits for certain machine models [24].

Dimitrov et al. [12] performed a number of milling experiments in order to compare high pressure cooling with high pressure through spindle cooling. During the experiments, single layer coated, multi-layer coated and uncoated inserts were compared for both cooling methods. I was found that when coated tungsten carbide cutting tools are used, improvements in flank wear under the concept of high pressure through spindle cooling are realised. Experiments indicated that the multi layered coating performance was the lowest and showed no benefit from pressurised cooling or high pressure through spindle cooling. Uncoated inserts showed clear benefit from high pressure through spindle cooling, yielding considerably lower values of uniform wear during the earlier part of the insert's life.

2.6 Cutting Fluids

Cutting fluids in general serve two major roles in machining namely cooling and lubrication [25] [26]. The flow of cutting fluid also aids in the removal of chips, minimise thermal shock in milling operations and keeps chips from igniting. When high pressure cooling methods are used, chips are often small and discontinuous as shown in Figure 9 .

Cutting fluids can be divided into three major categories: neat cutting oils, soluble oils and gaseous cooling. Each of these categories has their own characteristic application. Neat cutting oils are mineral oils that may contain additives. They are primarily used when the pressures between the tool and chip are high and when lubrication is a primary concern. Water soluble coolants are suitable when cutting speeds are high and tool pressures are low. It has however been found that cutting fluids do not penetrate the tool-chip interface when cutting speeds are high [26]. Here gaseous coolants can be utilised to overcome coolant penetration difficulties. The high cost of gases does however limit their use.



(a) (b)

Figure 9: (a) Long continuous chips (b) Short and discontinuous chips.

When a work piece is overcooled, it will become harder and tougher, resulting in reduced tool life [27]. Overcooling can also deteriorate the surface finish and dimensional accuracy of the work piece in severe cases.

Cutting fluids may cause environmental, health and logistical problems. Typical environmental problems are chemical breakdown resulting in water and soil contamination. Operators may experience dermatological ailments due to prolonged exposure. Government regulations are strict about disposal procedures. This results in high transportation costs to disposal sites [18]. Nitrogen composes approximately 78% of our earth's atmosphere, and because liquid nitrogen evaporates to nitrogen gas when used, it is considered environmentally friendly [11] [18] [19]. No operator ailments have been reported with regard to nitrogen.

3 SPECIALIZED COOLING TECHNIQUES IN INDUSTRY

It is common to find manufacturers employing technologies that are on a more advanced level than those published in open, academic literature. This is due to the limitations on intellectual property within the industry. This especially the case with unique specialist applications.

3.1 Cryogenic Through Spindle, Through Tool Cooling (MQL)

During the production of titanium alloy components for the F-35 Lightning II fighter jet, through spindle cooling, using liquid nitrogen has resulted in a 10 times improvement in cutting tool life for Lockheed Martin [28]. Another example is of MAG machine tool and systems, which uses an internally developed through spindle liquid nitrogen cooling system in all machine shops. It has a positive effect on life cycle costs due to reduction in cycle times, total number of machines required and increases in tool life [7].

Marketing media may indicate *what* is being accomplished by these new technologies, but not *how* these processes precisely work. However, as is the case with MAG, these technologies are slowly making their way to the market [29].

Figure 10: Cryogenic minimum quantity lubrication & through spindle cooling system *[29]*.

MAG's technology combines liquid nitrogen cooling with through spindle cooling for machining of difficult-to-machine materials (Figure 10). Such is the case with their MQL liquid nitrogen system that is said to provide a 60% speed increase in the milling of compacted graphite iron with carbide and four times using Polycrystalline Diamond tooling [30]. Full commercialization of the technology is due. The benefits for cryogenic machining aren't only economic or operational. In terms of environmental friendliness, there is no mist collection, filtration, wet chips, contaminated workpieces or disposal cost and less energy consumption without all the pumps, fans and drives that go into handling coolant [30].

Figure 11 graphically depicts the warmest and coldest areas on the tool/workpiece interface the temperature scale is indicated on the left. The measured temperature for the cutter is -32 °C, while the hottest area is measured to be 82 °C. MAG's cryogenic cooling technique is able to concentrate the cooling in die body of the cutter. Early experimental tests indicate that through tool cooling provides the most efficient heat transfer model and consumes the least amount of liquid nitrogen.

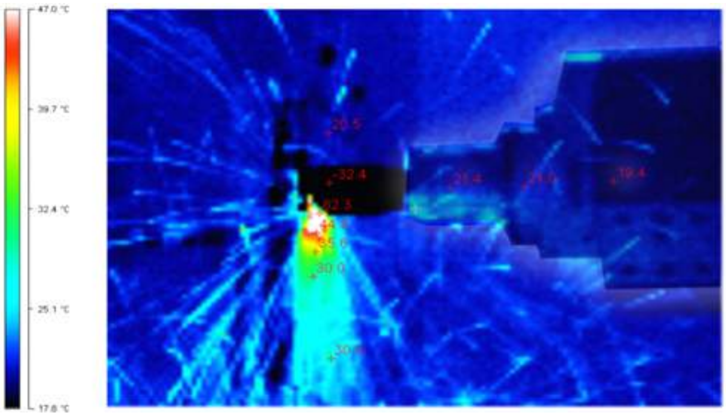


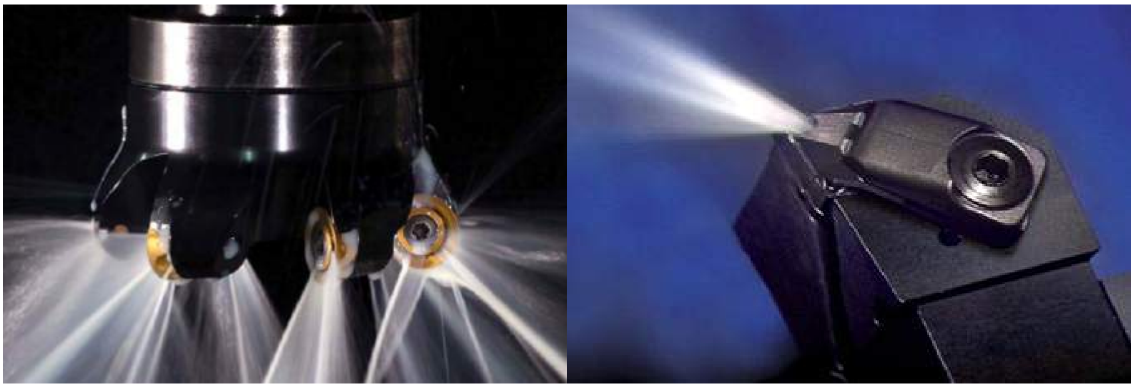
Figure 11: Infrared thermograph of spindle and workpiece temperature gradients *[29]*.

MAG expects 4 times increase in processing speed for milling compacted graphite iron with Polycrystalline Diamond inserts. In addition, the cryogenic through tool cooling is claimed to provide twice the tool life, compared to minimum quantity lubrication.

3.2 Through Spindle Cooling with Split Tool Inserts

The Kennametal Company pioneered through spindle cooling with split tools inserts in 2010 (Beyond Blast). This came as a result of Boeing's pre 2010 market research that indicated that there would not be enough titanium alloy machining capacity in the world during peak requirement for the new 787's as 80 to 90 percent of the material needs to be machined away for aerospace parts [31].

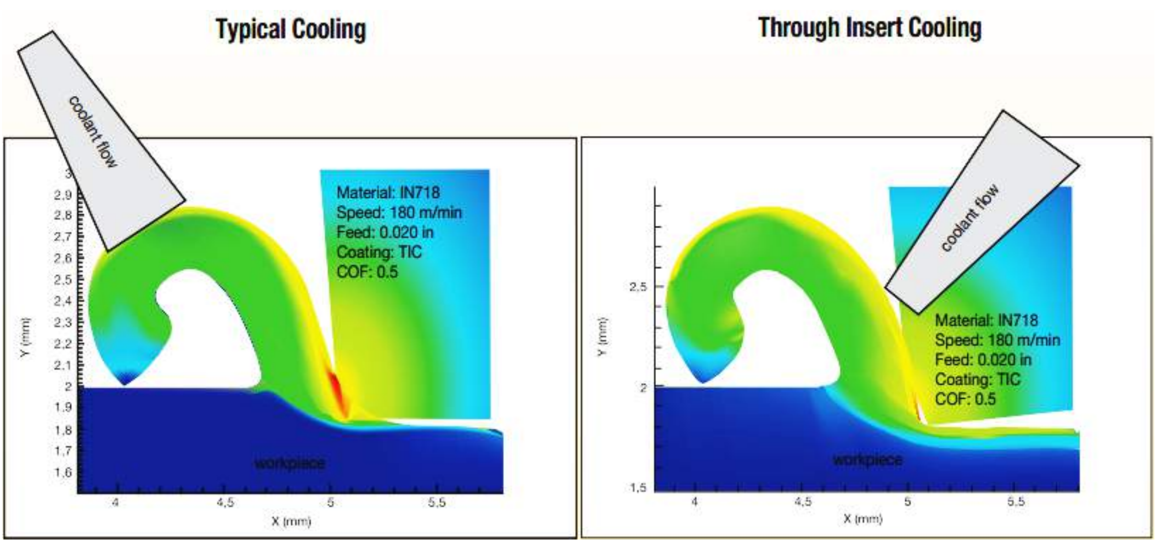
Kennametal's Beyond Blast split tool technology is similar to MAG's through tool cooling, with the exception being the type of coolant that is utilized. This method, dubbed Precision Coolant Technology (PCT) differs slightly from MAG's system in that it employs high pressure coolant to flow through the cutter body and eject from the split tool inserts instead of cryogenic coolant (Figure 12).



(a) **(b)**

Figure 12: Kennametal's Beyond Blast technology delivers high pressure coolant through split tool inserts for both milling (a) and turning (b) operations *[32]*.

Beyond Blast Precision Coolant Technology is available for milling and turning operations. Kennametal claims that it offers a cost reduction over conventional high pressure cooling methods, due to the insert that directs the coolant precisely where it is needed.



(a) (b)

Figure 13: Infrared representation of tool-chip interface for turning with typical cooling (a) vs. through insert cooling (b).

Cooling applications often miss the highest heat concentration location, generated at the shearing point (Figure 13). Impacting chips after they have formed proves typical cooling applications can even force chips back into the cut, accelerating tool wear. Part of the challenge is that the coolant-delivering nozzle is located relatively far from the workpiece.

With a split tool delivery system (Figure 13 (b)), coolant is delivered through the insert, at the cutting interface. Coolant is therefore delivered much closer to the shear point, causing pressure to remain stable. Delivery is therefore more reliable and controlled, significantly reducing temperatures at the point of the cut [32] [33].

Kennametal's KSRM tools for face milling applications are specifically aimed at large material removal rates. The KSRM tools employ round insert split tool technology with high pressure through spindle cooling. The cutter bodies for KSRM have up to 8 positions for indexable inserts. The inserts are channelled to precisely (Figure 14) direct the flow of coolant into the cutting interface, where it helps with chip lifting, chip removal, lubrication, and increased heat transfer.

Round insert cutters have a continuously variable entering angle, depending upon the cutting depth and causes a chip-thinning effect, suitable for machining difficult-to-machine materials [34]. Modern insert geometry developments have made the round insert milling cutters more widely suitable because of the smoother cutting action, requiring less power and stability from the machine tool. Today, it is not a specialized cutter anymore and should be regarded as an efficient roughing cutter, capable of high material removal rates [34].

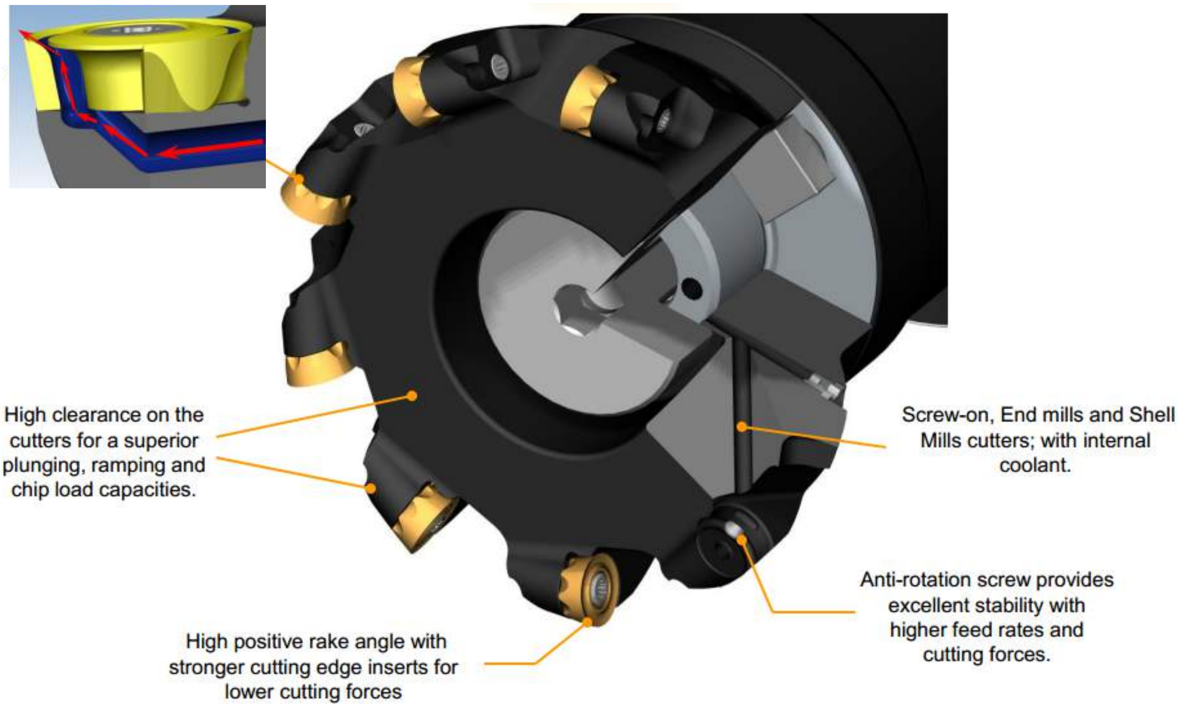


Figure 14: KSRM features and benefits ***[32]*.**

Kennametal benchmarked the Daisy Beyond Blast cutter body (split tooling) with T114526 and T117470 inserts, specifically designed for heavy roughing of Ti-6Al-4V and other difficult-to-machine materials. The cutting conditions for the experiments were:

Table 1: Kennametal Experimental Parameters

Workpiece Material	Ti-6Al-4V
Number of inserts	5
Hardness	42-46 HRC
Length of Pass	245 mm
Cutting Fluid	Water based synthetic
Coolant Pressure	1000 Psi (~70 Bar)
Cutting Speed	46 m/min and 58 m/min respectively
Chip Load (f_z)	0.25 mm per tooth
Axial Depth of Cut (a_p)	3.8 mm
Radial Depth of Cut (a_e)	51 mm

Table 2: Experimental Results

MATERIAL REMOVAL RATE AT 46 m/min		
Table Feed	Cutting Speed	Material Removal Rate
V_f = 183.03 m/min	V_c = 46.00 m/min	MRR = 35.47 cm^3
F_z = 0.25 mm	D = 100.00 mm	A_p = 3.80 mm
Z = 5.00 teeth	N = 146.42 RPM	A_e = 51.00 mm
N = 146.42 RPM		V_f = 183.03 m/min
MATERIAL REMOVAL RATE AT 58 m/min		
Table Feed	Cutting Speed	Material Removal Rate
V_f = 230.77 m/min	V_c = 58.00 m/min	MRR = 44.72 cm^3
F_z = 0.25 mm	D = 100.00 mm	A_p = 3.80 mm
Z = 5.00 teeth	N = 184.62 RPM	A_e = 51.00 mm
N = 184.62 RPM		V_f = 230.77 m/min

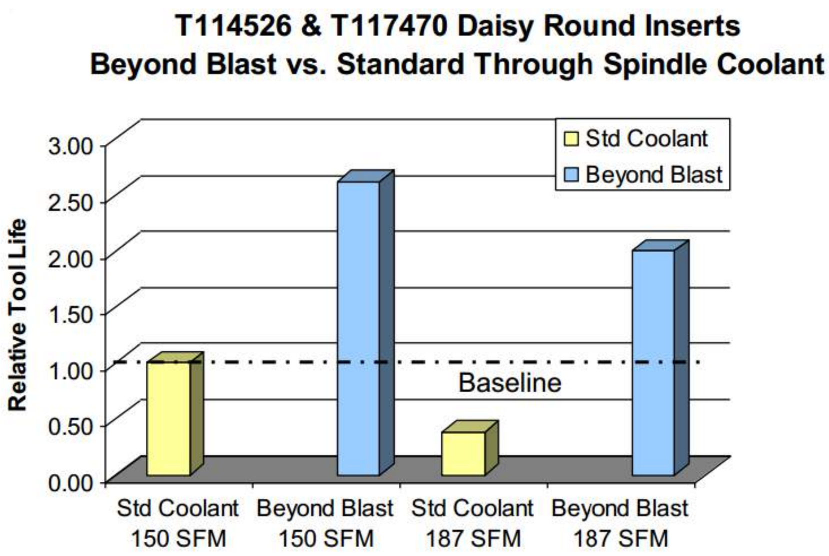


Figure 15: Beyond Blast Daisy round inserts vs. standard through spindle cooling.

Kennametal's experiment results indicate that round insert split tooling delivers high material removal rates for Ti-6Al-4V roughing at 35.37 cm^3/min and 44.72 cm^3/min. Kennametal also reported (Figure 15) a 2.5 times tool life benefit over conventional through spindle cooling.

4 DISCUSSION

High pressure cooling provides better chip removal and penetration than flood cooling. In addition it breaks the vapour barrier and successfully cools hot work pieces during high speed machining. Experimentation shows that increased coolant pressure doesn't result in increased performance in all aspects. There is a trade-off between coolant pressure and tool-life.

The direct oil drop supply system is an improvement on the minimal quantity of lubricant technique due to its use of water jets to reduce oil mist by 80%. Operational improvements are however incremental. The machining temperature of the direct oil drop supply system shows 4% improvement over dry machining and during experimentation flaking wear on the flank surface was observed. Minimal quantity of lubricant systems are cumbersome and relatively costly to install.

Liquid nitrogen holds potential for high speed machining applications. The effectiveness of this cooling method is dependent on the delivery system. As a result, more research and development from private companies has yielded products such as MAG's cryogenic through tool cooling. The technology offers a 60% speed increase with 10 times increase in tool life due to the extraordinary low temperatures maintained at the tool and work piece (-32°C and 86°C respectively). However, this type of cryogenic machining is currently specialized, relatively costly and therefore more suitable for high volume production.

Kennametal's round insert split tools (Beyond Blast) provide aggressive material removal rates for rough and semi smoothing face milling. Pocket milling tools are also available for intricate profile machining. During experimentation material removal rates of 35.37 cm^3/min and 44.72 cm^3/min at cutting speeds of 46 m/min and 58 m/min were observed. The use of round inserts causes a chip thinning effect that reduces cutting force and temperature. Round inserts in combination with the split tool cooling extends tool life by 2.5 times over other through spindle cooling applications. Kennametal's choice to implement water based cooling with round insert split tools permits wider industry adoption. The cutter bodies are designed so that it is compatible with all milling machines that are capable of through spindle cooling.

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APPLYING *LEAN* PRINCIPLES IN A SCHOOL ENVIRONMENT TO REDUCE LEAD TIME AND IMPROVE QUALITY

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ABSTRACT

In this paper the authors will present how *Lean* principles can be implemented in a primary school environment. We discuss insights into how to reduce lead-time to go through the curriculum while improving the results. We will provide insight into the value stream and wastes in a typical classroom environment. We then present the insights so far based on a pilot class implementation at a school in Johannesburg. We also show how the use of technology can aid in the implementation of *Lean* in a classroom environment. Elimination of "wastes' of *Lean* has always resulted in lead time reductions as well as quality improvements in industry and commerce. It is with this background in mind that we are testing the same principles in a classroom environment.

1 INTRODUCTION:

Lean manufacturing, *Lean* enterprise, *Lean* production or often simply, "*Lean*”, is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. "Value" is defined as any action or process that a customer would be willing to pay for [1].

Industry and commerce have been at the forefront of minimising waste using *Lean* in order to improve throughput and quality among other areas [2]. However in education systems globally and locally, the focus has been more on increasing enrolment figures and “driving” students through a fixed lead time syllabus. Success is primarily measured through enrolment figures and number of candidates meeting the minimum set criteria at the end of a twelve year curriculum. Unlike the South African matric education system where lead time has been fixed since time immemorial and the “pass mark” (quality level) has even been dropped, industry and commerce have been using various tools to reduce lead times while improving quality levels.

Improvement proposals and strategies crafted for South African schools in the past have always focused on content issues rather than technical solutions as stated by Clark [3]. Most proposals have never really focused on making the education system *leaner*. The main changes have focused on curriculum content as highlighted by Clark [3]. In some cases the content has been “diluted” to cater for known weaknesses (e.g. Maths literacy instead of proper Mathematics). In addition, some schools have been established as centres of excellence to address enrolment in “difficult” subjects e.g. Dinaledi schools[4].

In 2010, the Department of Basic Education came up with a Schooling 2025 improvement plan, of which the 2014 Action plan is part. This plan seeks to address 14 areas in learning mainly focusing among other things on quality of outputs, enrolment, and use of technology in education. This plan however, does not give any details of how to achieve it. It has been left open to schools to decide on how these goals can be achieved [5]. It is in this light that the authors wish to test if *Lean* can be used as a tool to resolve throughput and quality issues in education.

One of the reasons why the system of education has not been challenged to move in this way is because policy makers run education on a socio-economic platform [6]. If the institutions were to be run more along productivity principles similar to industry and commerce then there would be more emphasis on coming up with a *Lean* education system. The absence of technical solutions such as *Lean* in South African and global education in general has stagnated progress in this area when compared to the leaps that industry and commerce have made.

While acknowledging the problems in the education sector, Graeme Block agrees that in order to fix education, we actually need good technical solutions: “Yes, they must lead. The scrapping of OBE; better workbooks; less paperwork; emphasis on foundations of learning; these are all correct moves. However, we need more than good technical solutions “[7]. Although the application of *Lean* is still relatively new in schools, a few case studies exist on how schools in USA and Europe have been trying to adopt *Lean* in schools [8] and higher education as stated by Emiliani [12][13][14][15]. Most of these studies have been in improving administrative functions In most of these cases, education institutions have realised the expected benefits in cost reduction and quality improvement among others.

2 OBJECTIVES

The major objective of this research is to determine if the "academic production line" can be accelerated while improving quality. This entails reducing the curriculum lead time without compromising the quality of the outputs.

Secondary objectives will include

- Improve quality: a school must understand its customers' requirements and design processes that meet their expectations and requirements. Most of the DBE 2014 goals relate to quality improvement in schools.

- Designing an education tool to aid in the achievement of objectives: Industry has also been using technology to accelerate the achievement of *Lean* objectives. The authors will investigate how best to use technology in schools to aid in the core project objectives. Some of the DBE 2014 goals relate to the use of technology to improve schooling

2.1 Setting the scenario: if an industrial engineer was hired to run education

Let us imagine that an Industrial engineer has been appointed to run a company called DBE (Department of Basic Education) which manufactures a product called Matric. The Matric process goes through 12 sub processes called grades. Each sub-process consists of lessons. To achieve the goals of each lesson various tools called books/notes which are utilised. The processes operators are called teachers.

The task is to make this process *Lean* because since the process started, the lead time has remained constant at 12 years. The quality level has been set at 30% (which is the pass mark for Matric). The result has been that the international competitiveness of the "Matric" brand has been compromised and the Matric brand market share continues to go down.

In other words, it is possible to compare a classroom setup to a manufacturing scenario and therefore relate how *Lean* has been implemented in industry to the classroom environment.

3 HOW *LEAN* PRINCIPLES CAN BE IMPLEMENTED IN A PRIMARY SCHOOL ENVIRONMENT

3.1 Principles of *Lean*-adopting for the classroom

Using the five principles of *Lean* [1], we can propose a way to improve the current school education process. Following the established five-step thought process for guiding the implementation of *Lean* techniques, the approach for the classroom environment is proposed as follows.

3.1.1 Specify value from the standpoint of the end customer by product family.

Bicheno [9] states that it is an established marketing idea that customers buy results and not products. We have to understand who the customers and the customer's customer is or next process or next company along the chain so that product designs or service operations are not constrained by existing facilities or processes.

In the classroom, the student is the main customer. Our survey results at the school we are conducting the *Lean* project at suggest that the main value that the student requires is to achieve the best results (quality) in the shortest possible time (lead time). It is from that viewpoint that the classroom value stream should focus on delivering quality outputs in the shortest possible lead time.

Based on this, there is likelihood that the current classroom process may actually not be adequately designed to meet the customer's requirements

3.1.2 Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value.

According to Bicheno [9], this is a sequence of all processes all the way from raw material to final customer, or from product concept to market launch. The value stream should be mapped with a horizontal focus while concentrating on the viewpoint of the object (or product or customer), and not on the viewpoint of the department or process step.

The schooling value stream consists of a sequence of all the processes from enrolment of a student right through to graduation. In this value stream there are sub streams which feed into the main processes. The focus of this value stream is the viewpoint of the customer which is to get the best possible results in the shortest possible time.

A simplistic view of the current process shows that there are several steps which do not create value, and hence need to be minimised/eliminated.

3.1.3 Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer.

Make the value flow and if possible, use one-piece or one document flow to keep it moving. Avoid batch and queue, or at least continuously reduce them and obstacles in their way. Try to design according to Stalk and Hout's golden rule, never to delay a value adding step with a non-value adding step, although temporarily necessary, try to do such steps in parallel. Flow requires much preparation activity. However, the important thing is vision: have in mind a guiding strategy that will move you towards simple, slim and swift customer flow [9].

In the school process, the main aim is to move the students at their pace, with each student's capabilities being continuously identified and harnessed. This may imply even moving students within the same class at different paces so that those who have mastered the required outcomes of a chapter/section are not "held back" by those who still have to be "processed". The current classroom learning system is batch and has a lot of waiting which results in queuing while waiting among other things for examples: papers to be marked, holidays to be completed ,a teacher to be available or even for other students to catch up.

All this delays the customer (students) processes and the non-value adding processes subsequently delay the value adding steps.

3.1.4 As flow is introduced, let customers pull value from the next upstream activity.

Having set-up the framework, only operate as needed. 'Pull' in service terms means short - term response to customer's rate of demand, and not overproducing. In service, it is often capacity that is pulled, not inventory or product [1].

The proposed *Lean* processes should allow value to be pulled from subsequent processes. This means that for example if a student has met the objectives of a chapter, then they should not be stopped from moving to the next chapter so that they can start deriving value from the next "need". The current processes do not allow this to happen. In the bigger picture, schools should only be producing the required number of graduates at the correct times to meet the needs of the economy.

3.1.5 As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

Perfection means delivering only what the customer wants, exactly when required and without delay, at a fair price and minimum waste. The real benchmark is zero waste and not what your competitors or 'best practice is doing'. Remember that a human activity system, unlike a mechanical process, cannot be copied-because although the actions can be seen, the interactions are invisible. You can learn good practice but you cannot duplicate and expect it to work the same way. These five principles are not sequential, once off procedures, but rather a journey of continuous improvement [1].

In the classroom, the aim is to continuously eliminate waste until the curriculum can be covered in the minimum possible time while producing 100% pass results for all the students who are studying relevant content to take them to the next stage.

3.2 Methodology:

The overall approach is shown in Figure 1. The SPORTS (Strategy, Process, Organisation, Regulatory, Technology, and Site) methodology will be adopted for the implementation. This will take consideration of the overall end to end project requirements to ensure a smooth implementation which caters for all the technical (e.g. *Lean*, learning theory, IT requirements) and human requirements e.g. change management issues.

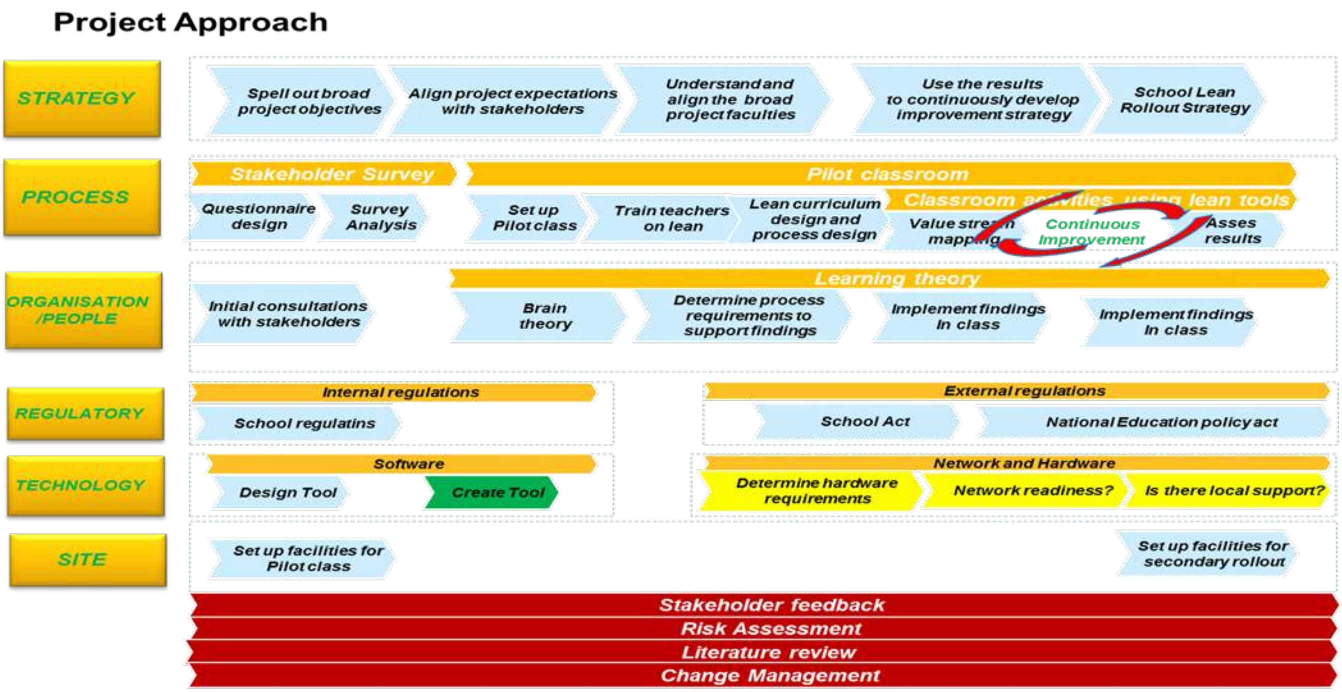

Figure 1: *Lean* in the Classroom: Project Approach

The Plan Do Check Act(PDCA) methodology is one of the *Lean* tools that will be adopted to cater for the continuous improvement cycle as shown in the diagram. The PDCA ensures that all activities which will be used to assist in the achievement of *Lean* objectives will need to be thoroughly planned, executed (Do), after which the progress will be checked and then any corrective action taken to ensure the goals are achieved. Other *Lean* tools will also be used where appropriate.

3.2.1 Plan

The school chose a subject which is viewed to be difficult (Maths) with the aim of improving quality (results) while reducing lead time.

We planned to look at and document all the processes that affect the classroom so that we could design "to be" value streams that align to the requirements of the customer. By doing so, will reduce "start-ups" and "over-processing" and thus help to reduce lead time while aligning all activities to the customer's(student's) goal.

We also planned to provide a detailed annual plan (timetable) with "impressions"/processes plan, "defects" identification and elimination plan to be achieved through root cause analysis. Root cause analysis is a tool used in *Lean* to determine the core factors causing a process failure [1]. During this analysis, techniques such as Fishbone analysis may also be employed. Fishbone analysis aims to dissect each problems into a fish/tree structure up to the lowest level in order to fully understand problems and eventually come up with suitable solutions [2]. Impressions in brain theory refer to the number of different processes that a student has to go through as part of the processes that help to ensure that the content being studied is retained in the long term memory [5]

Based on these we made a plan on how the classes are going to be conducted and how feedback to any scenarios would be taken care of.

3.2.2 Do

The classes will be run based on timetables which emphasize moving away from batch processing to "individualised cellular processing". This would reduce queuing and ensure that non value adding processes would not affect the value adding processes.

We are going to implement flipped class-to save time. In flipped classes, students watch videos and do pre-homework [6]. The teacher receives results and a "corrections" schedule for each student. The teacher or system plans the lesson based on student's pre-homework/flipped class performance. This saves time by reducing waiting time as the class skips this stage which was supposed to be completed in class. Where technology is not available, this process is done manually.

The teacher sets up "cellular class" design to enable students to go through the right impressions, while in the right groups identified through pre-screening based on the pre-homework.(see Figure 2 and Figure 3) This reduces over processing and introduces flow which aligns the teaching process to the customer's requirement. Each student's "defects" are identified and worked on so that ideally the student does not move to the next process with the previous process "defects". This process is repeated over the various curriculum topics.

Additionally, tests are individualised. The tests are not similar (batch) for all students but are based on each student's weakness (defects).

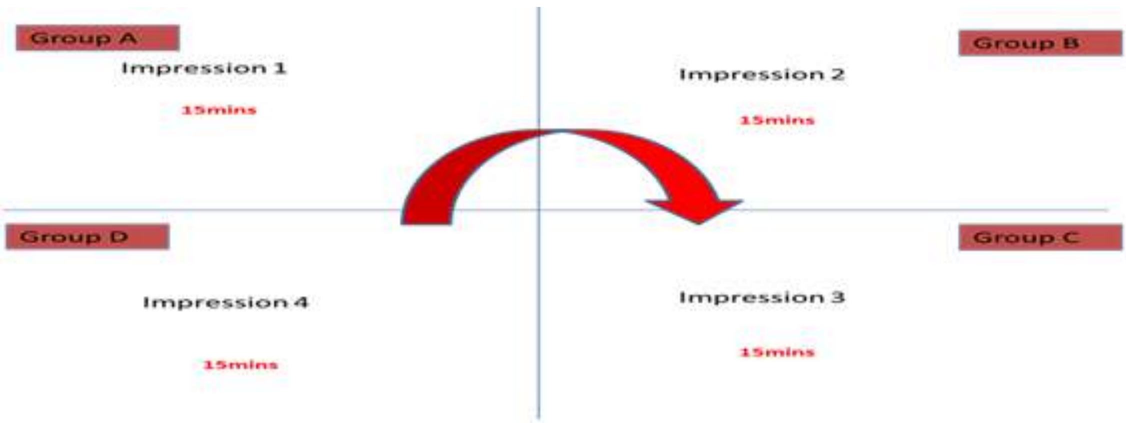

Figure 2: Class Design for *Lean*: One Lesson Structure

3.2.3 Check

The actual curriculum coverage is measured against the planned Key performance indicators (KPIs) for each individual student. These KPIs focus on quality of the output (results) and rate of coverage of the curriculum.

