An investigation into the improvement of maintenance quality in a production plant through the use of reliability management

by

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Declaration

I _Fulufhelo Elelwani Munzhelele__ hereby declare that this project report is wholly my own work and has not been submitted anywhere else for academic credit, either by myself or another person.

I understand what plagiarism implies and declare that this report embodies my own ideas, words, phrases, arguments, graphics, figures, results and organisation except where reference is explicitly made to another work.

I understand further that any unethical academic behaviour, which includes plagiarism, is seen in a serious light by the University of Johannesburg and is punishable by disciplinary action as stipulated by the university rules and regulations.

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Abstract

Extensive research has been conducted on plant reliability maintenance. However, getting the maintenance system in place remains the core of maintenance improvement. The purpose of this research dissertation is to investigate the impact reliability management has within production industries and its role in improving the quality of maintenance. This study will assist management to reflect on the cost-effectiveness and influence that the maintenance management system has within the organisation. The study will also contribute to existing knowledge in plant reliability maintenance. It is, therefore, significant for an organisation to establish good management practices and set maintenance as an integral part of their overall plant strategy.

The approach that was followed by this research is a mixed method – a combination of quantitative and qualitative. Data collection was carried out through a literature review, observations, a questionnaire, a survey, interviews and from company documentation. An employee questionnaire was prepared and distributed to 25 participants to conduct gap analysis and evaluate the maintenance practices within the observed company. A benchmark study was also performed using an online survey, based on 85 responses from employees in other processing plant industries within South Africa. The empirical study conducted with Company A's employees (mainly from the maintenance and operation departments) identified possible blunders, which transpired during the reliability management system implementation phase. Based on this sample the results obtained indicated that maintenance is done unnecessarily on the plant on average. The study also found issues regarding maintenance financial planning ineffectiveness, unavailability of spares and lack of skillsets to perform jobs. The online survey revealed that organisations do make use of Computerised Maintenance Management System (CMMS) to facilitate their maintenance. CMMS also has a positive impact on the overall maintenance processes and productivity. The study identified the importance of planning and scheduling shutdowns in advance, as a significant part of the maintenance annual budget and cost reduction.

Employees' active role in an organisation is important to its success. It is important for the CMMS software user to be trained to use capabilities incorporated in the software

to improve on the maintenance work processes and efficacy. However, the organisation also needs to consider the concept of life cycle cost of equipment to achieve effective maintenance management.

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Acronyms

CA	Criticality Analysis
CMMS	Computerised Maintenance Management System
ETA	Even Tree analysis
FMEA	Failure Mode Effect Analysis
FTA	Fault Tree Analysis
HSE	Health Safety and Environment
KPI	Key Performance Indicators
LCC	Life Cycle Cost
MI	Maintainability Information
MPI	Maintenance Performance Indicators
MPM	Maintenance Performance Measurements
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
OEE	Overall Equipment Effectiveness
PM	Preventive Maintenance
RCA	Root Cause Analysis
RCI	Root Cause Investigation
RCM	Reliability Centred Maintenance
TNA	Training Needs Analysis
TPM	Total Production Management
TQM	Total Quality Management

Chapter 1: Introduction

1 Background

Extensive research has been conducted on plant reliability maintenance. However, getting the maintenance system in place remains the foundation of maintenance improvement. Regular maintenance is essential and ensures that all equipment required for production is operating at maximum efficiency at all times. In recent years organisations have come to recognise the value of Computerised Maintenance Management System (CMMS) as a maintenance performance and improvement tool, which is increasingly being used to manage and control plant equipment (Wienker, et al., 2016). CMMS is a cost-effective means of managing a massive amount of data generated by maintenance, inventory control and purchasing. However, it remains essential for organisations to consider effective resource management and reliable equipment to enhance plant performance. The successful implementation of CMMS is not judged by the product, but by the maintenance improvement standards and strategies achieved. (Lemma, 2002). This is a critical factor in complex and large plants, however decisions are still on the qualitative level.

Recent studies have found that a majority of organisations continue to consider predictive and preventive maintenance strategies over reactive maintenance, cooperatively with Total Productive Maintenance (TPM) to achieve exceptional performance (Fredriksson & Larsson, 2012). Organisations also invest in CMMS because the systems are designed to support the document control requirements of ISO 9002 and are a key part of the TPM philosophy (Weir, 2015). So far, the influence of productivity and quality has progressively moved from man to machine, leading to the emphasis on availability, reliability and safety in chemical processing plants.

Over the years manufacturing systems have grown to be part of the global network of supply chains, eventually placing maintenance under pressure in order to develop more effective and efficient operations (Al-Turki, et al., 2014). Organisations seek to gain competitive advantage concerning cost, quality, service and on-time deliveries (Muyengwa & Marowa , 2015). Production plant industries are increasingly dependent on technology for productivity and therefore are continuously searching for better methods to improve their maintenance processes further. Even so, they continue to be responsive to the fact that poor maintenance practice may lead to reduced plant life-cycle (Mungani & Visser, 2013). The primary goal of any organisation is to minimise operational expenses and focus on increasing productivity by keeping maintenance expenses to a minimum. This research aims to establish how reliability management influences an organisation's maintenance process, leading to increased productivity and plant availability. For privacy reasons the author cannot give the exact name of the company. The company will be referred to as Company A throughout this research paper. This study will benefit the company and other production industries by identifying and validating the importance of implementing reliability maintenance management.

This organisation produces chemical products, which include surfactants such as sulphonic acid, sodium lauryl ether sulphate, lauryl sulphate and alkanolamide. The products produced are based on different acidity levels, as required by customer. The plant is automated and divided into three processes that run simultaneously. The control room has a Programmable logic controller (PLC) system which is used to run and operate the plant processes automatically. With the volume of equipment running in the plant, it is essential to minimise breakdown times to increase productivity (Tanwari, et al., 2011).

The importance of maintenance continues to rise due to the increase in technological complexity of equipment, machines and infrastructures. The inadequate practice of reliability maintenance continues to affect organisations negatively, reducing productivity and delaying deliveries to customers. Thus, it becomes essential for an organisation to implement improvement strategies to further enhance performance, productivity levels, quality and ensure on-time deliveries to customers. However, to guarantee sustained profitability or survival of an organisation cost reduction remains an important factor to consider (Ahuja & Khamba, 2008).

Introducing reliability maintenance is important and assists the maintenance manager to efficiently manage the plant maintenance operations and ensure waste is reduced to a minimum (Mutloane & Lotz, 2009). The implemented reliability management system monitors the overall production process, which ensures the sustainability of proper quality maintenance. Quality is referred to as the systematic identification, analysis, reduction, and eventual elimination of all variations around an objective and ensures that consistent reliability maintenance within an organisation is achieved. It is also the degree to which a product or service meets customers' expectations (Bhote, 1991). Maintenance influences the plant operations, maintenance practices and principles to maximise plant availability and reliability over the plants intended service life (O'Connor, 2002).

1.1 Research Problem

Production plants deteriorate early in their life-cycle if poor-quality maintenance systems are being applied (Enofe & Aimienrovbiye , 2010). According to the research conducted by Coleman, et al. (2019), "poor maintenance strategies can reduce a plant's overall productive capacity between 5 and 20 percent". Recent studies also reflect that lost production time due to unplanned downtime, costs industrial manufacturers an estimated R740 billion each year. Atech (2019) highlighted that the increased environmental and safety issues in plant operations is spawning new needs to the industry. Statistics suggests that more organisations are focused on improving their production practices and maintenance strategies, and this has led to an increased investment in reliability (Time Atech, 2019).

Several years ago, Company A did not have a reliability management system in place, and constant failures were experienced. When new management came in 2007, they decided to implement a reliability maintenance system to improve the quality of maintenance and increase productivity. They also decided to extend the production line from one to three lines, due to product demand growth. However, after a few years of implementing the reliability maintenance system, they only managed to reduce the breakdowns by 36%.

1.2 Purpose of the Research

The purpose of this study is to investigate the impact that reliability management has on Company A's production plant and its role in improving the quality of maintenance. However, to effectively implement a quality maintenance approach, Reliability Centred Maintenance (RCM) must be considered. The outcomes of this study are intended to assist management in reflecting on the cost-effectiveness and influence that maintenance management has within the organisation.

1.3 Research Questions

To fulfil the above stated purpose, the following research questions need to be answered:

1. What effects does the implementation of reliability management have on the quality of maintenance within the organisation?
2. What are the costs associated with the maintenance engineering system and maintaining such a system?

1.4 Research Objectives

To successfully improve the quality of maintenance the study focused on the following objectives:

1. To determine the barriers to implementing a reliability management system.
2. To establish possible causes that lead maintenance improvement initiatives to fail in delivering expected results.
3. To determine and eliminate primary causes of plant downtime that negatively impact the production output.
4. To establish the effects of the reliability management system on employee's performance and management's decision making.
5. To determine the extent to which reliability measures performed on equipment affect its life-cycle and assist in the achievement of reliability maintenance goals.
6. To suggest recommendations on how to improve the quality of maintenance through effective reliability management.

1.5 Delimitations

This research was conducted primarily in Company A, with the following objectives: to validate the effects of implementing quality maintenance practices and to determine how they influence and affect the organisation. This research study is aimed at the maintenance department and will thus not focus on, nor consider the work or decision-making processes related to production.

1.6 Limitations

The study is limited to reliability management and the necessary improvements required to achieve quality maintenance within production plant industries.

1.7 Assumptions

The study was conducted based on the following assumptions:

- Several production plants deteriorate much earlier in their life-cycle than they should, due to the use of inadequate maintenance approaches.
- The implementation of a reliability management system improves productivity and assists in the development of a maintenance approach.
- Reliability maintenance management assists in ensuring that plant operations are optimal, and that plant availability is maximised through preventive, predictive and condition maintenance.

1.8 Outline of Chapters

1.8.1 Chapter 1: Introduction

In this chapter, a general overview of the study undertaken on "improving the quality of maintenance within production plants" was outlined. The research problem was defined, the aim of the research was outlined, and the research questions and the objectives of the research were also identified. The method of research was discussed indicating the delimitation of the study, the limitation of the study, the reliability and validity of the study.

1.8.2 Chapter 2: Literature Review

In this chapter, the author reviews the theoretical framework of the study, which focuses on the importance of reliability maintenance management and its principles on plant maintenance. This information is linked to the objectives of the study, the research question and the topic. Appendices also provided to this chapter, leading to the formation of the actual concept of introducing quality maintenance by incorporating a reliability management system. Diagrams and models relating to quality maintenance practices requirements are provided in these discussions. The chapter concludes by identifying a number of reliability engineering approaches that are used in process development and improvement that lead to increased productivity.

1.8.3 Chapter 3: Methodology

In this chapter, the research methodology used is outlined. The research methodology guides the author on how to analyse the effects of implementing reliability maintenance in industrial production plants. The objective of this chapter is to cover the research methods being used that will help analyse the reliability maintenance system currently used within the organisation. The study design, the population and sample are described. The instruments used to collect the data are defined. The methods implemented to maintain the validity and reliability instruments were also defined.

1.8.4 Chapter 4: Data Analysis and Results

This chapter presents the interpreted data from the CMMS and the questionnaire responses, to determine the effectiveness of the maintenance system. The gathered data is analysed, and the implemented maintenance process is evaluated.

1.8.5 Chapter 5: Recommendation and Conclusion

Based on the analysis provided in chapter five, recommendations and possible implementation processes are provided. This chapter concludes the study. The outcomes of the study highlight the impact of effectively maintaining a production plant.

1.9 Summary

The paper has five parts. Chapter one introduced the study. It described the research problem, the research objectives and the limitations of the study. Chapter two provides a review of the literature associated with the topic, which lays a foundation for the study. Chapter three present the research methodology and data analysis techniques are discussed. In chapter four the findings are discussed and summarised. The paper concludes with recommendations and possible implementation processes of implementing a reliability management system and directs for future research.

Chapter two will define reliability engineering management and will highlight the maintenance strategies and CMMS benefits.

Chapter 2: Literature Review

2 Introduction

In this study, the author reviews the theoretical framework of the study, which will focus on the importance of reliability maintenance management and its principles on plant maintenance. To gain knowledge on the role of reliability maintenance management the author presents various maintenance strategies. This is achieved through an extensive literature study. Areas such as reliability management, maintenance strategy, maintenance management and quality management are studied to understand the strategic level of maintenance, and the roles of employees and management. The primary objective of the literature study is to create a foundation upon which to base the results.

2.1 Reliability Engineering

O'Connor, Patrick D. refers to reliability engineering as "the discipline of ensuring that a system will be reliable when operated in a specified manner". A reliability approach is simply a process that allows the plant to operate efficiently. Reliability theory is the fundamental principle of reliability engineering and it is a concept that integrates the employees, plant equipment and the organisational processes into an efficient system that achieves optimal benefit. However, for engineering purposes, reliability is defined as "the probability that a system will perform its intended function during a specified period under stated conditions" (O'Connor, 2002).

Reliability engineering is a multidisciplinary field which involves techniques and procedures to analyse reasons for failures and downtime for equipment. It also reduced the likelihood of frequent failure occurrence (Human, 2012). Reliability engineering is performed all through the whole life-cycle of a system, which includes development, testing, production, and operation. The function of reliability engineering is to develop the necessary requirements for the system, design the system to meet the requirements, set up an adequate quality program, and perform an appropriate analysis to monitor the actual reliability of the system during its life (Kostina, 2012).

Furthermore, reliability engineering assists in tracking production losses and extremely high maintenance cost equipment, so that management can make informed decisions in order to reduce those losses or high costs. Management achieves this by prioritising and focusing efforts on the most critical opportunities (Blanchard, 2016). Over the years reliability engineering has formalised methods to collect failure information. In the study conducted by Human (2012), methods used to identify or correct the causes of failures were quantified, for example, Root Cause Investigations (RCI's) and Root Cause Analysis (RCA's). RCI determines the root cause of an incident, whereas RCA analyses collected data in the RCI. RCA is carried out to enable management to develop a plan to eliminate or reduce the losses (Blanchard, 2016). Significantly, a reliable production system is considered a crucial factor for organisational competitiveness.

Reliability management reduces the need for reactive maintenance and improves work processes. Organisations aim for the most reliable production systems with the best availability performance. Reliability and maintainability play essential roles in ensuring the successful operation of plant process through plant availability (Yeh & Sun, 2011). However, process reliability has a major day-to-day impact on the plant's profitability, environmental integrity, and safety and loss performance (PlantWeb, 2003). Reliability can be associated with availability, maintainability and safety of equipment. Reliability improvements drive down maintenance costs while at the same time assisting to sustain the plant (Dunn, 1998). Reliability management assists in managing the organisation's environmental health and safety, asset capability, quality and production risk to achieve the strategic business objectives. Examples of tools that are used to identify and reduce risk are (O'Connor, 2002):

- Failure modes and effects analysis (FMEA),
- Criticality analysis (CA),
- Maintainability information (MI),
- Fault Tree Analysis (FTA),
- Event Tree Analysis (ETA).

Reliability is a function of the mean time between failure (MTBF) and the mean time to failure (MTTF). MTBF occurs when repairable plant equipment or components are repaired and returned to use. MTTF occurs when irreparable plant equipment or components are discarded after failure (O'Connor, 2002).

Operators should also be involved in maintenance, to help improve asset reliability. Their involvement adds value to maintenance, and thus it is necessary for management to develop effective operator inspection procedures. Involving operators in Reliability Centred Maintenance (RCM) analysis can assist the maintenance team to generate more reliable solutions because they operate the machines daily. Operators are usually the first to identify problems in the plant, whereas the maintenance team only performs routine inspections as planned. Thus, it is advisable to train operators to be able to identify symptoms of equipment in distress. Early detection of failure minimises the effects, which is essential to improving and sustaining asset reliability (Blanchard, 2016).

2.2 Maintenance

Liyange & Kumar (2003), classify maintenance as a value-adding process in today's dynamic and competitive business environment. Maintenance has an impact on production profitability, making it a profit centre rather than a cost centre (Enofe & Aimienrovbiye, 2010). Maintenance engineering is "the discipline and profession of applying engineering concepts to the optimisation of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment" (O'Connor, 2002). The maintenance function is to ensure that all production and manufacturing equipment is in optimum operating condition. Plant maintenance is referred to as the repairing of equipment at planned intervals, to prevent and avoid costly downtime due to sudden breakdowns (Sherwin & Jonsson, 1995). Maintenance focuses on making equipment available with increased reliability. Thus, preventive maintenance should be performed to ensure that all equipment required for production is operating at maximum efficiency. It is important for an organisation to maintain a high level of customer satisfaction throughout the plant's life cycle. Maintenance and maintenance policy plays a significant role in achieving a systems' operational effectiveness at minimum cost (Ruiz R., 2007). It is also the organisation's responsibility to develop and implement improvements, which focus on critical elements such as safety, dependability, and costs to maintain the plant's life cycle. Maintenance and continuous improvement decrease operational costs throughout the plant's life (Söderholm, et al., 2007). Modernised maintenance processes eliminate waste and produce high performance in productivity.

The importance of asset reliability at any time can be critical and can be enhanced by proper maintenance procedures. Financial benefits of maintenance are realised while planned maintenance is being practised (Lee Cooke, 2003). Important factors to consider during maintenance are to ensure: reliability is measured, standard operating procedures (SOP) are in place and followed, and scheduled maintenance plans are performed (Maletic, et al., 2012). Inadequate maintenance practices can adversely affect the competitiveness of the organization by reducing the output and reliability of production facilities and reducing the life-cycle of production facilities. Unreliable equipment availability caused by excessive system downtime reduces production quality, increases inventory and leads to reduced plant performance (Ahuja & Khamba, 2008).

However, Lee Cooke (2003) identified how maintenance workers continue to experience constant pressure to keep equipment running. A breakdown of one machine may cause further stoppages upstream or downstream in the plant process. To minimise the risk of downtime a backup team to continuously support the plant is readily available. Maintenance is performed when the plant can spare the equipment for repairs, generally after hours or during holidays (Sherwin & Jonsson, 1995). High reliability and availability of well-maintained equipment enhance the morale of personnel, whereas constant equipment breakdowns can be seriously frustrating (Lee Cooke, 2003).

Typical maintenance services that lead to quality maintenance are (Mamabolo, 2012):

- Root cause analysis (RCA),
- Design and implementation modification, plant upgrades etc.,
- Repair/ replacement strategies,
- Inspection plans,
- Optimizing outage duration,
- Maintenance schedule,
- Estimation of maintenance costs and investigation of alternatives,
- Optimization of stockholding,
- Forecasting of spare part usage,
- Life of plant plans.

Many failures on plant equipment are caused by lack of primary care, such as regular inspections. However, such failures can be prevented by utilising preventive maintenance (Sherwin & Jonsson, 1995). There are two main causes of fault or failure: these occur either when the equipment's function has degraded due to wear and tear or when there is a sudden change in the plant's operational function (such as high demand or product modification). Although maintenance may also be the best possible solution to prevent faults, maintenance by itself is insufficient, and other modification processes should be considered when equipment is continuously breaking down (Lee Cooke, 2003). Different maintenance methodologies such as RCM and TPM have been developed to manage the complexity and criticality of technical systems and their functions. The combination of RCM, TPM and continuous improvement strategies aims at achieving maintenance excellence (Söderholm, et al., 2007).

The availability of standby equipment discourages efforts to increase the reliability of the equipment through long-term improvement, since the purchase of spares remains critical. However, spares availability at the workshop is based on the criticality of the equipment or parts required. Common spares such as bolts and nuts should always be accessible. Another challenge organisations usually experience is the management of spares. Spares management is the foundation for a reliable plant operation. It is, however, crucial for management to determine what spares are required to create an adequate and comprehensive inventory system. The inventory helps manage the movement of spares and facilitates the procurement process. The procurement process has a significant impact on the quality of the maintenance process. The maintenance process just like any other industrial process depends on advanced and efficient maintenance management (Kans, 2012).

2.3 Maintenance management

Maintenance management is "the process of administering maintenance resources to ensure that the organisation does not encounter downtime from broken equipment or waste money on ineffective maintenance procedures. Maintenance management software programs can assist with this process" (Kumar, et al., 2011). The purpose of a maintenance strategy is to develop and create a program that meets the objectives of maximum availability/reliability and gains an in-depth understanding of the technical systems with a practical, structured approach (Waeyenbergh & Pintelon, 2002). Maintenance management is fundamental to the success of any organisation because an inadequately organised maintenance program can negatively affect the organisation through escalated maintenance costs and the unavailability of the plant due to breakdowns, eventually bringing the entire organisation to a halt (Scott Thompson, 2007). One example of a poor maintenance regime is when maintenance employees keep on fixing a pump (an essential piece of production equipment) which has already reached its life-span, instead of replacing it.

Maintenance management is an important activity in an organisation and ensures that any loss due to equipment failure is minimised. Maintenance management monitors the progress of corrective and preventive maintenance activities to make timely decisions on available resources, such as man-hours. Even so, the actual man-hours spent and the man-hours of planned work achieved should coincide with each other and should be evenly distributed throughout the entire maintenance period (Ip, et al., 2000).

Maintenance planning ensures the maximising of equipment uptime, cuts down on the need for emergency repairs, reduces production costs, saves time, and brings about better and more efficient production, increasing the organisation's profit. The cost of maintenance is influenced by the quality of the maintenance task, plant that changes over time (improvement strategies), planned maintenance tasks and unplanned maintenance tasks (Kumar & Suresh, 2008). Optimizing maintenance requires management to assess and identify the maintenance needs and activities required, and initiate a maintenance method. Maintenance methods are procedures in which maintenance activities are planned, scheduled and executed. Common maintenance methods are preventive maintenance, condition-based maintenance and corrective maintenance. The procedures and methodologies for assessing and assigning the maintenance activities into maintenance methods constitute a maintenance management system (Vismara, 2011).

The current problem within processing plants is integrating the maintenance into the company's management information system (MIS); in fact, even local systems seldom exist which can provide the data needed for optimisations. In most companies, maintenance is performed from a separate personal computer with little or no exchange of data with associated systems for stores and finance, using a simple, proprietary program that merely generates, plans and records. Although maintenance investments have a favourable effect on unit costs, production still takes the credit. This situation becomes quite a challenge for the maintenance employees: because of the expected increase in productivity, these employees also expect to gain from reducing the maintenance time that has produced the advantage. However they do not. In fact maintenance is usually perceived to have a lower rate of return than any other major budget item (Ablay, 2010; Bengtsson, 2007).

W.H. Kwong et al. (2000), refer to the maintenance management system as a tool that assists in obtaining maintenance data, performs analysis of the production system and provides management with detailed knowledge about the failure behaviour of the plant equipment. W.H. Kwong et al. (2000), focus on Maintenance Management Planning (MRPII) as the tool to carry out their study. The study emphasises how MRPII can best be applied when there is a proper design and integration of maintenance management within an organisation. MRPII does not only enable the manufacturers to manage their production planning and scheduling activities, it also enables management to analyse the maintenance history, perform cost analysis and study the failure trends, which determine labour and material availability to effectively perform maintenance (Ip, et al., 2000).

Priel defines the principles of maintenance management as “the effective use and coordination of information and resources”. Priel’s approach is achieved by ensuring that equipment availability and performance meet the output target, and that there is a balance between preventive and corrective maintenance costs (Priel, 1974). Soderhalm P. et al. (2007), analyse the maintenance process by using a generic process model to ensure that maintenance within an organisation aligns with other company internal processes. This method is aimed at increasing the understanding of the role of maintenance within a company and enhancing the fulfilment of external stakeholder (e.g. customers, shareholders and authorities) requirements. Maintenance is a business-process that creates valuable outputs. A process model provides valuable support for effectiveness, efficient and continuous risk reduction (Söderholm, et al., 2007).

2.4 Spares Management

Spare parts management assists in the elimination of prolonged breakdown problems. Spare parts planning and control are necessary in order to implement a spare parts management system successfully. It is therefore vital to implement a well-structured information system for spare parts and maintain inventory management. It is essential to evaluate the critical spare parts required for preventive maintenance and to consider the life-cycle of equipment within the company (Arts, 2013; Baluch, et al., 2013).

An organisation requires an optimal balance between spare parts availability, working capital and operational costs, within their span of control. An organisation also needs to consider all the tasks to be conducted and the decisions to be taken, to achieve the desired spare parts availability, possibly under constraints of working capital and/or operational costs (Driessen, et al., 2015).

Maintenance is either planned or unplanned and conducted in accordance with maintenance requirements. Capital assets are essential to the operational process and asset downtime must be significantly reduced. Extended downtime is usually caused by the unavailability of the required spares. The downtime of capital assets immediately affects the primary processes. Thus, implementing planned maintenance on capital assets is vital (Von Petersdorf, 2013). Maintenance employees should consider replacing parts which are worn or damaged to reduce the time spent on maintaining equipment. The worn or damaged parts are scrapped, and the parts which are still useful are sent to the repair shop for refurbished. The refurbished parts are stored for future maintenance; this principle is called repair-by-replacement and assists in the control of spares. Such parts are referred to as critical or consumable spares, and it remains the maintenance management responsibility to identify the critical spares and ensure that they are readily available (Driessen, et al., 2010; Arts, 2013).

2.5 Maintenance Strategy

The maintenance strategy is a management technique used to realise the maintenance objectives (EN 13306, 2001). A maintenance strategy functions as a roadmap which permits and incorporates alternatives. The maintenance strategy must stay adaptable, so that it can change according to the organisation's situation. The roadmap is dependent on the benchmarking results and from the organisation's best plant observations including what other organisations already do (Campbell & Reyes-Picknell, 2006). Based on the many advantages maintenance has, manufacturing plants are trying to adopt maintenance strategies to support their businesses (Muyengwa & Marowa , 2015).

Lee Cooke F. (2003) illustrate that “maintenance philosophy has evolved from reactive to preventive and now proactive approach.” While some organisations might view maintenance as an unnecessary cost, Lee Cooke F. suggests that an organisation which has adopted a well-structured maintenance strategy remains competitive within the industry. Plant maintenance strategies are optimised by cost-effective maintenance practices. Thus, to achieve efficiency, manufacturing organisations need to treat maintenance as a strategic issue. Maintenance should be considered as an

integral part of the plant strategy, considering its positive impact on the organisation's profit, productivity and quality (Maletič, et al., 2012). The study Lee Cooke F. conducted was based on the maintenance department of four companies. The study found that based on production pressure over the years, the organisations had been forced to resort to reactive maintenance within the plant (Lee Cooke, 2003).
However, maintenance techniques continue to change due to the increasing variety of equipment complexity and automation (Lee Cooke, 2003). Frequently, processing industries replace malfunctioning or dated equipment with the latest technology, rather than performing a critical evaluation of their maintenance plans. Replacement of equipment with new technology does not enable an inefficient maintenance program to be any more efficient. In fact, the goal of a maintenance and reliability system is to achieve a proper balance of maintenance activities, primarily those aimed at identifying impending failures to allow for timely corrective actions. The optimal maintenance and reliability system for a plant provides the right maintenance on the right assets at the right time.