One way will be to continuously identify the problems each student fails and recompile them and give to the students as homework. This "iteration" process is continuous to ensure that all the areas of weakness are picked up for each student.

3.2.4 Act

Action plans are put into practice to continuously remove any waste which affects the customer (student) value stream.

4 HOW TO REDUCE THE CURICULUM LEAD-TIME WHILE IMPROVING THE RESULTS

4.1 Lead time Reduction

The analogy we will adopt is that of a manufacturing approach. The "product" that has to be produced is a predefined grade curriculum. There are several sub processes (impressions) which every student undergoes to enable the "manufacture" of a quality product. Brain theory dictates that for information to be retained in long term memory, ten impressions have to be distributed over a period of time [7].

4.2 Processes/Sub processes

Table 1 and 2 give a proposal of the impressions (processes) from Impression 1 (I1) to impression 10(I10) that will typically be utilised in a *Lean* class to achieve the minimum "quality levels".

Table 1: General Depiction of the Impressions Matrix

I1(Day-2) Watch Video	**I2**(Day-1) Pre-homework	**I3**(Day0) Focused lesson	**I4**(Day1) Class exercise	**I5**(Week1) Class Activity
I6 (Month1) Test	**I7** (Month3) Project	**I8** Month6 Revision	**I9** Month 9 (link to similar concept in next grade)	**I10** Month 12 Hard Overall test

Table 2: Annual Curriculum Impression Matrix (showing weeks each will be covered)

	Impressions									
Curriculum Section(for Grade 3 Maths CAPS curriculum)	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I9**	**I10**
	D-2	D-1	D0	D1	W1	M1	M2	M4	M7	M11
1.1	W1	W1	W1	W1	W2	W6	W10	W18	W30	W46
1.2	W1	W1	W1	W1	W2	W6	W10	W18	W30	W46
1.3	W2	W2	W2	W2	W3	W7	W11	W19	W31	W47
1.4	W2	W2	W2	W2	W3	W7	W12	W19	W31	W47
1.5	W3	W3	W3	W3	W4	W8	W13	W20	W32	W48
1.6	W3	W3	W3	W3	W4	W8	W14	W20	W32	W48
1.7	W4	W4	W4	W4	W5	W9	W15	W21	W33	W49
1.8	W4	W4	W4	W4	W5	W9	W15	W21	W33	W49
1.9	W5	W5	W5	W5	W6	W10	W16	W22	W34	W50
1.10	W5	W5	W5	W5	W6	W10	W16	W22	W34	W50
1.11	W6	W6	W6	W6	W7	W11	W17	W23	W35	W51
1.12	W6	W6	W6	W6	W7	W11	W17	W23	W35	W51
1.13	W7	W7	W7	W7	W8	W12	W18	W24	W36	W52
1.14	W7	W7	W7	W7	W8	W12	W18	W24	W36	W52
1.15	W8	W8	W8	W8	W9	W13	W19	W25	W37	W53
1.16	W8	W8	W8	W8	W9	W13	W19	W25	W37	W53
1.17	W9	W9	W9	W9	W10	W14	W20	W26	W38	W54
2.1	W9	W9	W9	W9	W10	W14	W20	W26	W38	W54
2.2	W10	W10	W10	W10	W11	W15	W21	W27	W39	W55
3.1	W10	W10	W10	W10	W11	W15	W21	W27	W39	W55
3.2	W11	W11	W11	W11	W12	W16	W22	W28	W40	W56
3.3	W11	W11	W11	W11	W12	W16	W22	W28	W40	W56
3.4	W12	W12	W12	W12	W13	W17	W23	W29	W41	W57
4.1	W12	W12	W12	W12	W13	W17	W23	W29	W41	W57
4.2	W13	W13	W13	W13	W14	W18	W24	W30	W42	W58
4.3	W13	W13	W13	W13	W14	W18	W24	W30	W42	W58
4.4	W14	W14	W14	W14	W15	W19	W25	W31	W43	W59
4.5	W14	W14	W14	W14	W15	W19	W25	W31	W43	W59
5.4	W15	W15	W15	W15	W16	W20	W26	W32	W44	W60
5.5	W15	W15	W15	W15	W16	W20	W26	W32	W44	W60
5.6	W16	W16	W16	W16	W17	W17	W27	W33	W45	W61

Each student will also have this impression chart on their profile, which will progressively be coloured green or red to show whether it has been accomplished or not. The techniques/activities to be used in the *Lean* class to reduce cycle time are as described in Table 3 and 4.

Table 3: Summary Table Showing the Time Needed Within and Outside the Class to Cover Curriculum

Delivery Method	Number of weeks	Comment
Tech	42	Technology allows continuous learning even outside the classroom to build up on the required impressions
Class	19	This preliminary impression plan shows that the 8 impressions to be done in class require about 248 lesson which can be accomplished in 124 hours(taking each lesson to be 30minutes). This effectively leaves a slack of another 156 hours (Maths lessons are allocated 7 hours per week for 40 weeks). This already theoretically provides enough time to cover another grade (assuming same number of concepts to be covered at next grade)

Table 4: Time Improvement Techniques

Item	Improvement Emphasis	Comments
1. Flipped class:	Time	Record videos for students to watch classes before the main lessons(these are not substitutes for the main lessons)- the main lessons are now meant to address issues picked up from the pre-homework which is done before the main lesson
2. Automated marking	Time	Reduces teachers marking time from 4hrs a week to 2hrs. All multiple choice and structured questions can be automatically marked

4.3 Quality Improvement Focus

The current quality control system for the primary school system shows that even a lot of students who have not met the basic requirements of the previous grade are "pushed" to the next stage of the process(next grade) as detailed in the process shown in Figure 4. This scenario results in students struggling with even more advanced concepts in the subsequent grades.

Figure 4: Current quality control system in the Department of basic education

Figure 5a: Proposed "*Lean* classroom" quality assurance system

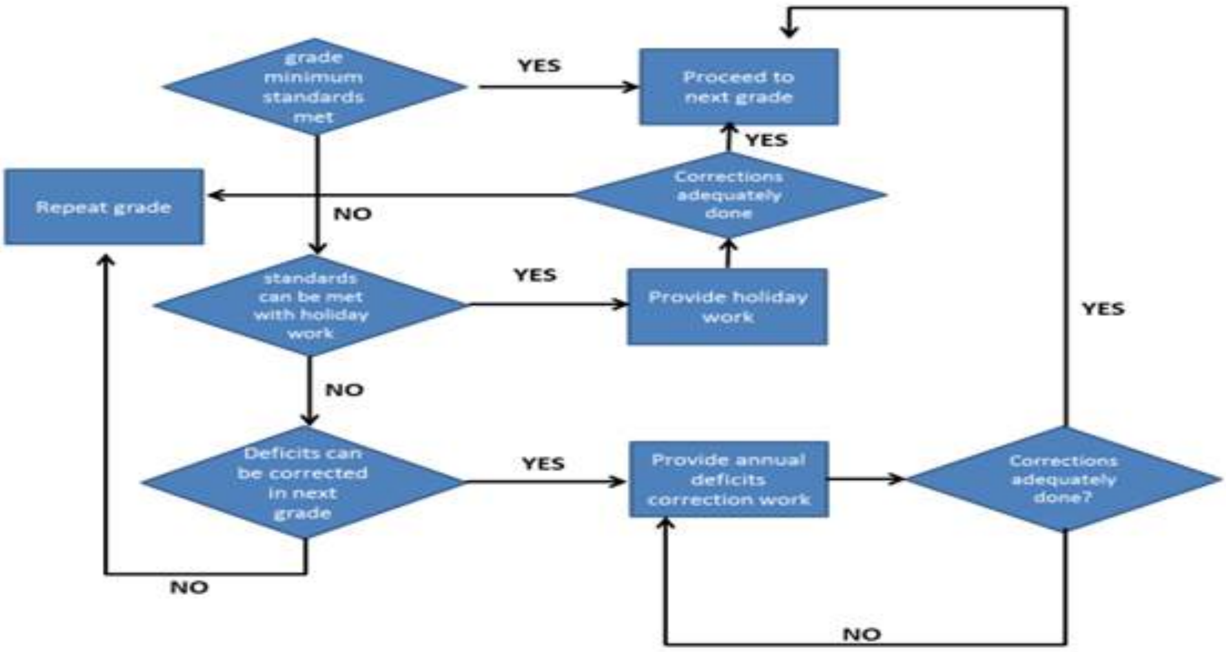

Figure 5b: Proposed "*Lean* classroom" quality assurance system

While the impressions as described above will help to improve quality of output, the cycle in Figure 5b ensures that any areas of weakness that have not been accomplished after these impressions are noted for each student, manually or electronically so that the student will get the necessary help from the teacher or by other means. Even when the student moves to the next grade, these 'errors' are still noted so that the next grade teacher can understand which prerequisites have not been accomplished. The internal reports will indicate where each student needs to work on in order to overcome "defects" and not meet challenges in the next process.

After each impression, a checking mechanism updates the teacher on whether each student has completed the prerequisites for each of the subsequent topics. The revision exercises will emphasize on those areas.

The proposed system thus moves towards quality assurance, whereby each stage is checked and passed off or if it is not satisfactory, then corrective measures are taken before moving to the next stage. Fig 5 below shows the actions that the project will take to improve on the quality output of the students results

Table 5: Quality Improvement Focus

Item	Improvement emphasis	Comments
1. Impressions	Quality	There will be 10 impressions spread over a year or more. This requires synchronisation of grades curriculum as some impressions run into the following year
2. Profile tracking	Quality	Each student's profile will have reports on what questions have been answered and what the performance was, what content has been accessed and for how much time. Videos and questions of corrections will also be attached to the profile, and will only be removed once satisfactorily completed.
3. Focus on individual defects	Quality	In the class, the emphasis of teachers/tutors should be to eliminate the defects identified in the pre-homework

5 VALUE STREAM AND WASTES IN A TYPICAL CLASSROOM ENVIRONMENT

The project will process map all the critical process that affect the classrooms. These processes include:

- Creation of an annual plan and timetable
- Conducting a lesson
- Conducting an activity(impression)
- Marking
- Giving feedback
- Setting a test

We then identify the "wastes" as shown in Table 6. We then redesign the process to eliminate/minimise the waste. The following is a redesign of the "wastes of *Lean*" to equate to the education practice example [12].

Table 6: Type of Waste Education Practice Example

Type of waste	Education Practice example
Motion (people)	• Students and teacher travelling to multisites, to different classrooms, throughout the same day. • Poor classroom layouts restricting the movement of the teacher around the students.
Transport (goods)	• Photocopying department is on a different site to the delivery of lessons, hard copy sent to reprographics via internal mail, copying completed and returned to site of origin (10 days lead time)
Skills utilisation	• Teachers delivering above their own knowledge as a stop gap, or even in reverse covering classes that do not utilize their full potential.
Over-Production	• Multiple copies of hand-outs just in case students have mislaid their copies! • may refer to developing too many different lessons/subjects that are not adding the required value
Over- Process	• Over assessment of same outcome which appears in different subjects/ modules, students undertaking additional subjects outside the ones required to get the next job. • Providing much more than what is required for the validation process. This can also be in the form of too many individuals involved in checking the same work.
Defects	• Students not achieving the required learning outcomes or having to re-sit/re-submit course work, • Lecturing staff marking and giving feedback more than once on the same piece of work.
Waiting	• Feedback on assessment or achievement of learning outcome(s), • Long waiting to start the next academic year. • Waiting for lectures to be done in class
Inventory	• Students can be classed as inventory, they are raw material at enrolment, work in progress for the period of programme study and finished goods until the qualification is obtained.

Another example of a process change will involve the annual plan creation. The process in Figure 5 depicts the current annual plan creation process (blue) and the proposed "*Lean*" to be process. The difference is that the two new green blocks have been added. In looking through the curriculums, it has been observed that there are common areas that can be grouped together. This will reduce the number of start-ups and increase the scope/coverage in single lectures. As one of the project aims is to accelerate the rate of curriculum coverage, the grouping of common themes across grades enables the reduction in over processing, as the impressions (processes) are then designed to cover common themes and thus reduce time needed to achieve the same goals.

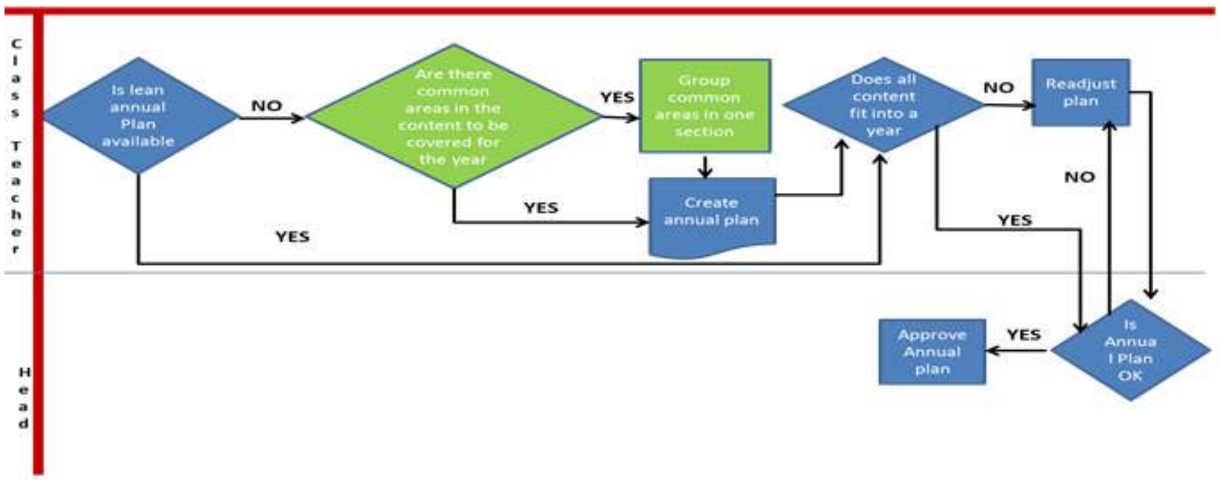

Figure 6: Creation of an annual plan

6 INSIGHTS SO FAR BASED ON A PILOT CLASS IMPLEMENTATION

6.1 Plan

The current method of creating an annual plan to involves fitting the curriculum into the number of days in the academic year whereas the lean approach will involve grouping curriculum content first into common themes and then structuring a “learning plan” based on content to be taught and the number of impressions(sub-processes) to be executed. The class timetable is to be created with more emphasis on achievement of the impressions plan.

6.2 Do

Currently all lessons are conducted within the classroom, however in the lean setup, a significant amount of work (up to 50%)that is normally done in the classroom and “extra impressions work” that is normally not done is now performed outside the classroom through videos, pre and post homework as well as revision exercises. This will reduce waiting time. Teachers will plan the actual lesson based on pre-homework feedback. This helps to focus lessons on areas of need and reduces over processing. Implement impressions plan using the “cellular-class” concept

6.3 Check

Currently all the Marking of student’s exercises is manual and time consuming. Introducing an IT tool will automate the process. This will reduce the time needed by the teacher to check students work and opens up more time for the teacher to do more value adding work such as delivering lectures and planning for lessons. Currently parents access to children’s work is limited to a few days when appointments with the class teacher can be made. However Sms/email notifications to parents on students’ progress and parents access to children’s work online will enables them to be actively involved in their children’s work and thus helping to ensure that they do their homework as parets will be asked to check on them.

Additionally at the moment homework/tests/exams are batched. The class gets the same homework regardless of different strength and weakness profiles. In the lean setup, tests are no longer random but more focused on "eliminating defects" identified in the prior processes. Individualised tests will now be based on identified "defects"

6.4 ACT

Currently students may do corrections through extra lessons and other students enrol for external classes in order to catch up on areas needing attention or in order to accelerate their learning pace. Lean classes will identify and correct all individual student's needs and ensure that any quality issues are dealt with at school. Each student will also be given a chance to cover the curriculum at the pace they can without being slowed down necessarily by the rate of other students

7 HOW TECHNOLOGY WILL HELP IN THE IMPLEMENTATION

Learning theory says that a certain number of "impressions" have to be performed to enable retention of information in the long term memory [5]. Table 2 above shows that using the recommended ten minimum impressions, there is enough time to complete the curriculum. . We also need to track that these impressions have been actually done

In order to properly manage the impressions without adding burden to the teachers' administrative work while also reducing the lead time to complete the curriculum, we designed an IT tool to help manage the process. This tool will help the class to implement the "flipped classroom" [6] concept which enables students to watch their teacher presenting lessons at home or wherever they are. The flipped classroom concept reduces the waiting time. Based on what they have watched, the students write a "pre-homework". The results are sent to the teacher who then plans for the next lesson based on how the students have performed in the pre-homework. In the lessons, the teacher focuses on the "defect areas". The aim is also to avoid unnecessary "processing" during the lessons. After the "more focused" lesson in which the teacher focuses on eliminating defects identified for each child, another homework is given to determine how much of the "defects" have been eliminated due to the more focussed lesson

7.1 What the technology will do to support *Lean* intervention

7.1.1 Enable Lean Planning

The teacher with upload Excel data with a given format/template. This data will consist of the curriculum topic, number of learning weeks available in a year(i.e. full year less holidays, examinations period, an allowance or trips and other activities, prerequisites, similar topics grouping, all types and number of impressions. After this the *Lean* curriculum planning tool will produce a plan showing a curriculum/impression coverage plan.

There will be a tracking system which will show how the classes are covering the plan and an alarm system to help implement corrective measures if the class is lagging behind.

7.1.2 Enable quality improvements through impressions monitoring

Brain theory advocates for about ten impressions spread over a period to enable long term memory retention of information. Long term retention mayimprove the quality of results. If all these required impressions are performed manually, then the actual curriculum coverage may be slower although it will still be possible to accelerate the classroom based on Table 2 above.. However if some of the impressions are done using an IT tool, then students can do these impressions outside the normal classroom time, which frees up classroom time to activities which enable the teacher to focus on “waste” removal activities, rather than batch processing activities. All this should result in quality improvements through better results.

7.1.3 Enable reduction of time through efficient utilisation of time.

The use of technology enables some of the work that is normally supposed to be done in class to be done outside normal classes enabling the acceleration of the curriculum. Using the grade 3 Maths curriculum, it is theoretically expected to improve the rate of curriculum coverage by up to 50% which results in theoretically saving two terms in each academic year resulting in a year’s reduction every two year cycle. The teacher also saves significant marking time as about half of the work will now be automatically marked. However the experiment will initially target a 25% reduction

8. CONCLUSION

The success of this project can have significant effects to the economy if the results are implemented in schools on a large scale. *Lean* has been known to bring significant improvements in industry and commerce and , thus successful implementation of *this project* can have the same results in schools, namely:

- reduced lead times for delivery of content
- better student results(quality of the output)
- budget increase per pupil over the long term

The education system is the major provider for skilled resources for the South African economy. It is also gets the second biggest budget allocation from the national fiscus. Acceleration can also potentially improve throughput for the job market. The students will benefit from the ability to finish the curriculum in a shorter period and enter the job market/college much earlier or use the extra time to polish up areas of need. In the long term it will also mean a need for less schools/infrastructure, leading to further budgetary savings. For example eliminating 1 year in a 12 year curriculum by accelerating the learning process by 8% can lead to a process cost reduction by R200bn over 12 years[based on the annual budget of R200bn [9]). This will also lead to a need for less infrastructure such as schools and related equipment.

Literature review shows that an industrial engineering based approach to reducing the cycle time is conceivable. It is the authors’ desire to assess if the success stories in manufacturing, health and finance [1] can be achieved in the education sector.

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OPTIMISATION OF WELDING WIRE SUPPLY AND DEMAND

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ABSTRACT

There is an increasing demand for stainless steel welding wire in the manufacturing, maintenance and fabrication of the Equipment M in South Africa. Due to the significant criticality of stainless steel welding wire consumables in the manufacturing of the Equipment M, it is imperative to eliminate waste and stock-out as the material is imported and the shortage of which can result in loss of sales. This research develops a method to calculate the measured demand for the newly built Equipment M, identifying the causes of wastage as well as suggesting the forecasting model for repairs and maintenance. This study shows that the measured demand of the newly built stock can be measured and calculated, however for maintenance and repairs, historical data is used to project future demand by reviewing the variation of historical data. The six sigma tools and methodology were used to identify the root causes of high increasing demand and the cause of variation.

Key Words: Lean Six Sigma, Demand, Supply, Forecast models

[1] The author was enrolled for the M-Tech in Industrial Engineering at the Tshwane University of Technology

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1 INTRODUCTION

The optimization of welding wire supply and demand study was based on a South African organization comprising a group of product focused businesses in manufacturing, maintenance and fabrication of equipment M. The organization is based in different regions namely; Region U, Region V, Region W, Region X, Region Y, and Region Z. The organization has long-term procurement partnerships with the supplier of welding wire to ensure a competitive advantage and continuous improvement. The welding wire study was initiated due to concerns on excessive demand of the stainless steel welding wire. The stainless steel welding wire is mainly used for welding carbon and alloy steel to stainless steel to produce a complete product (which refers to an end item sold to a customer). Stainless steel welding wire is a major welding wire used for both newly built and fabricated Equipment M. The high quality stainless steel is packaged in fifteen kilograms (15 kg) wire lot.

Past consumption was used to forecast future demand for both newly built and maintenance, in order to calculate the contract value for a long term procurement partnership with the supplier of the welding wire. In the past, the forecasted demand has proved to be unsuccessful as the contract value had to be reviewed on a monthly basis. This could result in a poor relationship between the customer and the supplier as confirmed by Szozda [1]. From the Szozda study it was confirmed that a good demand plan leads to better planning of purchasing and procurement, which reduces costs of materials and improves the relationship with the supplier. The forecasting process is critical for the business's success because poor forecasts can lead to insufficient or unnecessarily high finished good stocks, unused raw materials, misused production assets, and low profit margins [1]. The unreliable forecasted demand based on historical data made it difficult for procurement to have a fixed contract value linked to the procurement partnership. Improved, better wire forecasting model is thus necessary.

The main focus of the study is the following:

- Analyzing the current welding process from receiving wire in the stores, issuing to production line, consuming of wire and sourcing the wire from the supplier. Issuing refers to the supply of demand from the Enterprise Resource Planning (ERP) system to the production line.
- Developing a method to calculate the measured demand required for newly built using lean six sigma methodologies.
- Suggesting a forecasting model for maintenance and repair based on literature review.

The rest of the paper flows from a literature review, the research methodology used, discussion of the results and a conclusion to bring the paper to a close with recommendations for future work being given.

2 LITERATURE

This study mainly focuses on optimization of supply and demand for consumables using the lean six sigma methodology. The literature reviewed the supply chain and Lean Six Sigma, and forecast models used to forecast demand for fabrication. Authors define supply and demand, and also define Lean Six Sigma, in the context of this research.

2.1 Definitions

Kwaka [2] and Furterer [3] define Lean Six Sigma (LSS) as an approach that focuses on improving quality, reducing variation and eliminating waste in an organization. Six sigma is a project-driven management approach to improve the organizational performance by continually reducing defects [2]. LSS strives to include quality in the product and processes using empowered teams, and emphasizes reduction of waste and redundancy.

Supply is defined as the quantity of goods available for use and the actual replenishment of a product or component. Supply chain is a link connecting a set of facilities, companies, demand and supply points and service providers [4]. Demand shows a need for the item [5].

2.2 Lean Six Sigma in Supply Chain

In this study of optimization of welding wire supply and demand, lean six sigma tools were used to display the consumption data to identify the problems and come up with solutions to the problems. Ladd [6] stipulates that Lean Six Sigma must be utilized to eliminate variance across all supply chain processes. Further to this Ladd proposes the design and implementation processes that can eliminate refused orders due to product damage and create an operating model whereby orders are manufactured, packaged, and transported according to customer needs on a consistent basis [6]. Lean Six Sigma is an approach focused on improving quality, reducing variation and eliminating waste in an organization.

2.3 Forecasting model used to estimate future demand for fabrication

The South African organization was experiencing challenges due to high levels of demand variation. This caused difficulty in forecasting accurately because of the high speed of change in the marketplace and poor data accuracy, meaning historical data was no longer a good predictor of future demand. According to Pan [7] a scenario approach is used to handle the uncertainty of demand; the formulation is a robust optimization model with three components in the objective functions: expected total cost, cost variability due to demand uncertainty and expected penalties for demand unmet at the end of the planning horizon. Amaral [8] also identified a robust system as a platform for improvement. He highlighted that a robust system can normalize data from relevant enterprise systems and the system must be able to handle an increasing number of users and amount of information due to expanded products over time. Amaral [8] emphasized that organizations should incorporate the robust system into their ERP system to handle the uncertainty of the demand.

3 RESEARCH METHODOLOGY

Define, Measure, Analyse, Improve and Control (DMAIC) methodology was used to identify the root cause of the high increase in demand of the welding wire for Equipment M in South Africa. DMAIC refers to a data-driven life-cycle approach to six sigma projects for improving processes [9].

3.1 The Six Sigma tools used in each phase are also identified.

3.1.1 Define by identifying, prioritizing and selecting the right project. Value Stream Mapping (VSM), Kaizen event and brainstorming was conducted with cross functional teams to analyse the current welding process as well as identifying the root cause. A Kaizen event focused on a structured improvement project, using a dedicated "cross-functional team" to improve a targeted work area, with specific target [10]. Kaizen is derived from the Japanese word for continuous improvement. Table 1 shows the procedure which was followed in conducting the VSM.

3.1.2 Measure key process characteristics, the scope of parameters and their performances. In this phase welding wire demand information from the ERP system was displayed using a histogram and box plot. Consumption on the floor which refers to the demand used from the production line and practical analysis (welding wire demand measurements and calculations)

3.1.3 Analyse by identifying key causes and process determinants. Selection of the pilot region was done based on the box Plot and the histogram. Further analysis was conducted to compare the issued demand in the system (issued demand refers to the demand supplied to the production line) among used and measured demand.

3.1.4 Improve by changing the process and optimizing performance. The solution to the problems was identified and selected based on the risk and cost benefits.

3.1.5 Control by sustaining the gain. The monitoring plans that should be used are identified to maintain the proposed process and eliminate waste.

Table 1: VSM approach

Method Followed	**Method Description**
Define Problem	Give a background to the challenges experienced, stating the project description, aims and objectives, scope, and expected outcome
Data Collection	Walk to the workshops, identify the processes involved, find out the consumption rate, identify challenges which are experienced
Record Data	Display data in a form that all would understand
Root-cause analysis	Analyse all the challenges leading to the problem and the cause of those challenges
Ideal future state	Based on the challenges which are experienced, state the ideal solution which is sought in order to eliminate/minimise the problems
Brainstorm ideas (Prioritise)	Classify the challenges according to the effort which will be involved and which should be given first priority
Kaizen improvements	Identify Kaizen events to be conducted to eliminate/minimise the challenges

4 RESULT AND OBSERVATIONS

4.1 Display of consumption for the past 4 years

Six Sigma-Excel referred to as Six Sigma software was used to draw the boxplot and the histogram to display the overall consumption and consumption per region from 2009 to 2012. Box plots are a powerful display for comparing distributions. They provide a compact view of where the data are centered and how they are distributed over the range of the variation [11].

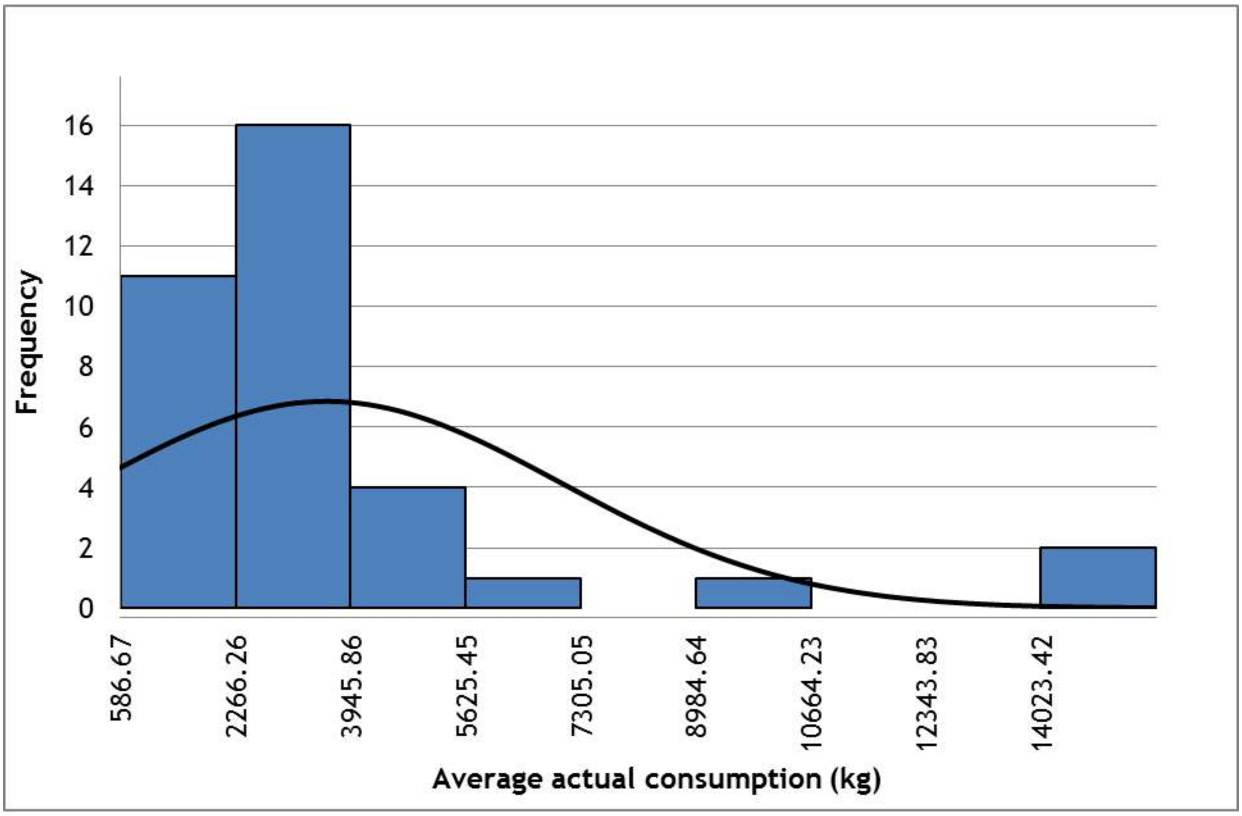

Figure 1: Histogram displaying the average consumption per month (2009/2012)

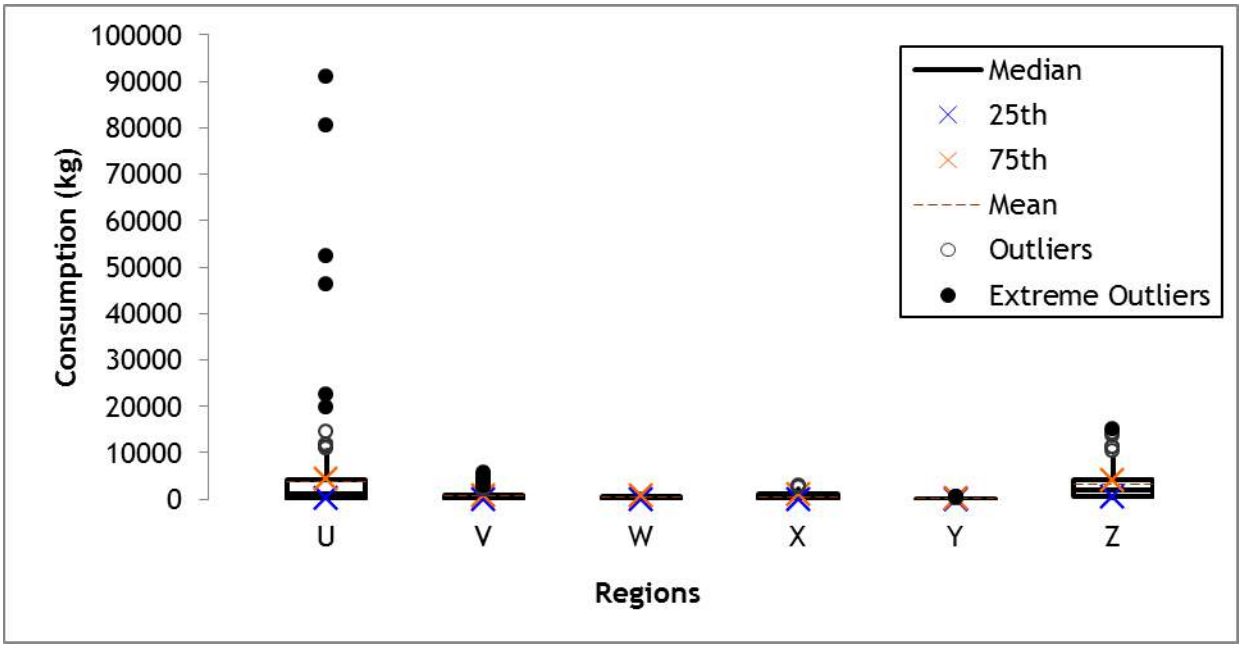

Figure 2: Boxplot displaying the consumption per region (2009/2012)

The histogram in Figure 1 displays the overall demand in (kg) from 2009 to 2012 shows an asymmetric long tail skewed to the left, it also shows that the data is not normally distributed and there are two outlying data points. This proves that there is high demand variation of the welding wire and the reason for asymmetric and high variation should be investigated. Figure 2 outlying data point fall under Region U as is showing seven extreme outliers. Outliers may be evidence of a contaminated data set; they may be evidence that a population has a non-normal distribution [12]. These Regions (V, W, X, Y and Z) the demand shows less variation. Region (V, X, Y and Z) the data contains outliers therefore it is recommended to further investigate the outliers. Region U based on Figure 1 and Figure 2 is the highest consumer of welding wire and it has more demand variation compared with the other Regions. More attention should be given to Region U to do further investigation.

4.2 Analysis of Region U

Region U was selected as a pilot study based on Figure 2 demand variation observations. Measured demand for newly built was calculated in the study as the forecasted demand proved to be unsuccessful. The reason the forecasted demand was unsuccessful was because of the demand issued to production line (supply) was less than the used demand (demand consumed on the production line). The difference between the measured demand and the used demand is regarded as waste in figure 3, as an additional ± 160 000kg was used which resulted in the realization of the outliers in figure 2.

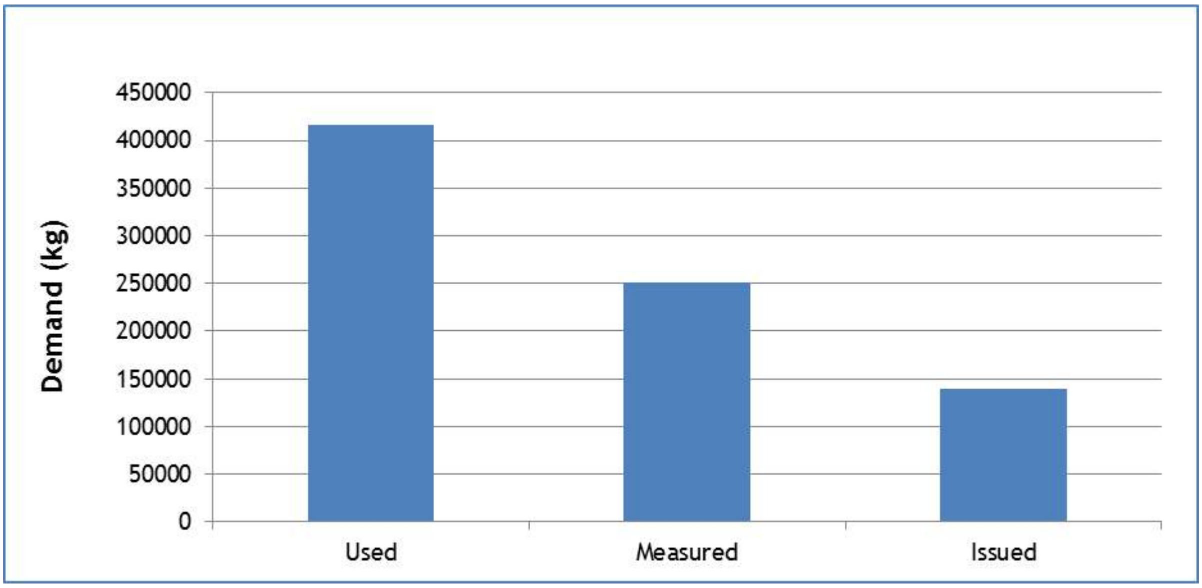

Figure 3: Demand comparison among "used, measured and issued"

4.2.1 Used demand

Used demand is based on the information which was collected during the walkthrough in the workshops. VSM was conducted to calculate the total wire demand consumed per workstation with the assistance of the operators and supervisors working on the floor on a daily basis. The total measured demand is 250 000kg which is required to build a complete product, while the production line used ± 410 000kg.This proves that the system is not updated accordingly when issuing welding wire to the production line.

4.2.2 Issued demand

Issued demand is the demand released from the Enterprise Resources Planning (ERP) system to the production line. Comparing the issued demand, used demand and measured demand on the production line, Figure 3 proves that there was a mismatch between demand issued (149 000kg) and demand used (± 410 000kg) which affected the forecasted demand and the long-term procurement partnerships with the welding wire supplier.

4.2.3 Measured demand

Measured demand refers to the practical analysis on the production line done by a Welding Inspector specialising in welding processes who does not work for the organization. Practical analysis was conducted to calculate the measured welding wire demand taking into consideration the safety margins, to know the demand required to manufacture a complete product. The following methodology was followed to calculate the measured demand for newly built:-

- The production lines where manufacturing took place were broken down into different workstations
- The welding wire consumption per welding station was calculated
- All components used to make a newly built complete product were identified and wire consumption was recorded during the manufacturing process.
- Prior to welding commencing the weight of the welding wire at every machine was recorded and the entire welding task for that workstation was observed to record the demand and waste
- Once every welder had completed his task the lots were removed and the weight recorded again

This amount however does not include the welding of repairs and maintenance which takes place at fabrication of Equipment M. The demand for maintenance and repairs cannot be calculated, it should be forecasted. The difference between the inspected demand and the production demand in Figure 3 proves that there is a high rate of waste.

5 DISCUSSION OF RESULTS

Table 1 showed the approach that was used for the VSM which leads to identification of major problems presented in Table 2 below.

Table 2: Problem Identification as per the outcome of the VSM

‘Cause’	Description
Incorrect process variables	Incorrect settings on the equipment leading to poor welding; hence reworks
Wire left on lots	Change of shifts results in welders starting the process with a new wire lot to avoid re-spooling, while there is one left from the previous shift.
High product demand	Increase in product demand leading to extra work shifts
Lack of equipment maintenance	Loose brakes on wire feeders making it difficult to adjust parameters
Wire left in guns and conduits	The conduit of the gun eventually get damaged, as no inspection is done prior to use
Damaged unused wire	Wire damaged during delivery to the production lines due to improper handling
Storage, handling and transportation	Poor storage and handling of the wire
Inconsistent unit of measure (UOM)	A different UOM was used for issuing and sourcing the wire which resulted in procuring less or more wire

Criteria weighting method was used to prioritize the alternative to reduce the waste. The method involves a pair-wise comparison of all the causes listed in Table 2. The pair-wise comparison is identified as comparable to the introduction of derivatives in calculus or eigenvalues in linear algebra [13]. Since there are several problems leading to wastage, it is often difficult to know which issues to look at first. However, the Pareto principle is a useful tool which is used to resolve the dilemma. The Pareto principles state that 80% of your troubles come from 20% of your causes. Hence, by focusing on the 20% of the causes, one would have eliminated 80% of the problem. Figure 4 shows the result of the Pareto analysis which was conducted. From the figure, 20% of the causes are identified by all the bar graphs which lie above the cut-off line of 80%. Hence by focusing on these causes, we would eliminate 80% of the problems.

The steps below give an outline and an extract of the process:-

Step 1: Listed all criteria to be analysed and weighed criteria against other criteria. These were listed in columns and in rows. Weighed criteria on the specific column against the criteria on the rows, noting that criteria cannot be weighed against itself. Allocated 0 if list important when compared to the other criteria, 0.5 if both criteria are important or 1 if both criteria were more important. The sum of the score per criteria is used to obtain the total score per criteria. To obtain the weighted %, the total sum per criteria is divided by the sum of all total scores.

Step 2: Grouped the criteria from highest to smallest according to the % weight from step 1. The cut-off line was at 80% as per table 3. This represented the problems that should be tackled first. By Pareto, it is believed that solving these problems will eliminate 80% of problems.

Based on the Pareto analysis shown on Figure 4, the causes were then categorized into three groups as shown in Table 3. Group 1 contributes 53.8% to the group percentage; while groups 2 and 3 contribute 29.8% and 16.4% respectively. The wastage as depicted by Table 3 is based on the Pareto Analysis shown in Figure 4. The Pareto principle states that eliminating 20% of the causes will result in elimination of 80% of the problems. Taking the current total wastage of R 4 639 679.99; if we solve group 1 problems, this would eliminate the wastage by 80% [4 639 679.99 - (4 639 679.99*80%)] resulting in wastage reducing to R927 935.99. Furthermore by solving group 2 and 3 problems, this would reduce the wastage by a further 20% resulting in wastage reducing to R0. Further investigation was done to identify the causes of waste.

Table 3: Causes categorized into three groups and estimate wastage

Criteria	Description of waste	Total score per criteria	Wastage estimate in (R)	Weighted score (%)	Cumulative Weighted score (%)	Groups	% contribution of each group
2	Wire left on the wire lot	12	R 325 591.58	7.02	7.02	Group 1	53.8
16	High quantities issued to the lines	12	R 325 591.58	7.02	14.04		
18	Lack of equipment maintenance	12	R 325 591.58	7.02	21.05		
8	Storage, handling, and transportation	11.5	R 312 025.26	6.73	27.78		
19	safety & housekeeping	11.5	R 312 025.26	6.73	34.50		
1	Incorrect process variables	11	R 298 458.95	6.43	40.94		
15	Welding core team	11	R 298 458.95	6.43	47.37		
17	Inconsistent unit of measure	11	R 298 458.95	6.43	53.80		
13	Change of shifts	9	R 244 193.68	5.26	59.06	Group 2	29.8
5	Wire left in guns and conduits	9	R 244 193.68	5.26	64.33		
6	Damaged unused wire	9	R 244 193.68	5.26	69.59		
12	Welding wire damaged from supplier	8	R 217 061.05	4.68	74.27		
11	Poor control of the welding process	8	R 217 061.05	4.68	78.95		
4	Maintenance schedule	8	R 217 061.05	4.68	83.63		
3	High product demand	6	R 162 795.79	3.51	87.13	Group 3	16.4
10	Poor workmanship	6	R 162 795.79	3.51	90.64		
14	Weak plastic wire lot	6	R 162 795.79	3.51	94.15		
9	Quality of wire during welding	6	R 162 795.79	3.51	97.66		
7	Availability of one type of wire	4	R 108 530.53	2.34	100		
		Total	**R 4 639 679.99**				

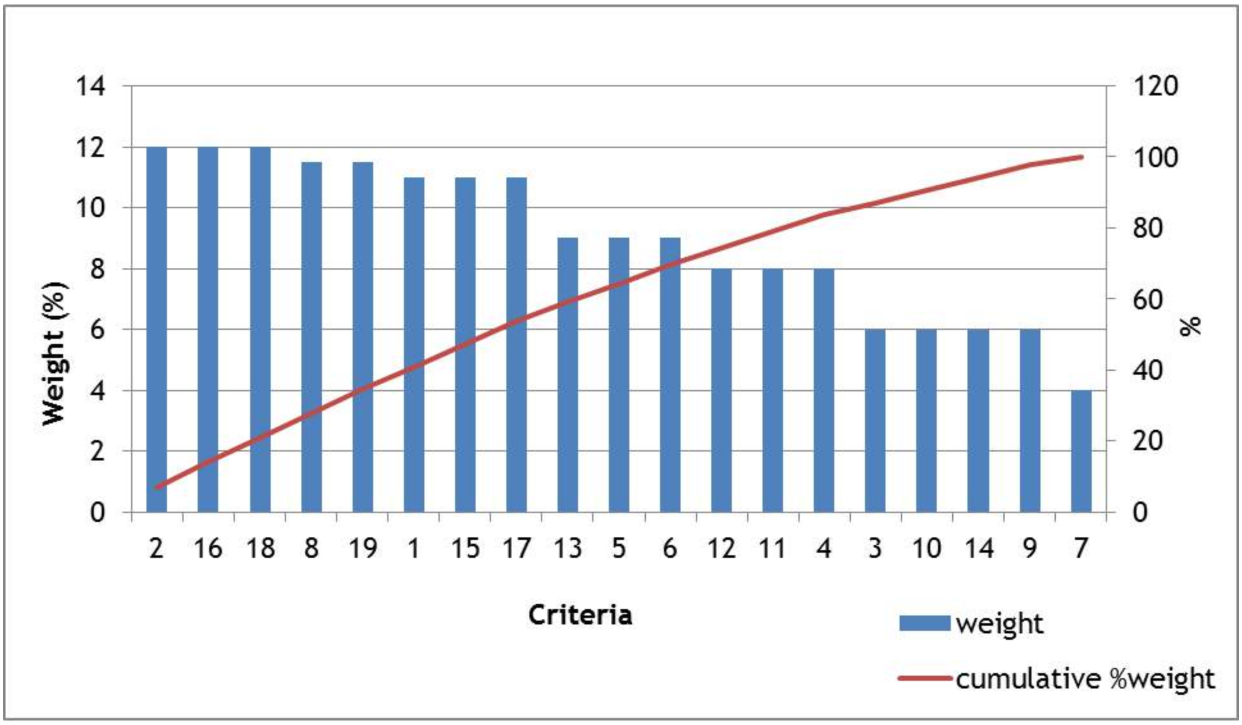

Figure 4: Pareto Analysis

6 CONCLUSION AND RECOMMENDATIONS

Reducing welding wire wastage is possible through an endorsed and controlled program. The organization should incorporate the robust system into its ERP system to handle the uncertainty of demand for maintenance and repairs. It was found that the major contributing factor to the wastage of wire was the personnel directly working with the wire, i.e. supervisors, stock controller and welders. The following recommendations were made in order to improve on the current status of wastage of stainless steel welding wire.

Storage and Handling Procedure of the welding wire is critical as it is a very sensitive product and mishandling of the wire can later on influence the wire feed during production. It was therefore necessary to devise a procedure on how the wire should be handled in an appropriate manner. The storage and handling procedure provides recommendations (dos and don’ts) to the personnel with regard to the following:

- Correct storage of the wire
- Correct handling of the wire
- Correct transportation of the wire
- Correct packaging of the wire
- Inspection procedure before the wire is used

Stainless steel welding wire is a manufacturing consumable, Liepman [14] says the two bin system can be used for manufacturing consumable and careful consideration is given to a part’s usage and the frequency with which the bins are replenished. Two-bin systems ensure the quantity of supply and provide system integrity [14]. The same methodology like two bin system can be used for issuing of stainless steel welding wire lot of 15kg to the production line, by exchanging an empty wire lot with the full wire lot for monitoring of waste and stock-out. If a full damaged or incomplete wire lot is returned to the stores, the reason for damaged or incomplete wire lot should be recorded before issuing a new full wire lot. This will reduce the wire left on the wire lot and damaged unused wire. The difference of using a two bin system for stainless steel welding wire will be an empty wire lot providing a replenishment signal instead of primary bin providing a replenishment signal and the secondary bin becoming the primary from which workers will pull.

Core team (core team refers to a cross-functional team involved in the welding process) awareness training and welding training for the welders; training is core in order to solve the problem of wire wastage. Most personnel are unaware of how delicate the welding wire is, and hence at times the damage of the wire/incorrect usage leading to wastage is due to lack of knowledge. The training will cover all the elements of welding including how to handle the wire correctly, how to mount the wire on the welding machine, what to do when one experiences problems with the wire. These are minor elements which have a significant impact if not addressed.

Table 4: Recommended solutions per criteria

<table>
<tr><th>Description of waste</th><th>Groups</th><th>Recommended Solutions</th></tr>
<tr><td>Wire left on the wire lot</td><td rowspan="8">Group 1</td><td rowspan="20">Storage and handling procedure
Issuing procedure (Just-In-Time)
Core team awareness training and Welders training
Safety training</td></tr>
<tr><td>High quantities issued to the lines</td></tr>
<tr><td>Lack of equipment maintenance</td></tr>
<tr><td>Storage, handling, and transportation</td></tr>
<tr><td>safety & housekeeping</td></tr>
<tr><td>Incorrect process variables</td></tr>
<tr><td>Welding core team</td></tr>
<tr><td>Inconsistent unit of measure</td></tr>
<tr><td>Change of shifts</td><td rowspan="6">Group 2</td></tr>
<tr><td>Wire left in guns and conduits</td></tr>
<tr><td>Damaged unused wire</td></tr>
<tr><td>Welding wire damaged from supplier</td></tr>
<tr><td>Poor control of the welding process</td></tr>
<tr><td>Maintenance schedule</td></tr>
<tr><td>High product demand</td><td rowspan="5">Group 3</td></tr>
<tr><td>Poor workmanship</td></tr>
<tr><td>Weak plastic wire lot (15kg)</td></tr>
<tr><td>Quality of wire during welding</td></tr>
<tr><td>Availability of one type of wire</td></tr>
</table>

7 ACKNOWLEDGEMENT

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ROAD TO EXCELLENCE: A PRACTICAL FRAMEWORK FOR GUIDNG LOCAL ORGANIZATIONS TOWARD SUSTAINABLE EXCELLENCE

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ABSTRACT

In recent years there is a trend in many Iranian organizations to apply a wide variety of management tools and systems such as ISO9000, TQM†, BPR‡, Excellence models, KM§, strategic planning and so forth. Unfortunately researches and experiences show that most of these systems and tools not only do not make the expected synergy, but also impose excessive cost on those organizations. Regardless of ignoring the context of the organization in applying the interventions and its implementation of design choices, it seems that a major cause of failure, roots in inappropriate selection of the systems or tools to be implemented due to ignoring those systems or tools rational precedence relationships. In this article, a practical framework is represented based on years of experiences of authors in MABENA consulting firm in delivering management consulting services to their clients (Iranian major companies in both public and private sectors). The presented framework is designed to shape a total organizational excellence model, due to Total Quality Management framework, proposed by Professor John. S. Oakland which incorporates the main components of TQM and other management tools and systems in strategic and operational fields. The framework presented in this article, if not regarded as a development to the original framework J.S. Oakland), can be considered as a customized total organizational excellence model for local companies (we named it as, "Road to excellence", (RTE)), which focuses on describing the logical identification of broader tools, approaches and techniques in the framework, clarifying the appropriate sub-elements of each particularly regarding Iranian organization's areas of interests and common challenges and delivering or proposing appropriate tools to run each of the elements effectively.

Keywords: Road to excellence, Total organizational excellence, framework, process maturity, change interventions

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† Total Quality Management

‡ Business Process Reengineering

§ Knowledge Management

1 INTRODUCTION

Many Iranian organizations in recent years have adopted a range of improvement approaches, tools and techniques in response to the great changes in the internal and external turbulences [7], [27].Turbulences in legal, economic, technological, political and environment parameters of company's external factors. As well as, organizations' top level managers increasing awareness, toward changing their companys' attitude to face future world situations. Which resulted in adoption of many quality management systems and other management tools and techniques simultaneously [7], [26], [27]. No comprehensive survey has been performed locally about the most common management tools and how effectively these tools have been performed [27]. But authors, by tracking the approaches, tools and techniques major local companies have used recently, the circumstances under which they have been performed and the degree of managers and employee's satisfaction of adopting those, been able to design a framework consist of the most commonly used management approaches, tools and techniques in local companies, and by adopting that framework, companies would be able to locate themselves in the road to excellence and select the appropriate tool(s) to improve their performance. The proposed framework also helps them to decide about how to adopt an approach effectively. The article delivers some methods, guidelines, instructions and tips for this purpose.

As already mentioned, the practical framework presented in this article is basically designed on the TQM referred to as "total organizational excellence model" of John. S. Oakland's framework illustrated below [1], [2].

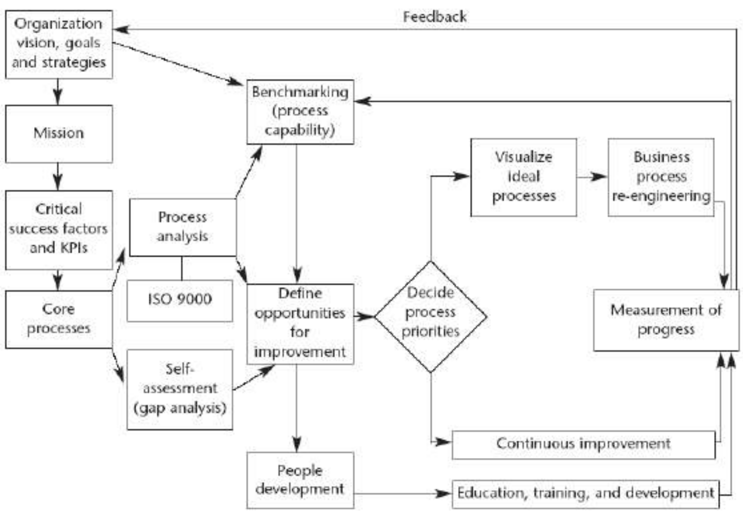

Figure 1: TQM implementation framework [2]

The framework presented in this article, may or may not be regarded as a development to the original framework illustrated above. But, the following issues which are apparent in the model, distinguishes it from any other similar frameworks:

It focuses on the most commonly used approaches, tools and techniques adopted recently in local companies (recognized by tracking the behaviour of a sample of local organizations in a one-year period).

It tries to broaden the related approaches, tools and techniques in the road to excellence model.

It tries to clarify the sub elements of each tool and technique and explain their precedent relationship not only by the TQM implementation framework logic but also by the contextual parameters of local companies such as organizational culture and paradigms.

It tries to draw a more customized and practical framework by mentioning the appropriate methods, guidelines, instructions and tips about how to adopt each element effectively.

1.1 Previous Research

MABENA consulting firm[**] during years of experience in applying customized strategic management model referred to as MABENA model for local organizations [7], [35] observed some facts which resulted in attracting our attention to propose solutions for raising congruency of change interventions with organizational and operational maturity levels and organizational context. This supports the emphasis in organizational development literature on the necessity of congruency between change interventions and organizational context in which the intervention is performed [9], [13].

We have tried to formulate strategic plans of firms according to their level of maturity by using the organizational life-cycle analysis based on Professor Adizes theory [24]. Diagnosing key organizational processes based on process maturity models [17], [20], [22]. We have also tried to design process improvement plans in accordance to processes maturity levels.

Unfortunately despite of developing strategic plans by these logics, we noticed many of MABENA major client companies had started adopting some other management tools before the strategic plan was started [27] which was against total organizational excellence concept. As a result, we saw a forest of management tools all implemented simultaneously. Such as; implementing ISO 9000 series in PEGAH, Iranian largest Dairy production corporation and RAJA, exclusively passenger train corporation ; implementing Structuring in National Iranian Oil Company; implementing EFQM in Pars Car Manufacturing Industry; implementing functional strategic planning in KWPA, Khouzestan province, Water and Power authority (second biggest in country), OPM3 (organization project management maturity model) in NPC-RT, national petrochemical research and technology company and so on.

These facts made us point our attention to track the common tools adopted, the circumstance under which they were adapted and the degree of satisfaction with these tools created. So as a result, to design a framework in which the location of strategic plan and other approaches, tools and techniques and their relations be clarified.

The Oakland’s framework was appropriate to start for expanding this idea. But, we needed a template to suits more appropriate with our specific requirements. Therefore, a new trend began.

These trends resulted in designing a template called "the Road To Excellence", (RTE) which is illustrated as figure 2 below and its main modules and elements, their logical relations, supplementary materials, instructions and guidelines are described as following.

2. RESEARCH METHOD

2.1. The RTE framework

The RTE framework illustrated below demonstrates the appropriate position and the logical precedent relationship among some common management approaches, tools and techniques

[**] www.mabena.com

used in recent years in major local companies [7], [35] (Specially the large and holding companies). The framework is a clear and comprehensive guidance map for incorporating the philosophy of business excellence based on total quality management approach and successful business strategy. We assume that if adopted appropriately and considered as a basic steering guideline by top managers with sufficient commitment and support. The framework is able to take the full advantages of the potential of management tools, decrease the cost of adopting and implementing, making the necessary synergy and maximizing the efficiency and effectiveness of performing the tasks in organizational and its divisional levels.

We have tried to make a distinction between different elements of the framework in below illustration by using different colours to show the nature of those boxes. The main tasks elements to be performed are filled with pink, the elements demonstrate clear outputs and deliverables of the framework are filled with blue and the common and famous tools that can be used to perform a task or generate the desired outputs are filled with green. The oval filled with grey, demonstrates change management which is an on-going process that should be applied in all change interventions regardless of the content, context or process of the change.

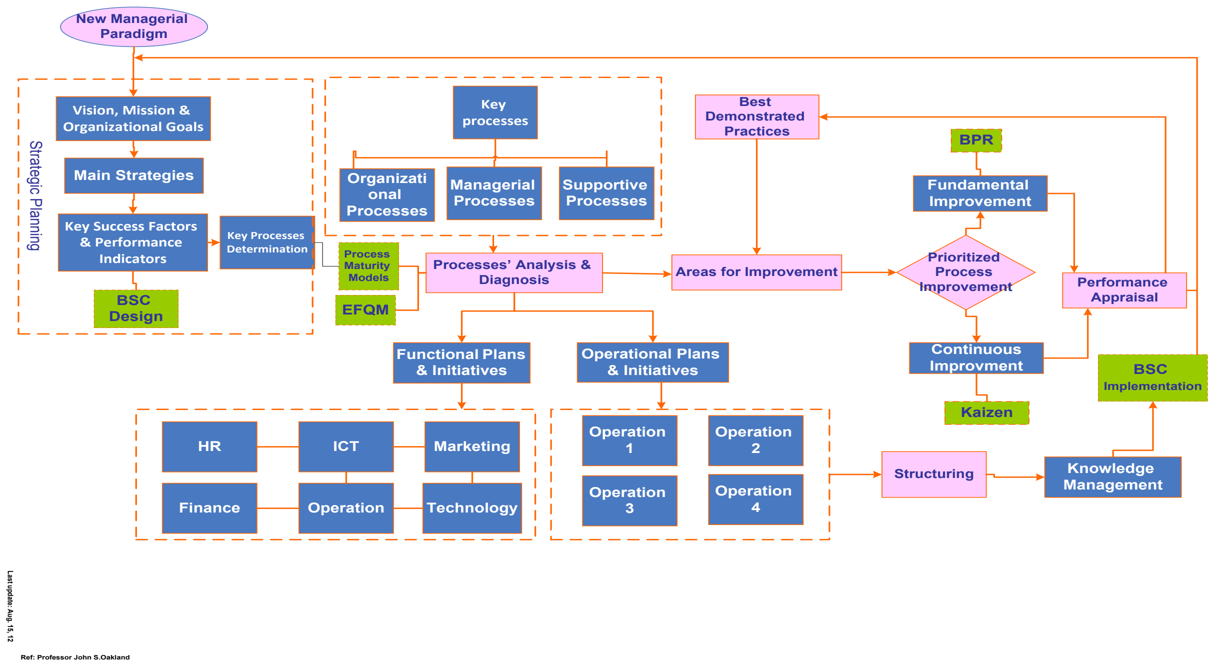

Figure 2: The Road To Excellence (RTE) framework

2.2. Description of the framework

2.2.1. New management paradigm

It all starts with accepting a new management paradigm. By new management Paradigm we mean that behaving based on this framework requires an evolution in the accepted sets of rules and defaults that determine values and specify ways of gaining success in specific boundaries. Understanding the existence of new paradigm is the first step to develop the capabilities required to adapt the framework. Managers see and forecast the future with glasses to the existing paradigms [1], [2] and every phenomenon is accepted or rejected accordingly. We assume deciding to act upon this comprehensive framework is such a fundamental decision that requires accepting a new management paradigm. According to the cultural web tool used in the organizational development literature [9], when the change occurs in the paradigm, all the other change levers such as symbols, stories, procedures and control systems need to be changed accordingly [9]. Given the fact that adopting this framework needs a shift in accepted paradigms of the managers, it is obvious that the degree of the success in applying the framework in practice, requires a great change in thought and belief systems and shaping all tangible and intangible levers of cultural web accordingly.

2.2.2. Strategic planning

Organizational excellence is at a crossroads today. The drastic change in the business scenario call for a speedy transformation of mission, vision, core values, core competence, management style, policy framework, management system, structures, process, renewal mechanism etc. [28].

The framework continues with the organization strategic plan. Strategic management is the process of formulation, Implementation, assessment and review of organization's objectives and strategies, Developing policies and plans to achieve these by allocating resources [5]. It is the highest level of managerial activity, usually performed by company's chief executive officer and the team. Strategic plan is believed to be the prerequisite of all operational activities and decisions [15]. It specifies a clear direction and path for the organization to reach its mission. Otherwise, the actual mission and strategic direction of a firm with its portfolio of products and services is not specified. Then, one cannot judge about the core processes of the firm [15].

Some organizations have progressed greatly in this area, those claim the performance of all employees toward mission and vision can be calculated (The concept of personal scorecards) and this can be used as a data entry to the reward and compensation systems [8], [15]. The concept of balanced scorecard and strategy focused organization put a heavy emphasis on the necessity to align all plans and activities in organizational, divisional and personal levels with the strategies and goals of an organization [8], [15], [16].

As mentioned earlier, MABENA consulting firm has also developed a customized strategic management model which is very useful for Iranian major organizations and has been successfully applied in many of them recently [7], [35]. The very vital point that has been taken into account in developing this model is the meaningful gap between the specifications of budget focused organizations (as is true for many Iranian organizations) compared to strategy focused organizations. This gap imposed the necessity of considering many issues in developing a local strategic management model (such as the day to day challenges, bureaucratic structures, slow decision processes, especially in cross- functional processes etc.) [7], [26], [27].

Having identified the strategic themes, the model continues with extracting critical success factors versus the competencies of the firm which their identification is of great importance in constructing the strategy map [8], [1], [2]. We have found it useful to adopt the following simple and easy to understand construct to distinguish between the CSFs and competencies of the organization.

Understanding the nature of the critical success factors can help companies investigate and improve their coopetition (competition and cooperation) strategies. Prioritizing the factors and sub-factors can help companies understand their relative importance and devise improvement plans that can maximize limited resources in dealing with several or all factors simultaneously [36].

Because of strategic importance of goals and CSFs identified in previous stage and the necessity of evaluating the achievement of goals, in this stage, KPIs are identified for goals and CSFs based on BSC principles in a systematic method. Before this, we should assess final strategies with previously specified goals [32].

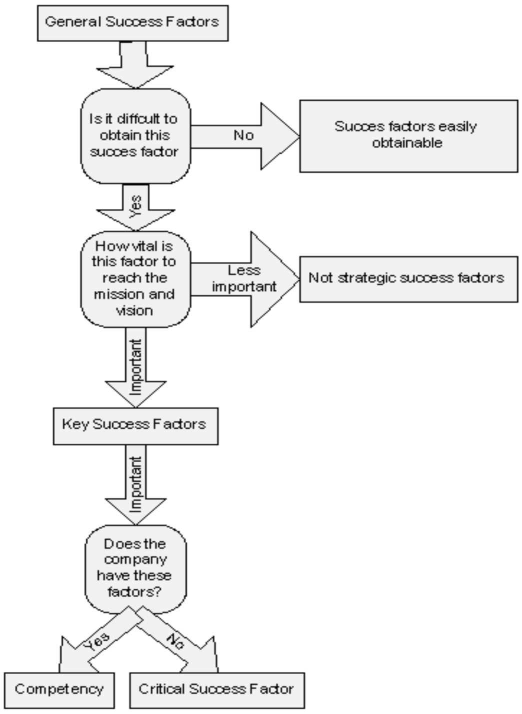

Figure 3: Construct of distinguishing the CSFs and competency [35]

Along with defining KSFs and identification of CSFs and competencies, it is important to identify the measures of your progress [2], [3]. "What cannot be measured cannot be managed" [8] is a known statement which certifies the importance of putting this box as a vital element in the road to excellence model. A good balanced Scorecard should include a mix of fundamental measures and a handful of strategic metrics [16]. These measures should be subject to periodic review and change, depending upon how you progress in achieving your vision and mission.

In MABENA strategic management model, three levels of key performance indicators exist which are index, measures and metrics.

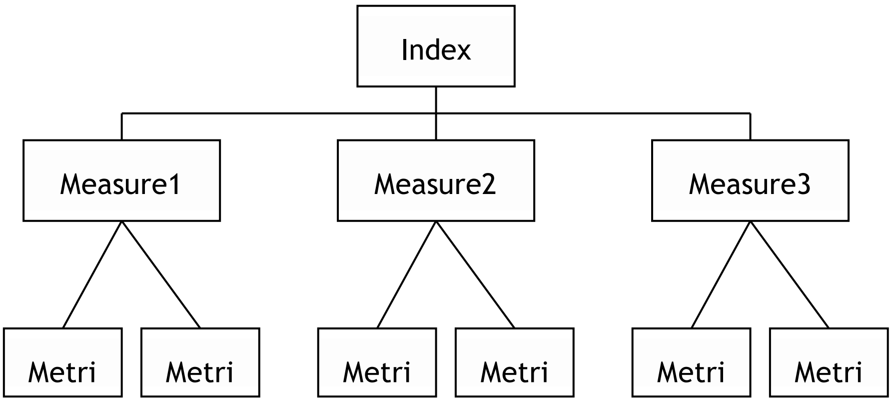

Figure 4: Key Performance Hierarchy in the road to excellence model [7]

An index is an aggregate of performance measures (lagging and leading) which the weight of each measure in constructing the index should be specified. A measure itself may be a combination of metrics each of which determines an aspect of the measure.

In the road to excellence model we have made a distinction between the Balanced Scorecard design and implementation. The process of designing the BSC consist of determining the perspectives of the scorecard, the strategic goals and their cause and effect relationships, designing the strategy map, developing key performance indicators to evaluate the progress of the company in achieving its goals, setting the desired value (target) of each metric and developing initiatives for each goal in order to obtain the set target [8], [15], [16].

Implementation phase is an on-going process usually supported by professional software by which you can evaluate each index periodically and prepare feedback reports so as to apply the necessary corrective actions [8], [15], [16].

2.2.3. Determining key processes

Having identified the main elements of strategic plan, the organization must identify its core processes [1], [2] We have found this step a very critical point especially for Iranian major organizations which suffer from lack of process approach [7], [14] and have serious weaknesses in cross functional processes despite of the probable functional expertise.

Process identification can be regarded the first activity in process management [14], [17] and as has mentioned, is a bottleneck for many organizations as they fail to recognize correctly their real core processes. We have found, it is useful to adopt the concept of process analysis matrix to be able to identify core processes correctly [19]. This tool is fully congruent with the RTE concept as it considers the CSFs and strategies of the firm as the main inputs of process identification.

During this identification, it would be helpful to make distinction among different types of organizational processes as for the aim of diagnosing these core processes, which is at the heart of RTE framework diagram [1], it helps us to recognize the appropriate tool for diagnosing.

There exists a total agreement in the literature of process management about how to classify different processes of the firm. The Process Clarification Framework (PCF) divides them into operating, management and support processes [18]. The primary and support activities of Porter value chain [5] matches in concept with PCF. Quality management systems such as ISO9000 also classify them into the same categories [14].