An organisation needs to examine first the scheduled maintenance activities currently being performed, to ensure a viable maintenance strategy (Armitage, 2015). An organization needs to make sure that there is an appropriate balance of conditional inspections, preventive replacements, monitoring technology applications, and run-to-failure strategies based on the behaviour of the observed assets. However, result-oriented organisations focus on the quality and volume of production throughput, followed closely by the cost to produce the required quality and volume. The organisation should consider being results-oriented organisations because this approach improves equipment reliability performance, which drives manufacturing cost down. If organisations focus solely on cutting maintenance costs they may suffer the consequences of maintenance costs drastically increasing in the future, due to a decrease in reliability (Jonsson & Lesshamma, 1999). Sondalini M. emphasises the importance of challenging business to meet precision standards by targeting for accuracy, controlled reliability, improved procedures with inspection and by having test plans specifying quality standards. Equipment reliability can be beneficial and unreliability can lead to poor production and high maintenance costs. Whereas, high equipment and production plant availability can enhance business processes. Therefore, for an organisation to improve equipment reliability, the correct business processes are essential to delivering the production outcomes required (Sondalini, n.d.).

Salonen and Bengtsson (2011), have conducted a study into strategic maintenance development and have found that in most industries substantial improvements regarding maintenance were based on the key performance indicator (KPI) approach. Management implementation of maintenance contributes to the organisation's competitiveness (Salonen & Bengtsson, 2011). Thus, Salonen and Bengtsson (2011), have drawn the conclusion that performance measures provide an important link, not only between the strategies and management actions, but also between the necessary support implementation and the execution of improvement initiatives. Performance measures also help maintenance managers to focus maintenance staff and resources to specific areas of the production system that will have a positive impact on manufacturing performance (Maletic, et al., 2012). Salonen and Bengtsson (2011), have also proposed a structure to follow when formulating the maintenance strategy. Figure 2.1 below illustrates this structure.

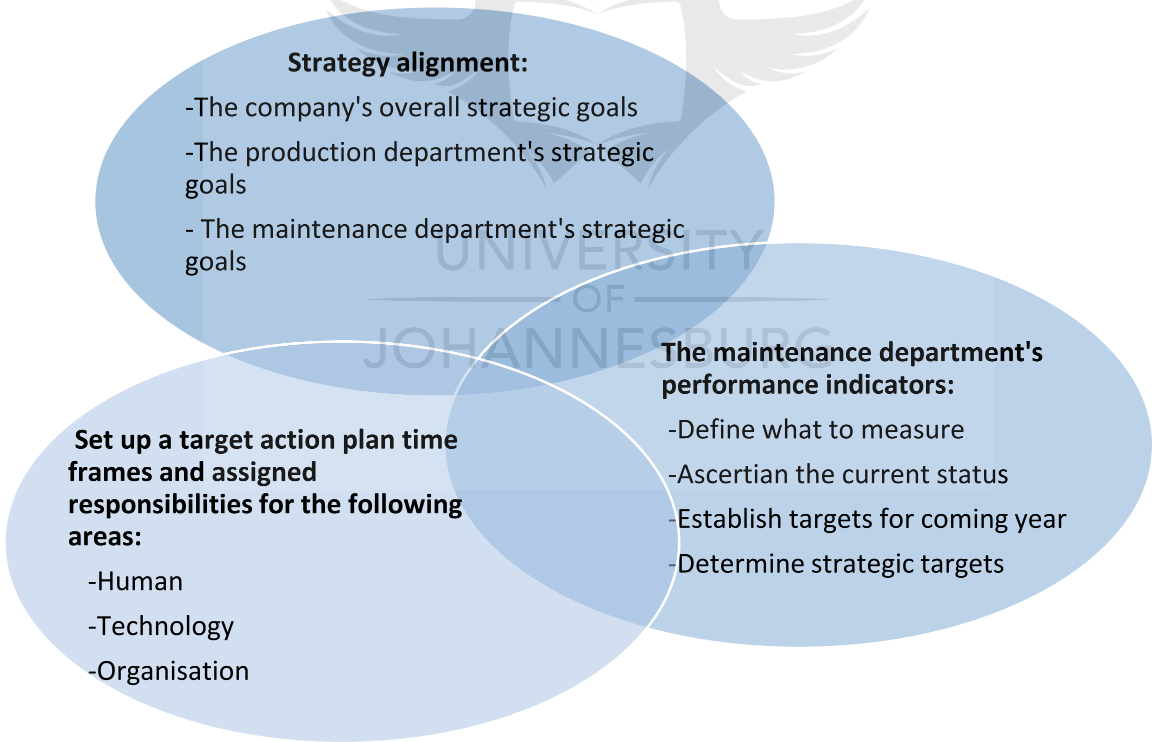

Figure 2. 1: A structure to follow when formulating the maintenance strategy (Salonen, 2011)

2.5.1 Implementation of a maintenance strategy

Management continues to realise the need to build its maintenance capability to ensure reliability and cost-effectiveness of its operation (Pun, et al., 2002). Management should consider the possible effects of contextual factors on performance because the type of production process used can determine the plants high and low performance. Cua et al. (2001) suggest that the implementation of manufacturing practices can mask the effect of contextual factors on performance. Kathleen and Schroeder (2002), have conducted a study to understand the relationship context between the process technology and the product development practices used within the plant. They have found that, not all companies have effectively involved their production personnel or modified their manufacturing practices to support processes. Kathleen and Schroeder (2002), have concluded that environmental, organisational and strategic contextual factors are essential influences on the technology practices of a plant (Schroeder & McKone, 2002).

Engineering process systems are designed and developed to ensure they perform effectively and efficiently. Marquez A. Crespo et al. (2009) classify maintenance engineering techniques within a process, by focusing on the eight management building blocks where maintenance engineering techniques play a significant role (Márquez, et al., 2009). Production environments continue to change, and more plants are automated. Increased automation, and the reduction of inventory buffers in the plant put more pressure on the maintenance system. The practical approach to maintenance management within an organisation reduces maintenance pressures.

The maintenance management model is divided into four elements, which are effectiveness, efficiency, assessment and improvement. To successfully implement the maintenance management model the organisation should (Márquez, et al., 2009):

1. Define the maintenance objective and KPI's.
2. Prioritize assets and define maintenance strategy.
3. Distinguish between high and low impacts.
4. Design preventive maintenance plans and resources.
5. Schedule preventive maintenance and optimize resources.
6. Execute, assess and control maintenance.
7. Asset life cycle analysis and replacement optimisation.
8. Continuous improvement and utilization of new techniques.

Figure 2.2 illustrates the maintenance framework techniques which are contained within a maintenance management model.

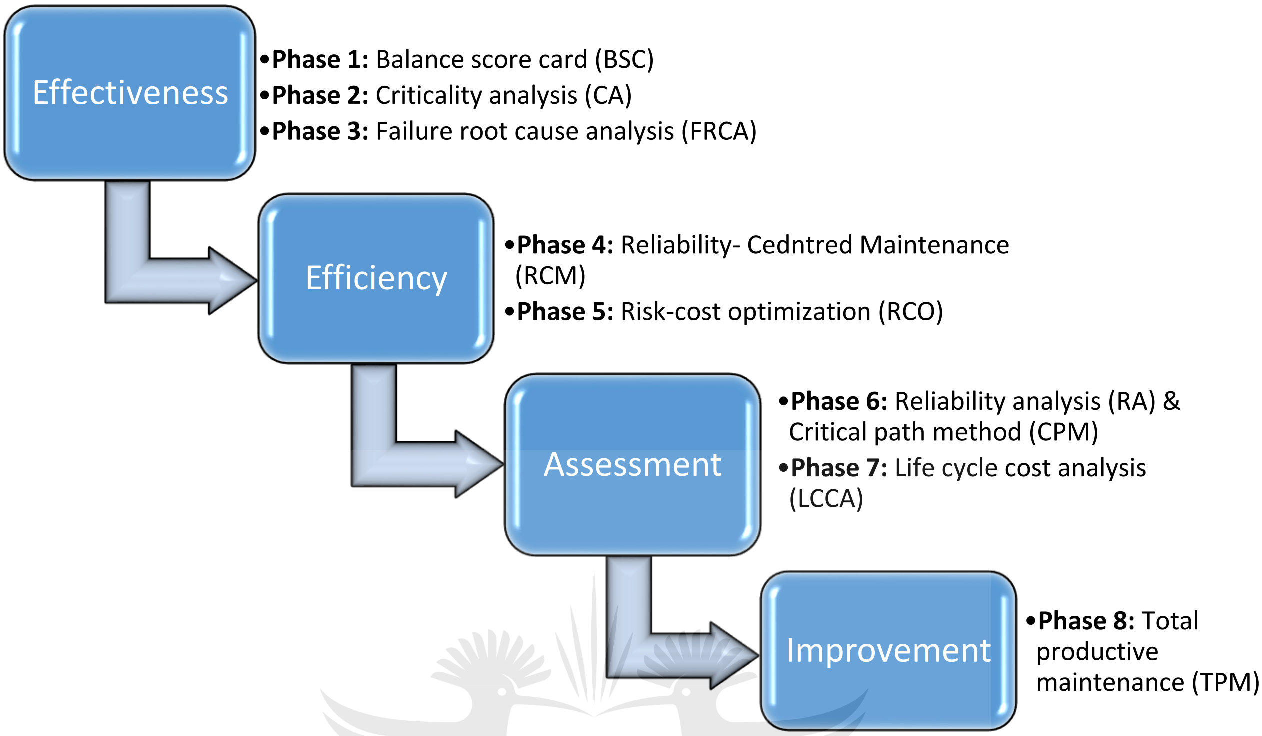

Figure 2. 2: Techniques within the maintenance framework (Márquez, et al., 2009)

The central aspect of the maintenance strategy is to determine the maintenance objective, dependent on the business plan. The maintenance objective enables the organisation to evaluate the effectiveness and success of the proposed maintenance strategy implementation and assists in minimising indirect maintenance costs. Indirect costs are costs associated with production losses and costs related to customer dissatisfaction with product quality. During the maintenance management implementation process, management needs to ensure that there are proper skill levels, proper work preparation, suitable tools and schedules within the department. These facilitate the maintenance management system's efficiency and help reduce direct costs incurred by unnecessary labour and maintenance resources which are not used continuously but just stored, probably for several years (Márquez, et al., 2009; Salonen, 2009).

2.5.2 Principle Maintenance Strategies

Maintenance strategies are divided into four principles as illustrated in Figure 2.3 below.

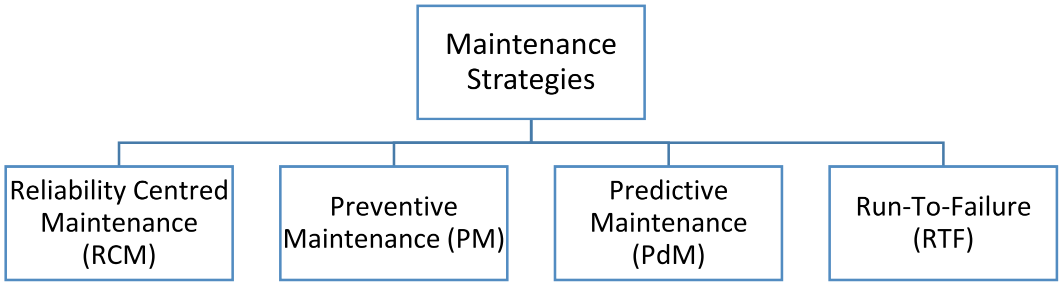

Figure 2. 3: Four Principles of Maintenance Strategies

2.5.2.1 Reliability Centred Maintenance

Reliability Centred Maintenance (RCM) is “a corporate-level maintenance strategy that is implemented to optimise the maintenance program of a company” (Moubray, 1997). RCM implementation examines the plant as a sequence of functional systems, consisting of inputs and outputs, which contribute to the plant’s success. RCM identifies the most critical functions of the organisation and then aims to optimise its maintenance strategies to minimise system failures and ultimately improve the reliability and availability of equipment. The most important pieces of equipment are those with a high probability of failure or have significant consequences if they fail. The maintenance strategy identifies possible failure modes and their consequences, considering the function of the equipment. Cost-effective maintenance techniques are determined to assist on minimising the possibility of failure. The most operative techniques are adopted to improve the reliability of the facility. Implementing RCM increases equipment availability, and reduces maintenance and resource costs (Moubray, 1997).

The application of RCM assists in finding the correct preventive maintenance schedule. It allows operators and maintainers to be involved in the reassessment of maintenance needs. It also assists in identifying plant areas that have been over-maintained or under-maintained. RCM is also very effective in highlighting plants that often fail due to excessive stress or abuse (Sherwin & Jonsson, 1995). The proper implementation of RCM offers the organisation a tool for achieving lowest asset Net

Present Costs (NPC) for a given performance level and risk (Mather, 2008). RCM does not necessarily recognise maintenance as an economic problem at the machine or plant level. It uses several well-established techniques such as FMEA or design audit, brainstorming and small group dynamics to determine the causes of each functional failure. The application of proactive maintenance on equipment assists in the identification of all failure modes likely to affect equipment (Moubray, 1997).

Sherwin David J. & Jonsson Patrik (1995), argues that using RCM only improves existing plant instead of correcting future plants, and makes junior staff responsible for assessing failure criticalities. They point out that the subjective judgements made by junior staff can be wrong, leading to adverse consequences. RCM seeks to avoid the requirement of a maintenance system to rely on reliability for accurate and complete data, analysed in a modern maintenance management information system (MMIS). Total productive maintenance and RCM can be augmented by a preventive maintenance policy based on failure-time distributions, inspection frequencies and costs (Sherwin & Jonsson, 1995).

RCM considers all asset management options such as (Mobley, 2014):

- Equipment function – The primary purpose the equipment was designed to perform.
- Functional failures – The inability of equipment to meet its specified performance standard.
- Failure modes – The way a failure occurs on equipment.
- Failure effects – The consequences of equipment failure.
- Failure consequences - The results of the action or process of failure.
- Proactive tasks - Planned course of action, set in advance when a failure occurs.
- Default actions – Failure finding.

The maintenance team's repair time response when equipment failure occurs should always be effective. The weakness of RCM can occur when there are changes in plant management processes, lack of a holistic approach and vague organisational structures (Mobley, 2014). A derivative of the RCM process can be used to optimise spares stocks and associated failure management policies, merely because the main reason for keeping stocks of spare parts is to avoid or reduce the consequences of failure. The lead time for a non-stock item is often determined by the time it takes to repair the failure, allowing to determine the severity of the spare item consequences (Moubray, 1997).

The bathtub curve in Figure 2.4, is commonly used in reliability engineering, and it demonstrates a hazard function. The bathtub curve is a combination of two or more different failure patterns. It embodies infant mortality, random failures and wear out and continues to show the probability of equipment failure with age (Moubray, 1997).

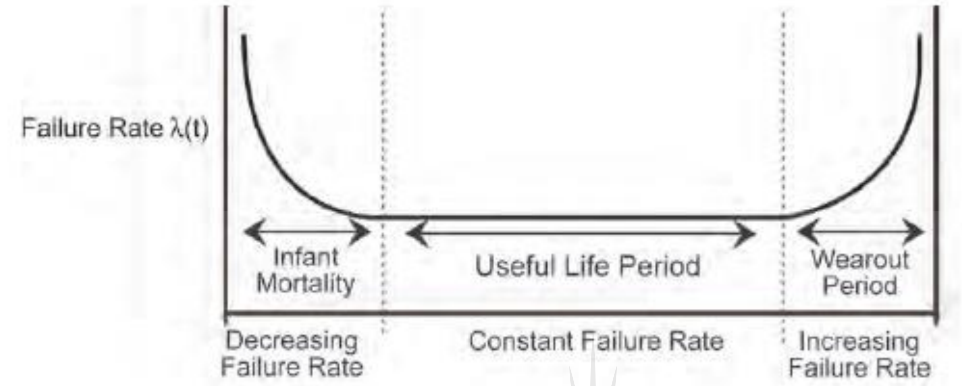

Figure 2. 4: Bathtub Curve

(Source adopted: O&M Best Practices Guide, release 3)

The bathtub curve displayed in Figure 2.4, also depicts the failure rate of plant equipment over time. Equipment can fail relatively early in the infant mortality period or last until wear-out period, whereas some equipment can fail during the useful life period. Infant mortality failures are highly undesirable and are caused by equipment defects. Useful life failures are random cases of "stress exceeding strength." Wear-out is a circumstance of life due to fatigue or reduction of materials (such as lubrication reduction in bearings). The equipment’s shortest-lived component limits the equipment's useful life. Just like “a chain is only as strong as its weakest link”. The manufacturer must ensure that all specified materials on the equipment are adequate for the intended life-cycle (Wilkins, 2002).

2.5.2.2 Preventive maintenance

Preventive maintenance is referred to as maintenance that is frequently performed on equipment to reduce the probability of failure. Preventive maintenance is carried out during the operation of the equipment to prevent an unexpected breakdown. Preventive maintenance is planned to ensure the availability of all necessary resources. Maintenance is planned on the basis of time or usage (Mobley, 2014).

Reliability-based preventive maintenance prevents failures and prolongs the useful life of plant assets. Evaluation of Reliability-based preventive maintenance is based on functional equipment failures and failure causes. The evaluation is developed by the identification of functionally significant equipment and, the identification of applicable and operative preventive maintenance tasks using the decision tree logic. Failure of functionally significant equipment can affect the safety of or economic impact on, operations and the maintenance context. The process used to identify functionally significant items depends on the anticipated consequences of failures using an analytical approach and sound engineering judgment. A top-down approach is ideal to achieve this process successfully (Mobley, 2014).

Most of the planned preventive maintenance takes place during annual shutdowns when production demand is lower than normal. The shutdowns are scheduled for plant maintenance. These shutdown schedules concern primarily the part of the equipment that cannot be accessed while the plant is running e.g. an evaporator, reactor or boiler (Lee Cooke, 2003).

Failure to plan for preventive maintenance is a major disadvantage for any production system. All estimated cash flows that occur during the entire plant life-cycle are reduced to a net present value (NPV) and totalled. To reduce total life-cycle costs and achieve the best performance of plant equipment, condition- based and periodic preventive maintenance is desirable. Appropriate preventive maintenance schedules, including component and equipment renewals, inspections, condition monitoring and overhauls, are essential for achieving a reasonable life cycle profit (Sherwin & Jonsson, 1995), this is illustrated in Figure 2.5 below.

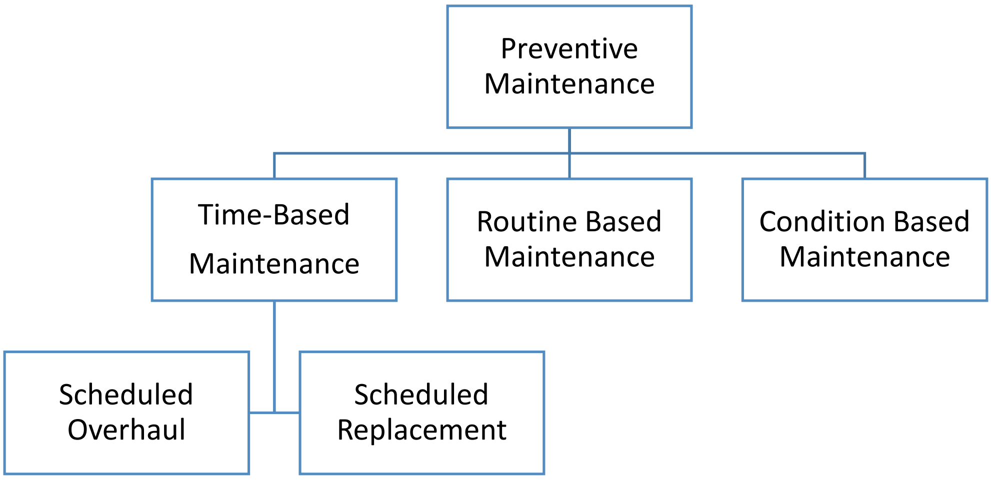

Figure 2. 5: Preventive Maintenance (Sherwin & Jonsson, 1995)

Preventive maintenance is essential to maximise the use of equipment with fewer failures. The equipment operations are continuously increased through plant production activity, and, when the specified operating hours are reached, maintenance is required (Yeh & Sun, 2011). The time points for maintenance occur randomly within the specified period. If maintenance is needed and the production line cannot be stopped, maintenance is often postponed. However, failure to perform maintenance when necessary poses a risk of product failure, affecting production and maintenance plans negatively. It is therefore important to effectively predict the time-point for preventive maintenance on equipment.

Preventive maintenance is more complex to coordinate than run-to-failure maintenance due to the planning of the maintenance schedule. Yet, preventive maintenance is less complex to coordinate than predictive maintenance, because it involves monitoring strategies. Planning is the main advantage of preventive maintenance and reduces the likelihood of reactive maintenance. Unplanned, reactive maintenance accumulates countless overhead costs which can be avoided during the planning process (Mobley, 2014). Unplanned maintenance costs include lost production, increased parts and shipping costs as well as loss of time in response to emergencies and the diagnosis of faults while equipment is not working. Preventive maintenance does not require condition-based monitoring (IAEA, 2007). Preventive maintenance eliminates the need and costs for conducting and interpreting condition monitoring data, and instead acts on the interpreted results, eliminating the need to own and use condition monitoring equipment.

2.5.2.3 Predictive Maintenance

Continuous breakdowns place unnecessary strain on the organisation's productivity. The implementation of predictive maintenance reduces plant downtime. Predictive maintenance techniques involve periodic repair and replacement of parts. The disadvantage of such practice is that it incurs unnecessary costs of replacement parts whose condition is still functional (Edwards, et al., 1998).

Various signs, conditions or indicators identify equipment failures, apart from related mechanical failures. The periodic analysis can be used in scheduling appropriate repairs upon indication of poor machine condition. This is also referred to as Statistical-based predictive maintenance and Condition-based predictive maintenance (CBPM). In the predictive maintenance condition, techniques such as vibration monitoring and thermography are applied to determine the condition of the plant and equipment (Edwards, et al., 1998). Condition Based Maintenance (CBM) is an increasingly used type of maintenance for its potential benefits, such as improved system reliability, cost-effectiveness over time and the opportunity it gives for a reduced number of maintenance operations (Milje, 2011). Figure 2.6 illustrates the Predictive Maintenance components, condition monitoring and inspections.

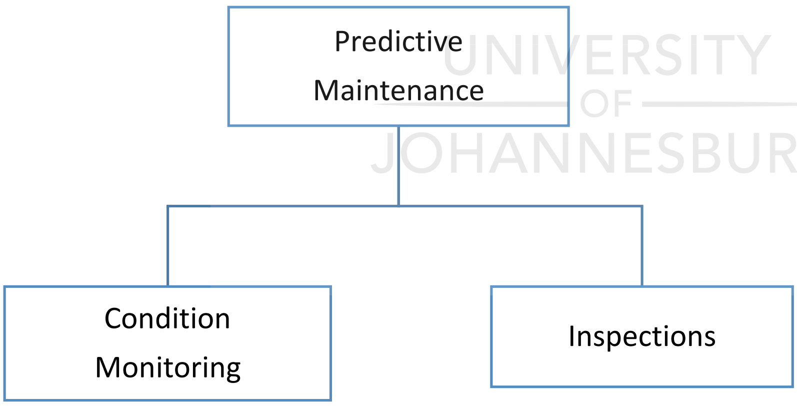

Figure 2. 6: Predictive Maintenance

A. Condition monitoring

Condition monitoring is the application of condition-based monitoring technologies, statistical process control or equipment performance for early detection and elimination of equipment defects that could lead to unplanned downtime or unnecessary costs (IAEA, 2007). Predictive maintenance evaluates the condition of equipment by performing periodic or continuous condition monitoring. The goal of predictive maintenance is to perform maintenance at a scheduled point in time when the maintenance activity is most cost-effective and before the equipment loses performance is within a threshold (Mather, 2008). Condition monitoring techniques are soley used on the critical equipment for which there is no standby equipment and that businesses cannot afford to lose, for example, blowers. Taking advantage of the available technology allows individuals to accurately assess the condition of parts and the presence of defects which would otherwise be impossible to detect.

Condition monitoring is a form of predictive maintenance where continuous monitoring of the condition of specific areas of equipment takes place. When a plant's pre-defined limit on the PLC is exceeded, an alarm output is turned on. This alarm output should initially input to a CMMS so that a work order is immediately generated. Typical conditions monitored in a chemical processing plant are; temperature, vibration, pressure and any other condition that can be detected by a sensor.

B. Inspections

Most predictive maintenance inspections are performed while equipment is in service, thereby minimising disruption of normal system operations. Inspection is the organised examination of equipment and can require activities such as greasing, cleaning, etc (Sherwin & Jonsson, 1995). Sensory inspections are common in any good inspection program. Sensory inspections use the bodily senses which are touch, smell and sight. Performing sensory inspections requires, routine daily inspections of critical equipment throughout the plant, this approach results in the identification of equipment defects and efficiently mitigates unplanned downtime.

2.5.2.4 Run to Failure

Run to failure is a maintenance strategy that allows equipment to operate until it breaks down, and then reactive maintenance will be performed (Moubray, 1997). A plan to fix the equipment is set in place ahead of the failure event, to prevent causing production issues. The run to failure approach requires spare parts and staff to be hands on when replacing the failed part and maintaining the equipment availability. Run to failure is different from reactive maintenance because there is an active plan set in place when a failure occurs. Run to failure is commonly used on equipment that does not pose a safety risk and has minimal effect on production when it fails. However, poor documentation can lead to poor troubleshooting and a loss of production. It is therefore important for management to develop an inventory list of all the equipment which can run to failure, to allow maintenance teams to plan for the replacement when a failure occurs. A typical example of run to failure equipment can be illustrated by the maintenance plan for a rotating machine (e.g. fan). After the fan fails due to pressure loss, a new impeller/ stator is obtained from stores and replaced at a convenient time. Run- to- failure is undesirable where the availability of equipment is necessary and the total maintenance costs can be reduced with a more proactive approach, such as preventive or predictive maintenance strategies.

Run to failure maintenance can be implemented using several maintenance methods and managed by tools such as; paper-based systems, spreadsheets and CMMS systems. CMMS enables different types of maintenance strategies to be operated simultaneously while monitoring the repair and replacement frequency of assets, including all associated costs. A good run to failure maintenance strategy is likely to require an inventory management tool because of the large number of spares needed for breakdowns.