2.2.4. Process analysis and diagnosis

Diagnosing core processes results in defining plans and initiatives of improvement [2], [7], [28], [16]. Depend on the type of the process diagnosed (whether operational, managerial or supportive) they can identify functional and operational initiatives. Supportive and management processes diagnosis help us define improvement plans and initiatives that when allocated to different departments or divisions of an organization, determine functional plans and initiatives. As process approach put a heavy emphasis on the integration between the activities and plans of different functions of a firm [8], we should fully integrate the results of core processes diagnosis to make sure, initiatives and plans defined for the improvement of each core process, not only, are not incongruent with other initiatives and plans, but also are fully aligned and integrated with each other toward achieving mission and vision. The arrows shown in the framework's illustration between operational and functional plans and also among different functions and operations highlight this requirement. We should mention, management and support processes which finally determine functional initiatives and plans are not limited to those which are illustrated in the RTE diagram. According to process clarification framework [18], it consist of managing human capital, information technology, financial resources, property, environmental health and safety, external relations and finally knowledge, improvement and change management. According to Porters value chain [5], it consists of managing firm's infrastructure, human resource, technology and procurement. This is also true for the operational processes as in the two mentioned frameworks have been specified. We have not mentioned any operational process in the illustration as they are highly customized and dependent on the nature and specification of the firms. Some Supportive and management processes that are the same in different types of organizations have been mentioned in the illustration.

However, according to the concept of the RTE, the core processes of each firm depend greatly to the main elements of its strategic plan [1], [2].

According to the RTE framework illustration, we have proposed two powerful tools for the aim of analysis and diagnosing the core processes which are self-assessment by means of an appropriate business excellence model and process maturity models.

Self-assessment is proposed as a powerful tool for this means as for any organization, improving performance through it, usually means working for improvement in the whole network of processes through which the organization's goods and services are produced and delivered [3], [4] and [19]. Processes lie at the heart of these self-assessment models (like EFQM, Malcom Baldrige [37]) and this is incongruent with the process approach of the RTE model.

However, the main focus of our attention is on the process maturity models which we believe is more useful for our aims of process diagnosis in the RTE model.

Adopting the process maturity concept for diagnosing core processes help to assess the processes reasonably and give clear indications on how to improve to reach next levels of maturity [17]. It also helps us to integrate improvement plans of all processes because if decided to improve the processes continuously, they should grow altogether in a balanced manner. The positive effects of reaching a process to high levels of maturity in not acquired unless the other core processes reach to the same level of maturity [17].

Although the original concept for a process maturity framework roots in the early 1980s and by the attempts of Watts Humphrey and his colleagues at IBM and for the goal of developing the quality of software [20], but until today the concept has spread into the other business processes [17] to improve continuously the capability of all organizational processes particularly the key ones.

The concept of “maturity” was seldom used to describe the state of an organization’s effectiveness at performing certain tasks. Today, we find this maturity concept being used increasingly to map logical ways to improve an organization’s services, particularly across the software industry. The original maturity model developed from the software engineering industry with the development of “the concept of process maturity” [33].

The concept was born in the Total Quality Management movement where the application of Statistical Process Control (SPT) techniques showed, improving the maturity of any technical process leads to two, reduction in the variability inherent in the process and improvement in mean performance of the process.

The maturity capability level of organization (N), suggests measurement goals that the company is ready to implement according to its measurement maturity. The measurement goals which belong to level N+1 should be implemented with care, and the implantation of measurement goals related to higher measurement maturity levels is not recommended [36].

Regardless of the original SW-CMM [20] which does not suit for our purpose. Perhaps the most famous and known process maturity framework is people capability maturity models (PCMM) which introduces stages for implementing the best workforce practices and progress continuously through each level [22]. As this model only covers one of the probable key processes of the firm (i.e. human resource management), it is a good idea to adopt or design suitable maturity models for specific processes a firm may have. However, we have also found it useful to adopt process survey tools (PST) designed by Philips [17], which is maturity grids designed for specific processes and functions. In this framework, each process is broken down into a number of elements or sub-processes that make up the entire process. For each of the elements, a maturity scale has been created and there are ten levels of maturity starting from basic in step 1 and world-class performance in step 10. By assessing their position against the maturity scales for each of the elements, organizations can establish a maturity profile for a particular process and gain insight into the steps they need to take to move in the direction of world class [17].

MABENA consulting firm has tried to make contributions in developing diagnosis frameworks and models for the processes particularly those which were missed or unavailable in the publications. A well-developed framework is a strategic planning roadmap for research and development process based on the technology strategies of organizations.

In MABENA model, identifying and diagnosing the key processes is an important issue. In this model after identifying the key processes, they diagnose by using the maturity model and the gaps will be identified [35].

2.2.5. Prioritized process improvement & Change management

By now a list of improvement areas has been defined for different processes of management, operational or logistics. Which if allocate to those existing divisions or departments of the company, allow the company to make up its functional and operational initiatives and plans. Benchmarking the process of identifying and learning from best practices of other organizations [10] also is a powerful tool for continuous improvement [1], [2].

Prioritization strongly depends on the targeted maturity level of each process defined in the previous steps [17]. It also determines whether continuously or fundamentally improve the process [1], [2]. Imagine a firm is in the lower levels of a specific maturity but have set target to reach the high levels of maturity (This target may be affected by many parameters such as benchmarking against best practices, the levels of existing and targeted maturity of other core processes, competitor performance etc.) [16]. As a result we may decide to improve this process fundamentally by an appropriate tool such as Business Process Reengineering (BPR). Otherwise (in case of deciding for process continuous improvement), tools such as Kaizen would be appropriate.

Another issue, the concept of reengineering is widely accepted as after years of flowcharting and attempting to improve processes. Many organizations found, continuous improvement is time-consuming, expensive and simply unnecessary [1], [2].

The Kaizen method of continuous incremental improvements as an originally Japanese management concept for incremental (gradual or continuous) improvement [21] is also introduced in RTE model as an appropriate tool. But, as mentioned before the tools proposed in the model may be substituted according to the context of the organization and the detailed objectives of change intervention.

According to the illustration, when Kaizen is compared with BPR, The Kaizen philosophy is more people oriented, easier to implement requires long-term discipline [21]. BPR on the other hand is hard, technology oriented, enables radical change but requires major change management skills.

Authors believe change management skills and tools covers the whole elements of the RTE model and should not be considered as something which is entered somewhere in this road. Recognizing and managing change whilst simultaneously improving business delivery processes is not only critical to business survival, but is a catalyst for generating growth [9], [13], [19].

Change management skills are so important in the whole road that it has been claimed that Business Excellence is the result of successfully managing change in your organization [13]. However we should consider, by this we don't mean, the whole process of change management should be adopted all along the road. The process of change management according to Comings and Worley [13], consist of entering and contracting, diagnosing, data gathering and analysis, delivering diagnosis analysis feedback, designing change interventions and finally leadership and change management in which the change agents use behavioural science skills to drive the interventions effectively. We emphasize on this final and perhaps the most vital step of the whole process of change management in the RTE model.

2.2.6. Structuring

There is a total agreement of the statement mentioned by Alfred Chandler who claims structures follows strategy in organizations [12]. Strategy is the determination of long-term goals and objectives, courses of action and allocation of resources, and structure is the way the organization is put together to administer the strategy.

Research results indicate Organizational structure affects performance, structure merits reassessment whenever strategy changes, and new strategy likely entails different kills and key activities [12].

Even those who challenge this statement [11], agree with the necessity of alignment between structure and strategy. The only difference is that they highlight the fact that some aspects of the strategic plan may be affected by the current structure or environmental parameters of the company. We don't regard this in contrast with our approach as we also believe in developing the strategies of the company; we ought to consider the limitations or opportunities imposed by the current structuring of the firm.

We believe that the comprehensive structuring not only follows strategy, but also follows the detailed elements of the strategic plan which are the plans and initiatives defined and prioritized in previous steps. By experience, we have found the main elements of the strategic plan (i.e. vision, mission, strategies and goals) helpful and necessary in designing organizational top chart but the full structuring (i.e. the detailed organizational charts and deciding about the degree of formalization, complexity and centralization) requires identification of the detailed initiatives and plan accompanied with a full understanding of the environment, technology and human resources capabilities [12]. That's why we have located the structuring in the illustration somewhere to assure the required prerequisite of this management role is identified.

2.2.7. Knowledge management

HR has always been central attention for organizations' concerns. Today, it has taken on an even more central role in building a company's competitive advantage. Increasing success depends on "people-embodied know-how". Thus, includes the knowledge, skills, and abilities imbedded in an organization's member. In fact, the key to a company's success is based on establishing a set of core competencies, integrated knowledge sets within an organization that distinguishes it from its competitors and deliver values to customers [28].

In the knowledge-based view of the firm, internal resources and capabilities, such as worker know-how, designs, customer knowledge and efficient processes, are keys to achieve sustainable competitive advantage. Knowledge is an especially valuable category of resources and meets Barley's criteria for resources capable of providing sustainable competitive advantages [32].

The hypothesized conceptual model is developed to simultaneously examine the relationship between TQM practices and organizational KM behaviours (that is, knowledge acquisition, knowledge dissemination and knowledge application) [34]. The link between TQM principles and organizational knowledge management behaviours are illustrated in Figure 5.

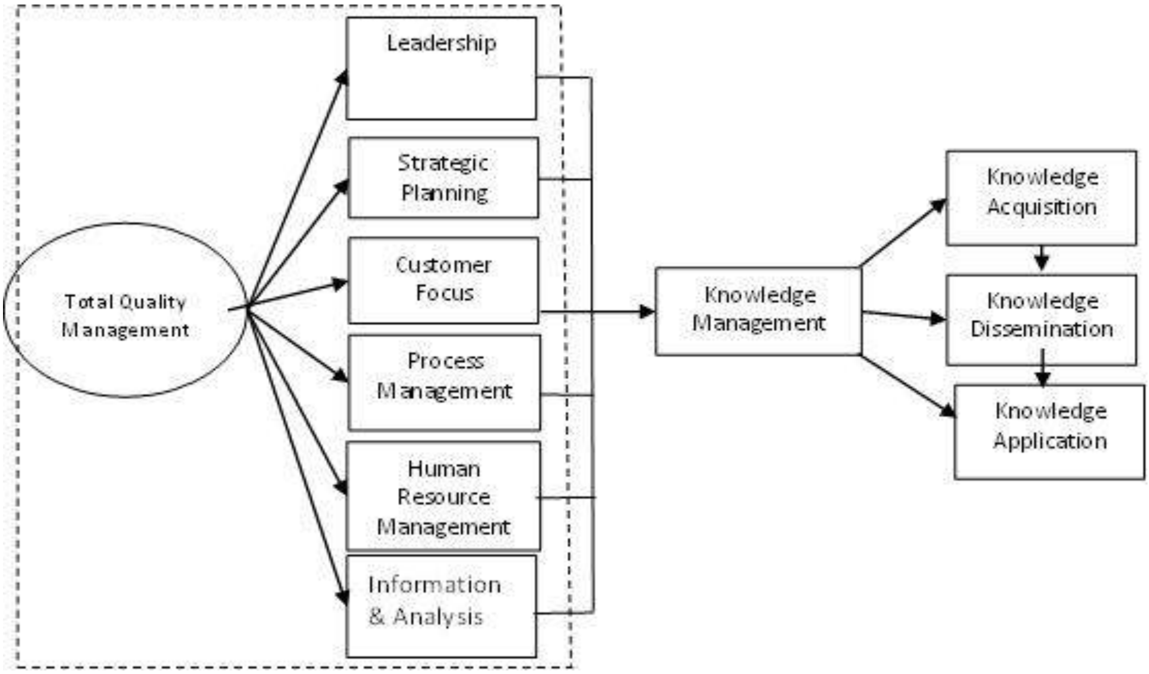

Figure 5: Model of knowledge management behaviour [34]

This model seeks to advance the literature regarding the relationship between TQM and KM Research and at the same time, to provide a means for both the practitioners and the academicians to better comprehend the link between TQM practices and KM behaviours. Apart from that, this framework propose the model to be used for the implementation of TQM practices and also to measure the organizational processes such as the effectiveness of strategic planning, leadership, process management, customer service, human resource management and the employment of information analysis [34]. Knowledge management was among the tools which we found has become an area of interest of many Iranian organizations recently [27].

Knowledge sharing as an important objective in potential coopetition, because it adds value to both organizations. It is a critical factor in maintaining a cooperative relationship between competitors [35].

As we know, People, technology and process are three main components of knowledge management [23], [25]. Most likely any strategic plan and implementation will impact all the elements to some degree. Therefore, careful consideration must be made when applying and adopting knowledge management systems as a driver of excellence so as to be aligned with the knowledge implications of the strategic plan and process improvement initiatives [24], [26].

Knowledge management in the RTE is considered as a total system providing the knowledge implications of different aspects of excellence concept. There had been some researches supporting this idea [23], [25]. Unfortunately we have seen Iranian organizations (MABENA's major clients) consider only the technological aspect of knowledge management and forget the two other important elements (people and process) [7].

A typical example would be a strategic requirement to share knowledge. An Iranian company would implement, say an Intranet, and wait for the benefits to kick in. Sadly, the company will gain little from its investment. The Intranet is a powerful infrastructure element but it needs to be established with People and Process implications not just Technology, and must be tied with a desired business objective. Change management considerations are paramount to the technology implementation. We believe that the boundary of these implications is more clearly specified when we have passed through the different elements of the RTE framework explained by now.

2.2.8. Performance appraisal and BSC implementation

"What must happen to all processes, of course is performance measurement, the results of which feedback to our benchmarking and strategic planning activities" [1], [2], [6].

Performance measures can play a variety of roles in an organization, as shown in figure 6. While performance measures can stand alone, they can also be combined with other management techniques to create more useful organizational tools [30].

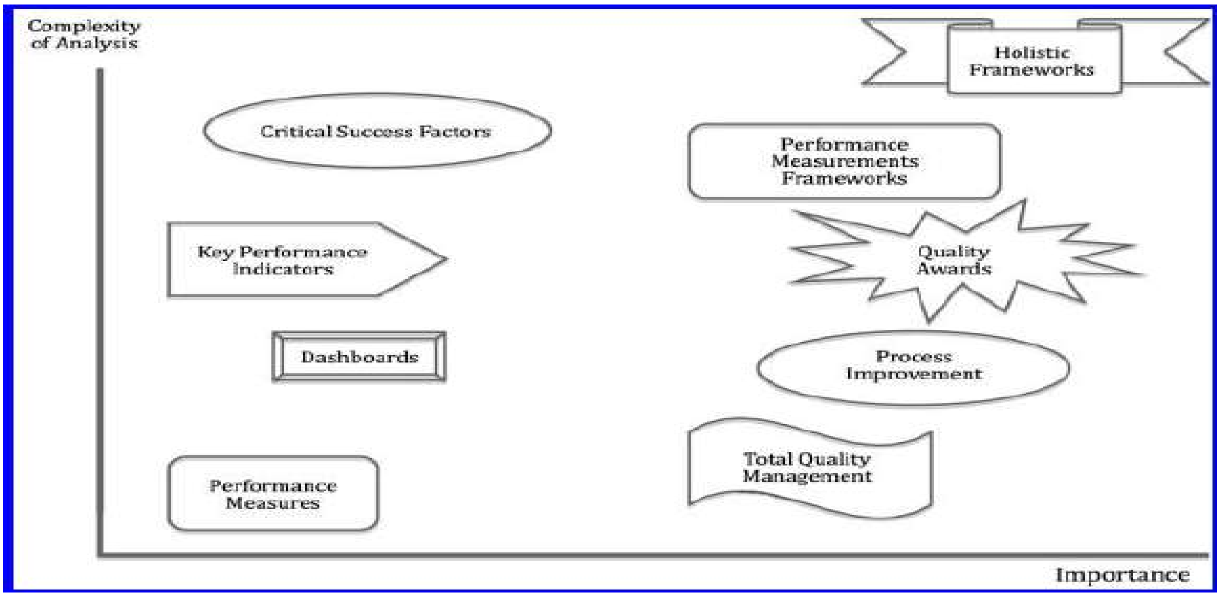

Fig 6: Overview of performance measures in organizations [29]

Almost all organizations will collect a plethora of performance measures, which are all characterized by the ease of their collection. The real value of performance measures is when an organization goes through a planning process that identifies performance measures that are linked to that organization's vision, goals, and objectives, whether they are easy to collect or not.

The Performance Pyramid

The Strategic Measurement Analysis and Reporting Technique (SMART) system, also known as the Performance Pyramid, was created as a management control system to define and sustain success (as shown in fig. 7) [29].

Fig 7: The Performance Pyramid [30]

This framework is designed for large corporations that have multiple operating units. The top level focuses on the organization's mission, vision, and strategies. The second level defines the objectives for each operating unit, while the third level provides more specific measures of operating success. The fourth level provides measures that are applicable for a department or unit within the business unit.

The above statement implies the concept of process measurement but we have found it useful to make distinction between strategic and operational metrics in performance appraisal topic. This is not a new classification as is the focus of attention in some other researches and publications [16].

The Balanced Scorecard (BSC), developed by Robert Kaplan and David Norton, is a comprehensive framework in which the mission and strategic directions of an organization can be interpreted via an array of performance measures [35], [36]. It was intended that the framework would give managers an all-inclusive view of the business yet allow them to focus on critical areas for improvement for strategic development purposes. As a result, it has been used mainly by businesses as a means of performance measurement and as a performance driver.

A commonly accepted strength of the BSC is the linkage of performance measures with organizational strategy. The BSC is very successful as a tool given this fact, a company may decide to evaluate for driving change within an organization in a way that is aligned with strategy. In essence, it is a strategy implementation tool [30]. A management team can clarify and translate high-level strategy into business objectives by applying the Balanced Scorecard [31]. Although many other approaches to strategy implementation exist, the specific appeal of the BSC is its reliance on the mix of operations and financial measures, which are simply linked to the organization's strategy.

The BSC approach is a tool for improving the business performance of individual firms. In using the scorecard approach, the key objectives of a firm are based on a firm's own specific strategy and not on any prescribed quality management approach.

Its strategic performance by implementing a strategic performance system like BSC and to evaluate its operational performance using the criteria's used in quality management systems like ISO9000.

According to the argument that a good scorecard consist of both strategic and operational measures [16], we may conclude that BSC is a comprehensive performance appraisal framework and the criteria used in ISO should strongly be in consistent with measures defined in BSC [8]. The RTE framework certifies this argument as if the quality management systems (like ISO9000) and strategic performance systems were considered as the elements of a same road, it was assured that the operational metrics defined in quality management systems were not in contrast or different from the metrics defined in strategic performance systems. Unfortunately, this is not mostly the case for many major Iranian companies (our clients) that either run quality management systems (like ISO9000) without having a formal or informal strategic plan or after adopting a strategic plan, do not bother them to revise the main elements of their quality management systems particularly the process measures.

By these explanations it is clear that by performance appraisal box in the RTE framework, we mean both measuring the performance of strategic and operational variables by a favourable performance management system (like BSC or the combination of BSC with the metrics defined in other specialized systems such as ISO9000).

3. CONCLUSION

This article presented a framework for guiding Iranian major organizations toward sustainable excellence. The framework emphasized on the logical sequence of adopting and implementing management approaches, techniques and tools. These were among those which Many Iranian organizations have shown tendency to adopt and implement recently. This article neither claimed to prescribe a general and universal framework nor it claimed to be a development to the original total organizational excellence model. But, it strongly claimed to develop a clear guide with useful descriptions and guidelines particularly for local major companies which we believe suffer a lot from ill adaptation of a mixture of management tools.

There are some extra researches which we believe would be helpful to be performed in order to compensate for some areas of improvement to this framework. First, as we mentioned no general study has been performed to distinguish the most commonly used techniques, tools and approaches the local organizations adopt recently. We have recorded this in a one year track of the firms we faced but a comprehensive study may reveal more reliable results. We also encourage other researchers to complete the framework by finding the position of many other management approaches in the RTE framework. We should finally thank our other colleagues in MABENA and co-workers who helped us in adopting these concepts in practice so as to design a practical roadmap.

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THE MIGRATION OF A KNOWLEDGE ITEM THROUGH THE LIFE CYCLES OF TECHNOLOGY, PRODUCT DEVELOPMENT AND THE ENTERPRISE

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ABSTRACT

This paper endeavours to define the migration of a knowledge item through the three different consecutive life cycles of technology, product development and that of the enterprise. As defined in a previous article about a universal knowledge framework, the knowledge item will be described using the knowledge cube structure. To further illustrate the migration route, four distinct, yet related examples will be investigated and the results discussed.

The examples are:

A. The idea that will later develop into a technology.
B. A technology that will be used in the design of a product.
C. A product that will be used in the development of an enterprise.
D. The end of life of the product system and the enterprise.

These examples are chosen so that it defines the beginning and end of each life cycle as well as the cross-over points between the different domains of technology, product and enterprise.

This article will conclude with some deductions regarding the knowledge migration through the Knowledge Migration Framework as defined by the combination of the specific life cycles (S- Curves) applicable to technology, product development as well as that of the enterprise.

* Corresponding Author

1 INTRODUCTION

This paper endeavours to investigate the migration of a knowledge item through the three different consecutive life cycles of technology, product development and that of the enterprise. As defined in a previous article on a universal knowledge framework, the knowledge item will be described using the knowledge cube structure developed before.

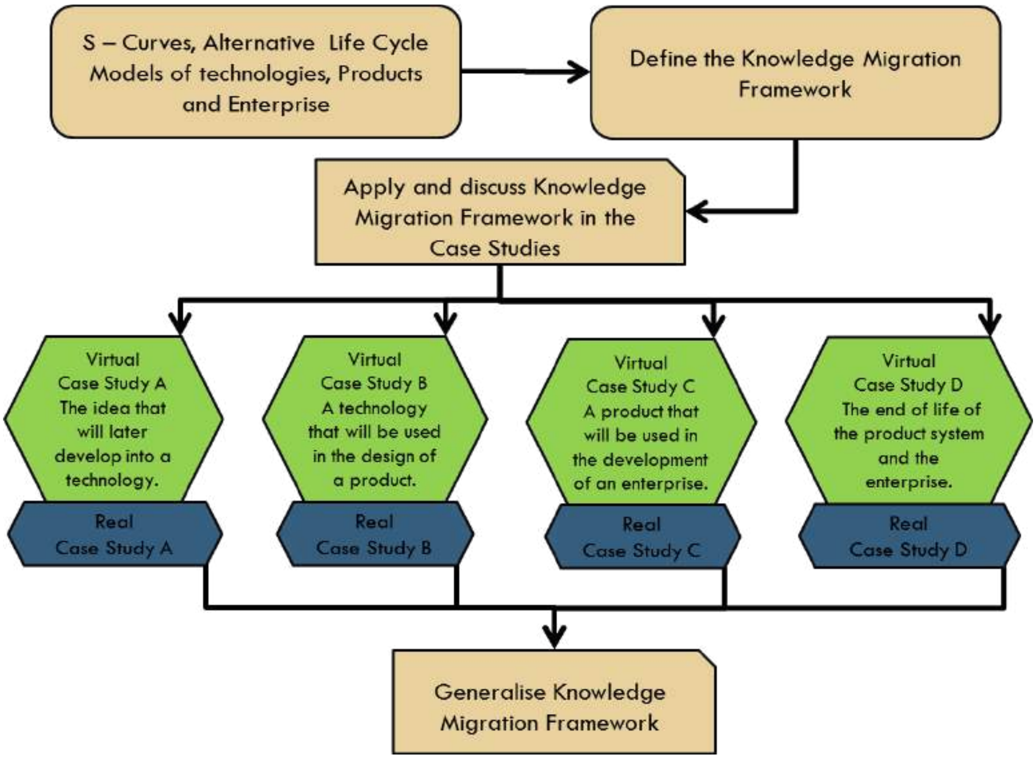

Figure 1: The Research Logic as applied to this article

The research logic as defined in Figure 1 requires the introduction of a number of models which are useful in its specific applicability but is required to provide research context. This article includes the virtual case studies A to D which will be fully described in this article but excludes the real case study as this research work still need to be performed.

This article will conclude with some deductions regarding the knowledge migration through Knowledge Migration Framework as defined by the combination of the specific life cycles (S-*Curves) applicable to technology, product development as well as that of the enterprise*.

2 THE KNOWLEDGE CUBE

From previous work of Pretorius and du Preez [1], it was concluded that a structural, a functional and a time elements can be derived as common denominators or domains in the various knowledge models studied.

These domains were further developed to form part of a new framework called the Knowledge Cube. This Knowledge Cube can be used, not only to present knowledge or to assess technologies, but to be used as the core breakdown in the description of any knowledge artefact (cognitive or physical) to be used in a standardised way of defining attributes of such an artefact i.e. the knowledge itself.

The Knowledge Cube domains are further defined as follows:

2.1 The Structural Domain

The structural component of the framework consists out of the scoping of the artefact as well as its physical decomposition up to the level of description required.

This component can take many forms, like a system breakdown structure, a work breakdown structure, an information structure or even a physical structure like an atom that can be de-composed to a set of neutrons, protons and electrons. This element in essence defines the "what" component of the artefact's attributes.

2.2 The Functional Domain

In both of the design methodology of Pahl and Beitz [2], and the axiomatic design of Suh [3], the function decomposition plays a key role, because this determines the functional structure.

This fundamental process definition is also confirmed by the Chen [4] in his mapping of the innovation production process. This component defines the "how" attributes of the artefact under review.

2.3 The Time Domain

Rozenfeld and Eversheim [5] argued that product development is essentially a knowledge creation process, therefore the knowledge management system links product development and knowledge evolution through the life cycle phases in context with the maturity state of the artefact.

The time or transformation, if time is not linear, is used to indicate the change process as well as the current or future state of the artefact's attributes.

A typical description of the life cycle process and/or status of a product development at any given point in time can be part of such a description. This "when" component is also used to define age, maturity and any attribute related to the passing of time, or logic, in order to be able to fully define the attributes of an artefact.

2.4 The Combined View

The three elements of the knowledge cube framework is depicted in a three dimensional view. It is further postulated that these three domains are sufficient to cover all attributes of any artefact. (Big or small, simple or complex, real or abstract) It should therefore be possible to define both the idea of an idea as an artefact, as well as a very complex weapon system like an armoured combat vehicle with its associated support systems.

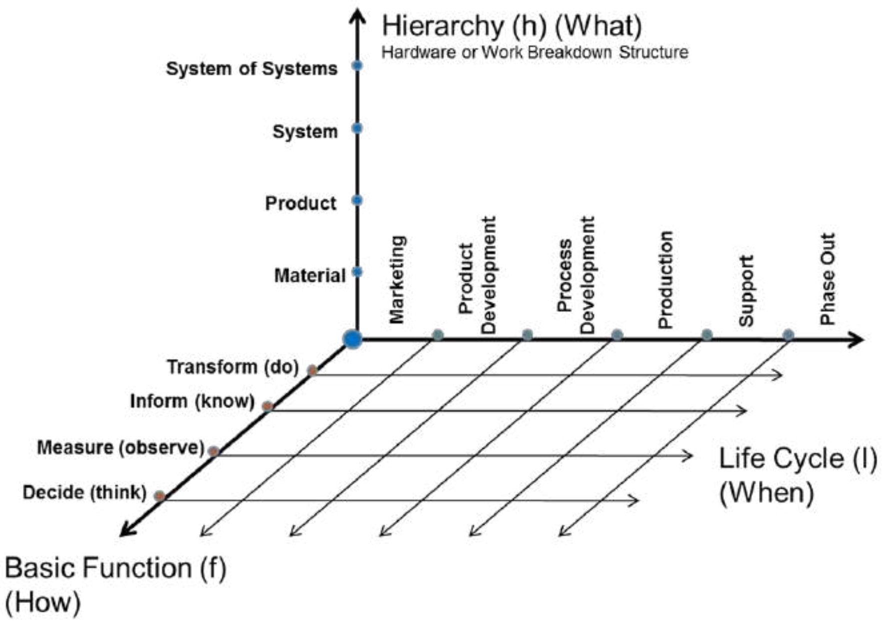

Figure 2: The Knowledge Cube defines the "What", "When", "How" Domains of any Knowledge Artefact's attributes [1]

2.5 Knowledge Cube Value System

The value of knowledge implemented towards action in one context may be absolutely worthless in another. The operative meaning is that things that we perceive as valuable do not necessarily have intrinsic value. According to Ariely [6], artefacts are valuable, with the potential for value or perception making their value-ability come true within the organization and in its environment.

It is perhaps wise to divorce the term value from knowledge as it only gets realised in specific application profiles for a single knowledge item. Different knowledge items also realises different values when measured against the intended value system for its specific applications.

By considering the elements of the knowledge cube one can define the value to the user in two ways:

- The expected value (Required):

  This is a description of the value that a customer requires from a product during a typical acquisition process.

- The realised value (Available)

  This is the sets of values realised or claimed by different product candidates. The gap between the required values and the realised or claimed values in the different knowledge domains will be used by the customer to decide on the preferred candidate.

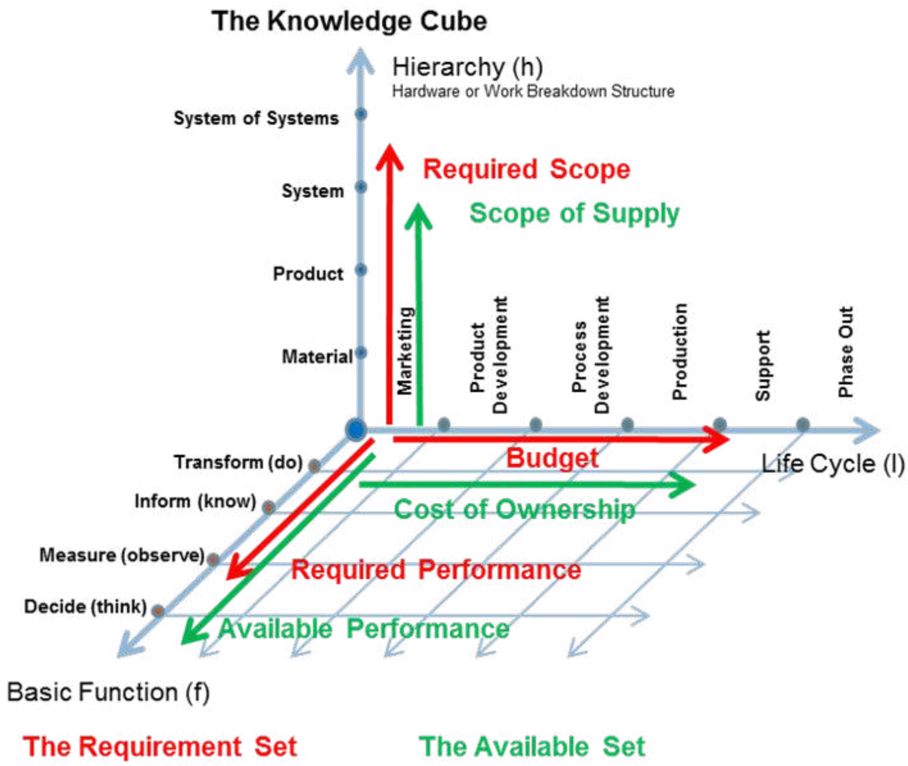

Figure 3: The Knowledge Cube Generic Value System

3 THE ENGINEERING CYCLES

3.1 The Basic Engineering Cycle

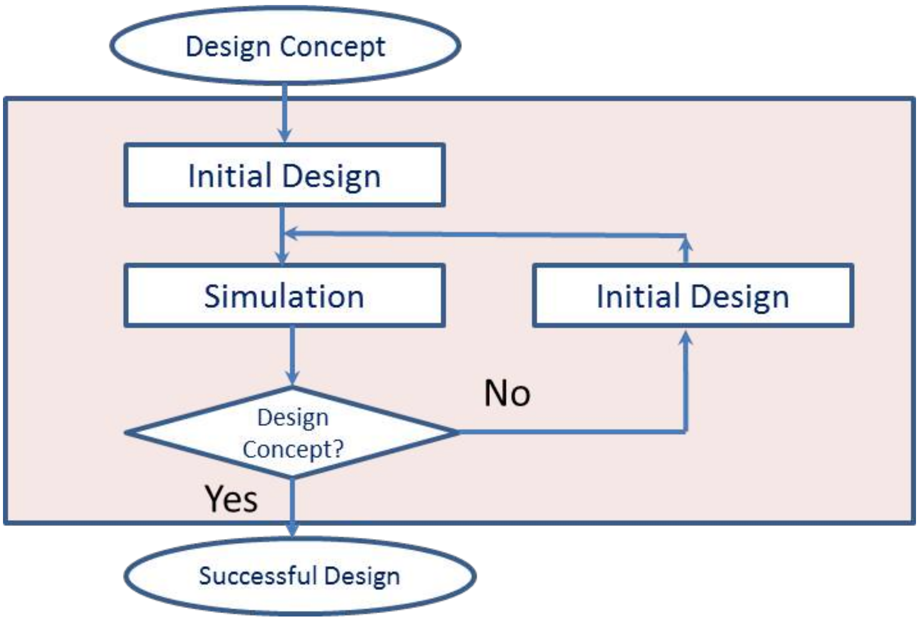

Figure 4: The Basic Design Loop - Brown [7]

Brown [7] defines the basic design loop as follows:

> *"Any design process comprises a basic sequence of tasks that are performed in various situations. Assuming that we have an initial concept about what should be achieved in the design process, the first step is to generate an initial design.*

The next step is the simulation of the design at hand. If the simulation reveals some errors, then the design must be changed to overcome the problems. The redesigned version is again simulated to determine whether the errors have disappeared. This loop is repeated until the simulation indicates a successful design."

Roozenburg and Eekels [8] defined the Basic Design Cycle with the following steps:

1. *"Point of departure in product design is the function of the new product, i.e. the intended behaviour in the widest sense of the word*
2. *In the analysis phase the designer forms an idea of the problems around such a new product idea (the problem statement) and formulates the criteria that the solution should meet*
3. *The second step in the basic design cycle is the generation of a provisional design proposal. The word 'synthesis' means: the combining of separate things, ideas, etc., into a complete whole.*
4. *Simulation is a deductive sub process. Simulation is: forming an image of the behaviour and properties of the designed product by reasoning and/or testing models, preceeding the actual manufacturing and use of the product.*
5. *Evaluation is establishing the 'value' or 'quality' of the provisional design.*
6. *Then follows the decision: continue (elaborate the design proposal) or try again (generate a better design proposal). Usually the first provisional design will not be bull's eye and the designer will have to return to the synthesis step, to do better in a second, third or tenth time"*

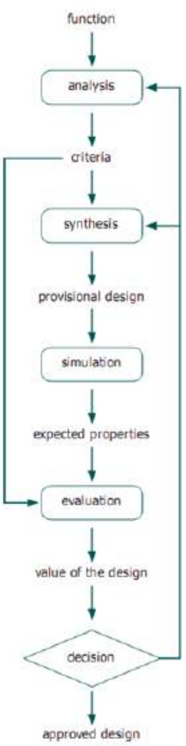

Figure 5: The Basic Design Cycle - Roozenburg and Eekels [8]

3.2 The Plan, Do, Check, Act (PDCA) Cycle

The Plan Do Check Act Four-step process are used in quality control and elsewhere as a simplified method for achieving improvements.

"These steps are: (1) Plan: determine what needs to be done, when, how, and by whom. (2) Do: carry out the plan, on a small-scale first. (3) Check: analyze the results of carrying out the plan. (4) Act: take appropriate steps to close the gap between planned and actual results. Named after its proposer, the US mathematician Dr. Walter Shewart (1891-1967). Also called Deming cycle, Deming wheel, or plan do check act (PDCA) cycle."

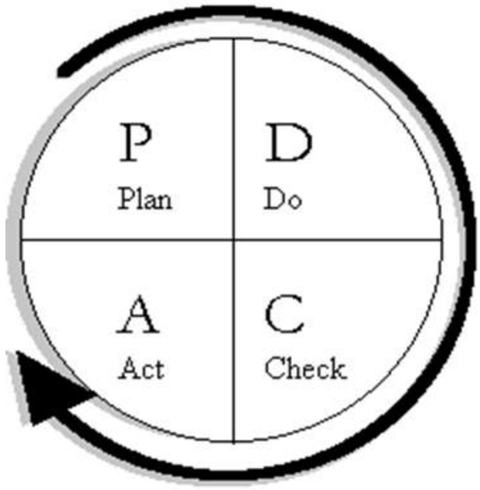

Figure 6: The Shewart Cycle [9]

Basic engineering design, in essence, is nothing other than taking an artefact's current knowledge (problem, requirement, unwanted status), deciding how to go about changing it, actually changing the knowledge base, measuring the effectiveness of the change and repeating the process if the outcome was not acceptable. This is also commonly known as an Engineering or Design Cycle and is eaqually applicable to technologies, products and processes.

From the above it is clear that the PDCA Cycle is just another way of defining a Basic Engineering Cycle. This PDCA Cycle can therefore be used to indicate changes in the status of knowledge of an artefact during its life spanning from an idea right up to a full fledged system.

A knowledge artefact defined by the knowledge cube framework, therefore advances in its knowledge status by means of the continuous application of the PDCA Cycle.

4 THE LIFE CYCLES

4.1 The Generic S-Curve

S-curves are useful to contextualise maturity and strategic positioning of objects which maps growth of revenue or productivity against time.

According to Aït-El-Hadj [10], the lifecycle of technology can be considered in four phases namely:

a. The technology rise
b. Growth
c. Maturity
d. Saturation

Narayanan [11] states that the life cycle of innovations can be described using the s-curve. In the early stage of a particular innovation, growth is relatively slow as the new product establishes itself. At some point customers begin to demand and the revenue from the product increases more rapidly. New incremental innovations or changes to the product allow growth to continue during this time. Towards the end of its life cycle, growth slows and may even begin to decline. In the later stages, no amount of new investment in that product will yield a normal rate of return. The s-curve is derived from half of a normal distribution curve.

With the stages combined this forms the classic **S-Curve** profile as defined below:

Figure 7: The Life Cycle defined as an S-Curve [11]

If we now apply the Basic Engineering Cycle as a means to propagate a knowledge item (Knowledge Cube) through the artefact's lifecycle and we use the PDCA Cycle for demonstration purposes, it implies that we continously repeat this cycle untill we reach saturation in terms of knowledge potential and end of life for the specific artefact.

During this propagation the knowledge about the artefact is continiously being enriched by the application of the PDCA Cycle up to the point where more effort does no longer result in more knowledge.At this point saturation or maturity is reached.

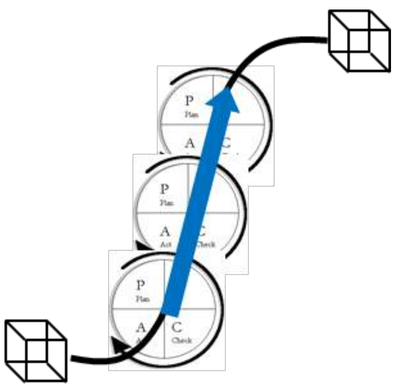

Figure 8: The Migration of a Knowledge Item through its Life Cycle

In order to further investigate the migration of a knowledge item through the life cycle we need to investigate different applications of life cycles with regard to technology, product develoment as well as the life of an enterprise.

4.2 The Technology Life Cycle

From Wikipedia [12], the free encyclopaedia technology is defined as:

> *"The word technology refers to the making, modification, usage, and knowledge of tools, machines, techniques, crafts, systems, and methods of organization, in order to solve a problem, improve a preexisting solution to a problem, achieve a goal, handle an applied input/output relation or perform a specific function."*

The Merriam-Webster [13] dictionary defines technology in the following way:

"a: The practical application of knowledge especially in a particular area

b: A capability given by the practical application of knowledge"

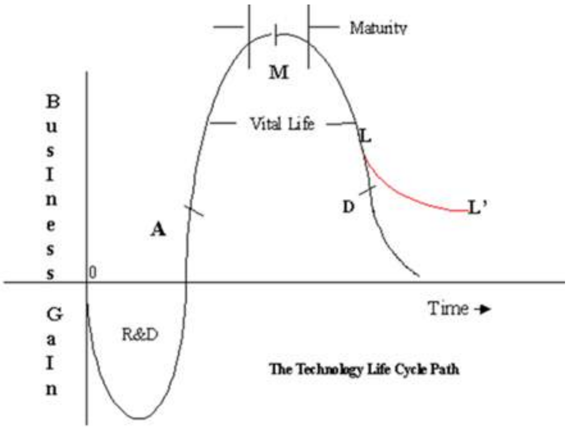

Figure 9: The Technology Life Cycle [14]

Jayalath [14] defines the technology into a research and development and a vital life phase after which the technology is no longer useful. Again we can visualise that the development of a specific technology's knowledge is through the application of the basic engineering or PDCA cycle.

A standard Technology Readiness Level Scale was initially developed by NASA and later adapted to the application in the acquisition process of the US Army through their Technology Program Management Model. [15]

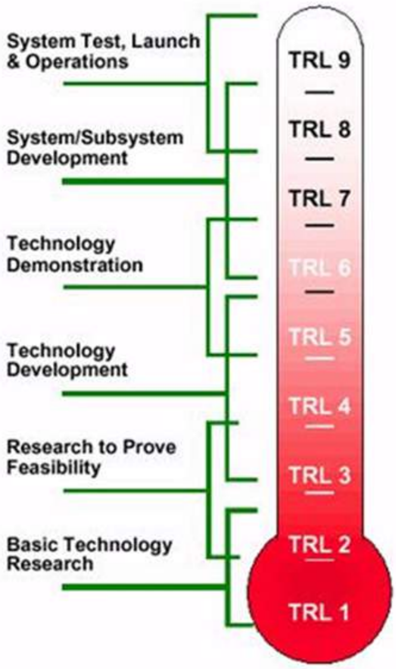

Figure 10: The Technology Readiness Levels for NASA [15]

4.3 The Product Life Cycle

The Business Dictionary [16] describes a product as:

> *"A good, idea, method, information, object or service created as a result of a process and serves a need or satisfies a want. It has a combination of tangible and intangible attributes (benefits, features, functions, uses) that a seller offers a buyer for purchase."*

As seen from the definition above no clear distinction can be drawn between the technology and the product life cycle start-up however in the interest of simplicity we will show two separate life cycles.

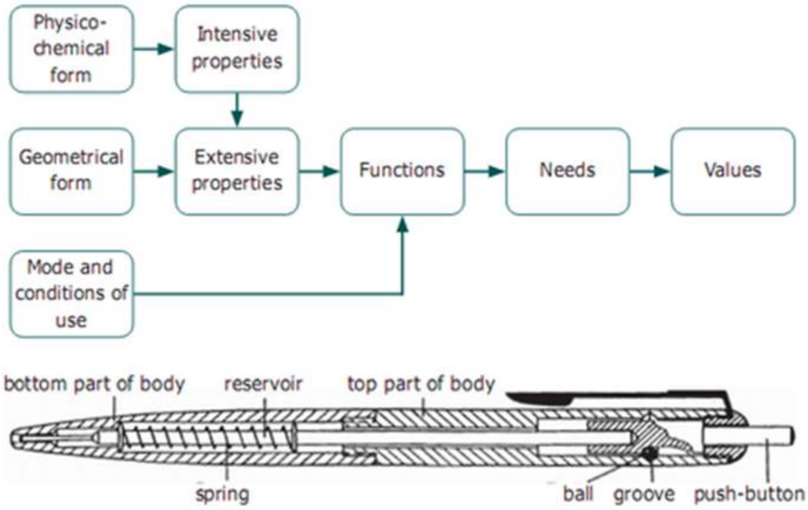

Figure 11: Model of reasoning by designers. Roozenburg and Eekels [8]

The Engineering Design Cycle and the Product Life Cycle (PLC) must not be confused with one another. The Engineering Design Cycle as defined above by Roozenburg and Eekels [8] is again the continuous process being used in order to forward or migrate the product's knowledge attributes through its own life cycle (PLC) up to the point where more effort does not result in a more useful product i.e. the end of life condition.

The Product Life Cycle (PLC) as defined by Noyen [17] describes the whole life cycle of a product, from the first idea to the disposal of the product. The PLC can be divided in several phases as shown below:

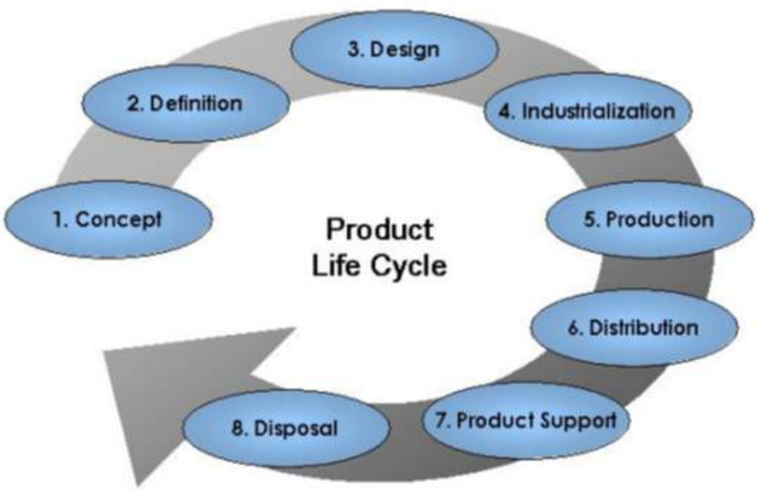

Figure 12: The Product Life Cycle. Noyen [17]

BAE Systems [18] in their Engineering Life Cycle Handbook defines the Engineering Life Cycle of a Product or System as having five major phases as follows:

- Concept Creation Phase
- Development and Qualification Phase
- Manufacture Phase
- Support during Deployment Phase
- Disposal Phase

In addition 13 distinctly different design review gates have been identified in order to manage the success of the knowledge migration throughout the life cycle. These are depicted numerically in the diagram below:

Figure 13: The Engineering Life Cycle of a Product or System. BAE Systems [18]

A whole variety of Product and Engineering Life Cycle Models exist in literature however the driving force of advancing the knowledge base of a specific product through its life is through the application of engineering effort in the form of repetitive engineering cycles.

4.4 The Enterprise Life Cycle

The Merriam-Webster dictionary [19] defines enterprise as follows:

- A project or undertaking that is especially difficult, complicated, or risky.
- Readiness to engage in daring or difficult action : initiative.
- A unit of economic organization or activity; especially : a business organization.

Of special interest to us is the Enterprise Life Cycle as defined by Noyen [17] as having six distinctive steps as depicted below.

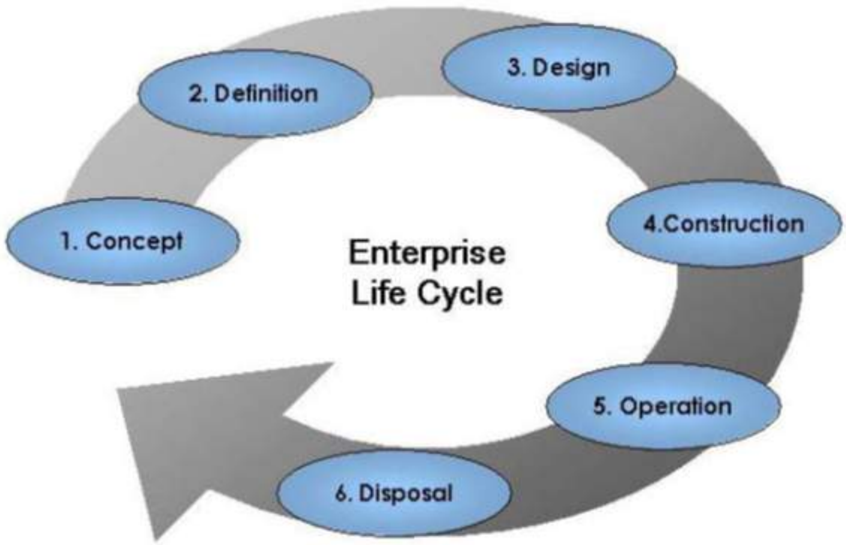

Figure 14: The Enterprise Life Cycle. Noyen [17]

From the above it is clear that we must endeavour to re-create the enterprise before it reaches the end of life stage.

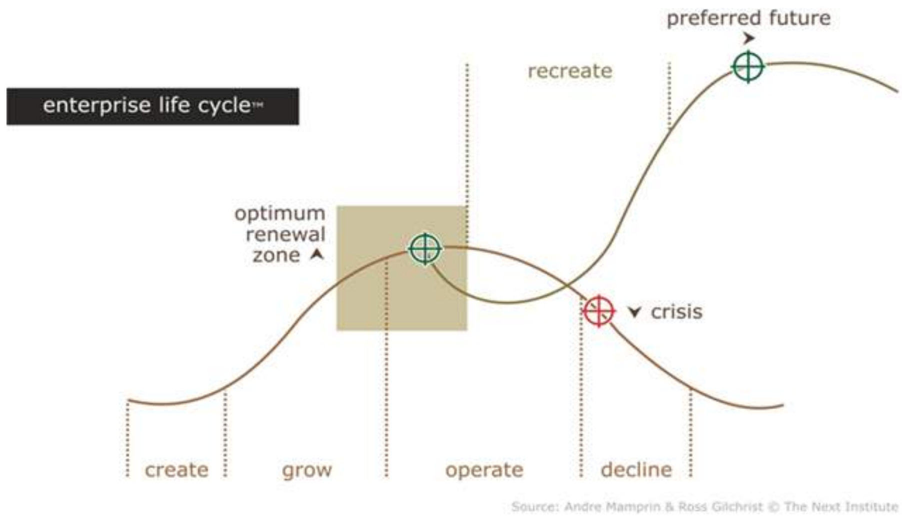

Figure 15: The Enterprise Life Cycle as defined by the Next Institute [20]

The classic enterprise life cycle also takes the form of an S curve as one half of the normal distribution and consists of the four basic phases of create, grow, operate and decline. The Next Institute [14] defines an optimal zone where conditions of energy, momentum, resources within the enterprise are most suited for the renewal of the enterprise. They further state that:

> *"The ability to recreate – to understand the Enterprise Life Cycle™ and renew in the optimum window – has become a fundamental requirement for creative and sustainable enterprise. If you're leading an enterprise, there's a conversation waiting."*

As was the case with the product life cycle, the enterprise life cycle also requires a method of continuous improvement. This is represented by the vast study field of Enterprise Engineering.

To take but one example, the US Department of the Treasury's [21] Enterprise Life Cycle refers to an organisation's approach for managing activities and making decisions during ongoing refreshment of business and technical practices to support its mission. This renewal process is defined in the figure below.

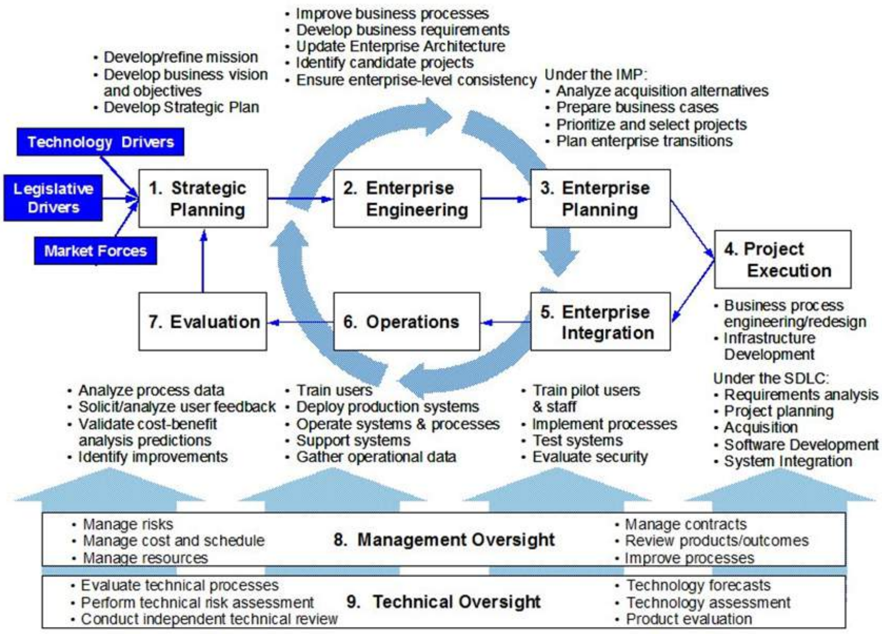

Figure 16: The Enterprise Life Cycle Activities inside the US Treasury Department [21]

Even in the most complex of Enterprise Engineering Models and Frameworks one can deduce the basic steps of planning, doing, checking and acting i.e. the PDCA Cycle as defined earlier.

The impetus for process knowledge enrichment during the Enterprise Life Cycle is again supplied by the churning of the PDCA Process.

4.5 Knowledge Migration Framework

If we now combine all of the above into the three consecutive life cycles of technology, product development and the enterprise and we define the common process that drives the change in the knowledge artefact throughout these cycles as the continuous use of the PDCA Cycle we can identify specific instances in the process that warrant further investigation.

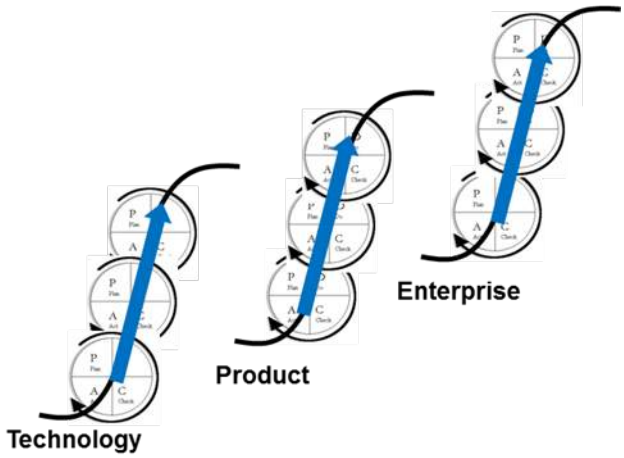

Figure 17: Knowledge Migration Framework viewed as the Combined Life Cycles of Technology, Product and Enterprise.

We can now investigate the journey of an idea becoming reality in a proven technology into a product used by an enterprise and eventually phase out.

It is assumed that different life cycles will integrate in a logical way, but this will be tested during the assessment of the actual or real case studies and documented and feedback will be provided on in a subsequent (SAIIE or other) conference.

5 THE VIRTUAL CASE STUDIES

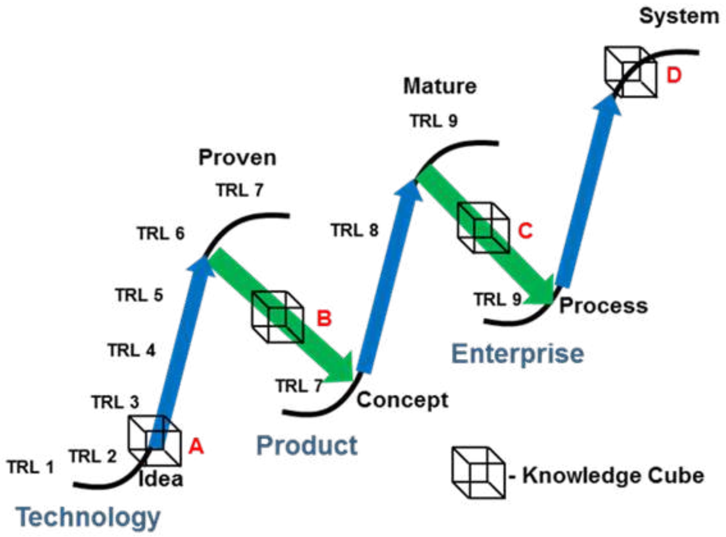

Figure 18: The Migration of a Knowledge Cube through the Life Cycles of Technology, Product and Enterprise – The Knowledge Migration Framework.

The following instances of the migration of a knowledge cube throughout the combined life cycles will be discussed:

A. The idea that will later develop into a technology.
B. A technology that will be used in the design of a product.
C. A product that will be used in the development of an enterprise.
D. The end of life of the product system and the enterprise.

The knowledge artefact that we are about to investigate starts with an idea for the active protection (counter blast) against blast mines built into an armoured vehicle which finds its way into a specific vehicle sold by the enterprise as a user system and eventually is supported in the customer environment during the mature stages of the enterprise life.

5.1 A - The Idea developed into a Technology

The structural domain of the idea knowledge cube can be defined as the scope, topic or description of the idea. In this case the idea to defeat a landmine blast by means of a counter explosion which forms a hydraulic wedge will clearly define the “what” component of the idea.

The knowledge cube’s functional domain where the main function is to survive; the first level breakdown then will be to protect. The further sub-functions will typically be to sense an explosion, to decide to react and to activate the counter explosion. This is the “how” domain.

The third knowledge cube domain is a description of the timeline where the initial blast takes 30 micro seconds to develop before sensing, the activation of the sensor within another 20 micro seconds and the activation of the counter blast within another 30 micro seconds giving the initial blast to raise about 500 mm before the counterblast is affected. This represents the “when” function. This 500 mm also represents the typical height of an armoured vehicle from the ground and is an obvious constraint for the idea to work.

If one considers two different applications of the idea for a normal commercial truck as well as for an armoured combat vehicle in order to assess the value of the idea, the following outcome can be envisaged.

Although the normal commercial truck is more than 500 mm high, it is not blast proof and the occupants will be worse off after the event and the application of the idea has therefore very little value.

In the instance of the armoured combat vehicle, the effect of such a system can be as much as 30% on the acceleration of the vehicle during a blast depending on other attributes of the vehicle (main cause of occupant's injuries) and will carry real value for the soldiers.

This idea it must be developed into a functional system working together to demonstrate the required results for the idea to work. This will, in all cases, be required for the application of any idea. The increase in knowledge is obtained by means of the application of the basic engineering or design cycle. As we have seen before, this can be depicted by the PDCA Cycle. This increase in knowledge will allow the life cycle of technology to move forward from an Idea to a successfully demonstrated consept, hence the notion of knowledge migration.

5.2 B - A Technology to be introduced into a Vehicle Concept

After the application of various engineering design cycles we eventualy get to a proven technology at TRL 7 where it is ready to be incorporated into a specific vehicle concept.

The "what" domain is the scope of the technology under consideration as well as to decompose the technology to be able to define the underlying technologies required for successful operation of the main operation. In the specific case, we can scope the technology that will enable us to sense an explosion within 30 micro seconds from a distance of 500mm. This technology can be based on Electro Magnetic Pulse, Optic or Radar principles and must be able to perform in muddy, dusty or submerged conditions.

In the "how" domain we define all the sub functions that need to be performed. This may include the function to sensor, the packaging, the signal filters as well as amplifying the signal etc. Please note that through the application of the system engineering process as defined by Blanchard and Fabrycky [22], we will establish a relationship between the physical and functional domains when we perform a functional allocation to hardware in order to establish the required performance levels of each piece of hardware and the interfaces that exist between the elements.

The "when" domain defines the maturity state of the technology as well as the historic and future processes it still has to go through after integration into a product design. This will typically include the logic of first demonstration of principle, laboratory (engineering) test to refine the technology as well as formal qualification tests to demonstrate functionality in the field, reliability and safety to name but a few.

Similarly as in the previous case we can establish the value of the technology only when we apply it to a specific solution. In this case we use the design philosophy of the vehicle in order to evaluate the potential value of the chosen design above other considerations. This is a typical engineering trade-off study during development.

It does not take a lot of imagination to derive the fact that if we are busy integrating technology into a product design that this is done through the application of a design cycle. The knowledge about the product and its functionality, is enriched through the application of this cycle, in simplicity defined as the PDCA Cycle, and will lead to a better understanding of the product and its functions i.e. knowledge.

5.3 C - The Product used in an Enterprise

When we consider a product, in this case an armoured fighting vehicle, we need to define the vehicle as well as all the main elements of the vehicle i.e. the hull, the hydraulic system, the pneumatic system, the suspension, the driveline, the electrical system, internal fittings, the air conditioning system as well as the payload in mass, interface, centre of gravity to name only a few. This physical decomposition again is defined in the “what” domain. When we plan work on such a vehicle we also perform a work breakdown structure in line with the hardware breakdown structure. This can further be developed into a contract work breakdown structure if we do consider sub-contracting work.

In order for us to understand how it works, we need to define the different functions that such a vehicle can perform its mission or series of missions. This is classically broken down into mobility, fire power, C3I2, carrying of special payload and survivability. All of these functions are normally further decomposed to such a level that it can be allocated to a single piece of hardware, work breakdown element or sub contract. This is also performed using the system engineering process referred to above.

The typical project life cycle will be used to define the “when” domain. In a classic acquisition process performed under the military standards we will define concept, definition, full scale development, production, deployment and phase out components to be planned in the most concurrent way possible. The maturity level of the product design expressed on the TRL scale, is a typical knowledge attribute defined under the time domain.

When different armies procure an armoured combat vehicle they normally publish a weighted user value system that will be used to measure the level of acceptance. This value system will contain a financial element with regards to capital and operational costs, technical performance against the requirement specification, reliability, counter trade and other non-technical factors.

Again here it must be noted that the same product will score differently for different user value systems, thus, confirming that the artefact’s attributes are independent from the applied value system.

The development of a product into maturity is done through the application of an engineering cycle of the product. Throughout a development phase of the product we enhance the quality and the quantity of our product knowledge and by doing so we migrate the product knowledge towards maturity as defined before. Again it was shown that the PCDA Cycle is a good basic representative of an engineering cycle.

5.4 D - The End of Life Conditions of the Product System

The combination of various products and services into a system will, in this example, define the highest level of scope. The first level of breakdown is normally the products (vehicle, weapon system, communication equipment) and their associated support systems. As in the previous example the work breakdown structure as well as the contract breakdown structure is all part of the “what” domain. In this specific case we need to understand the role that the product is taking on with regard to the enterprise’s sales in its next business cycle to get a clear view as to the contribution the product represents.

We must have a clear understanding of the specific role this product has in the make-up of the user defense system to enable us to understand the alternative product strategies that can enhance the extention of life for the enterprise. In addition, we also need to marry the enterprise’s functional design with the future demands, this may lead to an enterprise re-design to focus on the after sales or support of the product as this will form a major part of the future business of the enterprise. This product and enterprise descriptive decomposition forms part of the “how” domain.

As seen from the end of life of the enterprise the specific contribution in the next business cycle to be obtained from the specific product depicts the “when” domain.

The true value of owning an enterprise is measured in the successful execution of the various contracts within the boundaries of affordability and efficiency. In other words, the sustained ability to make a profit in the next business cycle. As demonstrated, this is the result of a specific application of the artefact throughout its life, starting at an innovation through the successful incorporation into a product and ending in the strategic make-over of the enterprise in order to face the future business challenges.

This process is typically defined as the Enterprise Engineering Cycle and holds the process as the basis for renewal of knowledge or learning. This is the classic application of process renewal based on the PDCA Cycle.

5.5 General Discussion

As discussed in each example above the knowledge base will be enhanced through the application of the PDCA cycle or its equivalent in all the life cycles shown. Without the application of such a process the level of knowledge and understanding at that specific point in time will remain stagnant.

We can therefore conclude that the change agent that causes the knowledge artefact to migrate through the various life cycles is the application of the engineering process in various forms.

The complexity and maturity level of the knowledge item both grow with progress of the migration process. There is definitely a knowledge continuum in evidence through and between the various life cycles.

As the migration progresses and subsequently the complexity increases, more players get involved in the sharing of the knowledge of the artefact and this in turn causes potential knowledge gaps to open. This is especially the case where a new participant with limited exposure to the process joins the stakeholder groupings.

5.6 Conclusions

The integrated life cycle feeds on knowledge work in a continuum as discussed above. We can also conceive a pre-planned knowledge migration through the various life cycles of the Knowledge Migration Framework by taking pre-determined shortcuts in the processes, thereby defining a specific concurrent knowledge migration path. If we understand this migration process we will also be able to manage the inherent technical risk of such a plan.

The knowledge work continuum also evolves over time and, by definition, has its own life cycle as well. In order to shorten the time scale involved, as is required by the need for competitiveness one can utilise this knowledge continuum to evaluate and shorten the standard processes.

Some critical questions to be analysed during the proposed case study execution will be:

- The fit of best knowledge migration process (PCDA Cycle) to be followed in each case study in order to optimise the learning experience vs. time required.
- The best way to manage technical risk and how to apply the parallel risk abatement programs.
- Identifying the best points in the process to consolidate the knowledge base into a formal baseline of technical data so as to minimise both risk and time throughout the process.
- The integration required (or the jump) between S-Curves and how to best bridge this gap.

Should the framework deliver consistent results, the benefit of the research outcome will be:

- The Knowledge Cube Principle can be applied to other areas of research in the domain of Knowledge Management.
- A deeper understanding of the migration of a data item through the Knowledge Migration Framework may result in a method of depicting the level of concurrency in a specific process.
- The overview of the models relative to the basic functions and lifecycle of an enterprise may lead to new understanding in the specific application of specific models highlighting the strong and weak areas of each one studied.

Additional research can be performed in the enterprise life cycle domain with regards to the Re-Correction Model as defined by Tan [23] may yield useful results. Further investigation of the framework surrounding the series of events when a knowledge item is presented to a customer in a successful way is also envisaged.

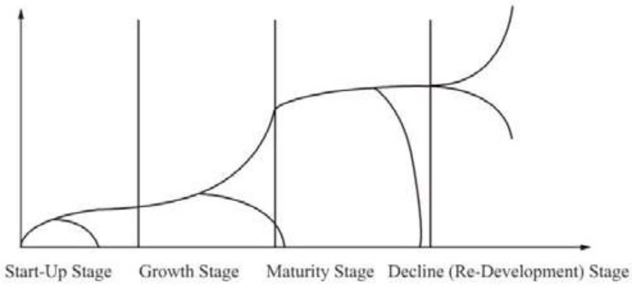

Figure 19: The Enterprise Life Cycle Re-Correction Model by TAN [23]

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FORMULATING A STRATEGIC FRAMEWORK TO PROMOTE SME DEVELOPMENT

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ABSTRACT

SMEs are critical to economic development within the South African economy by contributing considerably to the national GDP and private sector employment. However they are unable to overcome the primary obstacle of access to funding, which translates into an inability to attain the necessary physical, human and consulting resources.

Private equity and the venture capital sector has been critical in providing this necessary funding to support SME creation and growth in developed countries, but has been under-represented in South Africa. This is set to change by an amendment to Regulation 28 which allows pension funds to legally allocate a portion of the fund to private equity investments.

SMEs currently lack an understanding of the business value curve utilized by financiers to gauge the risk-reward characteristics of an investment. SME strategies need to convey how the business model will isolate imitators as well as bridge misfits between their current resources and future requirements in order to deliver on the strategic intent.

This paper utilizes a Systems Engineering approach through functional analysis to develop a framework that guides SMEs through detailed processes in order to develop a strategy aligned with investor requirements. The framework addresses the shortcomings of current strategic frameworks by taking into account the specific characteristics of SMEs and not being biased towards a specific industry or sector.

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1 INTRODUCTION

The South African economy finds itself in a concerning predicament. As is the case with numerous developing economies, South Africa hosts both a formal and informal economy. The formal economy produces the majority of South Africa's wealth, with the informal economy hosting much of South Africa's urban and rural poor. The economy however has come to resemble the activity associated with industrialized nations more than that of emerging markets or developing countries. This results in industry requiring skilled labor associated with developed economies rather than the primary production and manufacturing sectors which could alleviate unemployment by providing jobs for the unskilled majority.

With a large dataset of cross-country evidence the research community now widely accepts the importance of small to medium enterprises (SMEs) with regard to socio-economic development [1]. Accordingly, SMEs are responsible for a considerable proportion of employment, GDP contribution and poverty alleviation in both developing and developed economies [2].

A significant portion of the literature in economics has stressed the importance of entrepreneurship at the micro-level to achieve economic growth at the macro-level (e.g., [3], [4] & [5]. Consequently, the small firm has been touted as an outstanding vehicle through which the entrepreneur can channel his or her entrepreneurial ambitions, as the firm is seen as an extension of the individual who is in charge [6].

There now exists a wealth of evidence to prove that economic activity has shifted from larger corporations to smaller firms during the 1970s and 80s, the most cited and impressive example of this is the observation that the share of employment by the Fortune 500 companies has dropped from 20% in 1970 to 8.5% in 1996 [7].

Already SMEs are seen as contributing to economic development being responsible for 52% to 56% of South Africa's national GDP and 56% of private sector employment. Studies are proposing that as is the case with developed nations, the creation and growth of SMEs could be significant factors in the solution of SA's development issues [8].

With a host of frameworks attempting to explain the reasons for firm success at any point in time, it is found that they neglect to detail the processes involved in achieving the success by not taking into account the fundamental characteristic differences between SMEs and their more developed/mature counterparts.

Firm growth is a central area of focus in strategic-, firm- and entrepreneurial research. The factors that affect firm growth have been attractive to the sciences, but there has been no comprehensive theory, to date, to explain which firms will grow or how they grow [9]. Even when some explanatory factors have been identified, the connections between these factors and the economic environment have been disputed. The causes of success or failure are inseparable from questions such as:

- Why and how do firms differ?
- How do they behave?
- How do they decide on strategies?
- How are these strategies managed?