2.6 The barriers to implementing a reliability management system

Training on CMMS operation is often a key component of implementation and provides a disciplined approach to best system usage. Unfortunately, many companies are not deriving many benefits from their CMMS because the system has been poorly implemented. Mohamed (2005), has carried out research on identifying the barriers affecting quality in maintenance, focusing on the interactions between maintenance and quality. The study has identified technical, economic, managerial, organisational and cultural environmental barriers. This author’s case study highlighted that organisations do not actively promote quality in the maintenance area. This takes into consideration the influence of organisational, social, economic and political factors (change culture) on the quality of operations and performance inside the organisations. However, in a study by Singh, et al. (2015), three barriers to the implementation of maintenance systems in industries have been recognised as; lack of top management support, lack of overall equipment effectiveness (OEE) measurement and lack of strategic planning.

The shortcomings of CMMS occur when maintenance employees do not see CMMS as a tool that will assist on their job performance, be more efficient and improve work processes. Thus, management, maintenance employees and operators should be involved in the CMMS selection and implementation planning stages to help determine the type of system that is the best fit for the company and ongoing CMMS success.

Maintenance of a decentralised employee structure impacts negatively on the performance of the department (Vosloo, 2013), consequently preventing the maintenance department from achieving the desired state of maintenance. For example, when a conflict between maintenance and production employees arises, and the two departments are not working together, it affects the effectiveness of maintenance. Maintenance employees become overloaded with fixing equipment, having no time to conduct inspections or preventive maintenance. The motivation for maintenance employees implementing improvements eventually dries up, and they get blamed for failures and unproductivity. Thus, without a plan or process to manage reliability and maintenance management systems, culture change is impossible, and this hinders continuous improvement. Dhillion (2006), in a study on the impact of human errors on maintenance has established that the occurrence of maintenance errors increases as equipment ages, and these are due to the increase in maintenance frequency. Human errors occur due to incorrect repair or preventive actions and are classified into six categories (Dhillon & Liu, 2006):

- operating errors,
- assembly errors,
- design errors,
- inspection errors,
- installation errors, and
- maintenance errors.

Many CMMS fail soon after implementation, because they have been poorly specified, and the system does not meet the organisational requirements. These are initially because the proactive strategies get compromised in an organisation that is struggling to meet pressures to keep the plant running (Weir, 2015). Moreover, when planning and scheduling are reactive, the previously planned activities get dropped from the daily work schedule. Reactive maintenance is characterised by reduced equipment performance, unpredicted breakdowns and ongoing minor plant stoppages, which in turn lead to unexpected production losses and overspend of the maintenance budget. These characteristics make it challenging for management to adopt the maintenance management system because accurate equipment history is often not captured in the CMMS and therefore not available.

Strong support from management is essential to improve equipment performance and target the long-term sustainable maintenance management system. Thus, good leadership is critical to the maintenance and production team's overall success. Maintenance management's lack of involvement in tracking production losses and critical equipment costs leads to escalating costs, which in turn diminishes the most critical return opportunities. In the 21st century, organisations have been forced to adapt to an innovative state of mind and use a diverse knowledge spectrum to solve the possible problems of the future. However, this mindset has been challenged by the limitations that organisations have placed on maintenance budgets (Vosloo, 2013). The condition of maintenance workshops and stores also poses a real barrier to efficient maintenance practices.

2.7 The effects of the Reliability management system in an organisation

Liyanage and Kumar (2003), have observed that an increased number of organisations continue to realise the value that maintenance adds to their business process and are therefore treating maintenance as an essential part of their business. Maintenance is regarded as the innovation driving factor, allowing new technologies into the company for the company to be more competitive. Thus, maintenance is an important element of modern business and must be managed efficiently. This is further illustrated by the value driven maintenance (VDM) concept. VDM is a philosophy which was developed by Mark Haarman and Guy Delahay (2006), for ongoing maintenance improvement at any given time based on cost/benefit analysis. The value derived form maintenance is summarised into four value drivers in Figure 2.7, below.

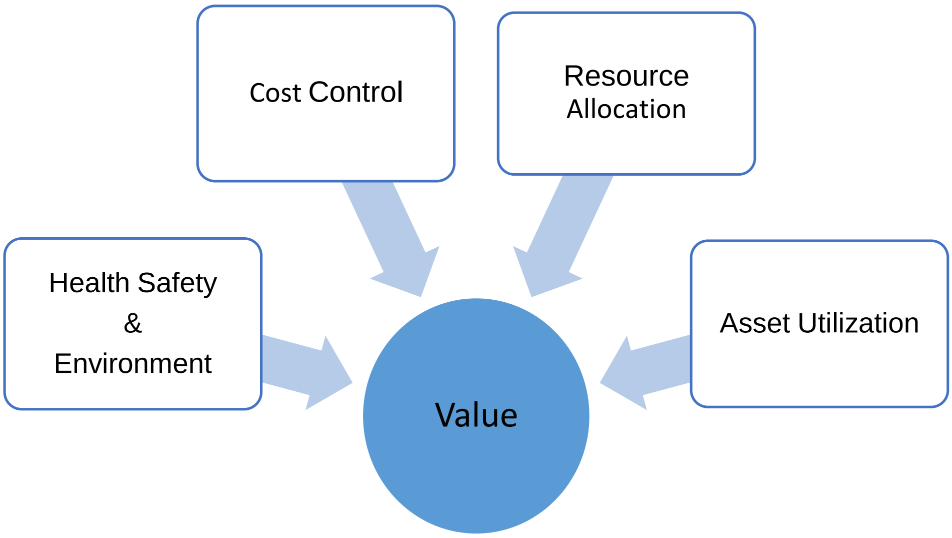

Figure 2. 7: Value Driven Maintenance (Haarman & Delahay, 2006)

Value drivers such as asset utilisation, resource allocation, cost control and Health Safety and Environment (HSE) have a major impact on the organisation's maintenance function. Asset utilisation ensures the availability of plant during operations and in declining markets, increasing asset utilisation aid in ceasing operation of unnecessary subsidiary plant while still meeting demand. Resource allocation manages spare parts and labour. Cost control regulates the maintenance cost, such as salaries, contractor costs, equipment, emergency deliveries and specialist tools which consume maintenance budgets. Cost control helps to reduce maintenance expenditures by reducing unplanned maintenance activities. HSE policy ensures that the organisation complies with the HSE regulations. Organizational compliance with HSE regulations reduces maintenance related incidences and avoids the risk of legal or obligatory government penalties (Haarman & Delahay, 2006). It is important for maintenance managers always to keep value drivers balanced to maximise stakeholders' value (Stenstrom, et al., 2013). To calculate VDM, the following formula is used;

$$PVPM = \Sigma \frac{(FSHE_t)[(CFAU_t) + (CFCC_t) + (CFRA_t) + (CFSHE_t)]}{(1+r) \times t}$$

- *PVPM = present value potential of maintenance*
- *$FSHE_t$ = HSE factor in year t (% compliance with HSE regulations)*
- *$CFAU_t$ = future free cash flow in year t from assets utilisation*
- *$CFCC_t$ = future free cash flow in year t from the cost control*
- *$CFRA_t$ = future free cash flow in year t from resource allocation*
- *$CFSHE_t$ = future free cash flow in year t from HSE*
- *R = discount rate*

Maintenance is crucial in any organisation, and without proper maintenance, assets deteriorate over time causing a loss in quality of the output produced. More importantly, it can also have a negative impact on the safety of the asset or the people that operate it. In world-class industrial operations maintenance efforts are used to make the company more competitive. Businesses such as DuPont Chemicals, Toyota of Japan, Meridian Energy in New Zealand rely on the maintenance team for making the business more successful.

Traditionally, management has viewed maintenance as a cost-centre within an organisation, because of the cost associated with the maintenance administration process. It is thus common for management to often ignore the additional benefits that maintenance can bring to an organisation, such as (Haarman & Delahay, 2006):

- Reduced reactive maintenance costs
- Reduced production start-up time after failure
- Reduced production scrap
- Reduce the costs of downtime due to missed orders and lost revenue
- Customer perception/satisfaction
- Improved quality of products
- Reduced environmental impact

To view maintenance as a value driver, management must move from cost-based thinking to value-based thinking. Effective maintenance adds economic value to a business by maximizing plant availability at the lowest possible cost (Haarman & Delahay, 2006).

However, Kit-Fai Pun et al. (2002), put stress on effectiveness-centred maintenance; this approach encompasses the core concepts of quality management, total productive maintenance and reliability-centred maintenance. Kwai-Sang et al. (2002) define effectiveness-centred maintenance (ECM) as an integrated approach which focuses on system functions, customer service and contributes to the continuous improvement of maintenance management practices within an organisation. ECM optimises organisational management decisions during the maintenance co-planning operations, the overhaul/renewal of equipment, quality improvement and ultimately determines the life-cycle profits for the overall effectiveness of the plant. ECM focuses on quality management, total productive maintenance and reliability-centred maintenance approach. Implementing ECM consists of four key elements as shown in Figure 2.8. The four key elements are; employee participation, quality improvement, maintenance development and performance measurement (Pun, et al., 2002).

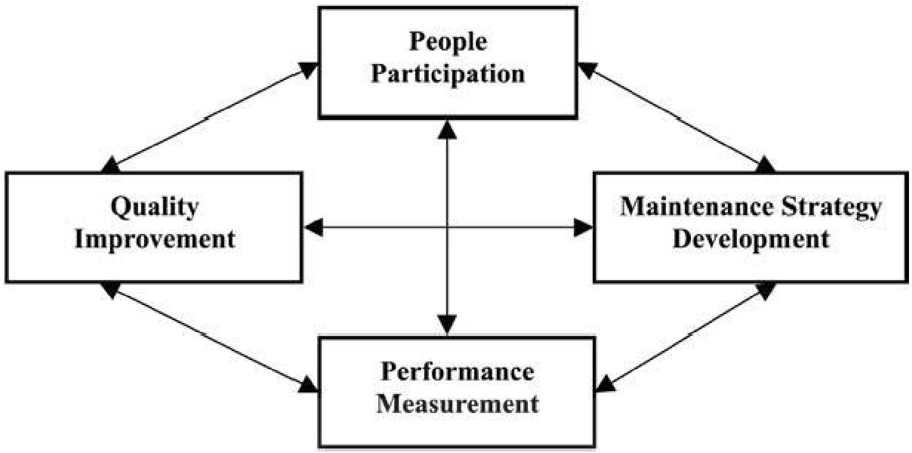

Figure 2. 8: Key elements of ECM approach (Pun , et al., 2002)

ECM incorporates the RCM logic analysis to support the TPM strategy within the organisation. ECM absorbs the key features of TPM which focus on improving the system availability and optimising the maintenance workload (Soares, 2010). In the study performed by Pun, Kwai-Sang et al. (2002), they carried out the ECM approach on plant availability, during a break-down, to illustrate how failed equipment can be replaced without causing any further delay of the plant production process. Here, by allowing the failed equipment to be repaired, while the plant continued to run, the customer was able to receive their product on time. The ECM approach thus improves the response time.

Failure of proper maintenance can cause great inconvenience to plant operation processes and often leads to severe negative impacts on society and the environment. It is therefore important to take into consideration the health and condition of individual pieces of equipment in a chemical plant. Constant equipment breakdowns cause substantial production losses and become expensive maintenance issues. This author performed a study aimed at developing equipment optimisation for a chemical process plant and identified plant equipment that needs particular focus (Tomo, 2012).

2.8 Measuring a plant's maintenance performance

Parida and U. Kumar, emphasise the importance of measuring maintenance performance as an essential element of strategic thinking for the manufacturing industry. Therefore, it is important for management to recognise maintenance as an integrated, essential part of the production. Furthermore, manufacturing organisations should infuse quality and performance improvement initiatives in all aspects of their processes to improve their competitiveness (Maletič, et al., 2012).

According to past studies conducted in the UK, EU and US maintenance costs continue to rise over time. Primary improvement in maintenance could lead to significant savings (Sharp & Kutucuoglu, 1997). Conversely, Weireman (1991) have found that one-third of maintenance expenditures are unnecessary or wasted. The transition to CMMS requires a significant investment. However, the return on investment depends on the suitability of the selected software package, the implementation effectiveness and the commitment of all employees to the reliability management system. A great extent of the CMMS financial returns is achieved through improved stock control procedures (Weir, 2015).

Gupta et al. (2007), have conducted a study on the reliability and availability in a plastic-pipe manufacturing plant. The research focused on determining the reliability of a (K, N) system. System reliability is an important issue in evaluating the performance of an engineering system. However, a complex system decreases the plant's reliability. Therefore, improvements in the plant reliability become vital, and the maintenance team should take up necessary precautionary measures (Gupta , et al., 2007). After years of operation, many chemical plants lose track of the primary goals of their maintenance system. This usually occurs after a plant has been experiencing rare equipment failures and frequent inspections aimed at preventing the recurrence of a particular failure has been continuously performed, thus causing a significant burden on maintenance employees (Armitage, 2015).

Armitage (2015), has conducted a study concentrating on how organisations in the chemical process industries can re-evaluate and restructure their maintenance plans to incorporate industry best practices. A plant can gauge its maintenance system status through industry benchmarking, surveys or by using a trial and error approach.

In the study, the Armitage (2015) has measured performance against a set of best practices in maintenance, which assists in identifying the improvement opportunities. Management and employees need to contribute to a more conducive working environment by improving cooperation and integrating communication between the maintenance and production departments (Fredriksson & Larsson, 2012).

The importance of maintenance productivity is best understood by the maintenance managers of the organisations. Maintenance managers should be able to identify, evaluate, and manage the difficulties that face them in their part of the organisation.

2.9 Maintenance decision making

Failure to implement the CMMS is an ongoing problem for industry experts (Weir, 2015). Management should consider researching the effects of implementing or modifying CMMS in the organisation as a high priority; to avoid the pitfalls in decision making. However, for an organisation to achieve its desired results from CMMS, management should consider the influence of the following components (Weir, 2015):

- the size of the organisation that will be using the CMMS,
- functionality required,
- facility type,
- budget and return on investment.

Maintenance, employees and management should all view a CMMS as a means for controlling costs and increasing capacity. For CMMS's success, management and employees need to take into consideration the organisation's culture and environment (Weir, 2015). A clear reporting process for planned and completed tasks helps management in improving their decision-making process. However, CMMS enables management to control resources and costs very effectively, because it provides access to the latest equipment maintenance data history and relative maintenance cost (Benchmate Systems Inc., n.d.). Triantaphyllou et al. (1997), have identified that maintenance requires the evaluation of cost, reparability, reliability and availability requirements. The study has used a sensitivity analysis to solve complex maintenance management (Triantaphyllou, et al., 1997). However, in a study by Almeida & Bohoris (1995), focusing on utility theory and multi-attribute utility theory, a framework was developed to solve maintenance decision problems (de Almeida & Bohoris, 1995).

Risk analysis is one tool that assists decision makers in prioritising and planning maintenance actions (Backlund & Hannu, 2002). Backlund & Hannu (2002), have carried out a comparative study based on the risk analysis of three hydro-power plants. The study has revealed the importance of a well-planned requirement specification and the need to analyse and interpret risk analysis results before stakeholders make decisions. Parida (2007), has conducted a study to assist with the identification and development of maintenance performance indicators (MPIs) for a mineral processing plant. Parida (2007), has established that the company analysed existing MPIs and used them to measure the performance of a section of the plant, in particular, breakdowns. The effects of MPIs was tested and validated within the framework of a multi-criterion and hierarchical maintenance performance measurement (MPM) framework. The study concluded with the identification of nine MPIs that will assist with assessing the status of plant and at the same time will facilitate the plant performance within a corporate strategy. This approach can be useful for plant managers, engineers and owners of assets to select and develop MPIs that can describe the health status of their plant and assets that eventually link to corporate strategy. The study has also helped to identify the impact of irregular stoppages that reduce process quality and productivity (Parida, 2007). Sharma & Sharma (2010), have conducted a study on system failure behaviour and maintenance decision making, to assist in modelling, analysing and predicting the behaviour of industrial systems, in order to facilitate the planning of maintenance strategies. The study's integrated framework uses RCA, FMEA and fuzzy methodology to facilitate the reliability analysts in maintenance planning, reliability and maintenance aspects, after understanding the failure behaviour of components in the system (Sharma & Sharma, 2010). Hassanain et al. (2015), have developed a multi-criteria decision-making model for use by maintenance teams and managers to consider before deciding on outsourcing. Outsourcing maintenance can have strategic, management, technological, quality, economic and functional characteristics. The study concluded that it was best not to outsource maintenance (Hassanain, et al., 2015).

2.10 Total Productive Maintenance and Total Quality Management

2.10.1 Total production maintenance

The evolving complexities of manufacturing equipment due to the continuous introduction of new technologies and automation has led the Japanese to introduce total production maintenance, which has integrated the lifecycle approach into factory maintenance and support. Total production maintenance (TPM) over the decades has helped organisations to reduce the costs associated with maintenance labour, materials and those due to production losses (Blanchard, 1997). Ahuja, I.P.S; Kumar, P., refers to TPM as a maintenance philosophy that requires the total participation of all the workforce. TPM is one of the world's leading production strategies (McKone, et al., 2001). However, according to Pramod et al. (2006) the objectives of TPM are concentrated on the improvement of an operator's capabilities and towards enhancing the quality of equipment maintenance (Pramod et al., 2006).

The objectives of TPM are to achieve:

- zero breakdowns,
- zero defects,
- moreover, improved throughputs.

The benefits of TPM are (Pramod , et al., 2006):

- Cultivating a sense of ownership of equipment among the operators.
- Development of cross-functional teams to improve individual employee and employer performance.
- Increase the life of equipment and plant.
- Identification of reasons for equipment failures.
- Increase in motivation level of employees.

In recent years, organisations have adopted strategies to improve the quality of products and processes in the competitive world of today. One of the current strategies adopted by modern organisations in this direction is TPM (Pramod , et al., 2006). TPM links the principles of maintenance engineering and TQM (Seth & Tripathi, 2005).

TPM incorporates the skills of all employees and aims to improve the overall efficiency of the facility by reducing the waste of time and resources. Total productive maintenance is typically a concept that can easily be applied to a production plant. TPM emphasises all aspects of production, as it seeks to incorporate maintenance into the everyday performance of a facility. TPM considers the maintenance performance as a factor when evaluating the performance of the facility (Ahuja & Kumar, 2009). The most important measurements of total productive maintenance is overall equipment effectiveness (OEE). The platform for TPM is the 5S, as shown in

Figure 2.9, which relate to the place where production occurs and are most apparent for the equipment operators (McKone, et al., 1999).

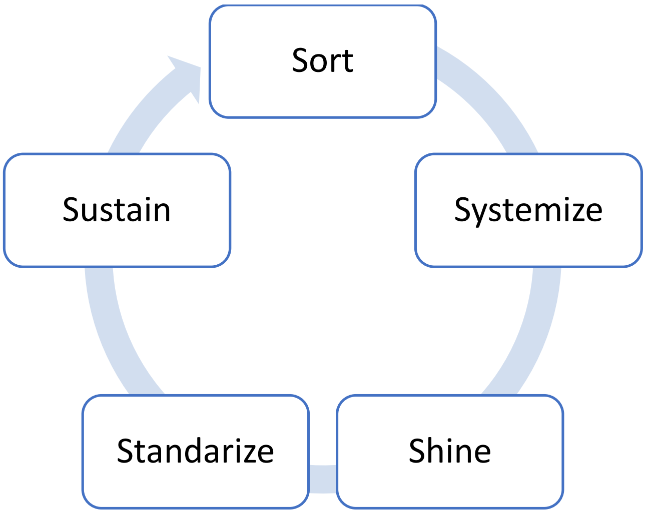

Figure 2. 9: Total Production Maintenance

Although the field of maintenance engineering has been dominant for several decades, the development of TPM principles has greatly improved its importance. Before the evolution of TPM principles, the maintenance engineering field was isolated from the holistic operational performance of organisations (Pramod , et al., 2006). By realising the importance of integrating TPM into the organisational working framework, Nakajima (1993) has made an important contribution by linking maintenance engineering and total quality control principles. However, according to the current literature, the ideal goal of TPM is to nourish the synergic benefits of TQM and maintenance engineering (Ahuja & Kumar, 2009).

2.10.2 Quality

Quality is guided by the set standards and meeting them. Hence, implementing quality while performing maintenance requires setting standards for every maintenance action performed on equipment to ensure a consistant standard is achieved every time (Sondalini, n.d.). Previous research has shown that during (After World War II), two quality specialists, Juran and Deming, introduced the statistical quality control approach to Japanese companies. These companies integrated quality into their management practices, and within 20 years, they managed to make a significant penetration into 'Western markets', because of the improved quality levels of their products (Evans & Lindsay, 1996).

In their case study Pramod et al. (2006), have been able to integrate quality function deployment (QFD) and total productive maintenance (TPM) to facilitate the attainment of world-class maintenance quality. This study was conducted using a model named “maintenance quality function deployment” (MQFD) (Pramod, et al., 2006). Arsovski et al. (2008), have conducted a study on opportunities for improving maintenance process quality by using integrated information system structures. The study that observed quality as the output characteristic of the maintenance process, is supported by the application of information technology. With ever increasing levels of automatization and quality, equipment maintenance is crucial, and the quality of the production process becomes more and more dependent on the maintenance process. (Arsovski, et al., 2008).

Many organisations view maintenance as the least controllable function, through which they have an opportunity to reduce costs (Mohamed, 2005). However, arbitrarily reducing the maintenance budget can lead to lower levels of operating capacity and reliability. Process quality improvement is achieved through continuous improvements and radical process improvement (re-engineering processes), and the development of procedures and instructions for securing quality in maintenance processes.

2.10.3 The relationship between quality, productivity and maintenance

Flynn et al. (1994) define quality management as an integrated method to achieve and sustain high-quality output. Quality engineering is the discipline that analyses a manufacturing system at all stages and improves quality. Quality engineering is the discipline that analyses a manufacturing system at all stages, improving the quality and output of the production process. Quality engineering is often regarded as the means of achieving a consistent maintenance management system within an organisation. Quality improvements methods are a means of improving the organisation with customers satisfaction and competitiveness. Quality is related to manufacturing, and reliability is more related to the validation of sub-system or lower item requirements, (system or part) integrated design and lifecycle solutions (Flynn, et al., 1994). A manufacturing process focuses on repetitive activities that achieve high-quality outputs with minimum cost and time.

Several studies have investigated the link between quality performance and cost reduction. Interactions between quality and production are interpreted from a maintenance point of view. The maintenance function consists of two production outputs: the primary production output, which is the desired product, and the secondary output, which is the demand for maintenance (Ben-Daya & Duffuaa, 1995).

Thus, the implementation of a robust maintenance program within an organisation is desirable to provide reliable equipment maintenance and reduce equipment process variation (Cua, et al., 2001). The principal role of maintenance is to maintain the quality of the elements involved in production instead of reacting from one repair to another. A good maintenance program has a positive effect on production by increasing production capacity and controlling the quality and quantity of output. When outlining the relation between quality and maintenance, it is necessary to indicate the product quality, production cost, machine condition and its life cycle (Maletic, et al., 2012). The quality of maintenance is not only influenced by the type of production machinery and maintenance policy. The quality of input elements (such as raw materials, production tools, methods and procedures, operational and maintenance skills and operating conditions) is influenced by the production process (Maletic, et al., 2012).

In a case study Alsyouf (2007), has found that loss of production because of unavailability of the plant due to unplanned stoppages and losses related to maintenance problems, resulted in reduced productivity. Hence, reducing production losses enhances product quality and yields more profit thus improving the company's competitiveness, generally through detecting and eliminating causes of problems at early stages (Alsyouf, 2007).

2.10.4 Total quality management

Chang (2005), refers to "Total quality as a philosophy that includes 'soft' aspects of management such as leadership and organisational culture, and 'hard' aspects such as organisational systems and statistical techniques." Total quality is a management philosophy that has gradually grown after some time and keeps on doing as such utilising Continuous Improvement (CI) as an important driver. Continuous Improvement is a part of quality management practices and contributes to the organisational efficiency and effectiveness considering the total productive maintenance. Quality and maintenance go hand in hand with a manufacturing set up, total quality management (TQM) and TPM share many threads of commonalities like employee involvement, cross-functional approach and continuous improvement. TPM helps to configure the necessary maintenance organisation structure, which facilitates the CI in maintenance practices (Maletič, et al., 2012).

The application of the correct principles of TQM improves the organisation's competitive advantage. For an organisation to successfully implement TQM, it requires all key TQM practices to be considered. However, inappropriate measurements can act as barriers to TQM implementation (Chang, 2005). Performance measurement remains a necessity in the mission for business excellence. Organisations should adapt their measures and measurement systems to facilitate TQM, to prevent failure in achieving expected benefits (Cua, et al., 2001). Lack of employees' knowledge of TQM practices and quality improvement techniques usually results in a lack of involvement and motivation to participate in teamwork and empowerment practices in the workplace (Sadikoglu & Zehir, 2008). To avoid this, employees require TQM training to improve their skills. Thus, autonomously operators can continue to attend to the daily maintenance of their equipment, without engaging the dedicated maintenance team.

2.11 Economics of Maintenance and Maintenance Risk

It is important to bear in mind that at a specific stage in the life of the equipment, it will be economical to purchase new equipment. Continuing to maintain the old equipment once it has surpassed its lifespan will require the extension of resources for the escalating annual maintenance cost. As the equipment continues to experience ageing effects, the inspection and repair costs associated with structural fatigue and corrosion will continue to escalate with each successive scheduled maintenance check (William, 2016).

High-risk organisations demand quality reliability. Thus further insight to strengthen reliability in a plant environment is ideal. Poor reliability in chemical plants may lead to significant damage or loss. Strengthening reliability is vital in operating organisations that are crucial to a society where errors would cause significant damage or loss (Offstein , et al., 2014). Postponing, avoiding, or eliminating a maintenance activity to reduce maintenance cost is weighed against the potential risk. Manufacturers' recommendations are important to reduce maintenance risk associated with a specific recurring technical maintenance problem. Therefore, it is important to determine the appropriate maintenance level for an acceptable level of maintenance risk and costs.

Risk is the likelihood of an event happening, which may have a negative impact on the plant processes. When applying the Maintenance management approach, it is vital for the plant assets to be prioritised. The assets are prioritised according to the probability/risk number (RPN). The assets found to have a high PRN number will be analysed first. If the number of resources available outweighs the assets at risk, management should mitigate risk by determining where the available resources can be applied first. Thus, the organisation’s risk management process should have a well-established risk assessment structure, which contains a mitigation plan and implementation strategy.

Risk assessment can be measured;

$$R = P\ x\ C \tag{1}$$

where, P is the probability and C is the consequence.

Risk assessment techniques are used to prioritise assets and align maintenance actions with business targets. Risk assessment reduces maintenance costs, associated with safety, environmental risk, production losses, and ultimately, customer dissatisfaction (Márquez, et al., 2009).

2.12 Tools and Systems used for Maintenance Management

More organisations are treating maintenance as an integral part of their business, because of their increased awareness, because well maintained plant creates added value to the organisation’s process (Liyanage & Kumar, 2003). Concerning the dramatic change in the use of technology, there is a growing reliance on software for managing maintenance activities. Therefore, maintenance productivity is important in governing the economics of production activities. Maintenance activities are multidisciplinary in nature. Thus it is important to measure the performance of maintenance productivity through an integrated approach (Parida & Kumar, 2009). Although the initial investment on CMMS implementation is a cost, in a study by Enofe & Aimienrovbiye (2010), the study declared maintenance to be a profit centre rather than a cost centre (Enofe & Aimienrovbiye , 2010).

Computerised systems assist on with the plant’s reliability, availability and mean time before failure by determining the failure and repair rates. Though system complexity decreases plant reliability, the reliability of a system is achieved by continuously monitoring it (Gupta , et al., 2007). However, companies with a high level of maintenance strategy effectiveness are characterised by high and effective integrated CMMS usage. (Kans, 2012) A CMMS system is a computer software that keeps records of all assets and helps the maintenance department to plan and track their maintenance tasks. CMMS can also be defined, as a valuable maintenance management tool that helps keep equipment running, allows the maintenance team to maintain a safe and compliant work environment, helps control costs and effectively manage resources. A CMMS software package is designed to maintain a computer database for the maintenance of an organisation. A CMMS increases asset efficiency and reliability while keeping the practice of maintenance as cost-effective as possible.

CMMS assists in facilitating the management of maintenance resources to monitor efficiency and to provide appropriately analysed management information for further consideration (Lee Cooke, 2003). The data collected from CMMS contributes to the efficiency of maintenance workers, the quality of management decisions and the verification of regulatory compliance. CMMS software is normally designed around a central computerised database into which maintenance and repair information is recorded. Lee Cooke (2003), developed a diagram, Figure 2.10 with possible input and output records to illustrate the CMMS process. The input information is manipulated to produce work schedules and job orders. The CMMS enables report generators for work-in-progress to be monitored and statistical management information to be produced.

A CMMS enables a manufacturing plant to simultaneously achieve high labour productivity, fast, reliable delivery and high-quality consistency. Unplanned changes to the production schedule have adverse effects such as delaying displaced jobs, increasing average throughput times and work in process stocks. Thus, the investment in replacement spare parts and standby or backup machines need to be controlled.

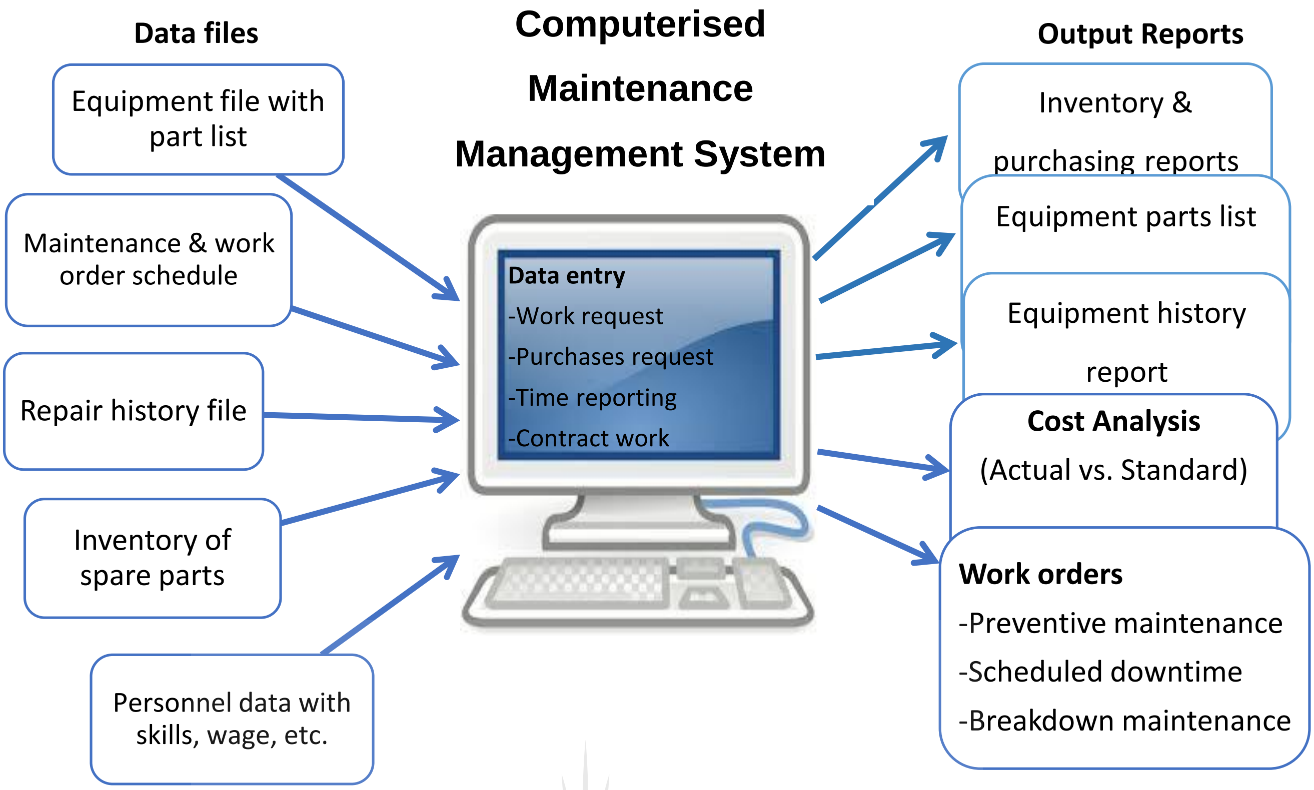

Figure 2. 10: Computerised Maintenance Management System

2.13 Measurements of Maintenance Effectiveness

The performance of the maintenance process is essential for the long-term value creation and economic viability of various industries. It is therefore necessary to measure the performance of the maintenance process so that it can be controlled and monitored. This can be achieved by taking appropriate and corrective actions to minimise and mitigate risks to safety and enhance the effectiveness and efficiency of the equipment maintained. A measure frequently used by industries is the maintenance performance measuring system for measuring maintenance productivity (Parida & Kumar, 2009).

Figure 2.11 below depicts the maintenance performance measurement system (MPM) indicating the identity between indicators and measures.

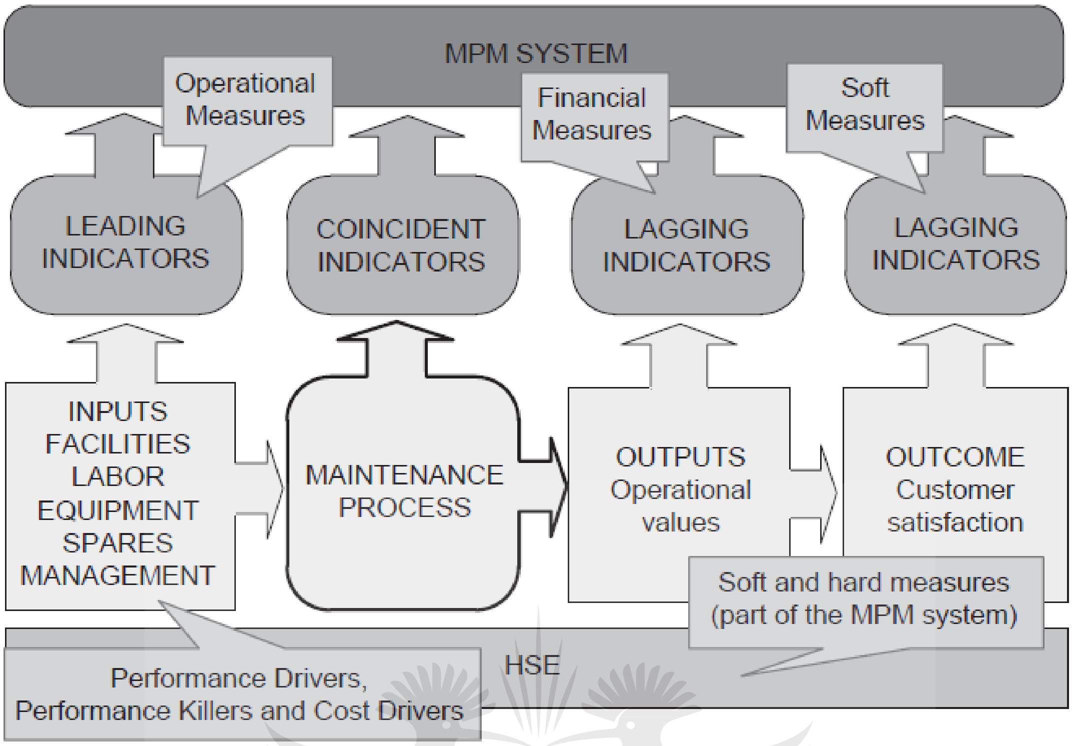

Figure 2. 11: Input-process-output model with integral MPM-system (Stenstrom, et al., 2013)

The performance drivers support input elements within the process, driving the business performance. The maintenance performance killer is the input element in a process that performs or hinders performance. Thus, the performance killer leads to poor performance, e.g. unavailability of resources, raw materials, spares, employees, system support, project support and time. It is the cost driver input element to a process that affects or drives costs. The leading indicator measures the inputs to a process, indicating future events. This involves preventive maintenance indicators, e.g. inspections and sensors. The lagging indicator measures the outputs of a process and indicates events that have already taken place. Whereas, coincident indicators measure events at the same time as they occur and indicates the actual condition of the equipment (Stenstrom, et al., 2013).

Minimising downtime should be performed in such a way that it has a positive impact on the product quality or employee morale and does not jeopardises a longer-term strategy to increase the amount of preventive over reactive maintenance. When optimising the work done by the maintenance department, several conflicting factors must be considered. The struggle then becomes which maintenance metrics the department should focus on. Table 2.1 below illustrates KPI based on their critical success factors.

Table 2. 1: Key Performance Indicators

Critical Success Factor	**Key Result Area**	**Key Performance Indicator**
Financial Performance	-Cost -Revenue	-Maintenance cost/ unit -ROI (maintenance)
Customer Satisfaction	-Quality -Service	-Number of complaints -Value for money -Referrals
Process Performance	-Equipment performance	-OEE
Employee/ Environmental Safety	-Health -Safety -Legal Requirements -Environmental	-Number of accidents -Number of HSE complaints -Employee complaints

Performance measurement is a management approach used to determine the performance gaps between current and projected performance. Management is responsible for setting maintenance metrics and benchmarks for plant operations to evaluate the effectiveness of the maintenance strategy and possible future improvement plans. Benchmarking is the process for setting standards to be used as a reference point for evaluating industry performance or quality. However, maintenance metrics (also known as KPIs, see 2.13.1) are required by maintenance managers to measure and perform metric calculations as demonstrated in Table 2.2 below.

Table 2. 2: Maintenance Metrics

Metric	Variable and Equation	Benchmark
Equipment Availability	$\% = \frac{Hours\ each\ unit\ is\ available\ to\ run\ at\ capacity}{Total\ hours\ during\ the\ reporting\ time\ period}$	>95%
Schedule Compliance	$\% = \frac{Total\ hours\ worked\ on\ schedule\ jobs}{Total\ hours\ scheduled}$	>90%
Emergency Maintenance Percentage	$\% = \frac{Total\ hours\ worked\ on\ emergency\ jobs}{Total\ hours\ worked}$	<10%
Maintenance Overtime Percentage	$\% = \frac{Total\ maintenance\ overtime\ during\ period}{Total\ regular\ maintenance\ hours\ during\ period}$	<5%
Preventive Maintenance Completion Percentage	$\% = \frac{Preventive\ maintenance\ actions\ completed}{Preventive\ maintenance\ actions\ scheduled}$	>90%
Preventive Maintenance Budget/Cost	$\% = \frac{Preventive\ maintenance\ cost}{Total\ maintenance\ cost}$	15% - 18%
Predictive Maintenance Budget/Cost	$\% = \frac{Predictive\ maintenance\ cost}{Total\ maintenance\ cost}$	10% - 12%

Source: Adapted from Industry Operation and Maintenance Metrics and Benchmarks

2.13.1 Maintenance Key Performance Indicators

Al-Hassan K. et al. (2000), emphasise maintenance KPIs as being best for measuring the effectiveness of an organisations maintenance performance. To measure the KPIs, the author makes use of lagging and leading indicators to provide information on the performance of maintenance efforts. The KPI measures the level and rate of achieving the objective. KPIs can also be used to measure the effectiveness of the changes or actions taken, to determine if they are bringing about any improvements. Typical KPIs for manufacturing include operating cost; asset availability, lost time injuries, number of environmental incidents, overall equipment effectiveness and asset utilisation.

Improving the level of productivity can assist in reducing maintenance costs. The organisation's management structure should incorporate maintenance and prioritise maintenance. The significance of maintenance has a serious impact on the success or failure of organisation objectives (Al-Hassan, et al., 2000). Industrial Management frequently faces challenges in devising suitable methods to measure productivity within an organisation. However, the total productivity of an organisational system is applied by capturing the impact of cumulative inputs on cumulative outputs (Saha, 1994).

Total productivity ratio = (Total tangible output/ Total tangible input) x100 *(1)*
Where;
Total tangible output = value of finished goods produced + value of partial units produced + other income.
Total tangible input = value of (human + material + capital + energy + other resources) used.
Specialised software packages are used for the computation of total and partial productivities in manufacturing organisations.

2.13.2 Monte-Carlo Model

Alexander D. (2003) defines Monte-Carlo analysis as a powerful tool for modelling the reliability of systems. Monte-Carlo analysis assists in decision-making within the maintenance management process, while taking account of different maintenance strategies, spare parts, operation skills etc. (Resteanu, et al., 2007). Monte-Carlo analysis uses statistics to mathematically model a real-life process and then estimates the likelihood of possible outcomes. Before performing a Monte-Carlo simulation, the statistical distributions of failure and repair processes must be determined (Alexander, 2003). To conduct a Monte-Carlo simulation, the system model is built. The system structure and behaviour are specified using graphical editors, which produce pattern charts (block diagrams) and fault trees.

The Monte-Carlo model as demonstrated in Figure 2.12 can be used to calculate the remaining lifetime of equipment with 95% probability by using an integrated weighted sensitivity level of the recipients (e.g. water or chemical). A well-developed Monte-Carlo model enables managers to create a reliable and accurate preventive maintenance plan stating the prioritised order in which the equipment must be overhauled or changed to avoid and minimise emergency discharges (Bergkvist & Örjas, 2014). Thus, the results of the Monte-Carlo analysis can be used to provide economic justification for reliability improvements to existing equipment or to the purchasing of new plant equipment (Alexander, 2003).

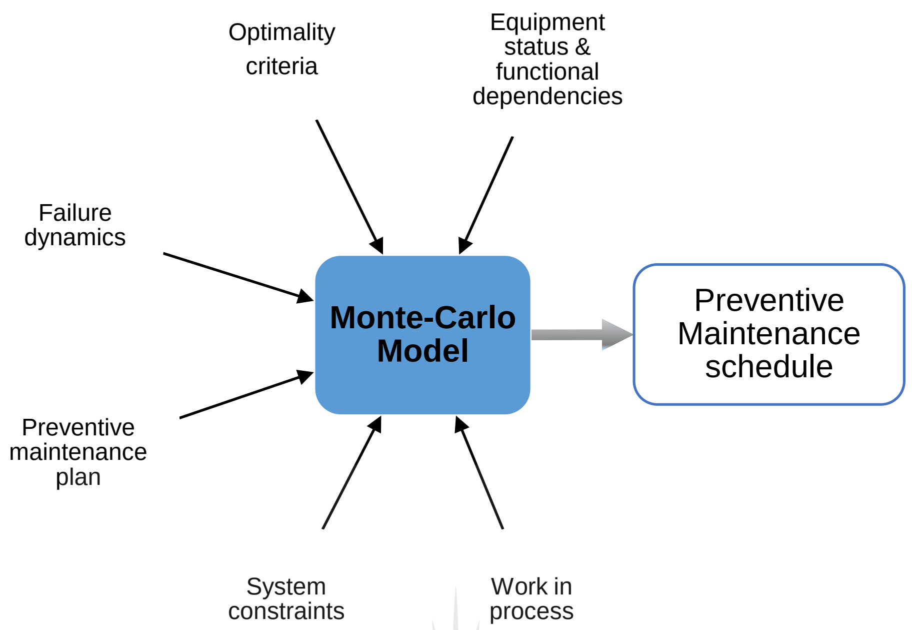

Figure 2. 12: Monte-Carlo Model (Alexander, 2003)

To establish preventive maintenance (PM) schedule, maintenance management should compile a PM plan, determine the system constraints, work in process, equipment failure dynamics, optimality criteria, equipment status and functional dependencies.

The Monte-Carlo simulation allows possible outcomes of decisions and assesses the impact of risk, allowing for better decision making under uncertainty. Monte-Carlo simulation provides decision-makers with a variety of possible probabilities to support any choice of action. Monte-Carlo simulation (O'Connor, 2002):

- Performs risk analysis by constructing models of possible results by substituting a range of values.
- Repeatedly calculates results, using a different set of random values from the probability functions.
- Produces distributions of possible results.

Monte-Carlo simulation samples random values from the initial probability distributions. These samples are called iterations, and the resulting outcome from each sample is recorded (O'Connor, 2002).

2.13.3 Overall Equipment Effectiveness

Production plants use overall equipment effectiveness (OEE) or overall plant effectiveness performance (OPE) indices for reliability, availability and productivity (Cesarotti, et al., 2013). OEE demonstrates the availability and performance of plant equipment according to its specifications. OEE can be used to monitor production process efficiency and help identify areas for improvement (Iannone & Nenni, 2015). While OEE is a good indicator of machine or system productivity, it can also show the behavior of system maintenance personnel. The OEE can be calculated using the following formula:

OEE = availability x performance efficiency x quality.

- Availability – The system is functioning when it is needed.
- Performance – A measure of system output divided by its maximum output.
- Quality – The number of good units divided by initial total units.

Table 2.3 below illustrates the OEE dependence factors.

Table 2. 3: Overall Equipment Effectiveness (Iannone & Nenni, 2015)

Dependency	What kills it?	How to improve it?
Availability	- Breakdowns - Machine idle time - Adjustment time - Stoppages	- Improve PM schedule - Reduce reactive maintenance - Retrain personnel - Have an effective parts strategy - Foster knowledge transfers
Performance	- Poorly operating equipment - Inefficient work processes - Materials variations - Lack of lubrication - Older systems	- Equipment overhaul - Regular equipment PM’s - Replacements
Quality	- Badly maintained equipment - System misalignment - Inconsistent raw materials - Guesswork	- Improve the quality of raw materials

Table 2.3, shows the factors for eliminating barriers to implement TPM successfully. TPM plays an important role in the implementation of maintenance techniques and overall equipment effectiveness. Overall equipment effectiveness (OEE) excludes

planned shutdowns such as preventive maintenance, holiday shutdowns and periods when there are no orders to produce.

When subtracting the planned downtime from total plant operating time, planned production time is what remains. Therefore, OEE is calculated using planned production time. To achieve an OEE of 100% a manufacturing facility should ideally produce the best product, as quickly as possible, with no unscheduled downtime. While realistically such OEE results are impossible to achieve, in individual manufacturing plants, a world-class OEE is considered to be 85% or better, however, the average OEE score remains ~60%.

2.13.4 Mean Time between Failure

Mean time between failure is the meantime that the system or equipment is in an inoperative state, calculated over a given period. The mean time between failures is an important metric where the failure rate of assets is managed. Moreover, it is an important indicator of expected performance. It has also become a fundamental component in the design of safe systems and equipment. Meantime between failure does not consider any scheduled maintenance such as recalibration, lubrication or preventive parts replacements. Mean time between failure (MTBF) can thus only be useful in determining the frequency of inspections or preventive replacements (Moubray, 1997). If the system is failing for the same reasons, the MTBF data is used to introduce some preventive actions such as greasing, inspections, calibrations and preventive repairs. Whereas, mean time to repair (MTTR) affects availability, mean time between failures affects availability and reliability. The following formula is used to calculate MBTF;

$$MBTF = \frac{\Sigma(Start\ of\ Downtime - Start\ of\ Uptime)}{Number\ of\ Failures}$$

2.13.5 Mean Time to Repair

Mean time to repair (MTTR) is the mean of all time periods taken to repair and restore a failed system or pieces of equipment to an operative state calculated over a given period. It is a fundamental technical measure of the maintainability of equipment and repairable parts. Maintenance time is defined as the time between the start of the incident and the moment the system is in operation (i.e. how long the equipment is out of production) (Moubray, 1997). To calaculate the accurate value of MTTR, the following assumptions should be made:

- One technician performs all tasks sequentially.
- Appropriately trained personnel perform the maintenance.

$$MTTR = \frac{Total\ Maintenance\ time}{number\ of\ repairs}$$

2.13.6 Gap Analysis

John, et al., (2013), define gap analysis as an approach that identifies gaps between the optimised allocation and integration of the inputs (resources), and the current allocation-level, which assist in revealing areas that can be improved. It involves comparing of actual performance with potential or desired performance (John, et al., 2013). The main purpose of conducting gap analysis is to ask the respondents both about the agreement with and importance of, different maintenance practices.

In D. Maletic et al. (2012), has investigated the role of maintenance in improving a company's competitiveness and profitability. To validate this, the author used the gap analysis approach to identify potential improvement in maintenance areas. The author suggested that maintenance practices related to a condition-based maintenance approach present the best opportunities for improvement (Maletic, et al., 2012). By identifying these types of gaps in a company, it is possible to discover areas where the company needs to put more attention regarding improvement efforts.

2.14 Summary

To gain knowledge of the role of reliability maintenance management within an organisation the author has presented various maintenance strategies, reliability maintenance tools and models. This has been achieved through an extensive literature study. Areas such as reliability management, maintenance strategy, maintenance management and quality management have been studied to understand the strategic level of maintenance, and employees' and management's role. The author also looked at tools and systems used for maintenance management and identified measuring tools to facilitate measuring the performance of an organisation's maintenance process. The primary objective of the literature study was to create a foundation upon which the results of this present research could be based.

Chapter 3: Methodology

In this chapter, the research methodology used is outlined. The research methodology has guided the author on how to analyse the effects of implementing reliability maintenance in an industrial production plant. The methodology used in this project aimed at gaining knowledge in maintenance from a strategic perspective, to understanding the present state at the Company A maintenance department, as well as maintenance departments at other organisations. This study is intended to generate results and discussions useful for Company A maintenance department.

3 Research Process

The approach that is followed by this research is a mixed method – a combination of quantitative and qualitative.

3.1 The difference between quantitative and qualitative techniques

3.1.1 Qualitative

Brewerton and Millward (2001), argue that quantitative methods focus on interpretation and the emphasis is on subjectivity rather than objectivity. However, there is some flexibility in the process of conducting research. There can be an orientation towards the process rather than on an outcome and an explicit recognition of the impact of the research process on the research situation.

During the collection of the data, the researcher interviewed managers who are responsible for managing their departmental production performance and quality system as part of their area of responsibilities. In addition, fifteen customers were interviewed togther with twenty two employees to find if the customer's needs were met on time.

3.1.2 Quantitative

According to Patten (1997), quantitative research is presented in numbers or quantities. This type of research emphasises that the data collected should be easily reduced to numbers, such as structured questionnaires and interviews with an objective format. This method can accommodate the selection of large samples and is suitable for studies that need to be conducted within a limited research budget by objective instruments such as an anonymous, objective questionnaire that takes little time to administrate.

3.2 Research Design

The research design is the structure of the study, which guides the author in directing and organising the research. Figure 3.1 below demonstrates the research design layout.

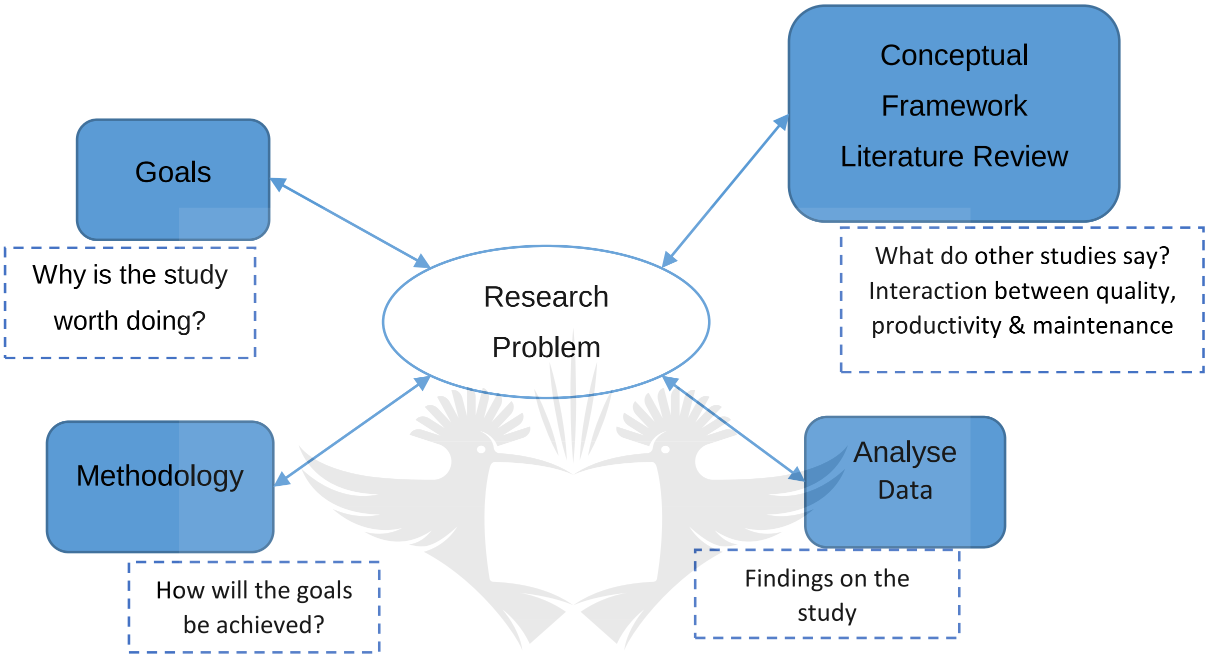

Figure 3. 1: Research Design

The research design assisted in guiding the author to successfully achieve the primary objectives of the study, by establishing:

- The scope of the study,
- The outcome the study is trying to achieve,
- The extent of workload, the effort required by the author, and how much the author will need to rely on the help of other people,
- The possible barriers the author may encounter,
- Possible resources the author may need to carry out the research,
- The estimated time it will take the author to complete the study,
- The ability to have access to relevant people,
- The author's motivation to carry out all the necessary actions.