Any effort to formulate a framework to aid businesses in steering their firms towards success and growth must be built on an underlying theory of the firm and firm growth as well as the associated theory of strategy.

2 THE FIRM: SURVIVAL & GROWTH

With the data in support of the role of SMEs in economic development the research community has been preoccupied with the importance of high-growth SMEs, arguing that a small portion of high growth firms are responsible for the majority contribution of new jobs and increased GDP output [10].

On the other hand non-growing or smaller firms do have their strategic fit within the larger economic system as they facilitate self-employment and support the development of their growing counterparts [11]. In either case, aversion to or inability to achieve growth has been identified as a principal reason for firm decline and ultimate failure [12].

In order to retain the socio-economic benefits of SMEs, these firms ultimately have to survive in order to maintain "the continuity of business" [1]. Storey [10] proposes that growth is synonymous with longevity where SMEs with negative or stagnant growth rates indicate future problems for the firm.

Other motives for growth along with continuity of business include the achievement of economies of scale, increased market share and subsequent profitability, exploiting new business opportunities, credibility in the market and achieving a higher market value for the firm [10].

Previous research has revealed that growth is a multidimensional phenomenon, the result of both internal and external factors. Wiklund [13] proposed an integrative model as illustrated in Figure 1 suggesting how entrepreneurial activity, the business environment, firm resources, owner attitude towards growth and strategic fit are combined to create a sustainable competitive advantage.

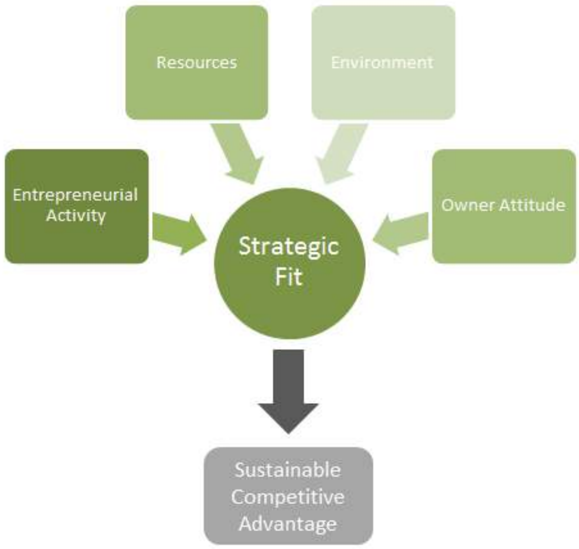

Figure 1: Firm Growth Model adapted from [13]

Entrepreneurial activity refers to a firms attitude towards innovation and risk taking in delivering new products and services to a market, as such it refers to how a firm operates rather than what it does [13]. Several studies have shown that companies with an entrepreneurial culture experience sustained high growth rates and outperform their peers [14].

The environment relates to external factors which can be exploited to deliver performance. The environment has aggregate benefits for all market participants in that the firm growth rate is affected by the industry growth rate [13]. However studies have found that high growth amongst SMEs is due to their ability to develop market niches [15].

According to Wiklund [13] a firm has three distinct resources at their disposal to deploy their strategy; physical, human and network resources. The idea is that these resources have to be combined and utilised in a manner to derive a sustainable competitive advantage [16].

Owner attitude refers to the firm owner's motive for starting and operating their business as studies have shown that people have a variety of reasons for doing so beyond financial incentives [10]. Wiklund [17] proposed that even though growth may not have been an entrepreneur's initial goal, that should the business owner be favourably exposed to the new tasks that accompany firm growth, they may develop a more positive attitude towards growth.

Strategic fit refers to the firm's ability to find a balance between these various factors and effectively compete in its market. Should a firm be unable to acquire the necessary resources or be ineffective in combining them to exploit a market segment, they will be unable to sustain a competitive advantage and will fail [13].

Academic studies suggest that firm performance and growth is predominantly a function of an effective match between the various internal and external factors [1] with firm growth rarely occurring by chance but rather being due to management's choices and subsequent conscious decisions with Weinzimmer [18] proposing that strategy is the most important determinant of growth.

2.1 Strategy & Growth

There are a number of definitions relating to strategy, however it can be accurately described as "an overall collection of business decisions and actions" [19] in order to gain and sustain a competitive advantage. Hrebiniak and Joyce [20] proclaimed that a successful strategy enables firm performance and effectiveness, the result of an effective match between the firm, its processes and the external environment.

The field of strategic management has been a popular topic for many decades with seminal work being conducted by many experts. As a consequence different frameworks have been popularised by various pioneers in an effort to aid firms to exploit their strengths and weaknesses in relation to the external environment, Table 1.

Table 1: A collection of some of the more important, to this study, strategic theories

Theory	Explanation
Scenario planning	Works by describing a small number of scenarios, by creating stories of how the future may unfold and how they might affect the issues that confront an industry [21] & [22].
Sensitivity analysis	Sensitivity analysis is the study of the amount of variation found in the output of a mathematical model due to the variability in the different sources of input into the model [23].
Game theory	Game theory allows the modelling of competitive interaction [23].
PESTE analysis	It is the analysis on the environment in which an industry operates. PESTE (Political, Economic, Social, Technological and Environmental) factors [23].
SWOT analysis	A SWOT analysis identifies the Strengths, Weaknesses, Opportunities and Threats of a particular organisation [23].
Porter's 5 forces	Porter's competitive forces are used to make an analysis of the attractiveness of an industry structure [23] & [24].
Risk and uncertainty management	Risk management strategies need to be tailored to the main characteristics of the risk source in question [25]. "Designers should deal with the upside of the probability distribution just as they deal with the downside. They should build in the capability to deal with these extraordinary circumstances. Dealing

Theory	Explanation
	with both the upside and the downside of uncertainties is not incompatible.” [26]
Open innovation	“…systematically encouraging and exploring a wide range of internal and external sources for innovation opportunities, consciously integrating that exploration with firm capabilities and resources, and broadly exploiting those opportunities through multiple channels.” [27] & [28]
Blue ocean strategy	“Competing in overcrowded industries is no way to sustain high performance. The real opportunity is to create blue oceans of uncontested market space.” [29]
Diversification strategy	Diversification strategy is an organisation’s focus on exploiting various industries of operations [23].

Whenever a business enterprise is established it invariable employs a business model. Teece [30] described a business model as that which encapsulates the logic of how the firm combines and utilises its resources to create and deliver value in order to deliver on its strategic objective.

Coupling competitive strategy analysis to business model design requires segmenting the market, creating a value proposition for each segment and combining the resources to deliver value to the segment you are targeting. A good business model will provide considerable value to the customer and collect a viable portion of this in revenues. But developing a successful business model (no matter how novel) is insufficient in and of itself to assure a sustainable competitive advantage.

In order to continually deliver value to the customer and maintain a competitive advantage the firm has to continually adapt the business model to the competitive environment by reviewing the combination of resources along with the structures for revenues and costs.

Critical to a firm’s survival and development once it has established a competitive advantage is its choice of strategy regarding growth [31]. Firms have three primary growth strategies at their disposal [32]: (1) build strategy, i.e. vertical integration and absorbing more activities within the value chain; (2) expand strategy, i.e. entering new markets or product segments; and (3) maintain strategy, i.e. emphasis on market dominance through efficiency, innovation and product differentiation within your current operating segment.

Within the expand and maintain strategies, Burns [33] proposes reviewing product/market strategies with options of (1) market penetration; (2) new product development; (3) new market development; and (4) moving into new markets with new products. Thompson [34] presents how these strategies can be realized though: (1) organic growth; (2) acquisition; (3) strategic alliance; and (4) joint venture. Given these available options studies have produced mixed results with theorists being unable to agree on a best course of action to accelerate growth [1].

Nooteboom [35] argued that a successful growth strategy would take into account the firm specific characteristics related to the size of the firm as well as the interacting internal and external factors. The different decisions and actions would thus follow and hold under different conditions. Given a set of entrepreneurial characteristics which may be beneficial in one configuration or context and action might work adversely in another.

Although the strategic frameworks and growth strategies previously mentioned have been widely accepted and successfully applied in industry, they do not take into account the specific characteristics of small firms and have been biased towards larger, more established corporations [36]. It is important to take into account the specific dimension of SMEs as small firms are not small big firms [1].

Smaller firms within an industry require distinctly different strategies compared to their larger counterparts. The critical requirement for small firms in these industries is strategic flexibility [37]. These firms have to be more flexible, have closer ties with their customers and have the ability to translate their vision into action more efficiently [38].

Smaller companies, generally, are the result of an entrepreneur's initiatives with less formal planning and control functions together with a lack of organisational and administrative systems [36]. These small firms also struggle with limited financial, technological and human resources, little information regarding the market and necessary economies of scale [38].

Although the small firms have numerous advantageous over their developed counterparts the ability and will to develop a business strategy is influenced by entrepreneurial motivation and competency [39]. Unless the firm owner has a strong belief in his ability to formulate a successful strategy and grow the firm they would not attempt formal strategy formulation but rather align their goals along a certain objective referred to as strategic intent.

In an entrepreneurial firm strategic intent, strategic ambitions and concentration on the actions to achieve the firm's objective [40], provides emotional and intellectual energy. Strategic intent is an anti-thesis of strategy focus which attempts to search for a fit between existing resources and emerging opportunities, whereas strategic intent stipulates an aspirational outcome and recognises the misfit between resources and aspirations and attempts to find a means or describes actions to bridge the gap. It provides a sense of direction and purpose for each stakeholder in the firm [41] & [17].

Interviews with founders of 100 major companies in U.S.A. explained that the entrepreneurs of high performing companies adopt strategic intent as a faster and cheaper method of strategy planning [42]. These entrepreneurs integrate action and analysis and emphasise the need for strategic orientation in management, knowledge about market, customers and competitors in a global environment of increasing competition and shortening product and service life-cycles.

In a study on the growth of small and medium manufacturing firm s showed that successful firm s exercised financial control and monitored key variables which relate to the strategic objectives of the firm [43].

2.2 Barriers to Growth

Even with the recognition that SMEs are vital to stimulating entrepreneurship and therefore economic growth, a number of obstacles inhibit SMEs from realising their full potential; a lack of access to managerial skills, finance, equipment and technology, regulatory issues, networks and international markets [44].

The regulatory environment plays a critical role in the establishment and operation of a small business [45]:

- Regulations can both help and hinder entrepreneurs.
- Entrepreneurs needed clear rules, which had to be predictably enforced.
- Over-regulation would impose burdens on all firms and that it could thus be viewed as a prohibitive start-up cost.

Similarly, managerial competencies are fundamental to SME development. Martin and Staines [46] proposed that a lack of managerial competency is the main reason that new firms fail. The lack of support services or their relatively higher unit cost was also found to hamper SMEs' efforts to improve their management. This is because consulting firms are often not equipped with appropriate cost-effective management solutions for SMEs. This was supported by the evidence provided by Kayanula and Quartey [47] who found that, despite numerous institutions providing training and advisory services, there is still a skills gap in the SME sector as a whole due to the inability of many entrepreneurs to afford such services.

Networking has also been established as a critical component to SME development as it can boost performance as well as increase access to finance, expertise, markets and collaborative partners [48]. Shane and Cable [49] concluded that networking reduces information asymmetry regarding negotiations with creditor/debtors and other financiers. Ngoc et al [50] point out that, “in the absence of effective market institutions, networks play an important role in spreading knowledge about a firm's existence and its practices”.

Investment in up-to-date technology is increasingly important to all firms, not only start-ups and SMEs. Technology helps the entrepreneur to implement their strategy by maximising business opportunities [51]. However, the use of technology also involves costs, where new or even established SMEs experience difficulty in purchasing the necessary technology this may hamper their growth and sustainability [52].

One important problem that SMEs often face, as indicated previously, is access to capital [53], and such lack of access or availability can be a practical constraint on firm growth [54]. Cook and Nixson [55]concluded that, “notwithstanding the recognition of the role of SMEs in the development process in many developing countries, SME development is always constrained by the limited availability of financial resources to meet a variety of operational and investment needs”.

Although a host of strategic models have been proposed to aid strategic development, these models do not detail the processes involved in developing the related strategies, nor do they take into account the specific characteristics and limitations of SMEs [1].

3 THE ROLE OF THE VENTURE CAPITAL FIRM IN SMES

In his study published in 2007, Thomas Dickinson proposed that private equity can serve a useful role in addressing many of the SME shortcomings [56]. Private equity fills the gap between the entrepreneur financing the firm himself and that of conventional capital market activity in growing private enterprises.

Private equity can, through its investment in local firms, play a catalytic role more efficiently than other forms of foreign investment where non-financial contributions are not guaranteed. The impact that private equity has had on firm development extends beyond the financial backing through the contribution of business expertise, training, networks as well as skills transfer which would raise the efficiency of the sector being entered [56].

3.1 Venture Capital

Venture capital is the money provided by investors to start-up firms and small businesses with perceived long-term growth potential. It is a very important source of funding for start-ups that do not have access to capital markets. It would typically entail high-risk for the investor, but the high risk carries the potential for above-average returns.[†]

The way venture capital has been defined differs between countries, where some countries include angel financing in venture capital, while in others, venture capital stretches to right before the maturity phase, Figure 2. The authors assume that venture capital financing reaches into early stage firm expansion with the rest of the private equity phases continuing from late stage expansion. Assuming this definition of venture capital does not change the

[†] Venture capital as explained by Investopedia, http://www.investopedia.com/terms/v/venturecapital.asp.

functionality of each phase which is discussed, but the discussions below are focussed on the areas of venture capital as stated by the authors.

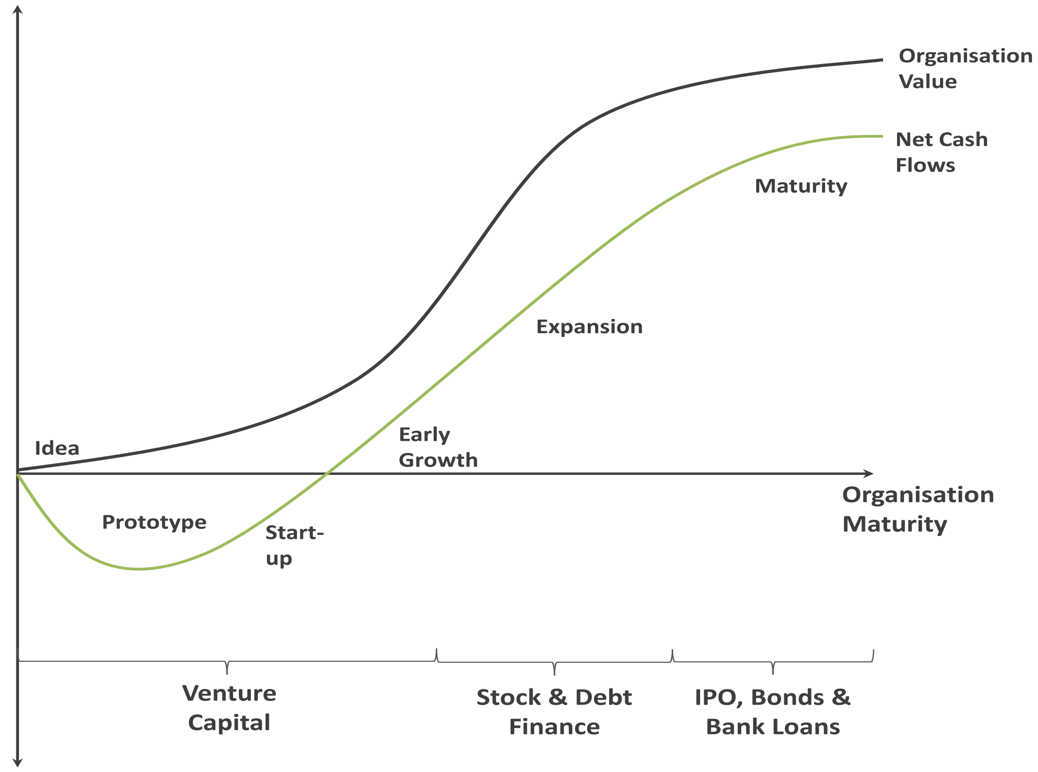

Figure 2: J-Curve: The business cycle and the Financial Demands Per Stage, adapted from [57]and [58]

The US and EU markets have a more developed venture capital market with prospering industries such as the technology industry's Silicon Valley reaping the rewards of the mature venture capital outlook.

In SA, the value of private equity financing that flowed into SMEs was less than R400 million (0.014% of SA's GDP) in 2010 [59], but this is expected to increase as an understanding of private equity and their funds are increased and fund managers will start to venture investments into these alternative assets, according to Regulation 28.

Regulation 28's aim is to ensure that the savings which South Africans contribute toward their retirement are invested in a prudent manner that not only protects the retirement fund member, but is also channelled in ways that would achieve economic development and growth. The portfolio composition is required to comply with the asset limits of Regulation 28[‡]. The alternative investments limit, which increased to 15% of the portfolio's limit, includes hedge funds, private equity funds and other assets, Table 2. It is the increase in this limit which is expected to increase the amount of funds available to private equity and venture capital funds.

[‡] Liberty corporate, available online at: http://www.libertycorporate.co.za/legal-matters/Pages/Regulation-28.aspx

Table 2: Alternative Investments According to Regulation 28 [60]

Asset Sub-Category	Total Limit	Per Issuer
Alternative Investments - up to 15%		
Hedge Funds	10%	Fund of Hedge Funds - 5% Hedge Funds - 2.5%"
Private Equity Funds	10%	Fund of Private Equity Funds - 5% Private Equity Funds - 2.5%"
Other assets not referred to in this schedule (excl. Hedge Fund or PE Fund)	5%	2.50%

3.2 The process of Venture Capital

The success of an investment with a portfolio of investments for a private equity (including venture capital) firm would be managed through the active management of this portfolio of companies and the timing and size of exits. This is accomplished through [61]:

1. Pooling capital in order to invest in private companies (gives smaller investors access to private companies experiencing growth greater than their publicly traded peers),
2. The delegation of investments through fund managers with the required experience and incentives to screen, evaluate and select firms with potential for high growth, and
3. The fund managers source exit opportunities and realise their gains by exiting firms and through this realise a return from the portfolio of firms for the private equity fund's investors.

In order for an investment to be exitable, a suitable buyer for the firm is needed which can be done through a number of means of which the main strategies include a private sale or an Initial Private Offering (IPO). The firm would thus need to be driven up the J-curve towards a purchasable firm or one that is suitable to be offered publicly, Figure 2.

In order for this growth to happen, the firm invested in would need to pass through or skip various stages of firm development in order to have grown. The firm, during initial assessments for investment, will be subjected to assessments in order to evaluate whether this firm will be able to survive through the various developmental phases into a position to be exitable.

The risks in a firm, as it moves from start-up to expansion differs. The initial risk in a start-up is predominantly the product risk (as in the risk of whether a product/service will be adopted) which transfer to the risk of whether the business is scalable or vertically integratable, collectively known as expandability risk along with management's ability to deliver on the strategic objective, namely execution risk.

The common investor assessment stages found in early stage financing, Figure 3, describes how an firm is initially evaluated based on the tangible, objective criteria, but this moves to a less tangible, more subjective dimension which is more observable in the entrepreneur's presentation. The team size or experience is less important in the later assessment stages compared to the significance of the entrepreneur's social skills such as impression management, persuasiveness, ability to think on their feet and to answer questions and advise over measurable factors [62].

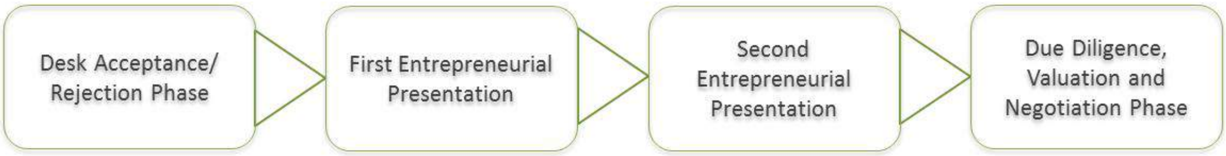

Figure 3: Common investor assessment stages of an firm adapted from [62]

In the end, the investor's view (be it influenced by the entrepreneur or not) determines investment readiness based on the firm's team, its operations, customer base, skills and competencies, its potential to scale and weighed against investment risks and returns and time to exit, [63] and [64].

The most important differences in the perceptions of investment readiness were summed up to the following four points, [62]:

- They must have some form of intellectual property,
- They require a fully formed management team with experience,
- They should have a product/service in the advanced stages of development, and
- They should have some established customer base.

These gaps need to be addressed by the entrepreneur to ensure that he has an increased opportunity of successfully applying for funding.

3.3 The Venture Capital Valuation Process

The difficulty for venture capitalists is the complication in the valuation process in an entity where the price is not defined by a market, but through the financial considerations which play only a small part next to other considerations such as the industry characteristics (structure, trends and markets) and the firm's characteristics (development stage, competitiveness, etc). Mainstream finance theory measures the economic value of any investment through the present value of future cash flow which presents some difficulty when applied to firm s in the early stage of its development as most information is not available to deliver on this calculation. This has often been the frustration between VCs and the entrepreneur and which is why an entrepreneur can set his firm up in a way which would result in higher valuations by VCs.

Research on VC valuation methods has highlighted the main factors which are taken into consideration when determining the value of a firm, [65]:

- Top management and the entrepreneur (arguably the most important)

  The firm is valued significantly higher if top management has the relevant industry experience, relevant managerial and start-up experiences prior to playing a role in the current firm. The spread of skills in top management also reduces the key man dependency risk.

- Differentiated industries

  Firms which operate in highly differentiated industries with positive industry growth add to the pre-money valuation of an organisation.

- Networks

  There exists a high correlation between the size of a network and the valuation given by the VC firm. The role of alliances and innovation capability positively influences the organisation's performance and its perception by the VC firm. The quantity and quality of these networks are salient signals to the VC firm which positively correlates to the speed and valuation of an IPO.

The set of criteria that can be addressed to increase the value of the organisation is found to be negatively correlated with the organisation's risk which highlights a higher probability of success for the organisation. The probability of success is also increased by VC firms through their non-financial contributions to the firm.

3.4 The non-financial Venture Capital contributions

Once the VC has selected an organisation as investment worthy, it will provide the organisation with the funding and coaching it deems necessary to develop its potential. VC firms that provide support for their investments see better performance and a more substantial return-on-investment, [66]and [67].

VC firms' exposure to a large number of organisations builds the necessary experience which results in an in-depth knowledge of the elements required at each stage of organisational development [67]. This experience, together with their extensive network of contacts, is crucial when deciding on an investment and the appropriate resources and configuration needed to grow the firm.

According to [67], [65], [63], [62], [64], [68], VCs address many of the barriers faced by SMEs beyond financial contributions highlighted in the following sub-headings:

- Entrepreneur and top management

  The VC firm's role in coaching and obtaining buy-in from the entrepreneur and top management regarding the strategy and operation of the firm.

- Industry structure

  The VC firm's leverage off its current resources in order to test future products and services in the market, evaluate customer needs, understand possible untapped markets, and connections within the industry.

- Firm structure

  A firm's ability to innovate as well as the human resources management practices form an important part of the resource based view which acknowledges the firm's resources as important for its competitive advantage.

  - Innovation capability

    VC firms facilitate the social ties with economic partners which supports the collaborative innovation capabilities of a firm. These ties lead to knowledge transfer which reduces the product development period and time to market.

  - Human Resources Management (HRM) Capability

    The HRM practices and employee retention is reduced through the VC firm's tacit knowledge (rewards systems, recruitment-, evaluation- and performance policies) which reduces HRM issues and thus increases the firm's probability of success.

- Networks

  VC firms use their networking capabilities to draw on the collaborative resources and expertise of a network. The networking capability adds a level of legitimacy which allows firms to obtain resources that would have been otherwise unavailable.

The firm's strategic readiness is one of the highlighted cogs that are assessed when the firm applies for financing. This preparedness of a firm's people, systems and structure to deliver on its strategy are defined by the intangible assets that are the foundation for strategic change, which most often involves new markets, products or corporate transformation [69].

4 STRATEGIC FRAMEWORK

Models are used to develop theories by isolating and studying a few key input and output variables under situation specific conditions [70]. These models are usually rigorous and have limited complexity with their relevance being a function of fit between its assumptions and reality. In strategy, no one model can embody all the variables of interest and thus the applicability of any model's findings are almost inevitably restricted to a small group of firms or industries whose characteristics fit the model's assumptions.

A framework in contrast encompasses many variables and seeks to capture as much of the complexity of practical situations. The framework provides the necessary variable and questions the user must answer in an attempt to guide the user to develop conclusions tailored to an industry and/or a firm [70]. The theory embodied in frameworks is contained in the choice of included variables, the way variables are organised, the interactions among the variables, and the way in which alternative patterns of variables and firm choices affect outcomes.

A framework allows for the fact that not all the interactions among variables can be rigorously drawn. The framework seeks to help the analyst to better think through the problem through understanding the firm and its environment, and defining and selecting among the strategic alternatives available, no matter the industry or starting position.

It is based on this thought process that a framework is used to build on the variables generated and proven by more simplistic situation specific models as defined through the background on the industry and fields of study.

4.1 Systems Engineering Approach to Problem Solving

The systems engineering approach to solving complex problems is to deconstruct the problem into functional units, finding a solution for each problem, reviewing the interaction of the various solutions, and where necessary finding new solutions, in order that the reconstructed holistic system may be the most efficient recombination of the various individual solutions.

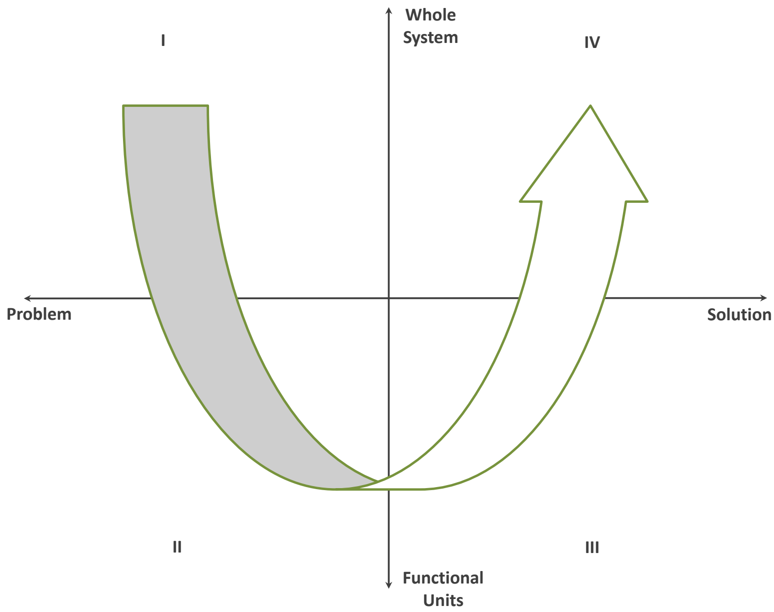

Figure 4: Flow of real world problem solving adapted from [71]

Figure 4 illustrates this approach as a system problem might be complex as a whole (I), but it needs to be broken down into smaller sub-problems (II). It is in the second quadrant where a greater understanding of the source of the individual issues is unearthed. A large number of sub-solutions can be found for the sub-problems (III) which can be pieced together to find a solution for the whole (IV).

An important part in a system's approach to problem solving is to ensure that the desired objective of the system is reached. A way in which to ensure this is through built-in feedback systems. In the real world flow op problem solving, this feedback system would be embedded between each of the quadrants.

4.2 Venture Architecture Framework

The Venture Architecture (VA) framework utilises the systems engineering approach to guide the entrepreneur through specific processes in order to formulate a tailored strategy and business model for their industry and environment.

Through the research on common growth barriers for SMEs, the role of venture capital, strategic formulation, and the system's engineering approach, the VA framework guides the entrepreneur and SME management team to develop a successful value proposition, business model and strategy in order align the SME with the value curve and attain the necessary funding and VC expertise to grow the business.

The VA framework, Figure 5, uses the same flow of information as detailed in Figure 4 and utilises proven tools and models to guide the entrepreneur or SME management to answer the relevant questions posed at each stage. The tools given in Table 1 and Figure 5 might be old or new, but they have been used through the authors' perspective on what is applicable.

These tools are given here to guide the entrepreneur to utilize them in a different way to reach the desired objectives per quadrant. These tools are not the only ones applicable to the task at hand as the framework is live and thus no exact recipe should dictate how strategists reach the deliverables.

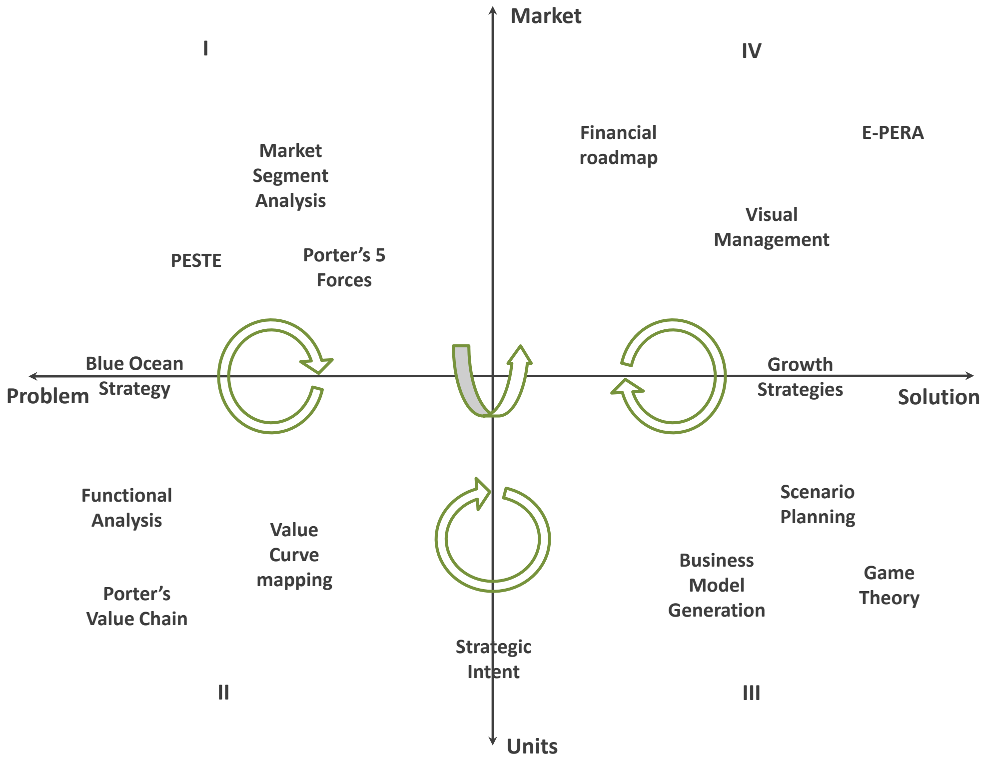

Figure 5: The Venture Architecture Framework

The **1st quadrant** (Q1) begins where every endeavour should start, by analysing the external market conditions. The tools prescribed to the entrepreneur or SME management should provide them with insight regarding the following issues (applicable tool provided in brackets):

- What are the future industry trends (PESTE)?
- What is current industry structure (Porter's Five forces)?
- How is the industry currently delivering value to the various market segments (Market Segmentation)?

The objective of the quadrant is to:

- Identify a displacement between segment needs and current offerings in the market (Blue Ocean Strategy).

The **2nd quadrant** (Q2) applies functional analysis to Porter's Value Chain & Value System (Porter 1991) to identify the various system, technology and resource elements used to perform the business functions. This is conducted along the various stages of the value curve, coined here as Value Curve Mapping, in order for the entrepreneur or SME management to answer the question:

- How (elements) are industry participants currently combining the various elements within the business function to deliver value to the customer?

The **3rd quadrant** (Q3) seeks to formulate a business model as a means for the firm to fulfill its strategic intent to deliver true value to a displaced customers segment (question asked in Q1). Utilising the knowledge regarding the elements able to perform the various business functions the business model should employ a combination of business elements which efficienctly and effectively delivers value to the customer together with various isolating mechanisms which would prevent the business strategy from being undermined by imitation by competitors or disintermediation by customers [30].

Deciding on a growth strategy to best deploy the business model the **4th quadrant** (Q4) aims to guide the entrepreneur to define how capital will be utilised to effect firm growth through one or all of the following strategies: vertical integration, efficiency gains? or expansion by means of a financial roadmap. By using the E-PERA framework the entrpreneur or SME management would have to define the systems and procedures to plan, co-ordinate and control the various business functions. By designing and implementing a visual management system the firm will have created a structured communication system and make knowledge more explicit and less tacit. The quadrant aims to address risk related to growth by providing the necessary structure and visibility of the way forward (Nooteboom, 2002)

The role of feedback in Figure 5, depicted by the circular arrow between the quadrants, highlights the fact that, as Eric Sevareid [71]put it, "The chief cause of problems is solutions". Every model, plan, mitigation strategy, etc. needs to be tested to ensure that it still fulfills its role without being the cause for larger issues.

5 CONCLUSION

As discussed in section 3.1 strategic models and frameworks have the ability to explain a firm's competitive advantage at a single point in time, however they neglect to detail the processes involved in developing the respective strategy and achieving the subsequent success.

The VA framework addresses the shortcomings of current strategic models in that it:

- takes into account the specific characteristics of SMEs;
- guides the user through detailed processes to formulate a strategy and business model; and
- is not specific to an industry or sector; and
- helps an entrepreneur build a strategy for his/her business.

The framework allows SMES to address their specific shortcomings through a combination of risk mitigating factors or actions in order to align their strategic intent and business model with venture capital demands to gain access to the necessary funding to grow their firm and leverage off the non-financial resources of the VC firms.

Ultimately the framework unites management and investors behind a unified vision, provides motivation in the form of strategic intent and installs the necessary communication and project management infrastructure to ensure plans are translated into action. The application of the VA framework to a specific set of SMEs will be illustrated at the presentation.

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ASSESSING THE TECHNOLOGY ACCEPTANCE OF CELL PHONES WITHIN THE CONTEXT OF THE PRIMARY HEALTH CARE SYSTEM OF SOUTH AFRICA

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ABSTRACT

The use of cell phones for health services and communication (mHealth) can potentially strengthen health systems in South Africa. This study is particularly concerned about the feasibility of cell phones to address the problem of limited access to health care in South Africa.

One of the success factors in the use of technology for service innovation is the degree of technology acceptance. The acceptance of mHealth in the South African context is not known.