The company's production plant is linked to a reliability management system. The author collected data and assessed it to identify the effects of implementing a reliability management system, as opposed to the old paper/ filing processes that were previously used in maintenance. The maintenance hours were noted and compared with the overall production hours. The logistics of spares and job card delays were also quantified.

The author established key performance indicators (KPI's) to evaluate the maintenance processes. The KPIs assisted in identifying future optimisation opportunities within the organisation. The author gathered data from the organisation's reliability management system based on the period 2013 to 2016 and used the results to validate the study. The author checked for trends associated with failure occurrences, initiated predictive maintenance and implemented scheduled maintenance based on equipment requirements. The author also investigated the preventive maintenance approach that the organisation follows. The investigation assisted in deriving possible root causes for the constant equipment failures so that the company would be able to implement improved methods to prevent future failure occurrences.

Key performance indicators were used to measure and improve on performance. These maintenance KPIs were established by gathering the following data;

1. Percentage of Preventive / Reactive maintenance
2. Percentage of work orders completed on time
    - Are there enough employees in maintenance?
3. Downtime hours/month
    - What are the causes of downtime and is the correct maintenance approach followed?
    - Are the standard working procedures being followed or implemented?
    - What can be done to improve downtime hours?
4. Cost of Spares Parts consumed
    - Why are costs too high?
    - Is the subcontracting approach effective?

The organogram in Figure 3.2 only illustrate the Engineering/ Production department, because this are the departments directly related maintenance and operation team and the study is focused on.

Figure 3.3 and Figure 3.4 illustrate the plant's production process; this process is referred to as Sulphonation.

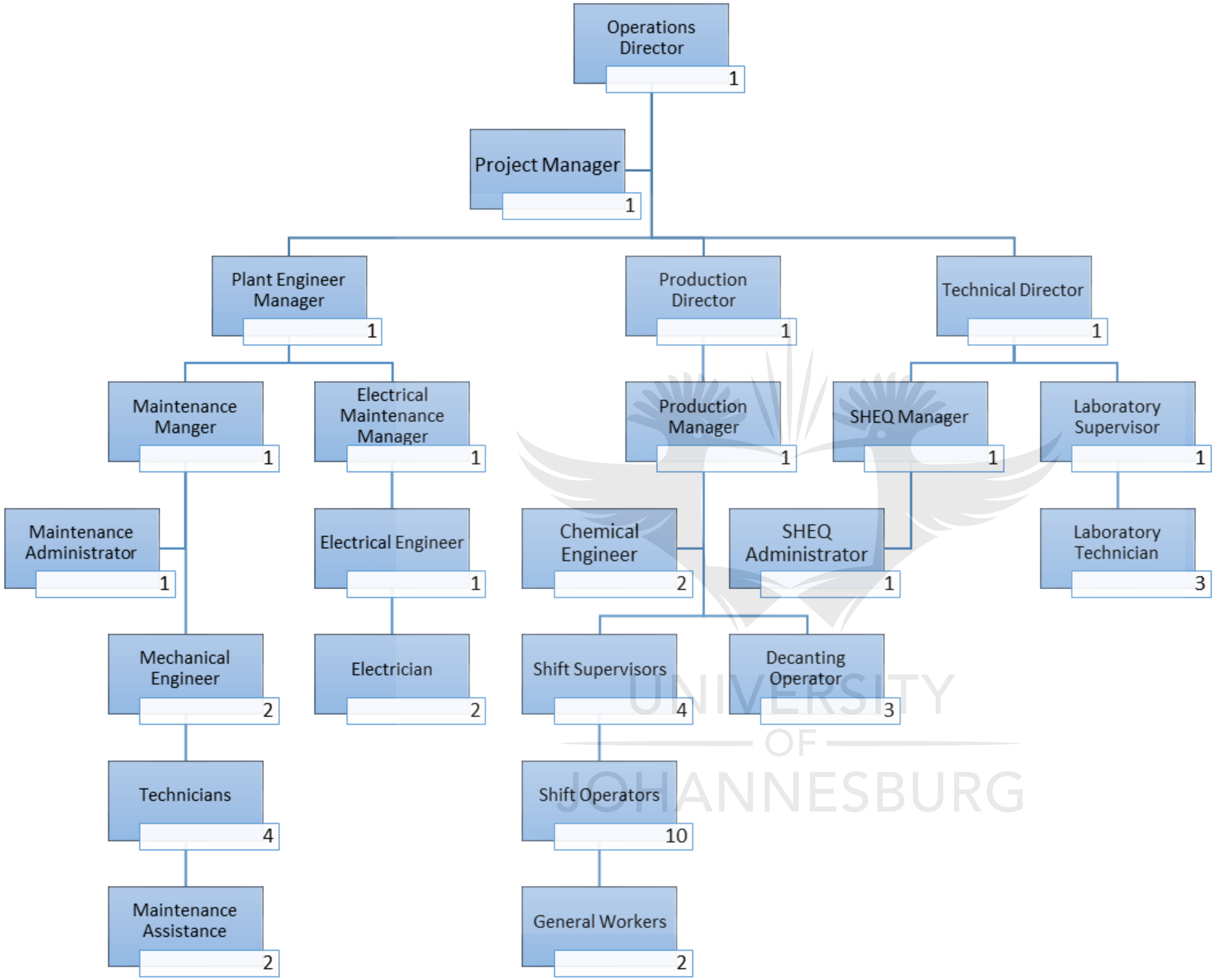

Figure 3. 2: Organisational Layout - Engineering/ Production Department

Source Adapted: Company A

PRODUCTION

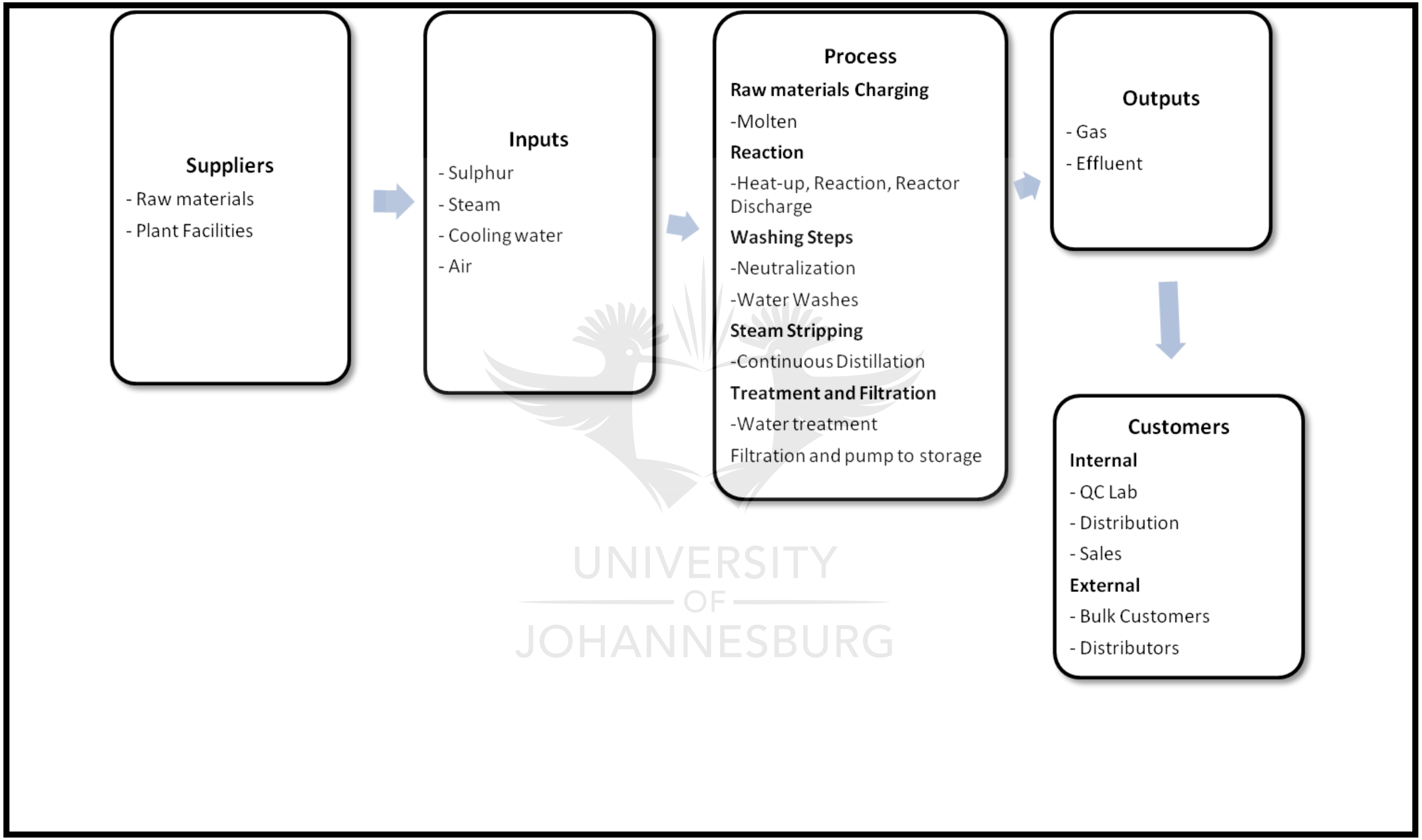

Figure 3. 3: Production Process

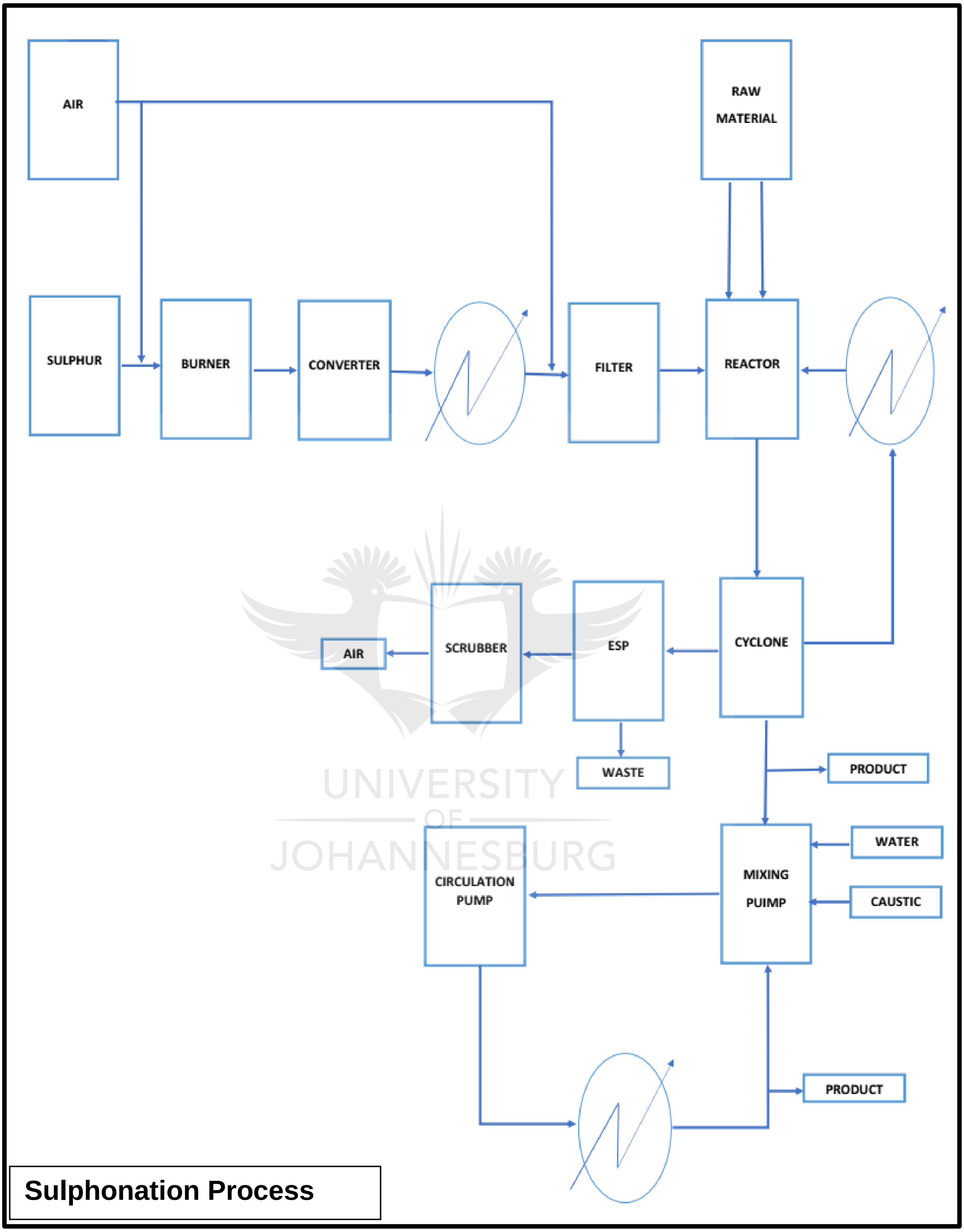

Figure 3. 4: Production - Sulphonation Process

3.3 Research Methodology

Research methodology is the systematic, theoretical analysis of the methods applied to a field of study or the theoretical analysis of the body of methods and principles associated with a branch of knowledge. Research methodology typically encompasses concepts such as paradigm, theoretical model, phases and quantitative or qualitative techniques.

The research methodology of this study includes a relevant literature review and a detailed case study on one local processing company. In Yin R.K. (2003), research, a case study approach was used to explore, describe, explain and compare data (Yin, 2003). However, Denscombe M. (2003), in his research argues that case studies focus on one instance's relationships and processes in a natural setting, but that the research would be improved with the possibility of using multiple sources and methods for both data gathering and analysis (Denscombe, 2003). In this study the triangulation method was used for data gathering as suggested by (Scandura & Williams, 2004). Triangulation is a powerful technique that facilitates validation of data through cross verification from two or more sources; it consists of the application and combination of several research methods in the study of the same phenomenon (Bogdan, 2006). This method needs to include an extensive literature review, a cross-functional web-based survey with a well-prepared structured questionnaire and in-depth case studies with interviews conducted on two subgroups mainly management and employees within the company. Triangulation offers more complex, overlapping descriptions of the case and makes the report more trustworthy (Lapan, 2009). Woodside identifies three triangulation aspects that the researcher must carry out in order to achieve a deep understanding of the case under study, namely (Woodside, 2010):

- the researcher must perform observations within the environments of the case,
- the researcher must ask probing questions of the case participants in order to obtain explanations and interpretations of "operational data" and
- the researcher must make an analysis of written documents and natural sites occurring in the case environment.

Site visits were made and the company databases and documents were analysed. Face-to-face interviews were conducted to serve as motivation for the findings. Leedy

(1997), argues how face-to-face interviews have the advantage of enabling the researcher to establish a relationship with the participants and gain their cooperation. This makes face-to-face interviews able to yield the highest response rate in research.

3.4 Research Instruments

Data collection was carried out through a literature review, observations, a questionnaire, a survey, interviews and from company documentation. A questionnaire was prepared to conduct gap analysis and evaluate the maintenance practices within the observed company. Information on maintenance processes was gathered through structured interviews; this setup interprets and verifies the descriptions made on the issues studied. The interviews and observations were complemented by studies of various documents such as monthly reports, minutes from quarterly meetings, operating instructions, daily operating memoranda, product specifications, product plans and internal investigations. The total time on data collection and processing was approximately three months.

1. The author carried out a literature review through surveying related scholarly articles and books related to the area of study. The literature review provided a list of sources that the author explored to demonstrate how the previous research fits in with the current study.

2. Face to face interviews were conducted, with promised confidentiality to facilitate candidate responses. Since, this is a time-consuming method, which usually requires the interviewees to be taken away from their workstations, the researcher decided to rather conduct structured interviews with management and only a few employees together with their supervisors to enable them to focus on the strategic issues that they deal with on a day to day basis regarding the quality of maintenance practices.

   The interviews focused on the following areas:

   - Alignment of organisational strategy with maintenance practices
   - Effectiveness of the current Reliability maintenance management system
   - Maintenance Key performance indicators
   - Future maintenance improvement opportunities to enable the company to be more efficient and effective and to increase the production rate.

- Development and training of management and employees
- The contribution of mentoring systems
- Rewards methods for staff members
- Customer satisfaction with product delivery rate.

3. A questionnaire was used in place of a data collection instrument. A questionnaire is a research instrument consisting of a series of questions and other prompts for gathering information from respondents. Burns & Grove (1993), defines a questionnaire as "a self-report form designed to elicit information that can be obtained through the written responses of the subjects." The information obtained through a questionnaire is similar to that obtained from an interview, but the questions tend to have less depth (Burns & Grove 1993). The purpose of designing the questionnaire is to gather information from management and employees within the organisation. The information gathered covered the plant maintenance processes, the reliability management system used and skill sets of employees. The author handed questionnaires to employees to complete. The author analysed and interpreted the results. The author implemented questionnaires because:
   - They ensured a high response rate as the questionnaires were distributed to respondents to complete and were collected personally by the author.
   - They required less time and energy to administer.
   - They offer the possibility of anonymity because subjects' names are not required on the completed questionnaires.
   - There is less opportunity for bias as they were consistently presented.
   - Most of the questions in the questionnaires were closed, which made it simple to compare the responses.

4. Another data collection instrument which was used in the study was a survey. A survey is a data gathering method that is utilised to collect, analyse and interpret the views of a group of people from a target population. Surveys can be used in various fields of research. The purpose of the survey in this study was to determine if plant industries within South Africa have successfully implemented reliability management within their maintenance process and, if so, to establish its effectiveness. The survey questions were structured in a questionnaire format to assist in accelerating the response rate.

The author created an online/ web-based survey, which was sent to employees in plant industries within South Africa, who use CMMS. A web survey tool called 'SurveyMonkey' was used to perform the survey. SurveyMonkey is an online service provided for efficient data collection. The survey took about 5 minutes to complete. The information gathered from the survey was analysed and interpreted to validate the effects of reliability management within industrial plant environments. The survey was conducted over a period of four months.

3.5 Population

The population is a complete set of people or objects or events that possess some common characteristic of interest to the researcher. The author used two populations in this study, the questionnaires and survey.

1. Twenty-five questionnaires were distributed to the company employees within the maintenance and operation department.
2. One hundred participants were expected to answer the survey.

3.6 Sampling methods

A sample is a subset of the population. When the sample represents the total population, the researcher may conclude that the study results can be generalised to include the entire population and settings being studied. Sampling is a process of selecting individuals for a study in such a way that individuals represent the larger group from which they were selected. This sampling method used in this study was designed to achieve the survey goals.

3.7 Sampling Criteria

1. The questions in the questionnaire covered specific subjects that would provide data related to the areas of research under investigation. The questionnaires were only sent to a sample of company employees. These employees had to meet the following criteria to be included in the sample.

   They should:

   - Be working for the company longer than three years (employee),
   - Work within the organisation 's production environment, and
   - Be willing to participate.

2. The survey sample was based on the type of industry and the participant position held.

3.8 Sample size

1. Initially, the author intended to circulate questionnaires to 25 employees.
2. The target for the survey was 100 people within maintenance, management and production. However, the final sample size was limited to the number of employees and management who were willing to participate in answering questions in all the subject areas of the research and who also met the sampling criteria.

3.9 Summary

The objective of this chapter was to describe the research methods, that were used to help analyse the reliability of the maintenance system currently used within the organisation. The design for the study, the population and sample were described. The instruments used to collect the data were described, including the methods implemented to maintain validity and reliability. The purpose of this analysis was to acquire information to help determine whether the implemented [maintenance monitoring] system contributes positively, using [data relating to] increased plant performance, plant life cycle, productivity, the achievement of objectives and to set targets towards implementing quality maintenance to enhance the plant's performance. Secondary data was collected from library sources and information provided by the organisation.

Chapter 4: Data Analysis and Results

This chapter provides information on the methods used to analyse the effectiveness of the maintenance system. The data gathered from the company was analysed, and the implemented maintenance processes evaluated.

To achieve the primary objective of the study, Chapter 2 dealt with maintenance, reliability management, productivity, quality, integration, employee involvement, maintenance (including types, tools and methods thereof) and TPM to explain factors critical for successful and effective maintenance management at Company A. Employees are the critical factor for operations success, because their involvement affects the morale, costs, productivity, quality and customer satisfaction. Thus, it is important for employees to be empowered into taking a more active role in operations decision-making. Currently the implementation of CMMS poses a challenging environment with regards to employee involvement and communication. The empirical study measures maintenance management system and processes to achieve the objective of the study.

4.1 Gap analysis

Gap analysis in this study involves the comparison of actual reliability management system performance with its potential performance. This approach recognises that if the organisation is not making the best use of current resources, implemented to enhance the efficiency of the maintenance this may lead the plant to perform below its potential. The objective is achieved by measuring the views of the employees with regards to the implemented reliability management system and identifying the thinking discrepancies that exist among the maintenance team and operators.

Data was collected for the assessment of the current state of the maintenance function in the observed company. As the economic data was confidential, the data used in the analysis was transformed using several suitable factors. For the empirical examination, data was retrieved from the CMMS. The data was further analysed using excel to obtain information regarding equipment productivity, products wastage, planned maintenance stoppage time, unplanned maintenance stoppage time and economic data (assets cost).

The maintenance department is divided into two groups, mechanical and electrical. There are two shifts per day, one in the morning and the other at night. During the day the maintenance team consists of:

- one mechanical engineer and three technicians,
- two electricians and
- three maintenance assistants

The production personnel consist of:

- two shift supervisors and
- five operators.

Whereas, during the night shift there is one shift supervisor and two operators. Maintenance personnel is always placed on standby in case of any breakdowns. The plant operates 24hours a day, 7 days a week. The operating lines are dependent on the product demand rate. When the demand rate is high all three production lines are in operation, while on normal production months one line is off and is used as a standby production line in case there is a breakdown. The workload varies from day-to-day, based on the planned maintenance, inspections, and on possible breakdowns that might occur.

The quality and quantity of tools available to the technicians are adequate and the required tools can easily be ordered. Failure-finding and diagnostic equipment for plant assets are unavailable, and proper inspection is inadequate. The company has a SCADA system that the operators use to monitor the plant processes, equipment performance or failure. The SCADA system monitors the temperatures, pressure and flow, etc. It has no functionality to measure important mechanical factors such as vibration, cyclic loading, and heat on the bearing. The company relies on contractors for servicing equipment and failure diagnoses. Contractors often cause a higher rate of occupational accidents which leads to a safety risk requiring internal management.

Although being a medium-sized company, having contractors can be less challenging compared to that of bigger organisations since the line of communication is shorter and allows flexibility in decision making. The challenge remains to include the contract workers in the company's management processes as maintenance is a typical ancillary activity that organisations outsource to external service providers. The maintenance tasks carried out by the contractors are rooted in preparation and follow-up tasks that are usually carried out by internal employees. In a study Holmgren (2006) established the maintenance flow chart to demonstrate the management of contractors within a typical maintenance process although communication remains important to identify how contractors interact with organisational activities to help prevent accidents.

A typical maintenance contractor's process would consist of the following steps, as shown in Figure 4.1:

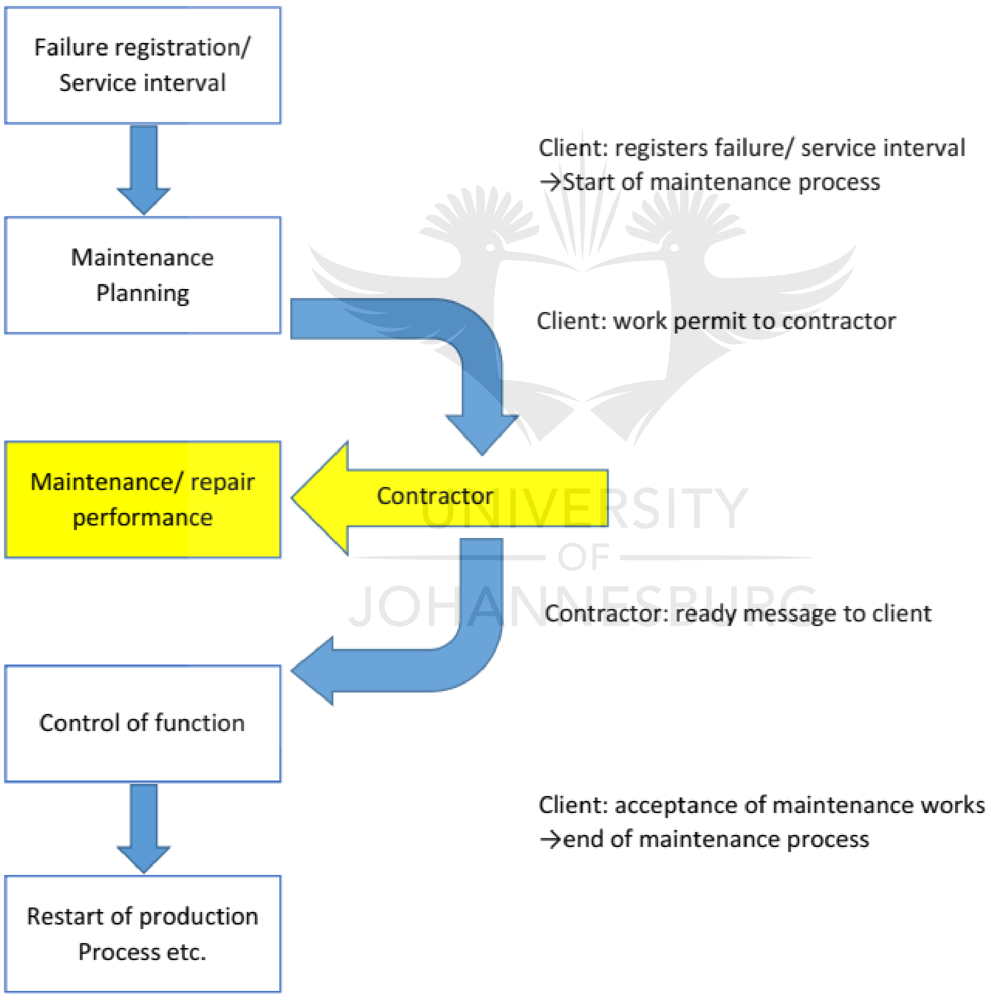

Figure 4. 1: Maintenance Flow Chart (Holmgren, 2006)

The SCADA system used allows the plant to be automated and reduce the number of people required to operate the plant. It also assists in reducing cost associated with human error, improves the quality of production and provides consistent results.

Hence it creates an improved problem solving instrument where an individual can simply pull the process graphs and investigate the problem areas.
The advantages of utilizing SCADA are;

- Reduction in maintenance costs, through centralised control and monitoring that minimise downtime.
- Improvement in production quality, as process data analysis can lead to error prevention before they occur.
- Operators work more effectively with SCADA, because it simplifies the entire plant process and provides a comprehensive overview of the plant operations.
- Alarms are centrally managed and assist to improve on the operational efficiency.

Spare parts need to be further revised to secure availability at all times. Spare parts assure long-term plant operation. Inventory management practices for spare parts within the maintenance storeroom is critical because it reduces premature failure of equipment within the plant. A well-managed storeroom supports the maintenance department's efforts to keep production equipment running at the most efficient levels possible. The maintenance team should consider developing a well-structured inventory system to reduce waste and inefficiencies. This will assist in the implementation of best processes practices and business practices which will increase the company's competitive advantage. There is currently no designated person responsible for the storeroom operations and management. Duplicate equipment is bought because it becomes misplaced. This leads to routine repairs becoming an emergency-expedited purchase creating unnecessary expenditure. Whereas, if there was a storeroom employee responsible for spares, they would have a process in place. This process would require the storeroom employee to receive a requisition for a spare part or assembly, then go to the storeroom location and pull out the part and issue it to the work order. This would also allow management to identify the spares necessary to keep in the storeroom.

Operators usually choose to address the need to prevent breakdowns in production by creating their own extensive and expensive spare parts stockpiles. They end up keeping equipment for a long period within the stores, which introduces a high probability of failure leading to production time being lost. There would also be the added cost of having the supplier expedite a replacement part, which would by far exceed the cost and effort only to keep necessary parts in store or to maintain the original units properly. A spares inventory is therefore an important preventive maintenance practice for rotating spares such as motors, gearboxes, pumps and valves to ensure that the units operate at full capacity.

It is essential for maintenance to have the required spare parts available to maintain equipment to ensure that it performs as expected when put into service. It is also important to ensure that all spares are stored appropriately in the storeroom.

The following Figure 4.2, demonstrates the critical spares frequency for a pump. It is important for maintenance always to assess whether the non-availability of parts affect plant productivity. This allows them to determine if the spares required are critical spares that need to be in stock or non-stock spares.

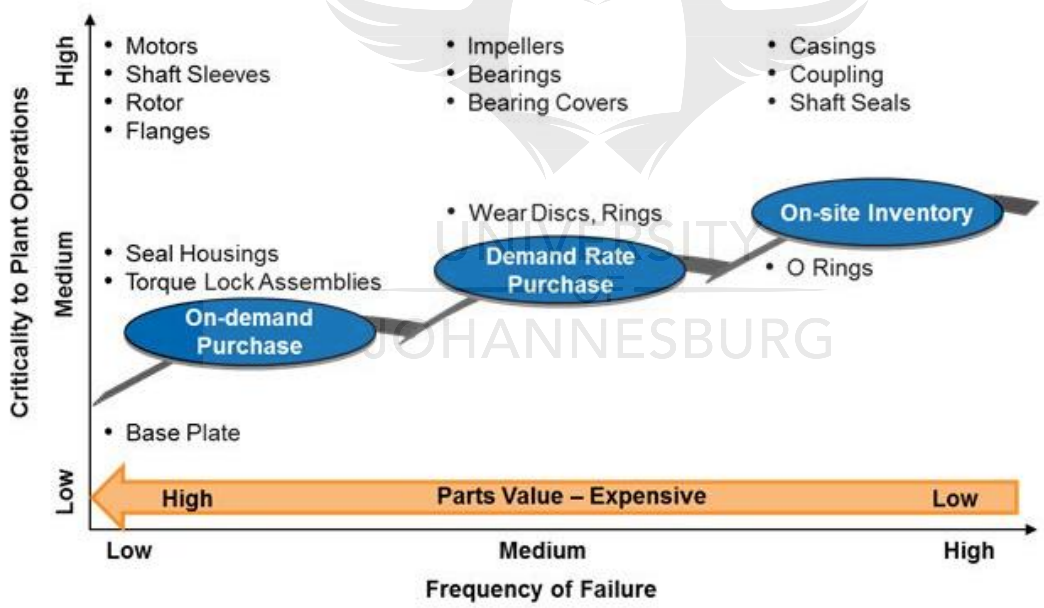

Figure 4. 2: Spare Parts Inventory Management Practices based on Criticality (Ramadoss, 2013)

Non-availability of critical spares stops the plant from running for several hours. The maintenance team has formulated and implemented a critical spares list (refer to Appendices 7.7). The issue is that the list is not constantly followed up and updated to ensure that all the spare parts are available when required. It is also important for the fast-moving spares to be ordered in advance and kept at a minimal amount in store, e.g. bolts, gaskets, etc. The critical spares analysis approach helps to determine the kind of spare part that needs to be kept on-site. Therefore, maintenance should also consider keeping a minimum number of spare parts on-site to save on inventory holding costs and storage space.

The technicians' view is that they are sometimes forgotten and are not involved when an important decision regarding maintenance is discussed. The technicians believe that additional training in new maintenance technologies can further modernise maintenance work. The technicians' opinion is that the supplier should provide further training on the maintenance of new assets, rather than the general overview provided. The technicians believe that regular training workshops can help to further develop the maintenance department. Thus, skills training will reduce the cost associated with sending the equipment back to the supplier every time failure occurs. The equipment can then be maintained in-house.

Management needs to identify where skills are lacking and budget and implement a training plan. Employee training and development is part of good management practices and good risk management strategies. It is important for management to establish a training and development program, since this will positively impact the employee's performance and at the same time preparing them to carry out the organisation's mission successfully.

The 5S implementation (see section 2.10.1) has been quite a challenging factor within maintenance. To be effective, 5S should be the plant's standard operating procedure and must become part of the daily routine of the plant and repair workshop. The mechanical team seems to be struggling with 5S implementation, whereas the electrical team and operators have sustained 5S implementation and have shown it to work satisfactorily. The mechanical team's workshop is not always cleaned up and organized, there is no shelving, the storage area is not packed, and equipment and tools are just piled up. When working on equipment it is difficult to retrieve spares, because they do not have a specific person allocated to be responsible for handling spares. Thus, spares are always misplaced in the workshop.

The technicians' working conditions are not satisfactory. Usually the repair station is crowded with unnecessary tools and it is a challenge to work in. The technicians waste time searching for parts and tools. There is unnecessary inventory and machinery, which becomes costly to just keep in store and which usually hide production problems thus making it harder to improve process flow. A disordered workplace is inefficient and therefore becomes unsafe to work in. This leads to employees' poor morale and a higher defect rate, because tools that do not receive sufficient maintenance tend to break down and cause defects.

It is always important for management to remind employees of the 5S and its importance, which is (Grover, 2012);

- **Sort**: requires the maintenance assistant to ensure that the workspace is not cluttered with items not required for that repair.
- **Set** in order: refers to the arrangement of items within the workshop so they are easy to use.
- **Shine**: involves keeping the workshop and workstations neat and clean at all times, this includes keeping tools and equipment in order, so they are ready to be always used.
- **Standardize and sustain**: is aimed at maintaining the benefits provided by the first three.

Risk can be reduced by minimizing the consequence of an event or by reducing the frequency of an event. The focus chosen as the key operational risk management strategy plays an important role in the future success of the organisation's production. Table 4.1 shows a range of common maintenance and reliability strategies divided into chance reduction strategies and consequence reduction strategies.

Table 4. 1:Risk (Sondalini, n.d.)

Risk = Chance x Consequences

Engineering & Maintenance Standards	Preventive Maintenance
Design-Out Maintenance	Corrective Maintenance
Precision Maintenance	Predictive Maintenance
Standardized Operating Procedures	Breakdown Maintenance
Statistical Process Control (SPC)	Total Productive Maintenance
Failure Mode Effect Criticality Analysis (FMECA)	Non-Destructive Testing
Reliability Growth Cause Analysis	Vibration Analysis
Hazard and Operability Analysis (RCFA)	Oil Analysis
Training and Up-skilling	Thermography
Quality Management Systems	Motor Current Analysis
Planning and Scheduling	Prognostic Analysis
Continuous Improvement	Emergency Management
Supply Chain Management	Computerised Maintenance Management System (CMMS)
Accuracy-Controlled Enterprise 3Ts (ACE 3T)	Key Performance Indicators (KPI)
Design and Operations Cost Totally Optimized Risk (Doctor)	Risk-Based Inspection
Defect and Failure Total Costing (DaFTC)	Value Contribution Mapping (Process Step activity-based costing)
De-Rate/ Oversize Equipment	Logistics, Sores and Warehouse
Reliability Engineering	Maintenance Engineering
Done to Reduce the chance of failure	Done to reduce the cost of failure

Chance reduction strategies focus on identifying potential problems and making business system changes to prevent or remove the prospect of failure. The chance reduction strategies view failure as avoidable and preventable. These methodologies focus on improving business processes rather than improving failure detection methods and expend time, money, and effort to identify and stop problems so that the chance of failure is minimized. The maintenance activities that benefit the maintenance team are those that reduce the frequency of a failure event, stop an equipment risk incident from happening, and prevent the equipment failure event. However, reducing equipment failure frequency automatically increase its reliability.

With high reliability comes high availability, high throughput, and low maintenance costs (Sondalini, n.d.).

4.2 Case Study and Observation

The case study and observation were carried out to examine the maintenance's environment and employees setting. The author spent 18 days (non-consecutive) in the plant observing the maintenance and operation departments to understand the nature of the organisation better. The author also performed a document review as part of the company observation. This included records, files and reports concerning various levels of the organisation, such as the company policy, organisational structure, maintenance departmental reports, maintenance process and procedures.

Company A has been in operation since April 2001 and develops, manufactures and supplies a range of surfactant products commonly used in the detergent and toiletry industries. The company has been registered with ISO 9001 since November 2004. The company has an approximation of 95 employees and consists of the following divisions;

- Sales & Marketing
- Technical (Quality Control, Research & Development)
- Engineering
- Financial/ Administration
- Production
- Warehousing
- Logistics
- SHEQ

In 2007, new management implemented a planned maintenance approach apart from the reactive maintenance that was practiced. A few years down the line, the organisation still practices planned maintenance but is often forced to perform reactive maintenance. Thus, management decided to install a reliablity management system to enhance the plant's maintenance. Reliability approach is simply a systematic approach for efficient and profitable operation of the plant. The concept integrates employees with the equipment and the process in an efficient system that benefits everyone. The production supervisors and the operators control the daily operations of the system to ensure it works. Process reliability affects the profitability, environmental integrity and safety and loss performance of the plant on a daily basis. The reliability process involves:

- Mechanical failures prediction
- Root cause analysis of failures
- Plant data collection
- Data processing
- Data analysis
- Performance improvement
- Application of ergonomics or, as better known, human factors engineering.

The plant runs for twenty-four hours a day, covering two shifts. Planned downtime is usually scheduled when production is low or over the weekend. For the past years, reliability management processes such as predictive, preventive and condition maintenance were not being practiced. This resulted in management struggling to obtain accurate results to illustrate the root cause of the constant plant failures. This failure has negatively affected the plant availability, leading to constant production downtime.

- The Cworks CMMS is usually used for basic maintenance scheduling and work order generation. Maintenance technicians are not aware of the usefulness of CMMS. It is important for the CMMS users to understand how the system will help their equipment to get prompt and effective maintenance. The maintenance technicians must view CMMS as a tool that will assist them in their daily tasks and it is important for management to understand how CMMS will help them get metrics and reports that can improve their decision-making process. Thus, the author observed that CMMS could work more effectively in Company A, if fully utilised.

- In 2008 new management decided to extend the production lines, they added a third production line to assist with productivity. This was unnecessary because the demand rate did not grow as projected and currently the third line is usually used as standby. Extension of production lines creates unnecessary cost, because it is extra production capacity that the organisation can do without. One plant-line is usually used as stand-by during the low demand times of the year. It is mostly used in situations when the break-down will cause a delay in productivity or when the demand is high.

- The highlighted observations of production lines extension could have also played a factor in the maintenance going wrong. Extension of the plant leads to more equipment, requires adjustments and advanced systems.

- The workspace safety checklist during equipment overhaul is not always performed. For example, before overhauling the reactor, oleum pump, etc. during shutdown a safety officer has to perform a safety check. Safety checks ensure the environment is safe to work in. Once the safety check is completed the maintenance technician gets a job order and working procedure. However, the safety checklist is often omitted, and the working procedure is not followed. The maintenance team carries out the repairs based on what they have been taught. Personnel involved in the maintenance, inspection and overhaul of a critical part require the skills to handle the special nature of the equipment and ensure the correct instructions and processing associated with it. Unauthorized repairs or modifications of equipment may have dangerous consequences. Maintenance personnel may only work on equipment once the job card is issued.

- There seems to be a limited connection between maintenance strategy and business strategy, since the maintenance management is not as effective and unnecessary costs are acquired. Employees do not actively participate in maintenance or improvement strategies (insufficient communication, motivation).

- There is insufficient practise on maintenance efficiency measurement and long-term planning. Management has no developed maintenance KPI process in place, thus maintenance efficiency is not evaluated and there is no set goal. Management must consider that the maintenance process of the organization is critical for long term value creation and economic sustainability. It is important that management and employees start participating in ensuring performance and maintenance processes are measured. This will allow controlled and monitored actions to be taken, such as corrective actions to minimize and mitigate risks relating to safety; meet societal responsibilities and enhance the effectiveness and efficiency of the plant. Management could consider the maintenance performance approach to measure maintenance productivity. To do so, management needs information on maintenance performance to plan and control the maintenance process.

- Inadequate budgetary control in maintenance, e.g. spares (department buys with personal funding and claims back from the company). Duplication of spares keeps on occurring because the spares are not stored in a common place and recorded on a regular basis. Thus, spares constantly get lost and are untraceable.

- Maintenance cost keeps on escalating on a yearly basis. This can be reduced by implementation of the KPI and establishing a spares inventory system.

- There seems to be a shortage of personnel within maintenance and operations, leading to delays in planning maintenance activities, which leads to reactive maintenance. It was also observed that the work orders are not assigned to specific maintenance personnel, which is another factor causing a delay in tasks. The work order is always handed to any available personnel during that period. If all personnel are busy and a break down occurs, management often partakes in the repairs.

- Management gets too involved in the day-to-day maintenance, and they get less time to spend on improving and strategising the maintenance process.

- The pitfall of the current maintenance situation is recognised, but limited work has been done to improve it. As a result, the maintenance team has become used to the reactive approach to tackle the constant breakdowns.

- Implementing reliability engineering management has helped the organisation to improve the quality of maintenance. The downfall is that they are not entirely utilising the reliability management system. The organisation has implemented a preventive maintenance strategy, but the rate of reactive maintenance is not decreasing. Management needs to consider improving the efficiency of the preventive maintenance strategy for it to be more efficient.

- With the CMMS the organisation was able to reduce the breakdowns by 36% from 2006 to 2016 (in 10 years).

- Due to outsourcing, some of the maintenance activities are critical and need to be considered:
  - The separation of equipment owners and equipment managers.
  - Complex accountability for equipment management.
  - The measurement of equipment maintenance performance.
  - Its continuous control and evaluation.

- With the continuous utilisation of plant equipment, it is physically subjected to vibration, cyclic loads, pressurisation and thermal conditions etc. which causes failure. However, maintenance is essential to ensure full functionality of the plant (William, 2016). Most of the critical parts on the production lines have been identified. The resulting workload is managed and prioritised on a very informal basis and there is no written procedure to illustrate the work processes.

4.3 Interview with management

4.3.1 Questions

1. Is the process more reactive/ planned maintenance?
2. What approach is followed to measure the downtime hours?
3. Are there standard working procedures in place? Which ones?
4. How are stores managed?
5. Are the spare parts readily available during maintenance processes?
6. How does the department keep track of spares costs?
7. Are work orders, maintenance hours recorded?
8. Does management have a structured long term plan to improve on the quality and reduce the cost of maintenance?
9. Does management have a five/ ten-year strategic maintenance plan for budget purposes with Top management?
10. Is there a budgeting process?

11. Is reorders quantity, safety stocks based on logical reasoning?
12. Does the system help in the day-to-day running of the maintenance department?
13. Does management conduct an economic analysis of each new item of equipment to determine the ROI (Rate on Investment)?

4.3.2 Answers

During the author's interview with management it was observed that:

1. Management insists that although the plant experiences regular breakdown incidences, planned maintenance is still practiced, and they would not really regard the process as being reactive. This can be debatable, because during breakdowns management is also hands on maintenance and assist the maintenance employees in fixing equipment. Possibly implying that the workload is excessive for the employees and the plant breakdowns are frequently occurring, leading to reactive maintenance practices.

2. Time taken to perform breakdown repairs and preventive maintenance is not recorded on the work-order, therefore the time taken to perform tasks cannot be evaluated.

3. Management's response is that they do have some working procedures in place. Their concern is that the working procedures available are not being utilized and followed. Once employees feel they are familiar with fixing an item of equipment they stop following the work procedures and take their own shortcuts, which leads to a safety issue. There is no one currently to follow them around to ensure that they are following the procedures, because it gets too busy in the plant and everyone is focused on their tasks. The author argues that it is every plant's requirement to have a SHE representative in place to ensure that correct procedures are followed and to validate that the organisation has procedures in place for every critical item of equipment. This is a matter of concern regarding the quality of maintenance processes.

4. Maintenance manager, Project manager and engineers are responsible for purchasing spares. Electrical and instrumental critical spares are orderly stored

in the electrical storage room, whereas some of the mechanical spares are randomly stored in the workshop and the critical spares are just stored in various locations within the management and engineering offices.

5. The spare parts readily available are those in the critical spares list. The other spares are ordered as and when required. Management and engineers each have a credit card, which is used to buy the spares when a breakdown occurs, or planned maintenance is done. The receipt is usually sent to the engineering manager to authorise before being sent to finance. Whereas managers send the receipt directly to finance and there is no one to validate the items purchased on the receipt. Although this seems to be working, it is not effective and makes it difficult to monitor the spares costs. Some manager complains about the duplication of spares and spares getting misplaced because there is no recording system if spares were purchased and had not been used.

6. There are no records kept for spares purchased and no tracking process in place. The general spares are bought as and when required. This risks the duplication of spares and the occurrence of unnecessary costs. The maintenance department also does not conduct reviews of the high use, high cost parts used to initiate a maintenance improvement study.

7. The work orders maintenance hours are always recorded by the maintenance team. The work orders also include important inspections and work required for preventive maintenance purposes. Important inspections and maintenance requirements are derived from the equipment operations and maintenance manual. The information on the work order is captured into the maintenance system by the maintenance administrator.

8. There seems to be an issue with structured long-term planning to improve the quality and reduce the cost of maintenance. Some managers feel that the CMMS implemented is working effectively, whereas others feel that improvements should be implemented, and more planning is required. It is vital for the CMMS and procedures to tie together all the activities in maintenance. The system needs to tie the assets to the repair act and provide labour time

and costs for all activity. Thus, for the system to be effective management needs to be involved and support it.

9. There are no kept record tracking and trend ratios between scheduled and non-scheduled work. Management does not have a strategic maintenance plan for the maintenance budget purposes with top management. Although the project manager assists the maintenance team to plan maintenance shutdowns and is also in charge of production plant process improvement strategies.

10. A budget is provided monthly. Management does not have a structured process on which they manage their budget, but only make sure they do not go over the allocated budget. The maintenance department is allocated maintenance budget every six months from top level management. This budget is calculated against the previous year's costs. The budgeting process is not likely to serve the best overall long-term interest of the organisation. The maintenance department costs are not properly managed, which leads to overspending. The budgeting processes are short-term projections and will have a negative effect on the organisation in the future if it is not controlled and modified.

11. There is no formal structure to reorder stock. The employee or manager reorder stock when they see that the stock quantity has decreased or is unavailable. In most instances the employee does not inform the manager when the stock quantity level is running low. Rather, they wait to inform the manager when they are using the last stock or when they want to perform a task and the spare parts are not there. There is no annual physical inventory review of all parts in stock to update them on the stock on hand, reorder point, etc. To run a great maintenance department proper planning is essential to ensure that high priority jobs are executed. Thus, proper planning and scheduling will save execution time. It is always important for the scope of work to be noted and the required spare parts to be available before starting the job.

    To control maintenance, the maintenance team should get the parts under control. Get rid of used parts, keep the workshop clean and neat, and ensure that all parts are stored in order. Some parts for critical equipment are stocked, because the lead time on the part would create unacceptable downtime. For the CMMS to be successful, it has more to do with the attitude of the organisation rather than the quality of software. The usefulness if the system means to answer questions quick enough to impact the decision on products.

12. The system does assist in the day-to-day running of the maintenance department, but it is not fully utilised. As a small organisation they are faced with a challenge to practice reliability engineering practices entirely and completely utilize all the functions on the CMMS being used. This is because the organisation does not have enough capacity to employ enough employees to monitor the system, causing a lack of quality maintenance within the plant. To have a fully functional CMMS they would require several employees to monitor and manage the system effectively. They would require stores employees to manage mechanical, electrical and instrumental spares. They would also require maintenance, procurement employees to always keep the stock up to date.

13. The critical spares list is only documented on an excel document in the database and is not updated in the CMMS, thus the work orders do not contain the critical spares required for the specific maintenance. Management does not conduct an economic analysis of each new item of equipment to determine the ROI.

4.4 Employee Survey

To augment the findings from the interview questions with management, the author collected further data on the study through a questionnaire survey with the employees. The employee questionnaire survey consisted of the ‘Likert Scale’, which requires the employees to indicate their level of agreement with the statement by ticking an answer most appropriate to them.

Data was collected with the aid of questionnaires to further evaluate the employees’ views of the current maintenance process. The questionnaire was mainly used to obtain the opinions of the employees of two technical departments' employees, namely operations and maintenance. This includes the CMMS administrator from maintenance and excludes the laboratory employees from production, which is appropriate because the implementation of reliability management mainly involves employees from the two departments mentioned. The two departments combined consist of only 32% of the organisation's employees. Despite that, improvement and proper implementation of reliability management processes has a great influence on both maintenance and operation.

Both the maintenance and operation department were given the same questionnaire, since this will assist to identify the different views of each group towards the maintenance processes in place. The questionnaire was divided into two sections. Section A of the questionnaire contained the demographic information for respondent profiling, e.g. department, education, age, etc. Section B contained the empirical study and consisted of three sets of questions. To measure maintenance practices, respondents were asked to report the level of satisfaction or agreement considering three different categories:

- Skill development and communication
- Performance CMMS
- Work practice

The survey questionnaire is presented in (Appendices 7.1).

A total of twenty-five (25) questionnaires were distributed to the maintenance and operation employees. Three (3) respondents did not submit their responses or questionnaire was declared invalid, because some information was missing.

4.4.1 Section A

Section A is the first part of the questionnaire the maintenance and operation employees had to complete. This section of the questionnaire gathers background information regarding the employees.

There were only 22 employees from the maintenance and operation department who completed the survey as demonstrated in Table 4.2 and Figure 4.3.

Table 4. 2: Employee educational background

Qualification	Employees	Percentage
Without Matric	6	27%
Matric	8	36%
College	5	23%
University	3	14%

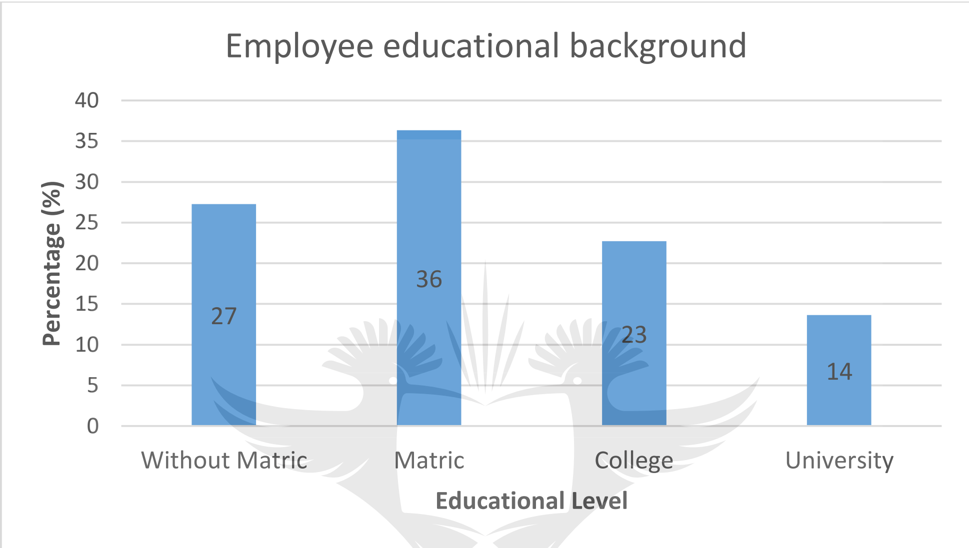

Figure 4. 3:Employee educational background

Figure 4.3 shows that there is a higher rate of employees with just matric at 36%, as opposed to having a tertiary qualification. Whereas, there is still a high rate of employees without matric at 27%. This is evident that there is a skill set development requirement within the two departments. The company has more employees in operation than in maintenance.

4.4.2 Section B

The literature review in Chapter 2 serves as the bases for developing and constructing the questionnaire. The questions in the questionnaire were derived from the literature review study to gather information which will help the researcher answer the research questions. This was specifically used to reveal inadequacies and possible improvement areas of a local company's maintenance system.

1. Computerised Maintenance Management System Performance

Table 4.3 and Figure 4.4 illustrate the CMMS performance results. CMMS support improves reliability and performance. To successfully implement CMMS the organisation needs to be ready. CMMS is a tool to facilitate the effective implementation of the organization's maintenance management process. To overcome the barriers of failure in implementing CMMS, top management needs to be involved. CMMS improves the planning and scheduling of maintenance tasks, reduces stockpiling and provides high quality reporting and easy access to history data. Maintenance work is planned, monitored and documented. CMMS enables resource planning. All maintenance work and job orders are kept in a central database. Users can easily search for open, planned and closed maintenance work.