The technology acceptance model (TAM) can be used to evaluate mHealth acceptance in South Africa. In this paper the evolution of the technology acceptance model (TAM) is reviewed, together with variations of the model that is applicable to mHealth services. A pilot study was performed in the private health care sector of the Western Cape, which showed a mean neutral response to using mHealth. Strong notions against using mHealth balanced as many positive notions towards using mHealth.

Future work includes a full scale study considering elements from both the TAM, together with e-business adoption elements.

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1 INTRODUCTION

1.1 What is eHealth and mHealth?

1.1.1 eHealth

The word “eHealth” (also written e-health) comes from a combination of “health” and the “e” in electronic. The term was first used by with other “e-words” to convey the new opportunities that the Internet could bring to healthcare [1]. A variety of definitions exist for eHealth, and no standard definition has been agreed upon. From a systematic review of published definitions [2] two universal themes of “health” and “technology” was identified. For this study, the definition from Vital Wave Consulting [3] is used, namely “the use of information and communication technologies (ICT) for health services and information.”

1.1.2 mHealth

The word “mHealth” (also written m-health or mobile health) is the combination of “health” and the “m” in mobile. The term was first defined in 2003 by Istepanian [4] as “the exploitation of the mobile telecommunication and multimedia technologies and their integration into new mobile health care delivery systems”. mHealth form part of eHealth, seeing that mobile phones are part of ICT. The definition for mHealth used for this study is also from Vital Wave Consulting [3] used, being “the use of mobile communications for health services and information”.

1.2 A problem in South African healthcare

In 2002 the UN launched the Millennium Development Goals (MDGs) which define various targets for nations to reach by 2015. Three of these goals are health related [5]:

- MDG4: Reduce mortality of children under 5 years of age (target two-thirds reduction 1990–2015)
- MDG5: Improve maternal health (target three-quarters reduction of maternal mortality per 100 000 live births 1990–2015)
- MDG6: Combat HIV, AIDS, malaria, and other diseases

From 1990 – 2009 South Africa has shown a reversal of progress on MDG 4, with no progress on MDG 5, and insufficient progress on MDG 6 [6]. In 2009 child mortality was 69 per 1000 live births, with maternal mortality being 400–625 per 100 000 live births [7].

The primary health care system of South Africa has limited resources to address these health care needs. With only 0.13 doctors per 1000 patients and 1.9 hospital beds available per 1000 patient in the public sector [8], access to health care in South Africa is limited.

1.3 The Potential of mHealth to address this problem

The large scale uptake of mobile phones has created a platform that can be exploited to increase access to healthcare services and information. Mobile phones are able to reach further than any other technology or health infrastructure [3]. In South Africa over 99% of the population is covered by a mobile phone network [9], with 90% of households having a functional mobile phone in their dwellings [10].

Both the United Nations (UN) and the World Health Organization (WHO) have recognized the potential of using mHealth [11]. In a global survey on mHealth [3] 112 countries reported at least one mHealth initiative.

With mHealth being a new development, concrete evidence is still growing to show the benefit of using mHealth. Thus far, the following benefits have been shown [3]:

- Increased access to healthcare information
- Improved ability to diagnose and monitor sicknesses
- The delivery of health information that is both more appropriate and applicable
- Increased access to continual training for health workers

1.4 Technology acceptance

Even though the need for mHealth services exists, the acceptance of using cell phones for health care services has to be investigated. One model that is extensively used for technology acceptance prediction is the technology acceptance model (TAM). The main factors for the TAM's wide spread use is given below: [12]

1. It is economical, IT-specific, and offers adequate explanation and prediction on diverse populations in diverse contexts
2. It is grounded in sound theory with well researched and validated psychometric scales
3. It has gained much empirical support for its explanatory ability and has become a leading model for acceptance of technology.

2 PURPOSE AND METHODOLOGY

The purpose of this paper is to investigate the assessment of technology acceptance for cell phones within primary health care system of South Africa.

This accomplished firstly through a review of the technology acceptance model (TAM), together with variations of the model that is applicable to mHealth services. Secondly, a pilot study is described in which a technology acceptance questionnaire was administered amongst a sample of private health care facilities in the Western Cape.

Future work is described, including the model that will be used to assess technology acceptance of cell phones.

3 TECHNOLOGY ACCEPTANCE MODEL (TAM)

3.1 Origins

The technology acceptance model (TAM) was first proposed by Fred Davis in 1985, based on the Theory of Reasoned Action by Fishbein and Ajzen [13]. The model suggested that motivation to use a system can be explained by three factors: Perceived ease of Use, Perceived Usefulness and Attitude towards Using [14].

In 1989 Davis, Bagozzi and Warshaw modified TAM to include the variable "behavioural intention to use". After a longitudinal study in 1989 they concluded that perceived usefulness (PU) and perceived ease of use (PEOU) have a direct influence on behavioural intention (BI), thus eliminating the need for the attitude towards using variable. The TAM was finalized in 1996 by Venkatesh and Davis into the model as shown in. [14]

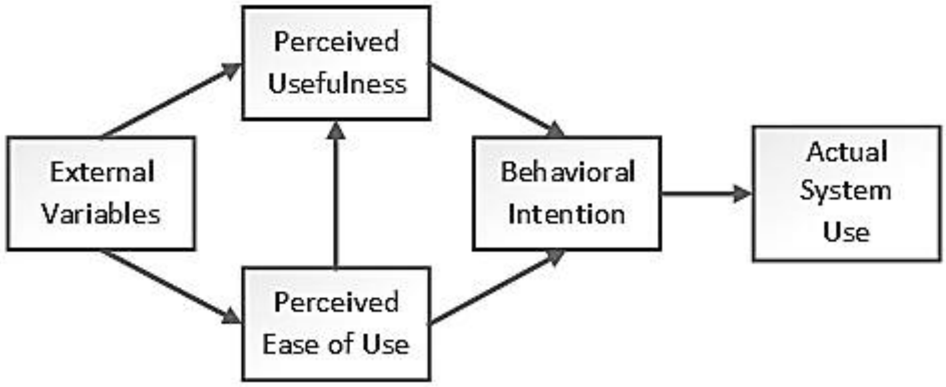

Figure 1: Final version of TAM [3]

3.2 Development

Although TAM predicted system usage, it could not explain the reasons behind users' perception of system usefulness. In 2000 Venkatesh and Davis [14] addressed this limitation by developing TAM 2 which includes additional variables that act on perceived usefulness (PU). They continued to work on TAM by including variables in an extended model of TAM in 2000 to explain factors that act upon perceived ease of use (PEOU) [15].

In 2003 Venkatesh, et al [16] combined previous research on information technology acceptance into the unified theory of acceptance and use of technology (UTAUT).

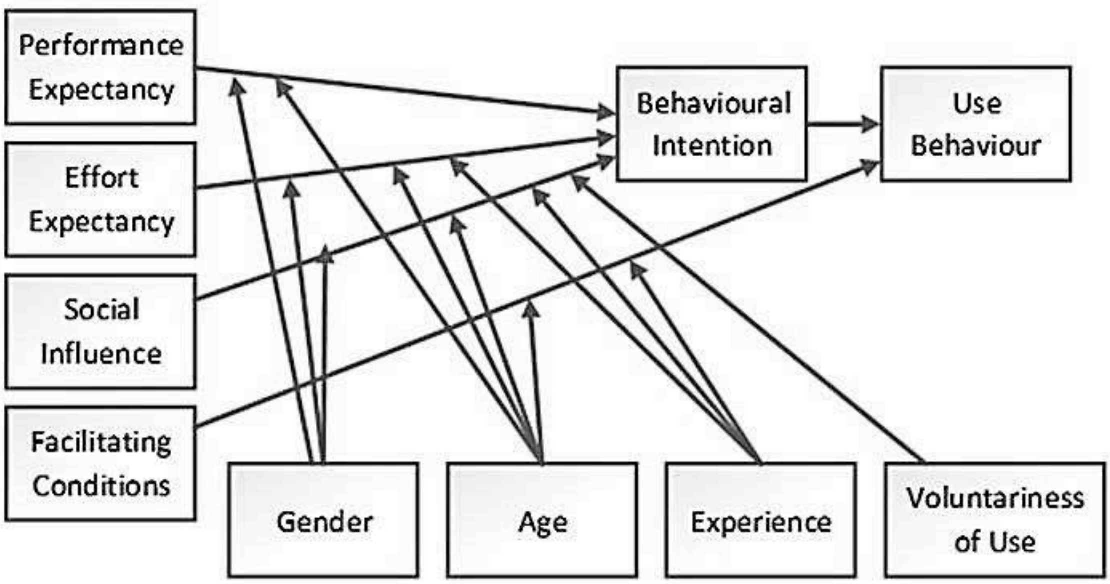

Figure 2: The Unified Theory of Acceptance and Use of Technology (UTAUT) [5]

A study by Cilliers and Flowerday [17] applied the UTAUT to health information systems in the Eastern Cape Province. A population of clinics were surveyed with telemedicine systems already implemented. Results showed that social influence and facilitating conditions influenced acceptance of using telemedicine. Lack of awareness and lack of knowledge were identified as barriers to implementing telemedicine.

3.3 Extensions

The TAM has been extended or combined with a variety of models in order to describe technology acceptance in a diversity of fields. In the research field of cell phones, mobile commerce has received a lot of attention [18]. Models extending TAM has also been developed for mobile commerce [19], but this study focusses on the field of using cell phones for health care. Applicable models are hence reviewed.

3.3.1 E-Health

Wilson and Lankton [20] tested the TAM, motivational model and an integrated model (Figure 3) on users registered for an e-health service. It was found that all three models predicted behavioural intent well. The integrated model did not predict behavioural intent better that the other two models. Perceived usefulness extrinsic motivation (PUEM) was common for the models and predicted 68% of the variance in the behavioural intention (BI).

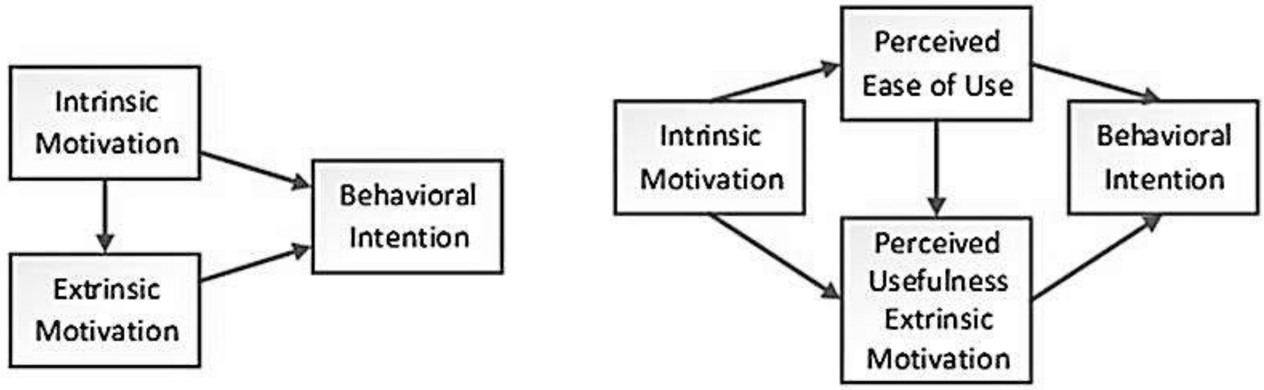

Figure 3: Motivational model (left) and integrated model (right) [8]

The above study showed that perceived usefulness (PU) is a major predictor of behavioural intention (BI).

3.3.2 Mobile service

López-Nicolás et al. [21] extended the TAM in order to describe user acceptance of mobile services (Figure 4). Variables related to the theory of diffusion of innovation (DOI) were included in the model, in term of social influences. All relationships were found significant except between perceived status benefits and perceived usefulness.

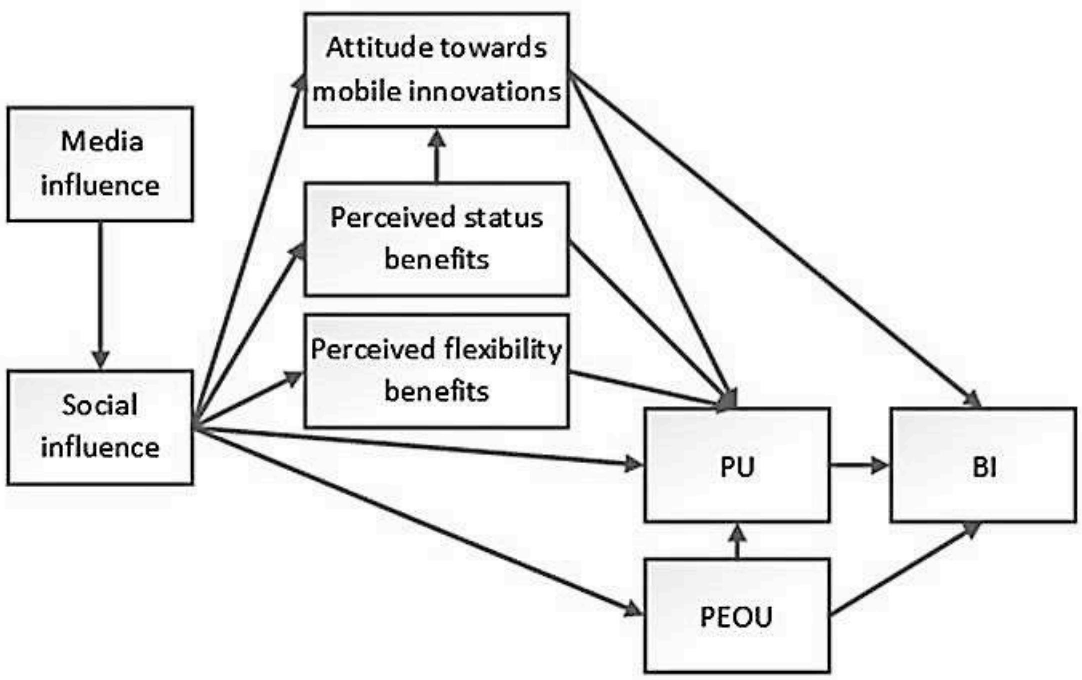

Figure 4: Concept model for mobile service acceptance [9]

The above show that attitude towards innovations have a significant influence on behavioural intention (BI).

3.3.3 Mobile health care

Wu et al. [22] combined the TAM with the model from theory of planned behaviour in order to describe hospital professionals' acceptance of mobile health care (Figure 5).

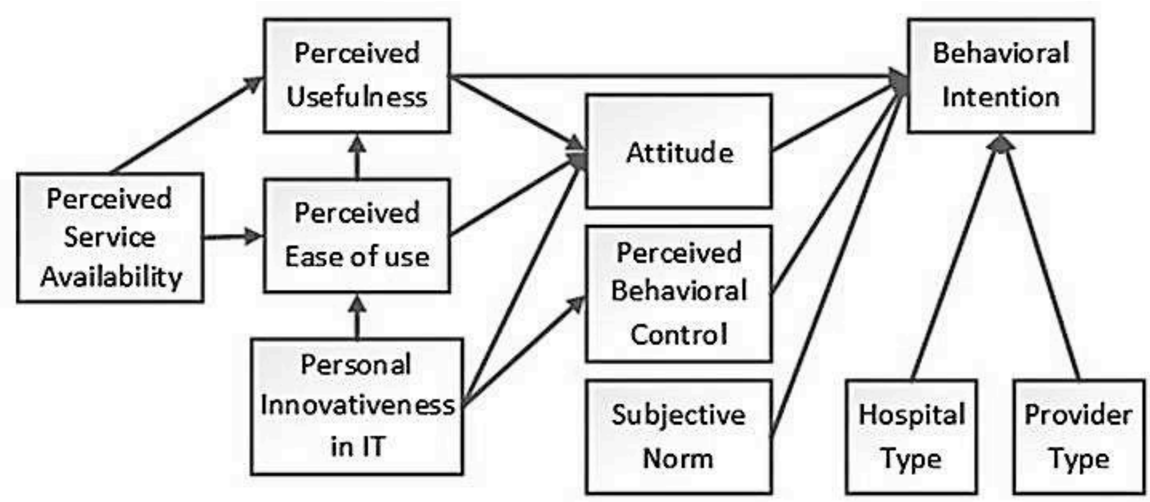

Figure 5: Adoption model for mobile health care [10]

Significant influences of the behavioural intention antecedents were reported. Perceived usefulness in particular was found to be a key factor in promising the use of mobile health care. Larger hospitals were also found to have a higher intention to use mobile health care, likely due to resource availability and responsibility for quality health care services.

3.4 Summary

TAM is a flexible tool to use, and has good empirical evidence for predicting technology acceptance. For the field of mobile health care TAM has been adapted for the specific context. Additional variables have been included to better predict behavioural intention.

4 PILOT STUDY

A pilot study was done in order to explore the South African environment for mobile health care services.

4.1 Method

The population for the pilot study consisted of private health care facilities, with pharmaceutical businesses making up most of the respondents. Surveys were given through e-mail or telephonically.

The survey was based on the integrated model (See section 3.3.1), to investigate a broader field of "using mobile phones for work purposes in health practices". The model considers the factors behavioural intention (BI), internal motivation (IM), perceived ease of use (PEOU), and perceived usefulness external motivation (PU-EM). Statements were created to describe these factors for which respondents rated their level of agreement to the statements. The scales reached from 1-7 ranging from strongly disagree to strongly agree, with 4 being neutral.

4.2 Results

Of the 83 surveys that were sent out, 13 surveys were completed in full, with one incomplete survey being discarded. Hence, the response rate was 15%. Table 1 shows the results from a descriptive analysis of the responses, with Figure 6 showing a frequency analysis of responses.

Table 1: Pilot survey descriptive results

	Median	Inter Quartile Range	Positive responses
BI	4	5	38%
IM	4	4	43%
PEOU	5	3	60%
PU-EM	4.5	5	50%

From Table 1 it can be seen that the medians for the factors were neutral or near neutral. The behavioural intention had the least positive responses, showing an overall neutral or negative response. The perceived ease of use had a small inter quartile range, with the most positive responses. This shows that a high perceived ease of use does not necessarily reflect a high behavioural intention. Perceived ease of use may be a qualifier for behavioural intention in this context of cell phone usage.

From Figure 6 it can be seen that responses were either strongly negative or positive skewed to the right. Perceived ease of use (PEOU) received the highest positive ratings, with perceived usefulness external motivation (PU-EM) receiving the most negative responses.

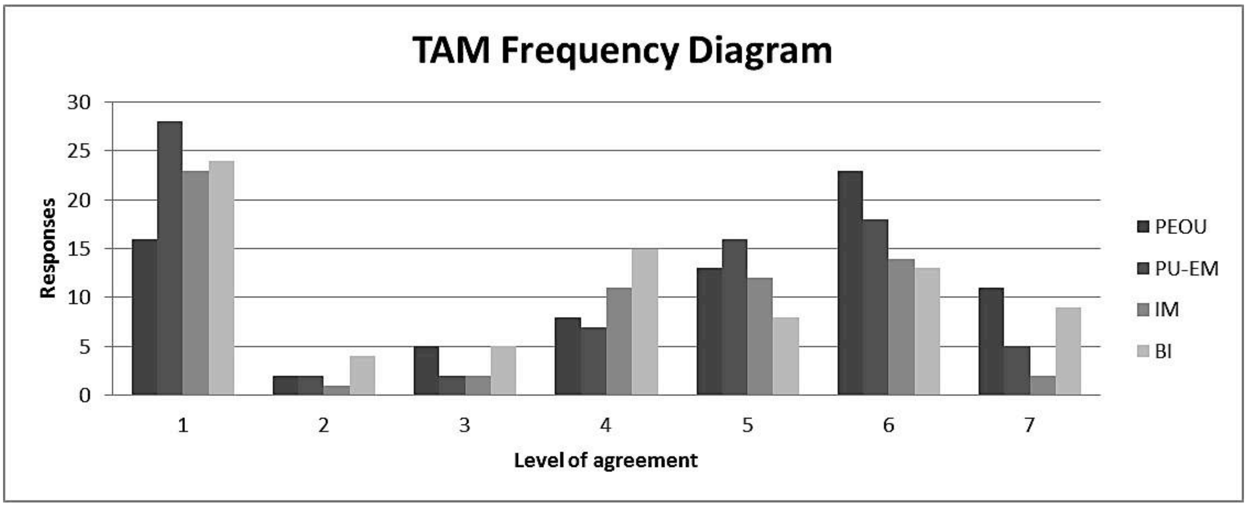

Figure 6: Frequency analysis of responses

4.3 Discussion

The percentage of respondents could be increased with more rigorous screening of potential respondents. The pilot study showed neutral median responses, with strong opinions for those that were against the use of cell phones for work purposes. Behavioural intention was not found strongly positive, even though perceived ease of use was found mostly positive.

Additional comments from the surveys showed that some employees were not allowed cell phones at work, and that some managers were strongly against the use of cell phones by employees. Other managers indicated that they saw no need for cell phones at work, seeing that they have sufficient ICT infrastructure. This could explain some the strong negative responses.

5 CONCLUSION AND FUTURE WORK

In view of pilot study, the research focus of the full scale study will be from the perspective of health care institutes regarding the exploitation of the customer's cell phone for providing value adding health care services (using mHealth services). The population will be managers from private health care facilities including pharmacies (both retails and service) and hospitals. For the full scale study, a model will be used that combines results from research as reviewed in this paper. The following section describes the model and the basis of elements used.

5.1 Model

5.1.1 Elements for TAM

In order to measure the technology acceptance of managers, the following elements will be used in the model:

- Behavioural intention
- Perceived usefulness
- Attitude
- Institution Size

These first three elements were chosen because they directly work upon the behavioural intention, which in turn works on the actual use. Perceived ease of use will not be included, as it is expected to be high for cell phones, regardless of behavioural intention. The size of the facility was included, seeing that larger hospitals were found to show a greater behavioural intention (see 3.3.3).

5.1.2 Measuring context

In order to measure the context behind responses to technology acceptance, a model regarding the business's technology adoption will be included. An extensive review of models used in determining technology adoption at firm level was conducted by Oliveira and Martins [23]. One model, also by Oliveira and Martins [24], investigated e-business adoption. This model was tested extensively and concluded that the following factors influence a business's adoption of e-business:

- Perceived benefits and obstacles of e-business
- Technology readiness
- Competitive pressure
- Trading partner collaboration

Including these factors in the survey, together with factors from technology acceptance, will give a wide picture of the acceptance of the private health care sector for cell phone based health care services. The proposed model is shown in Figure 7.

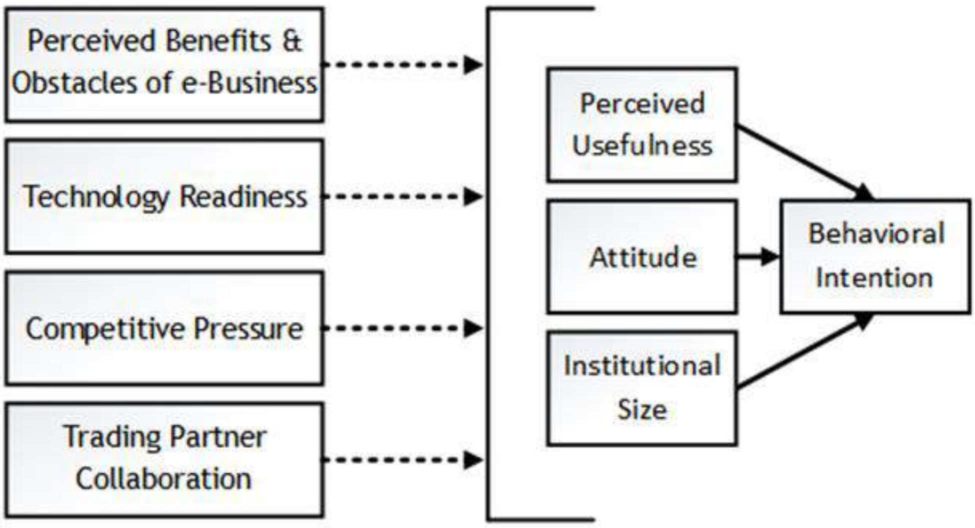

Figure 7: Proposed acceptance model for cell phone based health care

5.2 Conclusion

By applying the above model, empirical data concerning the market for using cell phones in primary health care of South Africa can be determined. This information could be used to develop systems to improve health services and information delivery.

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DEVELOPMENT OF A TOTAL PRODUCTIVE MAINTENANCE REPORT CARD FOR CRITICAL MACHINES

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ABSTRACT

This project describes a total productive maintenance (TPM) implementation at the Weir Minerals Africa Isando plant where previously a critical machine experienced a breakdown lasting 30 minutes or more every day. A system was created to track the number of breakdowns and availability of critical machines. The proposed solution consists of a report card for each critical machine, which includes a machine diagram, the frequency of breakdowns, a root cause analysis, a list of critical spares and a planned maintenance schedule. The proposed solution is a starting point upon which a comprehensive preventative maintenance program will be developed.

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1 INTRODUCTION

1.1 Background

The ever-increasing competition in today's industry has compelled delivery commitments and operating costs to be an important consideration when securing customers. Costs associated with equipment breakdowns, degraded equipment and unavailability of spares and data, lead to downtime of the plant, production losses and wasteful activities. In order to meet increased market expectations and reduce operating costs, industries have focused efforts on reducing unplanned downtime. The maintenance department is being increasingly viewed as an indispensable function of the production system [1-3].

A Weir Minerals Africa plant in Isando South Africa has initiated a maintenance improvement plan to minimise equipment downtime and increase equipment availability. The plant's current maintenance programme is reactive and plant machinery suffers from a high level of downtime. This paper describes the design and initial results of a maintenance and reliability engineering programme to implement best practices at this plant.

1.2 Literature Review

Total productive maintenance (TPM) originated as a response to the need for the improvement in operational performance. According to Nakajima [4], TPM is a company-wide initiative to achieve zero machine breakdowns and defects. By eliminating these breakdowns and defects, operational efficiency and productivity can improve with a reduction in cost and inventory. TPM is a widely used strategy for enhancing maintenance performance. It has been successfully implemented in organisations for over three decades and is vital tool for any organisation to sustain its competitive advantage [5].

To date, relatively little research has been conducted on the implementation of TPM within the South African context. A search conducted in the South African Journal of Industrial Engineering on the keywords, "*TPM*" and "*total productive maintenance*" revealed no results. A Google Scholar search on the keywords, "*total productive maintenance in South Africa*" revealed only one study on TPM [6]. A further Masters dissertation [7] detailing a TPM case study in South Africa was found.

Van der Wal and Lynn [6] qualitatively observed perceptions of TPM and its implementation at a paper mill in South Africa. The effects which TPM implementation had on employee development, productivity, quality and change in the organisation were examined. TPM was implemented through the establishment of multi-disciplinary teams and continuous improvement projects which allowed employees to assist in the improvement of plant productivity and organisational competitiveness. Results from the study indicated that through the implementation of TPM activities, including visual management, autonomous maintenance and company-wide involvement, improvements in quality, productivity and cost were observed.

A more recent study, conducted by Ncube [7], examined the implementation of TPM on the manufacturing performance of a Mitsubishi Colt production facility. The findings indicated that the successful implementation of TPM needs both production and maintenance departments to be involved. Furthermore, it was observed that training is essential to observe the positive impact that TPM has in the plant.

1.3 Aim of this Study

The lack of research on TPM in the South African manufacturing environment highlights the need for such a study. This case study will raise the profile of TPM in South Africa and illustrate important aspects of the approach such as maximising equipment effectiveness, improving maintainability and ensuring total participation of employees [1].

2 METHODOLOGY

The Weir Group consists of three divisions: Minerals, Oil and Gas, and Power and Industrial. The Minerals division manufactures slurry equipment including pumps, screens and rubber linings for the mining and minerals industry. The Weir Minerals Isando site primarily manufactures slurry pumps and houses a machine shop, rubber plant, foundry and pump test bay facilities. The Maintenance Department at this site carries out all planned and unplanned maintenance on all machines in the plant.

TPM focuses on what are called the six big losses: breakdowns, setups, small stops, reduced speed, start-up rejects and production rejects. The scope of this project was narrowed down to focus only on breakdowns.

The data obtained from the plant's computer maintenance management system (CMMS) was inaccurate and incomplete. This required that data be collected using temporary systems using Microsoft Excel to verify the frequency of breakdowns and the availability of the critical machines. These temporary systems were used to analyse the current state in Section 3.

This quantitative data was augmented using a semi-structured interview with maintenance personnel to obtain in-depth information regarding critical components of the machine as well as critical spares.

The initial first step in the project was to incorporate the CMMS into the day-to-day tasks of the maintenance personnel so that they would receive better guidance and so that the maintenance function could be better measured and managed.

3 CURRENT STATE ANALYSIS

3.1 Identification of Critical Equipment

An equipment impact matrix which positions the various machines according to financial cost of repairing the failure versus impact of failure on operations was created, as shown in Figure 1. Critical machines with a high financial cost of repair and a high impact on operations were considered for further analysis as they have the greatest impact on plant operations.

Financial Cost of Repairing Major Failure		Low	Medium	High
	Above R150000		•Compressor •Boiler 3T/H •Shot blast rub •Heat treat 1&2 •Auto clave 1&2 •Fastloop •Femco H •Top hat 1&2 •Femco VL 12s •Gen set	•Intermixer •Black mill •Festoon •White mill •Press 6 •Press 14 •Press 15 •Press 16 •Kuraki •Dorries •Scrap crane •Shake out •Furnace trans •WEB136 •WEB 105 •WEB 106 •Cincinnati
	Above R5000		•Chemlock booth •Generators •Hanger shot blast	•Foundary transformer •M/C transformer •Rubber plant transformer •Furnace control system •Fastloop PLCs
	Below R5000	•Tools •Air guns •Grinders		
		Impact of Major Failure on Operations		

Figure 1: Equipment impact matrix

3.2 Number of Breakdowns and Availability

Details of critical machine breakdowns were obtained from morning maintenance meetings in which the previous and current day's breakdowns were discussed. The data recording began on 8 October 2012 and will continue to be used to develop a database to record the operating history of the equipment until the CMMS is fully functional.

Using this information, the number of breakdowns of critical machines was calculated to determine trends. Data for the month of December were omitted as this is the period during which planned maintenance is carried out. Figure 2 shows the number of breakdowns averaged over the period of October 2012 to January 2013.

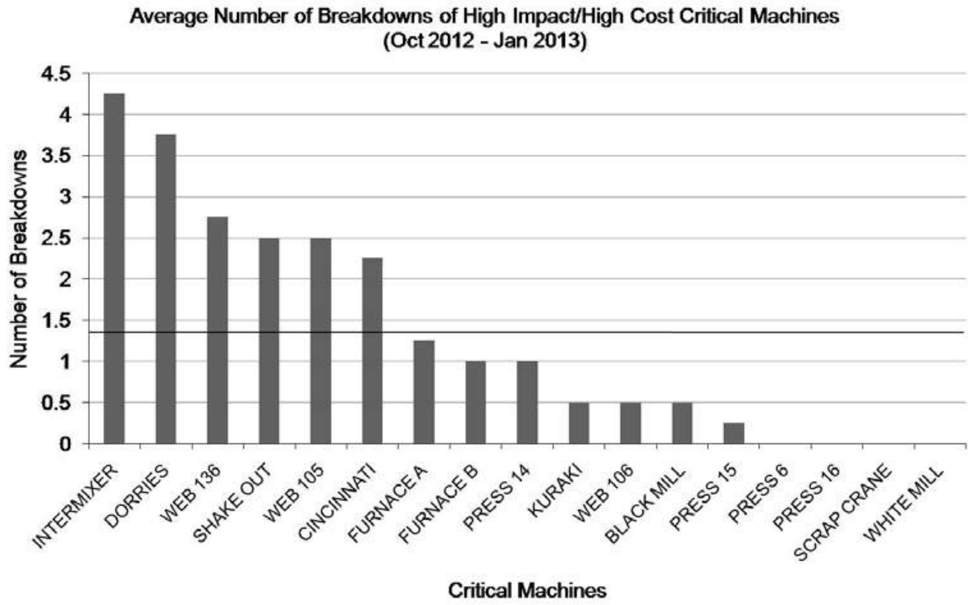

Figure 2: Frequency of critical machine breakdowns from Oct 2012 to Jan 2013

Based on the number of breakdowns, the available hours for all the critical machines were averaged over the months under consideration. The percent availability was averaged over the indicated period and is shown in Figure 3.

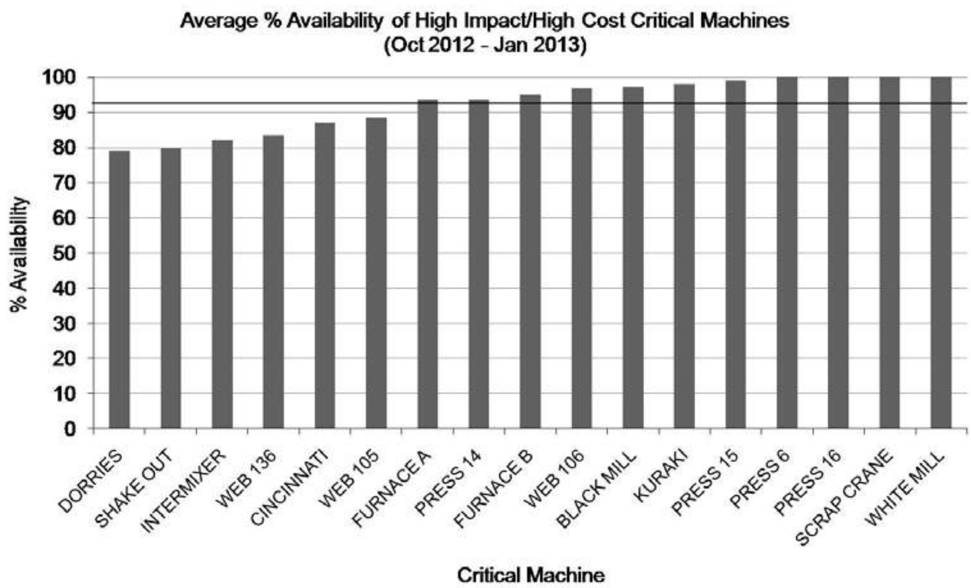

Figure 3: Availability of critical machines for Oct 2012 to Jan 2013

The average machine availability is approximately 92%. This is below the world-class benchmark of 97% [8].The benchmark value of 97% is specific to mechanical availability and where maintenance activities employed are corrective, rather than preventative, in nature. [8].