Table 4. 3:Performance of Computerised Maintenance Management System

1. Performamce of CMMS						
Maintenance and Operating Employees (Only)						
Q-No.	How much do you agree or disagree with:	1 Strongly Disagree	2 Disagree	3 Unsure	4 Agree	5 Strongly Agree
1	Is RCM considered when equipment failure could cause injuries, the equipment is critical or has high downtime cost?	5	12	3	2	0
2	Do you regard maintenance process as effective, with regards to plant availability?	9	7	0	4	2
3	Do you have a maintenance schedule?	0	0	2	5	15
4	Is there a review of slow moving items to see if they belong in stock?	11	7	4	0	0
5	Is the CMMS used to make orders?	0	4	0	7	11

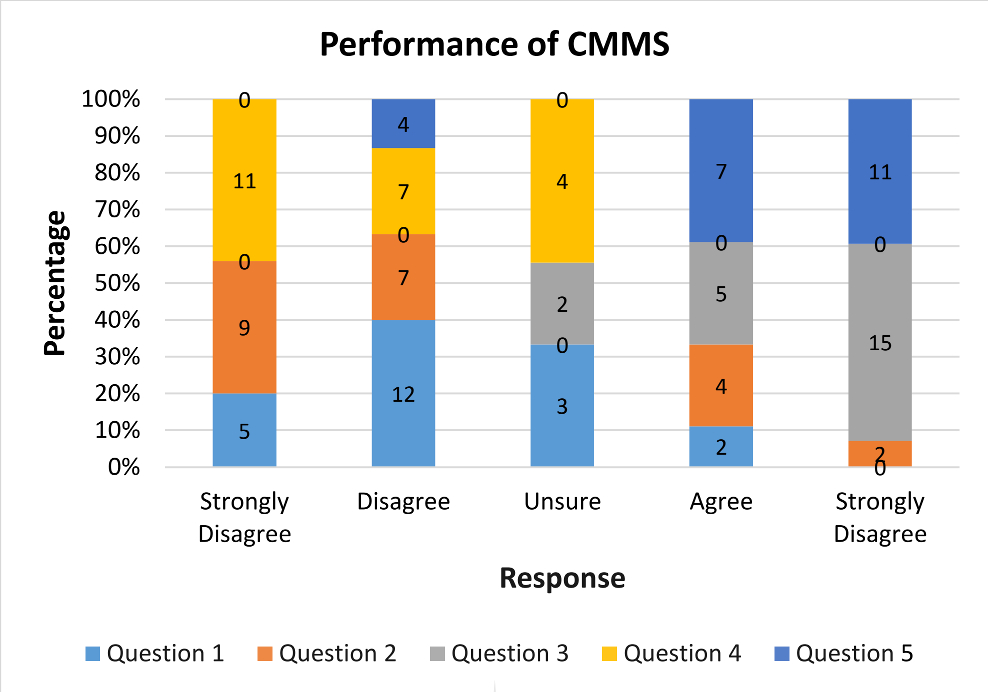

Figure 4. 4: Performance of Computerised Maintenance Management System

Q.1. Is RCM considered when equipment failure could cause injuries, the equipment is critical or has high downtime cost?

Most of the employees seem to disagree with the fact that RCM is considered in cases where equipment failure could cause injuries, critical or has high downtime cost. The maintenance team is required to always carry out periodic inspections to uncover occasional deficiencies and attend to these in reasonable time. However, this is not the case. While most of the maintenance at Company A is done through preventive maintenance, there remains a high rate of breakdown leading to reactive maintenance. Management needs to remind the maintenance team to avoid reflex repair when equipment breaks, but rather do reflective maintenance. Consequently, reflex repair promotes shortcuts which usually lead to risky working conditions, because risk assessment is omitted before performing the task. Maintenance and operating teams need to conduct a periodic review of equipment failure history to see if the maintenance tasks are well directed. This can be achieved by performing equipment root cause analysis and economic analysis leading to better decisions made.

Q.2. Do you regard the maintenance process as effective, with regards to plant availability?

The consensus from both maintenance and operating employees is that CMMS is a good concept, although the current state of maintenance is still focused on reactive maintenance. The operating employees strongly regard the maintenance process as ineffective. This is basically because they are constantly required to assist with regular maintenance breakdowns, which usually interrupts the plant's productivity. Meanwhile, the maintenance employees also disagree with the maintenance process being effective. They point out that plant availability can be better if they were not rushed into completing projects just to keep the plant running. They believe if they were well trained in the process, there would be fewer breakdowns and plant availability would increase.

Q.3. Do you have a maintenance schedule?

Both maintenance and operating employees strongly agree that there is a maintenance schedule in place. The maintenance schedule is only reviewed and updated on an annual basis. However, maintenance employees are not involved in updating the schedule. It is only updated, drafted and signed-off by production, maintenance, project and the engineering manager.

Q.4. Is there a review of slow-moving items to see if they belong in stock?

It can be observed that 50% of the maintenance and operating employees strongly disagree, 31,8% disagree that there is a review of slow-moving items in stock, whereas 18,2% are unsure. It was also noted from management's interview feedback that there was no other stock list currently in place apart from the critical equipment list. This list is only updated when new equipment is bought and management regards it as being critical.

Q.5. Is the CMMS used to make work orders?

It can be observed that 50 % of the maintenance employees strongly agree and 31.8% only agree that the CMMS is used to generate work orders and are given work orders to carry out preventive maintenance. However, 18.2% of the operating employees seem to disagree that CMMS is used to make work orders. The possible reason for this is the fact that there is are continuous breakdowns and employees are forced to response reactively, thus resulting in work orders not being provided to perform repairs. During my visit to the company the maintenance administrator and maintenance manager also confirmed to work orders not always being presented during breakdowns, but rather updated after the repair is completed.

Generating work orders can be a lengthy process that requires the performance of risk assessments, RCA and approval from the maintenance manager, therefore wasting time. Time is critical during a breakdown and any delay in repairing the failure interrupts productivity. Thus, management usually requests maintenance employees to repair the equipment instead urgently. If more personnel are required for the task, the operating employees are requested to assist, and management also has to step in.

2. Skill development and communication

The implementation of CMMS requires the involvement of knowledgeable and experienced personnel. The organisation needs to select key users to operate the management system. Table 4.4 and Figure 4.5 illustrate the skill development and communication results. The key users are sent for training to learn the benefits of implementing the system. Ineffective communication of the CMMS implementation to employees can lead to change resistance. To overcome the barrier of change resistance, management should have a well-planned change management process where employees are openly addressed as to their roles, responsibilities and process. CMMS helps maintenance employees to communicate quickly and effectively.

Table 4. 4:Skill development and communication

2. Skill Development & Communication						
Maintenance and Operating Employees (Only)						
	How much do you agree or disagree with:	1	2	3	4	5
Q-No.		Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
1	Is the competency of maintenance employees satisfactory?	1	6	0	13	2
2	Are skills & development training provided to employees?	8	11	0	3	0
3	Is there regular communication between management and employees involvement with CMMS?	13	9	0	0	0
4	Does management conduct meetings with employees to set priorities?	10	9	0	3	0
5	Are operators trained to do routine maintenance?	6	12	4	0	0

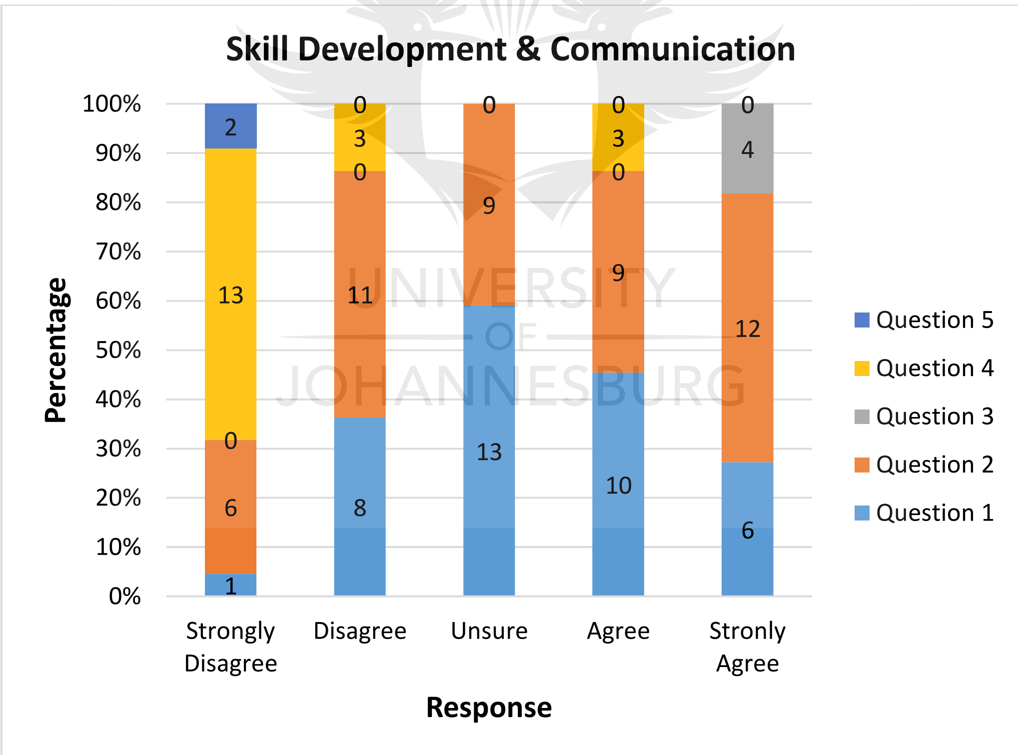

Figure 4. 5:Skill development and communication

Q.1. Is the competency of maintenance employees satisfactory?

This question requires employees to assess their teammate's competence level. The results indicate that 59% of the employees are satisfied with their teammate's competency. Irrespective of frequently being inconvenienced by the reactive maintenance practices, maintenance employees still manage to respond to the plant's issues promptly. However, 27% of operating employees seem to be dissatisfied with the maintenance employee's competency. They feel that the maintenance team requires further skills development to improve the efficiency of the plant, since this will lower the rate of breakdowns and stop inconveniencing the operators. The operators are always stopped on their tasks and required to step in and assist maintenance employees to get the plant running. Nonetheless, the maintenance team still argues that they are understaffed and if they had enough teammates, they could actually have a better chance of ensuring that all the scheduled maintenance is performed on time.

Q.2. Are skills and development training provided to employees?

Both maintenance and operations employees are dissatisfied regarding training and development skills provided. They argue that there is no skills development provided to the employees to advance their skills further. Management is currently failing to meet the employee's requirements for training.

The operators also agreed that it would be ideal for them to be trained on some maintenance tasks. However, the maintenance team disagrees with this suggestion, since the operators always complained about their own workload. The maintenance team suggested that it would rather be ideal if they were trained on advanced maintenance duties, employ more staff in maintenance and reduce subcontracting.

Employees feel that problems concerning productivity can be solved by efficient training or by developing handbooks and manuals to assist them in performing the tasks. The employees also feel that, although some problems can be solved with training, others can still be solved by management engagement and efficient resource allocation.

Q.3. Is there regular communication between management and employee involvement with CMMS

Both operating and maintenance employees (59%) strongly disagree and (41%) disagree that there is regular communication between management and employee involvement with CMMS. They emphasise that the implementation of CMMS could have been successful if management communicated with and involved employees from the start. Although initial communication with employees took place, there was no active engagement with employees.

Q.4. Do management conduct meetings with employees to set priorities?

Both maintenance and operating employees seem to disagree with the fact that management conduct meetings to set priorities. They are just handed work orders, from which they must perform the task and once completed it is signed and handed over to the maintenance administrator to be captured and update on the CMMS. Whereas, only 14% agree that they are involved when management conduct meetings with employees to set priorities.

Q.5. Are operators trained to do routine maintenance?

Both maintenance and operating employees disagree that operators are trained to do routine maintenance. Most operators are not competent and there seems to be an issue with their skill sets, because they struggle with basic routine maintenance tasks. Operators are employed with just matric or no matric at all and there is no proper training performed. They are generally taught the basics of operating the system and expected to learn the rest on the job. This poses as a disadvantage, because there is no on-going training for operators to improve operations on the system. The company should initially send the operators to get formal training, since this will assist them in correcting minor faults they observe on the system and therefore improve on the quality and accuracy of maintenance requested.

3. Work Practice

Maintenance is important to keep equipment and the work environment safe and reliable. Table 4.5 and Figure 4.6 illustrate Work Practices results. Inadequate maintenance can lead to dangerous situations, accidents, and health problems. The organisation’s CMMS should include health and safety documentation, procedures, checklists, and workflows for any type of maintenance work to ensure compliance. The maintenance history records assist in proactive maintenance techniques such as root-cause failure analysis and reliability engineering. CMMS can be utilized to accumulate the data for KPIs for use in evaluating the organization’s maintenance program.

Table 4. 5:Work Practice

3. Work Practice						
Maintenance and Operating Employees (Only)						
	How much do you agree or disagree with:	**1**	**2**	**3**	**4**	**5**
Q-No.		**Strongly Disagree**	**Disagree**	**Not Sure**	**Agree**	**Strongly Agree**
1	Do you support the implementation of Reliability Management?	0	3	0	14	5
2	Do you always work per work order?	7	3	0	8	4
3	Are all repairs classified e.g. corrective, routine, breakdown, preventive maintenance etc.?	0	2	4	7	9
4	Are work orders costed for labour, parts and other cost?	8	12	2	0	0
5	When deficiencies are found by inspection, are they written up as corrective work and completed in a reasonable time?	8	7	5	2	0
6	Do repeated failures automatically trigger an investigation to find the root cause to correct it?	4	2	2	10	4
7	Are the resources identified (labour, materials, tools, machine access and permissions) before a job is scheduled?	0	5	5	9	3
8	Does the maintenance schedule consist of jobs whose resources are in-house?	7	2	8	4	1

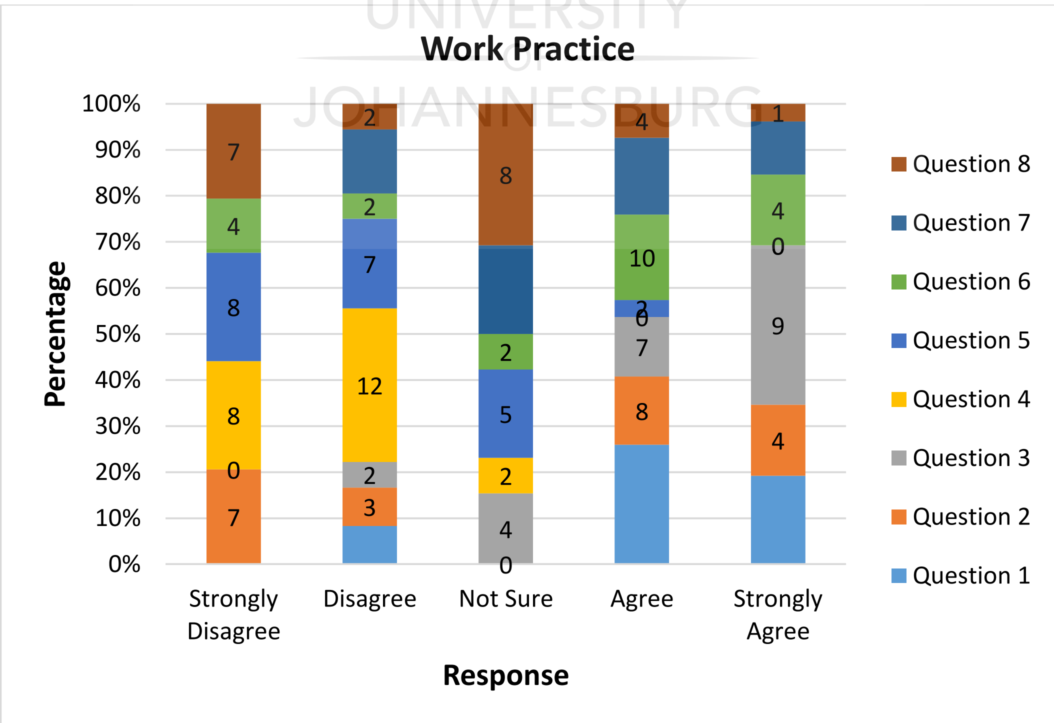

Figure 4. 6:Work Practice

Q.1. Do you support the implementation of Reliability Management?

The results on the graph illustrate that all employee's strongly support the implementation of reliability management. They believe that it will assist them in planning their weekly tasks and managing their job better. Consequently there is strong support from employees that management at Company A should fully implement CMMS to ensure reliability management is effective. The strong positive feedback received from employees is an indication that an effective change will bring success to Company A maintenance.

Q.2. Do you always work per work order?

The 77% of the operators strongly disagree as opposed the 89% of maintenance employees that maintenance work is carried out per work order. Overall the results demonstrate that 36% of the employees agree to work per work order. They emphasize the fact that work orders are provided for regular maintenance, but in some cases work orders are not provided prior to starting a job. This is usually due to the continuous reactive maintenance taking place within the plant. It is likely that in the case of emergency repairs, the work order is only updated after the maintenance is performed. Work performed without work orders cannot be accounted for and problems actually fall through the cracks, because the issue is not recorded anywhere. The risk of such problems can arise in the future and pose a hazard. Finally working per work order can assist in identifying employees experiencing problems, which will contribute to identifying the gap to determine the type of training employees require.

Q.3. Are all repairs classified, e.g. corrective, routine, breakdown, preventive maintenance etc.

The results reflect that 41% of the employees strongly agree and 32% agree that repairs are classified. However, 18% of the operators' response results reflect that they are unsure and disagree with the fact that all repairs are classified.

Q.4. Are work orders costed for labour, parts and other cost?

It is alarming that no employee seems to agree that there is any sort of work order costing in place. The results indicate that 55% of the employees disagree and adding to that, 36% strongly disagree that work orders are costed for. The organisation seems to have problems formalizing the maintenance processes and also allocating work orders per employee's availability. The time to repair equipment is not captured, this inconveniences management when planning maintenance activities and makes it challenging for management to prioritize tasks and manage the maintenance processes. However, restrictions should be set on rush jobs. It is important to note that work orders have a significant advantage in the maintenance and production department as they assist with cost collection, proof of safety, job control, etc.

Q.5. When deficiencies are found by inspection, are they written up as corrective work and completed in a reasonable time?

The results reflect the deficiencies found during inspection are not always recorded and completed in reasonable time. About 36 % of employees strongly disagree, while 32% also disagree that such is practiced. Whereas, only 9% of the employees in supervisory roles seem to agree.

Q.6. Do repeated failures automatically trigger an investigation to find the root cause to correct it?

The results indicate that 64% of the employees agree and strongly agree that failures are always attended to, and investigations are carried out to determine the root cause and correct the problem. Only 18% of the employees disagree with this practice entirely based on that they are in operations and do not always follow through with the entire maintenance process and due to their complaint on constant plant breakdowns.

Q.7. Are the resources identified (labour, materials, tools, machine access and permissions) before a job is scheduled?

The maintenance employees seem to disagree with the fact that all resources are identified before performing a job. They often find that some spare parts are missing, and they must order them first and wait before they continue working on the job. The only time the resources are identified and made available is when there is a planned shutdown on critical equipment such as the reactor, boiler, fan, pump etc.

Q.8. Does the maintenance schedule consist of jobs whose resources are in-house?

From the case study it was observed that most items are purchased as and when the repairs take place. There is no proper storage within the department and some spare parts become misplaced and there is no one accountable if the stock is finished. From the results it is also noted that 41% disagree, while 36% are unsure with the maintenance schedule consisting of jobs whose resources are in-house.

The electricians, however have a proper storage area and always purchase enough stock in advance. The downfall is that some of the components are over stocked and they stay too long within the shelves. There is no one specifically monitoring the stock. They buy as they use, and there is hardly any spare parts shortage when they work on a job.

4.5 Summary

Respondents in this study were employees from the engineering and production departments since maintenance has a great influence on these two departments. The studies conducted reflects the link between quality management and improving maintenance activities.

4.5.1 Work practices within Company A

Both the maintenance and operating departments seem to agree with the notion that on average maintenance is done unnecessarily on the plant. This is since some PM are scheduled unnecessarily due to the periodic nature of CMMS. The departments also complained about the fact that there is no dedicated person to purchase or order the spares and they feel that somehow spares become lost or misplaced. The maintenance department complained that the operators are not doing what they are supposed to do in terms of first line maintenance (plant inspections), which is the responsibility of operators. This is based on the perceptions that operators are not always doing inspections on the plant in order to address plant problems before they become a failure.

The maintenance financial planning is ineffective and there is no budget in place. The maintenance department has a skill shortage, has no developed measures of maintenance performance and there is a shortage of advanced instruments and machines to perform maintenance. The maintenance process in place is ineffective, and top management is not fully committed. There is lack of employees' involvement. The organisation does not have clear rules for the use of updating checklists and there is no good housekeeping system (5Ss).

Repair times are influenced by the maintenance team's speed of response to equipment failures. We can see that from the questionnaire analysis, most of the employees are not happy with the repair times during maintenance. This is due to employee shortage, the unavailability of spares and lack to the skill set in performing the task.

4.5.2 Sharing of responsibilities

Sharing of responsibilities within the maintenance team and operators will assist in improving the quality of maintenance. Major improvements will be realized if operators would assist with some of the maintenance duties, such as inspections and identifying repeated failures, since they are in the front end of the plant process and can easily spot problems as they arise. The challenge will be that the operators feel that their scope of work will increase. Whereas, the operators agreed just to help and not to permanently doing maintenance tasks. The maintenance team indicated that they had a lot on their hands and were continuously forced to do reactive maintenance, so they could not assist with the operator's duties. They also indicated that it would make their working condition easier if the operators could assist with the inspections, this would reduce reactive maintenance tasks.

4.6 CMMS Data Analysis

Data was collected for further investigation into the study. Gathering data is an important endeavour for benchmarking and measuring progress. Just paying attention to data entry, problems encountered, and posting results, spontaneously lead to improvement. This data will assist Company A to establish some powerful continuous improvement processes that can be implemented in future.

With regards to the empirical examination, a special form was prepared to obtain data, such as plant availability, productivity rate, scheduled maintenance, breakdowns and economic data, such as equipment and maintenance costs. The information was extracted from CMMS and a standard spreadsheet software was used to analyse the data.

Figure 4.7 represents ‘On Time’ and ‘Late’ work orders performed per year on the plant, from 2011 to 2016. The graph indicates that there is a positive response to maintenance on a yearly basis. The work orders seem to be processed on time.
The ‘On time’ work order show an increased from 65% in 2011 to 88% in 2016.
The ‘Late’ work orders show a decrease from 35% in 2011 to 12% in 2016.

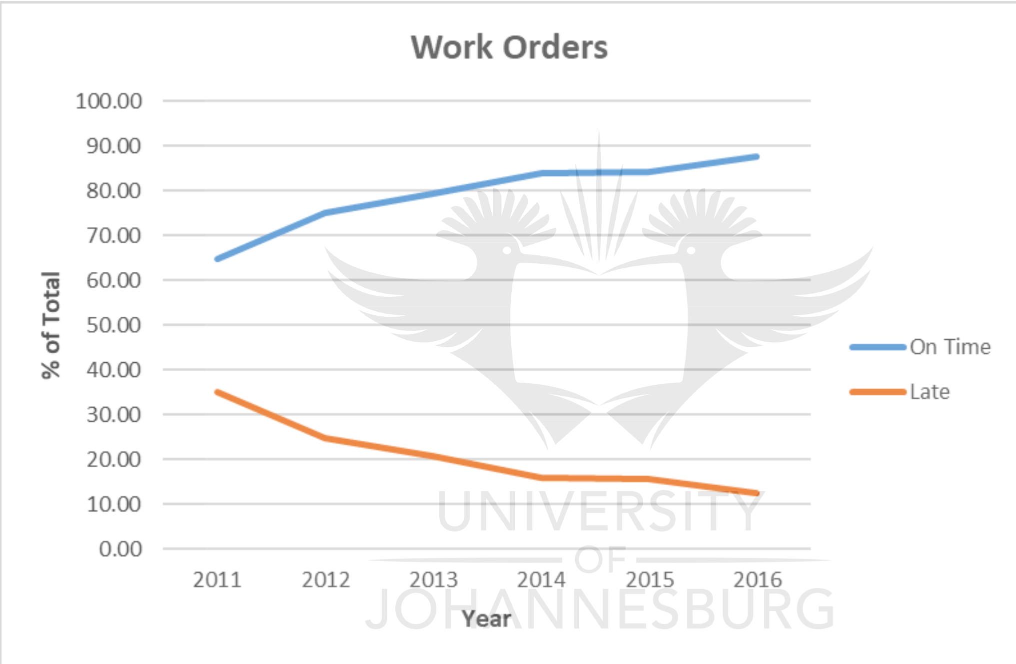

Figure 4. 7:Work orders (2011-2016) - refer to Appendices 7.3

Work order quantity shows a decreasing trend, which highlights that there is a decrease in unplanned maintenance. Planned maintenance continues to be performed, whereas due to constant breakdowns there are often delays. This delay causes the maintenance tasks not to be completed as scheduled, primarily because they must first detect the failure and strip the failed equipment which usually takes up maintenance time.

As reflected with the maintenance costs in Figure 4.8, the high costs usually occur during the shutdown periods. This is since the equipment is overhauled, repaired and serviced. The sub-contractors also come to service equipment during this period. Management plans the plant shutdown schedule at the beginning of the year, after receiving the company's annual productivity performance figures. Thus, an annual budget is allocated to the various departments. The maintenance budget is allocated monthly to the Maintenance managers.

- In 2013, the plant shutdown was planned during June and November.
- In 2014, the plant shutdown was planned during May and new equipment were purchased during August for plant improvement.
- In 2015, the plant shutdown was planned during May/June and December.
- In 2016, the plant shutdown was planned for February/ March.