4 RESULTS AND DISCUSSION

4.1 Proposed Solution

Information used to improve the machine availability was obtained through interviews with maintenance personnel as well those responsible for implementing the plant's CMMS. This proposed solution involves implementing a total productive maintenance plan on the CMMS that includes a report card for each critical machine. The report card details: a picture of the machine, a machine diagram, the frequency of breakdowns, a root cause analysis, the critical spares, and a planned maintenance schedule. These will be discussed in turn.

The machine diagram highlights the strategic functional components which are crucial to the machine's operation. In addition, the sub-components and sub-systems are noted as well as their interaction with one another. Figure 4 shows an example of a machine diagram.

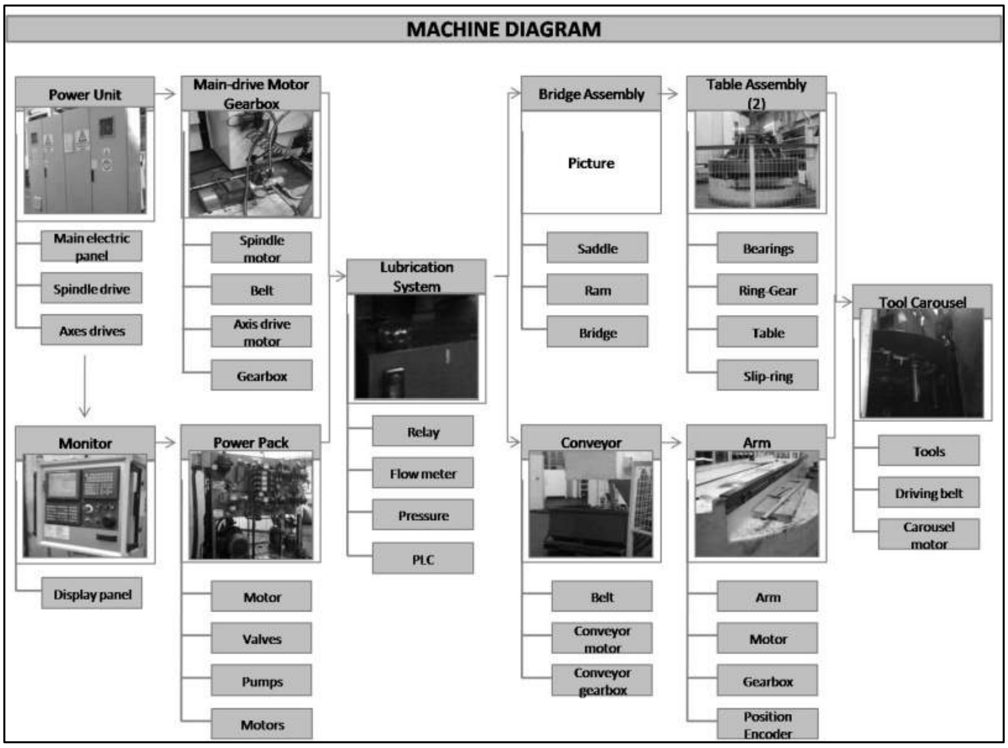

Figure 4: Machine diagram

Using the existing management information system, all the unplanned maintenance carried out from 1 January 2012 to 31 December 2012 was collected and entered into a spreadsheet. This information was then divided based on the critical components identified in the machine diagram. This information was used to draw up the frequency of component failure as shown in Figure 5. This historical data will help identify components which are prone to failure.

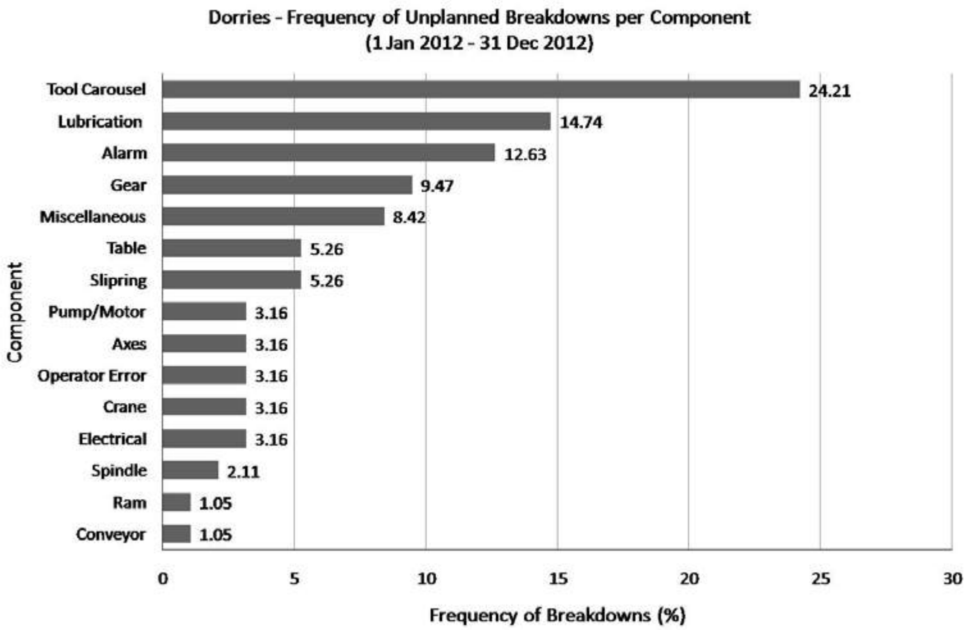

Figure 5: Frequency of component failure per critical machine

A root cause analysis (shown in Figure 6) highlights recurring maintenance issues and determines their root causes. This information is important when developing a preventative maintenance schedule.

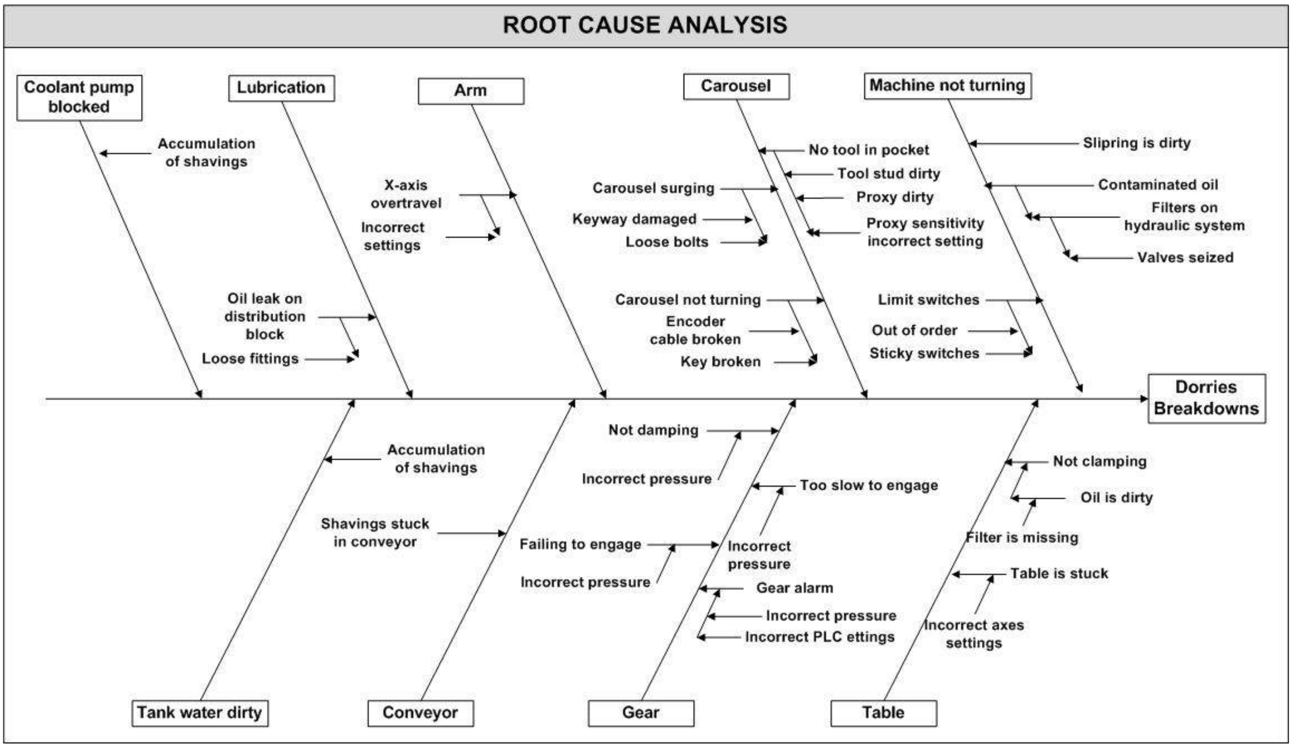

Figure 6: Root cause analysis

A list of critical spares (shown in Figure 7) includes supplier lead time, availability and stock levels for each critical piece of equipment. This information will be updated by maintenance personnel as required.

CRITICAL SPARES				
Spare Part	Availability			
	Supplier Lead Time	Yes (✓)	No (×)	Stock level
Slip-ring				
Main-thrust bearing				
Main-centre bearing				
Filters				
Strainers				
Drivers/ Controls				
Bolts and nuts				
Screws				

Figure 7: List of critical spares

Lastly, based on the information gathered above, a planned maintenance schedule, including a daily, monthly and annual schedule was developed for the critical machines under consideration.

The final report card format for each critical machine is shown in Figure 8.

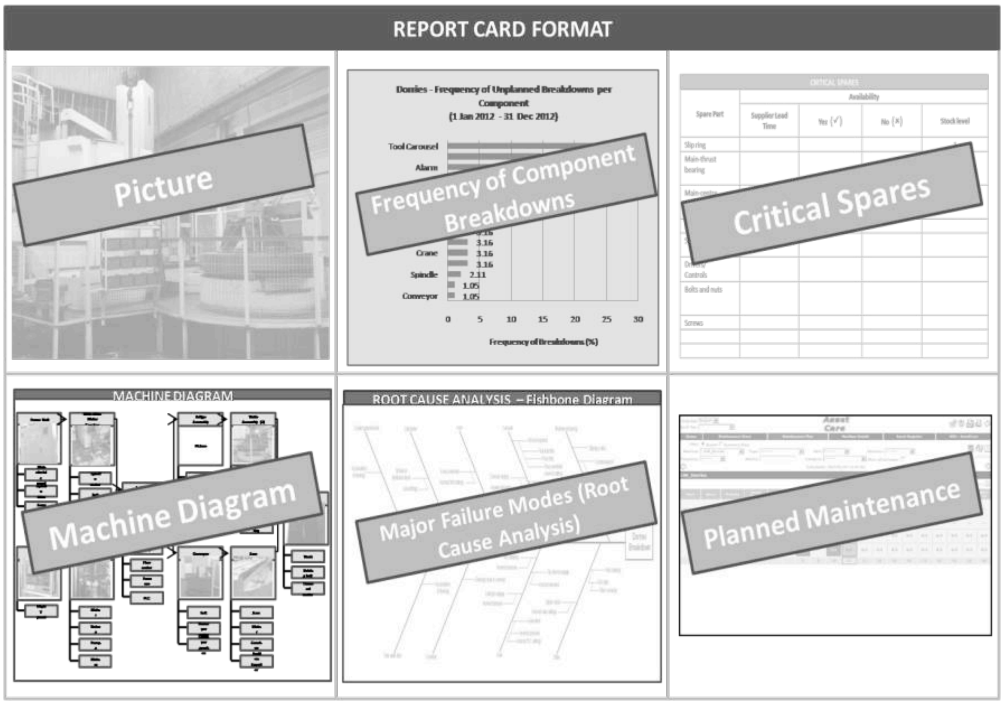

Figure 8: Sample of report card

The proposed solution employs a visual management technique to bring critical equipment issues to the forefront. By using this technique, the information can be easily accessible and visible to employees and managers. The report card aims to encourage employees to expose the problems and issues regarding critical machines so that these may be resolved.

5 CONCLUSIONS AND FUTURE WORK

The use of reactive maintenance at the Weir Minerals Africa Isando plant has resulted in a large portion of the daily workload consisting of managing equipment breakdowns. Due to lack of data regarding frequency of breakdowns and machine availability, a temporary system to collect this data was developed. The machine availability was measured to be approximately 92%. This is below the world-class benchmark of 97%.

The proposed solution to improve the machine availability consisted of a maintenance report card for each critical machine. The report card includes a machine diagram, the frequency of breakdowns, a root cause analysis, a list of critical spares and a planned maintenance schedule. This will be a starting point for a comprehensive preventative maintenance programme for the plant.

The proposed solution has not been fully implemented. Further work is required to implement the maintenance programme, measure the corresponding machine availability using this maintenance programme, and compare this value to the previously measured machine availability of 92%.

6 ACKNOWLEDGEMENTS

This study conducted on TPM has been made possible by accessibility to the maintenance department and maintenance personnel at Weir Minerals Africa, Isando.

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A CONCEPTUAL FRAMEWORK FOR CONVEYANCING PROCESSES

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ABSTRACT

Land is an asset and still remains a valuable factor of production even in the modern era of knowledge economy. In many parts of the world, land is a limited resource, hence, in most countries, custodianship and ownership of land and landed properties tend to be generally guarded through meticulous capturing, recording and storage of appropriate data and information. A legislative provision for the transfer of custodianship and/or ownership requires the involvement of different role players in the conveyancing processes that culminate in the registration of land and associated immovable property. In some countries, the conveyancing processes tend to be complex and cumbersome. Thus the proposition in this paper is that complex and cumbersome conveyancing processes and systems affect business activities that often involve the acquisition and/or transfer of custodianship or ownership rights to land and immovable property. The paper provides a conceptual framework for conveyancing processes based on a content-based review of land and immovable property registration systems in several countries.

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1 INTRODUCTION

Conveyancing is the legal transfer of property from one owner to another. Ownership is mostly in the form of a real right, although limited real rights may also exist in the form of servitudes or other rights in property, e.g. a creditor's right against the owner or registered leases (Van der Walt and Pienaar [1]). From a pedagogical viewpoint, conveyancing involves business processes traditionally designed to transfer land and/or associated landed property from one owner to another. In civil society, and in general, ownership is defined in terms of legal right, hence conveyancing is perceived as a legal convention. The reality is that the actual transactions and activities that result in the transfer of ownership are derived from specialised business processes of the various private firms and public agencies (role players) that are involved in conveyancing.

Processes exist regardless of the functional structure of the organisation. Processes may also encompass sub-processes that may be endogenous (i.e. internal within an organisation) or exogenous (i.e. linking to processes in other organisations). The first improvement step is to analyse a process end-to-end so as to understand the interrelationships and value potential (Heckl &Moormann [2]).

The modern era of globalisation and a knowledge economy features very high levels of competition, thus, innovative processes that improve business efficiencies (for example, reduce costs concurrently with increasing revenues) rapidly prevail. Conveyancing processes broadly include:

- valuation of property (e.g., by actuarial scientists, quantity surveyors, real estate agents, etc),
- financing activities (e.g., by banks, financial institutions, etc.),
- contracts (e.g., by attorneys, notaries, and conveyancers),
- statutory registration (e.g., by municipal and local government agencies, internal revenue services, etc.); and of course, and
- custodians and owners (sellers and buyers).

The above implies that conveyancing processes involve the various types of business organisations identified (in parentheses above) as role players.

Acknowledging that conveyancing processes link different role players, many countries have developed systems (either manual or electronic) for capturing, recording, transfer and storage of property related data and information arising out of the transactions and interactions between the activities of the respective business organisations involved. Inefficiencies within respective role player sub processes can readily make the conveyancing processes cumbersome by creating bottlenecks and further complicate the processing times of the interlinking manual or electronic systems. The purpose of this paper is therefore to develop a conceptual framework for conveyancing using international best practices in a supply chain end-to-end setting.

2 LITERATURE OVERVIEW

An operation is composed of processes designed to add value by transforming inputs into outputs (Pycraft [3]). Davenport [4] defines processes as a structured and measured set of activities designed to produce specific outputs for a particular consumer or market. Organisations pay particular attention to the design and management of their internal processes with successful practices becoming part of the business processes. Lampert, Stock and Ellram [5] proposed that all firms within a supply chain must overcome their own functional silos and adopt a process approach in order to successfully implement supply chain management. We are therefore in agreement with Hammer and Champy [6] who viewed processes as sets of activities with the logical internal/external relationship that they result in a product or service demanded by a customer. The process therefore starts and ends with the customer.

All organisations encounter process timing problems (for example, unplanned down-time, expensive rescheduling actions, and staff shuffling), which, often times results in customers waiting, and late delivery of a service or good. On-time and turnaround time are desirable clichés that delight customers (Slack [7]). Proponents of total quality management principles generally argue that the concept of 'leanness' may be applied to deliver a product on-time and reduce service turnaround times (Trent [8]).

Hammer & Champy [6] introduced the concept of reengineering as a fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, productivity and competitiveness. Instead of redesigning, some organisations merely computerise the manual processes and hence continue to follow the original logic, thus gaining no real improvement (Guha, Kettinger and Teng [9]). An important redesign would involve the substitution of sequential activities with simultaneous activities in order to reduce the turnaround time in processes.

3 RESEARCH PROBLEM AND METHOD

This continuation of existing logic while automating, seems particularly evident in most conveyancing processes, including the South African conveyancing processes. Each type of role player involved in the conveyancing processes reengineered their own internal sub processes. More often than not, the reengineering is not undertaken in conjunction with other stakeholders, thus increasing the complexity of the conveyancing processes and the full supply chain. From a customer viewpoint (i.e. buyers and sellers), on-time and turnaround times are measured across all the sub processes that result in the successful transfer and registration of custodianship or ownership. Real value is added by removing unnecessary activities and aligning the entire chain of conveyancing processes. This may be easier said than done because it could imply that some of the various types of organisations would need to align certain aspects of their corporate goals and strategies with the reengineering effort. Extrapolating from Malerba [10], from the viewpoint of sectoral innovation it may not be as far-fetched for the role players to work together to remove bottlenecks that adversely influence the conveyancing processes.

This discourse is based on a review of available literature on international conveyancing processes and systems, as well as interviews with key stakeholders from a selection of international conveyancing systems. The narrative responses of the interviewees are summarised in the paper in order to present a conceptual framework for South African conveyancing using a supply chain management approach.

4 REVIEW OF CONVEYANCING PROCESSES IN FIVE CASE STUDY COUNTRIES

In this section, we describe very briefly, the conveyancing processes in Barbados, The Netherlands, Australia, Taiwan and South Africa. Some of the case study countries demonstrate conveyancing processes which can be regarded as innovative with regard to land administration and transfer.

4.1 The conveyancing processes in Barbados

It seems that landed property in Barbados largely exists in unregistered system of titles, although there are some districts where titles have been registered. This follows from direct telephonic interview with Hathiramani [11] and Savitri [12]. They indicate that it would be advisable to use a local attorney-at-law when purchasing real estate in Barbados, so that the title can be properly investigated and other requirements properly dealt with. Tribal areas in Barbados present challenges, especially where land has been distributed in terms of family arrangements, which in fact are still regarded as communal properties. In terms of title registration, Barbados seems to have successfully migrated from an entirely manual system to a partly computerised conveyancing system (Barnes [13]). The land administration system in Barbados is designed to a large extent for middle and upper income groups. The rising problem of *squatting* (occupation of land without the express permission and without the completion of any formal application to acquire rights), together with large unregistered areas, makes Barbados an interesting case study.

There are currently two systems of recording or registration of landed property in Barbados. These are the “common-law system”, and the “registration system”. Under the common law system, a title must be traced from owner to owner as far back as what is called “a good root of title” (usually a conveyance) which has to be *at least* 20 years old. A seller must be in possession of all the original title deeds from the date of the root to the date of the new transaction.

The registration system does not include deeds but rather, a simple certificate of title or charge, which contains all the information about the property. Land for which title has been registered, a disposition is effected by a transfer, lease or other prescribed form in accordance with the relevant legislation (Gittens [14]). The title is backed by government; this means that Barbados follows a *positive system* of registration. The Land Register typically contains a brief description and plan of the land as well as the existing certificate of charge/title.

The conveyancing process in Barbados in summarised as illustrated in Figure 1.

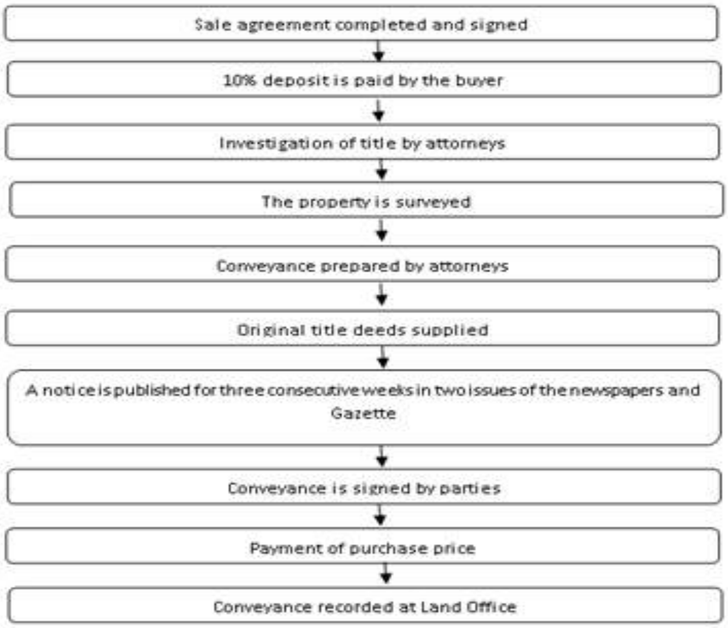

Figure 1: An illustration of conveyancing processes in Barbados

4.2 The conveyancing processes in The Netherlands

In The Netherlands, the land registration and the cadastre, i.e., a system of maps and diagrams, are combined into one organisation. The Civil Code in the Netherlands provides for a closed system of real rights. The Netherlands operates on a *negative system* since the government does not guarantee the accuracy of the title register. The Land Register was computerised in 1999 and paper documents are scanned on receipt. The paper pre 1999 was scanned onto a microfilm and may be transferred into a digital format on request. The electronic recording of deeds started in 2005. Electronic copies and an advanced electronic signature are delivered together. The Registrar maintains a supervisory role and the conveyancer remains responsible for drafting and submitting the deed, as well as signing of the deed on behalf of the seller, buyer and other role players. The transaction is recorded in a national register as opposed to previous duplications in regional registers as well. Electronic dispatches are received a day earlier than paper documents and payment can be effected a day earlier - the same legal certainty exists as with the paper documents (Louwman [15]).

A key feature of the conveyancing processes in The Netherlands is the significant role of the notary public in linking the other types of role players (West [16]). The Netherlands makes use of electronic cadastral registers referred to as the Automated Cadastral Registers (AKR). Maps are kept in a survey and mapping information system (LKI). These two systems are appropriately interfaced, especially to coordinate updating of the relevant data and information (Wakker, van der Molen, and Lemmen [17]). An understanding of the conveyancing processes in The Netherlands is articulated as illustrated in Figure 2.

Figure 2: An illustration of the conveyancing processes in the Netherlands

4.3 The conveyancing processes in Australia

According to Garoupa *et al*[18] the Torrens system introduced in Victoria, South Australia in 1862 is a method of recording and registering land ownership and interests on a single title document. As the land titles register contains all the information of ownership, it is not necessary to prove ownership and other titles by other longer documents such as the title deeds. Countries that use the Torrens system include Australia, New Zealand, Ireland, Malaysia, Singapore, Iran, Canada, Madagascar, England and Wales. The Torrens title system works on the following three principles:

i. The maintenance of a public register of titles and interests on land

ii. The assurance that, once registered, a title or interest cannot be defeated

iii. The guarantee of a compensation fund in the event of an fraudulent or erroneous registration

Although each state in Australia has its own land registration practices and procedures, however, all states have adopted the Torrens system for land title registration. Essentially, the title is changed from seller to buyer at the Deeds Registry while the title document is kept with the bank until the loan is fully repaid by the buyer. In Australia, the state guarantees the accuracy of the state deeds register which means that Australia has a positive land registration system. The unique feature of the conveyancing processes in Australia is that a buyer/seller or “information broker” may buy a self-conveyancing kit. This means that conveyancing does not require formal qualifications or certification per se. A summary of the conveyancing processes in Australia is illustrated in Figure 3.

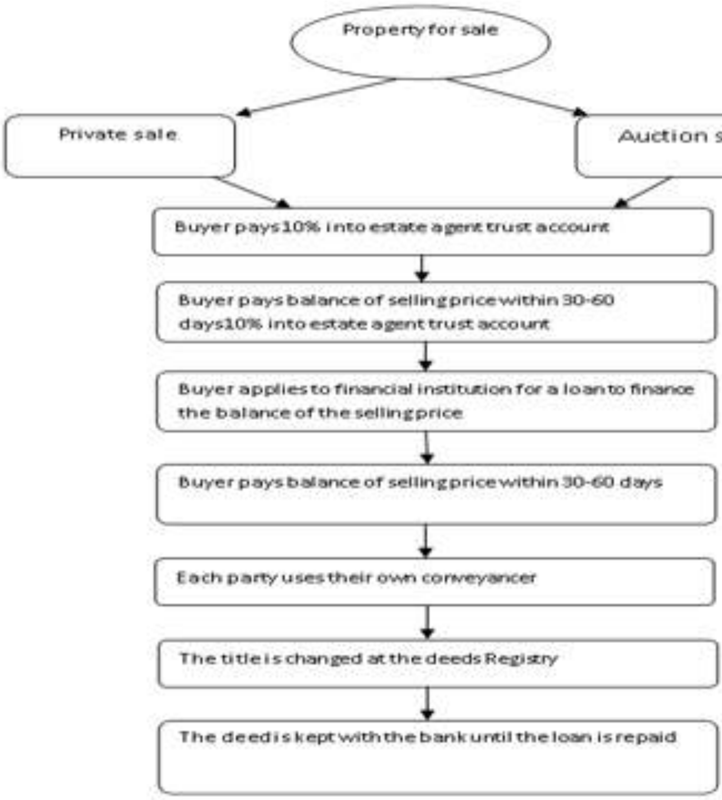

Figure 3: An illustrate of conveyancing processes in Australia

4.4 The conveyancing processes in Taiwan:

In Taiwan, the role players involved in the conveyancing process include buyer, seller, estate agent, bank, *tisu* and land office. Uniquely, a *tisu* is a not a qualified attorney but a person certified by the local government to assist the buyer, and focuses on drafting contracts between

- buyer and seller
- bank and buyer

as well as the preparation of mortgage documents, property documents and transaction documents. The Taiwanese conveyancing process is illustrated in Figure 4.

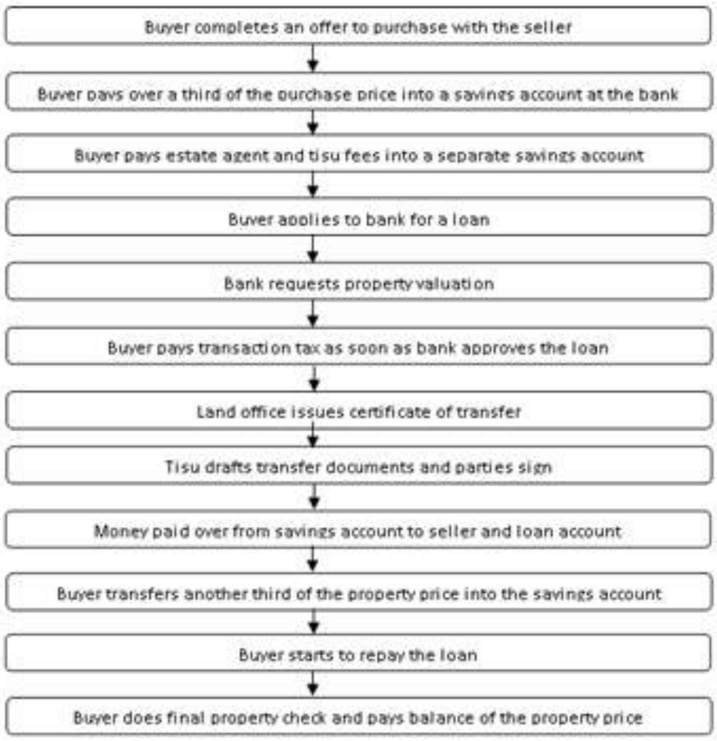

Figure 4: An illustration of the conveyancing processes in Taiwan

4.5 The conveyancing processes in South Africa

The South African Land registration system shows aspects of both a positive and a negative land system (Ramwell, Brink, West [19]). Although the SA Deeds Office does not guarantee the correctness of a title (negative system), third parties do rely on the accuracy of the legal position of real rights registered with regard to immovable property. The land register is linked to a cadastral which is an aspect of a positive land system. Parties and role players in a typical conveyancing process generally include estate agents, sellers, buyers, conveyancers, financial institutions, government agencies such as the Deeds Office Registry, Internal Revenue Service (IRS), local and municipal authorities.

In some cases, the transactions that are included in a single property exchange may involve several different attorney firms, each of whom represents the respective role players, and all of whom will be required to lodge their respective documents at the Deeds Office Registry. Where more than one property is involved (e.g. in the case of developments where all units are registered at the same time), the transactions may be linked to even more role players; hence, it is not uncommon for the entire conveyancing process to comprise of more than one hundred transactions before completion of the property exchange. The process tends to be exacerbated where the transactions involve manual interlinks and information transfer loops between the various role players. Even automated processes are not immune to risks that may arise, for example, from data inaccuracies and asynchronous time delays.

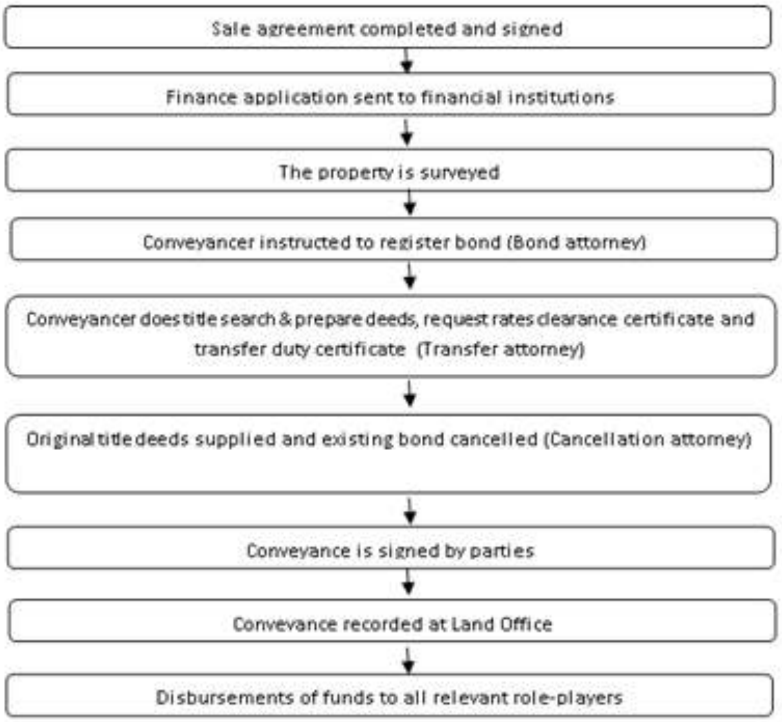

Figure 5: An illustration of conveyancing processes in South Africa

4.6 Comparative summary of conveyancing processes in the selected countries

For brevity, based on the different processes followed by the countries included in this study, the following processes are identified:

Table 1: Summary of the conveyancing processes in different countries

	Barbados	The Netherlands	Australia	Taiwan	South Africa
Sale agreement completed and signed	X	X	X	X	X
10% deposit paid by buyer	X		X	X	X
Full purchase price is paid to notary		X			
Buyer pays a third of the purchase price at the bank				X	
Buyer pays estate agent and tisu fees into separate savings account				X	
Buyer applies to financial institution for a loan	X		X	X	X
Bank requests property valuation	X	X	X	X	X
Investigation of title by attorneys	X	X	X	X	X

Buyer pays transaction tax as soon as bank approves loan				X	
Conveyance prepared by attorneys/ notary/ tisu	X	X	X	X	X
Original title deed supplied	X				X
Notice published in Gazette	X				
Buyer and seller signs deed	X	X	X	X	X
Buyer pays another third of property price				X	
Payment of purchase price	X	X	X		
Land Office does final checks		X	X	X	X
Conveyance recorded at Land Office & provides evidence of the record	X	X	X	X	X
Deed is kept with the bank until the loan is repaid			X		X
Buyer does final property check and pays balance of the property price				X	
Buyer starts to repay loan	X		X	X	X

5 CONCEPTUAL FRAMEWORK FOR CONVEYANCING PROCESSES

Using the information gleaned from the literature and interview respondents for the countries that formed part of this study, the following procedures appear common to all the countries' conveyancing processes. These procedures can therefore comprise the basic elements of a framework for conveyancing processes in an international context. The framework is illustrated in the table below.

Table 2: Conceptual model for conveyancing processes

Conceptual international framework
Sale agreement completed and signed
10% deposit paid by buyer
Buyer applies to financial institution for a loan
Bank requests property valuation
Investigation of title by conveyancers
Buyer pays transaction tax as soon as bank approves loan

Conveyance prepared by notary/ tisu/ conveyancer
Buyer and seller signs deed
Buyer pays another third of property price
Payment of purchase price
Land Office does final checks
Conveyance recorded at Land Office & provides evidence of the record
Buyer starts to repay loan

It is clear from the literature that many countries follow different approaches. Some processes may be more complex and may take much longer in some countries than in others. The common steps identified should be the basic steps that seemingly would need to be present in a basic conveyancing end-to-end process. Some foreign multinational corporations need to acquire immovable property for their investments in other countries. According to a newspaper article (re: Financial Times, 15 November 2012 [20]), Massmart's intention to open more branches in Nigeria may be delayed by cumbersome landed property transfer processes. In fact, the article surmises that "...when an organisation requires landed property infrastructure and facilities as complimentary assets, it is not far-fetched that cumbersome processes of landed property acquisition may adversely influence the supply chain and business operations".

It is important that South Africa incorporates international best practices in conveyancing to minimise challenges that may adversely affect foreign investment opportunities. Land is a valuable and oftentimes, ownership tends to meticulously contested. Transfer of ownership requires processes that should be uncomplicated and less cumbersome. Business organisations in all industrial sectors, whether public or private, depend significantly on landed properties, thus, it is in this regard that this paper incorporates an international perspective to provide a framework for conveyancing processes.

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