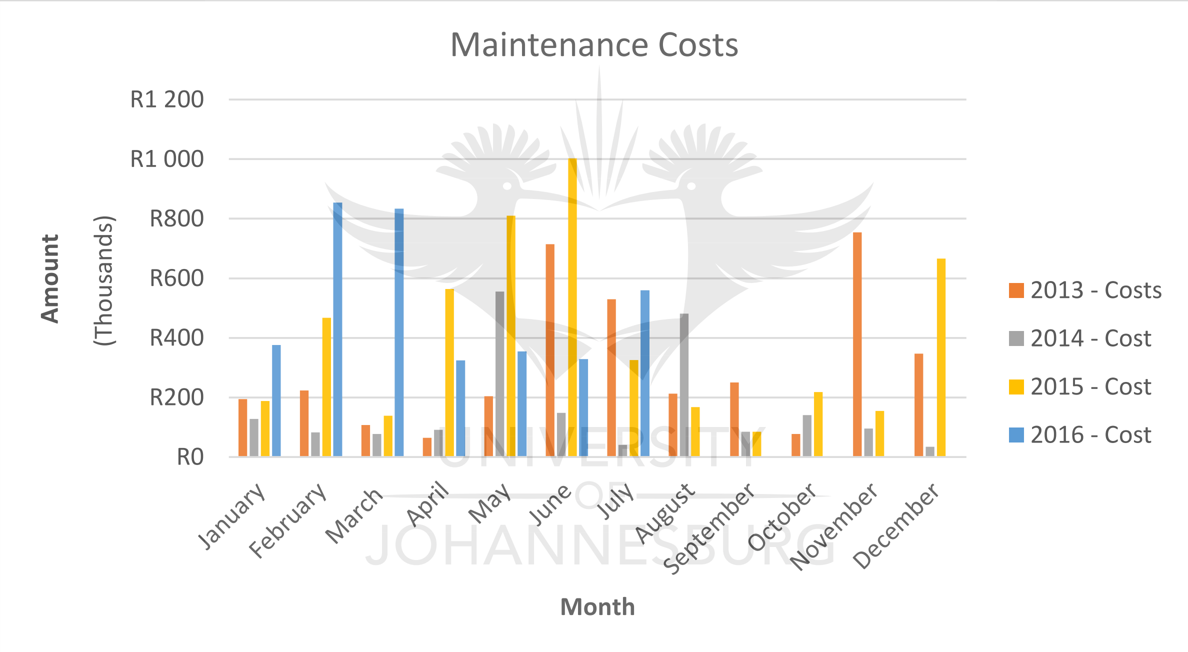

Figure 4. 8: Estimated Maintenance Costs (2013-2016) - refer to Appendices 7.4

From this result in Figure 4.8 it can be observed that Company A experienced the highest maintenance expenditures during 2015, whereas the cost of maintenance continued to be high during 2016. This should be alarming to the maintenance department and management need to undertake an annual review into possible causes of the constant high maintenance cost during the consecutive years. The maintenance department should also consider establishing an annual budget, since this will assist them to monitor and control maintenance costs.

Figure 4.9 identifies the product manufactured, this is the average calculated across the entire month and it includes normal, low and zero production days. Zero production days can result from many causes, including unplanned maintenance, breakdowns and lack of demand. Ultimately, it is the key measure of the output of the plant, and improvements should be reflected in an increase in this value (which, in the example, is 800 000 tonnes). This quantity is useful in the development of realistic production plans. It also sets a benchmark against which future performance improvements can be measured.

The low production months observed are;

- June 2013 at 390 000 tons
- December 2014 at 350 000 tons.

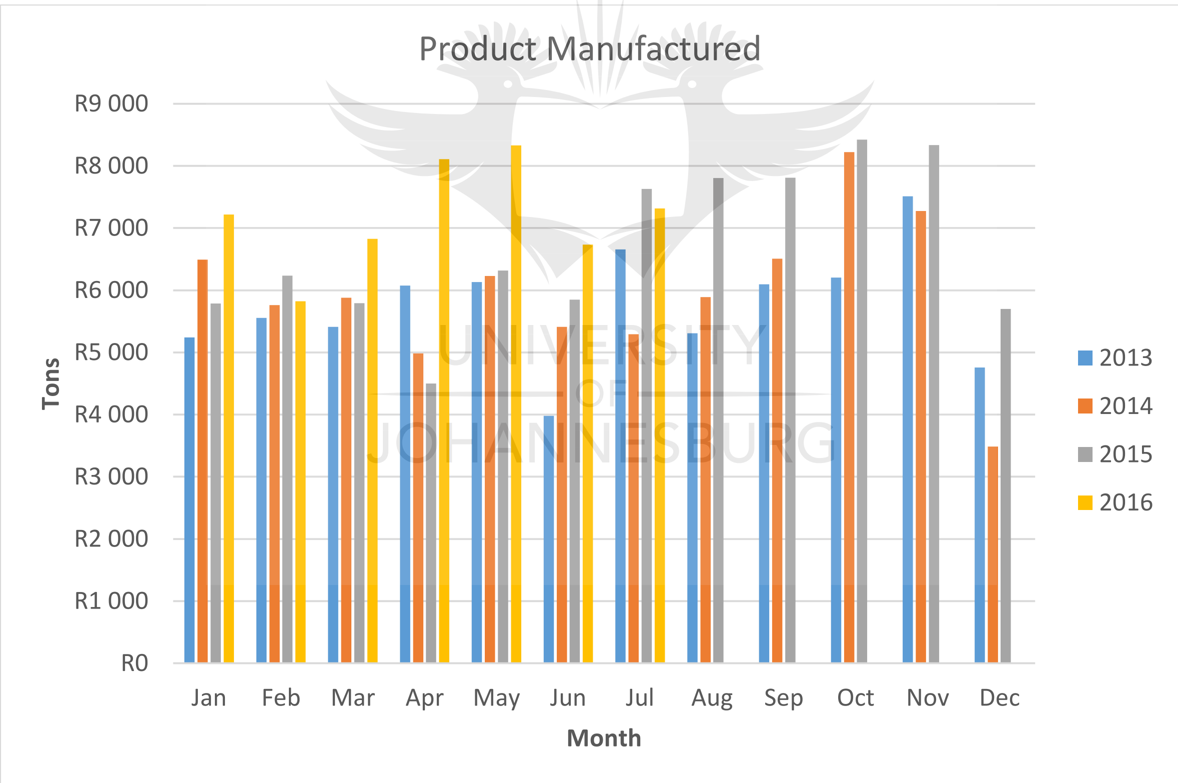

Figure 4. 9: Product Manufactured (2013-2016) - refer to Appendices 7.5

If management would use the 700 0000 tons as the average benchmark for the best productivity, June 2013 is regarded as 55.7% and December 2014 is 50% below the estimated production for the month. This can be used as the key performance indicator for the plant. It is always important for management to investigate the causes of low production months and try to reduce their number. Techniques such as Pareto Analysis and Root Cause Analysis should be applied, typically by the maintenance engineers, with the aim of identifying and eliminating equipment defects and failures. Losses may also be reduced by adjustments to the maintenance plan and by applying condition monitoring techniques. Production losses due to run-up and wind-down times, or other operational causes, can be identified and addressed, typically by process engineers and operators. The advantage of determining the low production months is that it provides a basis for the degree of low production.

Comparing the maintenance cost with the product manufactured graph, a trend can be derived. During the high maintenance period the productivity is negatively affected. Figure 4.10 and Table:4.6 illustrate that the maintenance team were performing more preventive maintenance, thus an improvement can be seen from 2011 when more preventive maintenance was practiced. This reflects positive results, whereas more focus is still required to reduce the 28% breakdown occurrence.

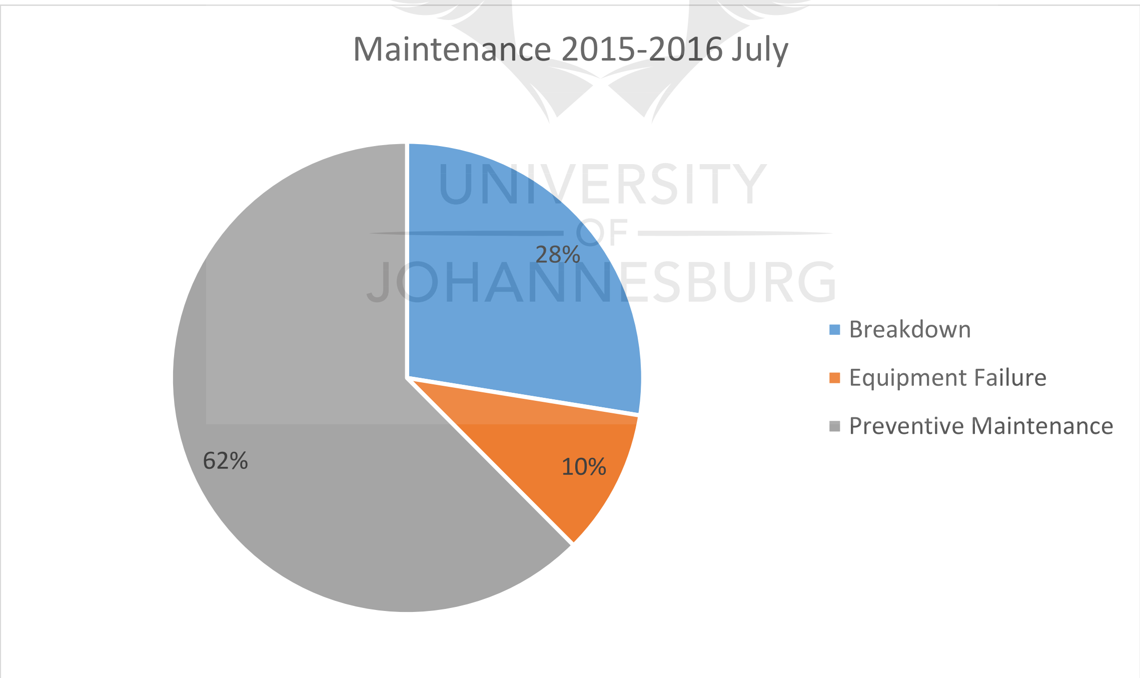

Figure 4. 10: Maintenance Status (2015 -2016)

Table 4. 6: Maintenance Status

Type of Maintenance	Amount	Maintenance 2015-2016 July
Breakdown	184	28%
Equipment Failure	67	10%
Preventive Maintenance	417	62%

The preventive maintenance schedule in Figure 4.11 indicates that during March there were 56% of jobs closed, 28% were still open and they had experienced a minimal of 3% cancelled jobs. A shut down was scheduled for the month of April, where most equipment such as the boiler and reactor are overhauled for maintenance.

Whereas, as the year progresses a maximum peak of 75% on closed jobs was reached during July. The rate of cancelled jobs continues to decline from 23% in June to 3% in August. From April to August the rate of closed jobs is almost 0%.

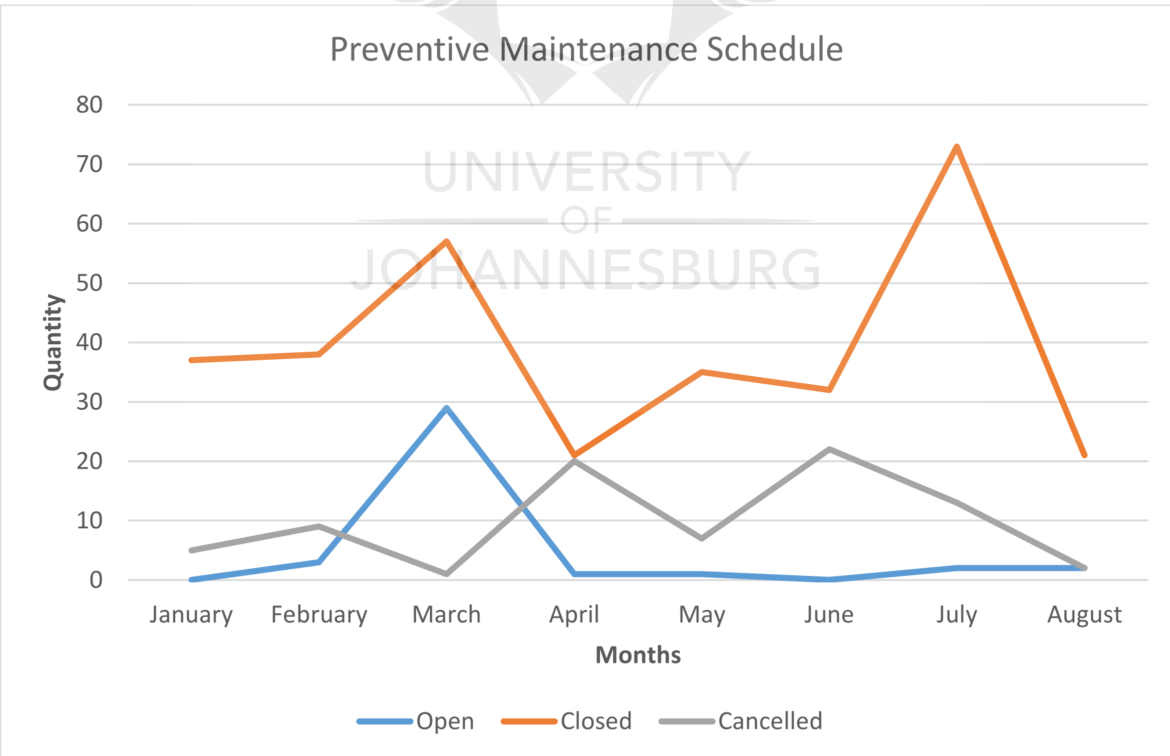

Figure 4. 11: Preventive Maintenance Schedule (2016) - Refer to Appendices 7.6

Preventive maintenance is important to maintain the high use of the equipment and low product failure levels. Equipment operation is constantly increased with plant production activity whereas, when the equipment specified operating hours are reached, maintenance is required. The company also has regular inspections performed on a regular basis. However, it is found that the equipment hours are reached, and the equipment must be maintained, but the production line cannot be stopped. The maintenance team is then likely to postpone the maintenance, which has a negative impact on the equipment. This could lead to product failure and seriously affect production and maintenance plans. Consequently, it is important to always have preventive maintenance in place, which is adhered to.

4.6.1 Application of RCM on plant operations

The plant consists of three production lines, in the following analysis the author will focus on production Line 2. The plant runs 24hrs, seven days a week. The estimated period of scheduled shutdowns is five weeks, which is two weeks in March/April and three weeks in December.

$$5\ weeks = 5\ x\ 7\ days = 35\ days$$

$$1\ year - 5\ weeks = 365 - 35 = 330\ days$$

$$330\ days\ x\ 24hrs = 7920\ hrs$$

The plant is estimated to run for 7920 hrs without failure, but since there are constant breakdowns and scheduled maintenance this is impossible to achieve.

The design capacity of Line 2 is 5000 kg/l.

Calculating the current rate:

- Sulphur flow rate = 450 kg/h
- Sulphur molecular mass = 32 kg/mol
- Concentrate efficiency = 97%
- LAB molecular mass = 240 kg/mol

$$\frac{450}{32}\ x\ 0.97\ x\ 240 = 3273.75$$

$$\frac{3273.75}{0.74} = 4424\ kg/h$$

$$\frac{4424}{5000} = 88.5\%$$

This simply demonstrates the production operation on average, without the disturbance of breakdowns.

It was observed from the CMMS database that constant failure usually occurs on the pumps, this is often caused by pump leakage. From the retrieved data, it was observed that the pump with constant failures was LAB product reactor feed pump (116-P3-Pump) on Line 2. The pump is regarded as critical equipment and there is one spare pump in stores.

It is estimated that the cost of replacing a pump after failure is R32 000.00 an hour. It takes roughly two hours to replace a pump, thus the maintenance cost is estimated to be R64000.00.

4.6.2 Determining MTBF

Number of failures per year = 2

The pump is inspected every four months. It is recommended that after every 6 months the seals should be replaced.

The average time between failures:

$$\frac{5years}{4failures} = 1{,}25$$

Failure rate:

$$\frac{1}{MTBF} = \frac{1}{1{,}25} = 80\%$$

The average time between failure is 1 ¼ years, which leads to a failure rate of 80%. This is a short period for a pump to operate which means that the constant breakdown can cause up to 24hrs shutdown. What could be the reason for the high rate of pump failure?

4.6.3 Finding the root cause of a pump

A pump that is properly selected, properly assembled and operated within the intended range will have a long service life until it inevitably succumbs to wear. Whereas if it is not selected correctly it will continuously experience failure. These repeated failures can be prevented by conducting a root cause analysis approach. Successful application of the analysis and determination of the root cause should result in the elimination of the problem.

It is advisable to always evaluate a pump's failure history before pulling it into the workshop and the maintenance team start with the repairs. This is where we regard the CMMS plays a major role in ensuring reliability management is maintained. The CMMS assist the maintenance team in retrieving equipment data, which is why the CMMS should always be updated correctly and fully utilised.

The root cause (needed to effectively prevent failures) cannot really be found by only looking at statistics, it is important for employees also to carry out an analysis. Root cause analysis (RCA) is usually performed on equipment with consequential events, repetitive failures, perform below standards or require CPAR. Root cause analysis is an important component in the maintenance department and it assists in eliminating the source of equipment failures to prevent the issues from recurring.

4.6.4 To determine the root cause of the reactor feed pump, the 5 Why's approach can be used.

1. Why was the plant line shutdown?
   The pump seized
2. Why did the pump seize?
   There was insufficient lubrication on the bearings, so they locked up.
3. Why was there insufficient lubrication on the bearing?
   Maintenance and operators did not check the pump oil level.
4. Why did maintenance and operators not check the oil level?
   Weekly inspections are not being carried out
5. Why are inspections not carried out?
   There is no weekly inspection procedure in place.

To visually view the 5 Why's process, the Causes and Effect diagram approach can be used as illustrated in Figure 4.12.

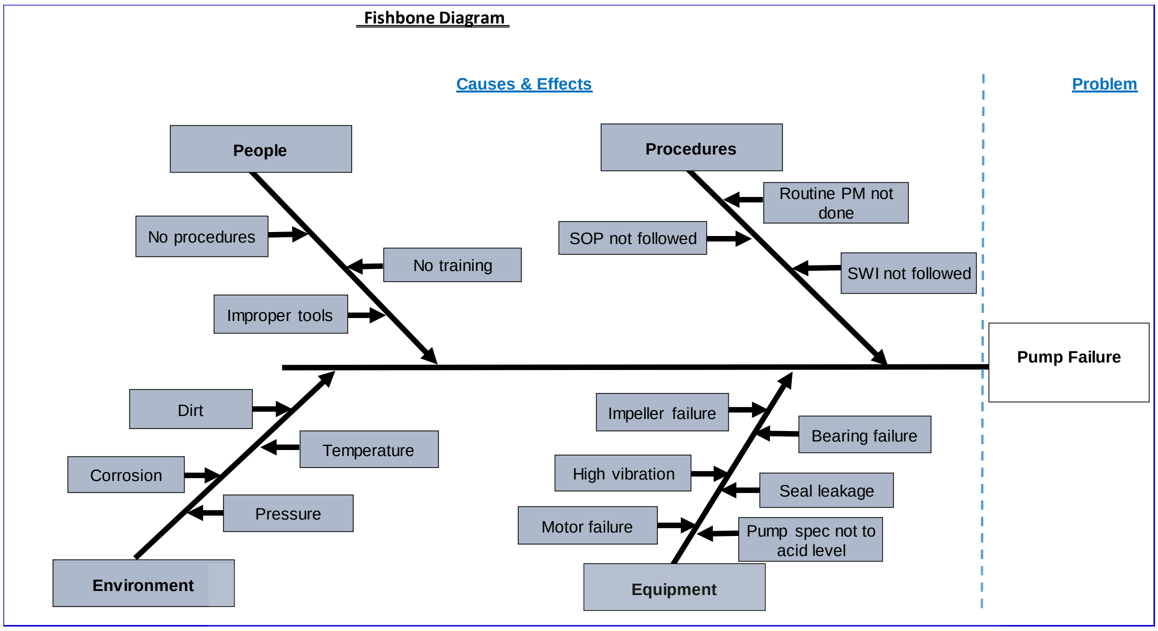

Figure 4. 12: Pump Failure-Causes and Effects Diagram

Through conducting an RCA and Causes and Effects diagram, the author found the constant causes of pump failure to be due to lack of inspection procedure. Thus, the corrective action to be taken by management is to implement a procedure to indicate the weekly inspection processes to be carried out.

Below are a few examples of possible pump equipment failures;

1. Impeller fail because,
   - Impeller has worn out – Manage this failure by changing impellers before the end of useful life.
   - Impeller jammed – Manage this failure by installing screen in the suction line, to view if there are foreign objects in the suction-line.
   - Impeller is adrift – Manage this failure by training people to fit impeller correctly
   - Cavitation occurred – Mechanical seal leak – Loss of primary contamination
   - Lack of lubrication (Root Cause) – High bearing temperature (Failure Mode) – Alarm; possible shutdown (Effect on user)

When a seal is leaking, the maintenance technician must determine if the seal has failed or worn out. A worn-out seal will leak when the seal face has worn away completely.

2. Seals fail because,
    - The seal face is open: when the shaft moves due to end play, bearing wear, bent shaft, shaft whip, vibration, impeller imbalance, system NPSH incorrect causing cavitation etc.
    - Due to heat: Heat affects the elastomer, which is the part most sensitive to extremes of temperature. Change in the state of the fluid being pumped.
    - The chemical environment causes a material failure: incorrect material used

3. Bearing fail because,
    - Debris ingress: causes increased friction
    - Filter failure: blockage
    - Oil contaminated: bearing overheating and oil specification changed or inadequate system sealing
    - Misalignment: not aligned on fit

Identifying the causes of failure can lead to avoiding failure in the future and will extend pump MTBF. Thus, applying a structured approach such as root cause Analysis assists maintenance to determine the causes of failure. Figure 4.13 illustrates how many parameters interact to cause repeat failures in pumps. It is recommended for a pump to stay near the centre of the Reliability Curve.

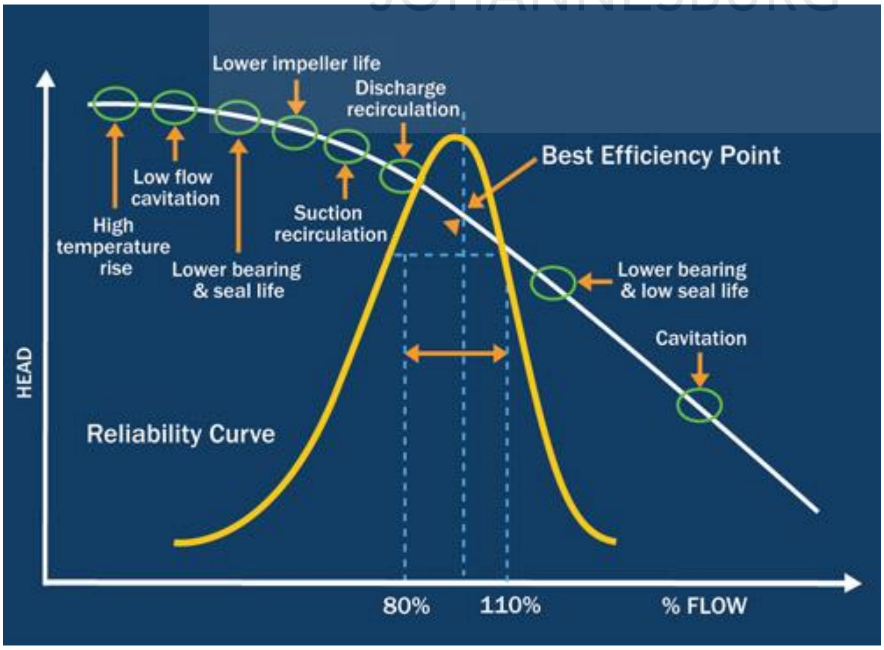

Figure 4. 13: Pump Reliability Curve

4.7 Online Survey

The author conducted an online survey, using Survey Monkey. The author initially targeted a total of 100 responses, but due to time constraints the author managed to achieve a total of 85 responses. The online survey results are presented by graphs and tables. This information was extracted from the author's online survey and a standard spreadsheet software was used to analyse the data. The tabulated results highlight selected survey findings and are expressed in percentages. The base for each table was the total number of respondents per question. Based on the survey results five respondents did not respond to all the questions. Appendix B contains the online survey questionnaire and responses. The online survey consisted of 29 questions and was divided into five sections which are:

- Departmental identification
- Computerised Maintenance Management System
- Maintenance Management
- Preventive Maintenance
- Planning and Scheduling

The main purpose of the online survey was to gather data from different organisations to substantiate how employees view reliability management. The online survey questionnaire assisted the author in determining the overall effect of implementing reliability management within an organisation. The online survey results will aid as a base to establish if the implemented reliability management system within different organisations has assisted them in improving on the quality of maintenance, by answering the research questions as addressed in chapter one.

4.7.1 Departmental identification

The results in Figure 4.14 and Table 4.7 indicate that the total response consisted of; 69% maintenance, 13% operation, 13% production and 5% others.

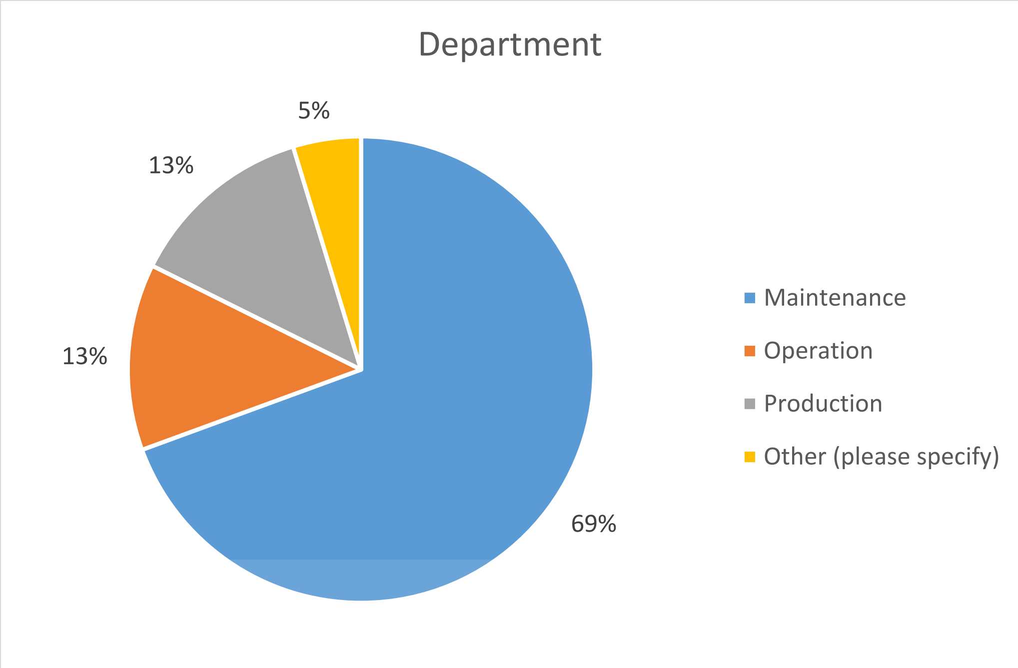

Figure 4. 14: Department

Table 4. 7: Question 1- What department do you work in?

Answer Choices	**Responses**	
Maintenance	69%	59
Operation	13%	11
Production	13%	11
Other (please specify)	5%	4
	Total Respondents	**85**

The online survey, Figure 4.15 and Table 4.8 also indicates 51% of the responses to be from an intermediate level. Employees at the intermediate level are hands on with maintenance and more exposed to the activities that take place in the plant with regards to maintenance.

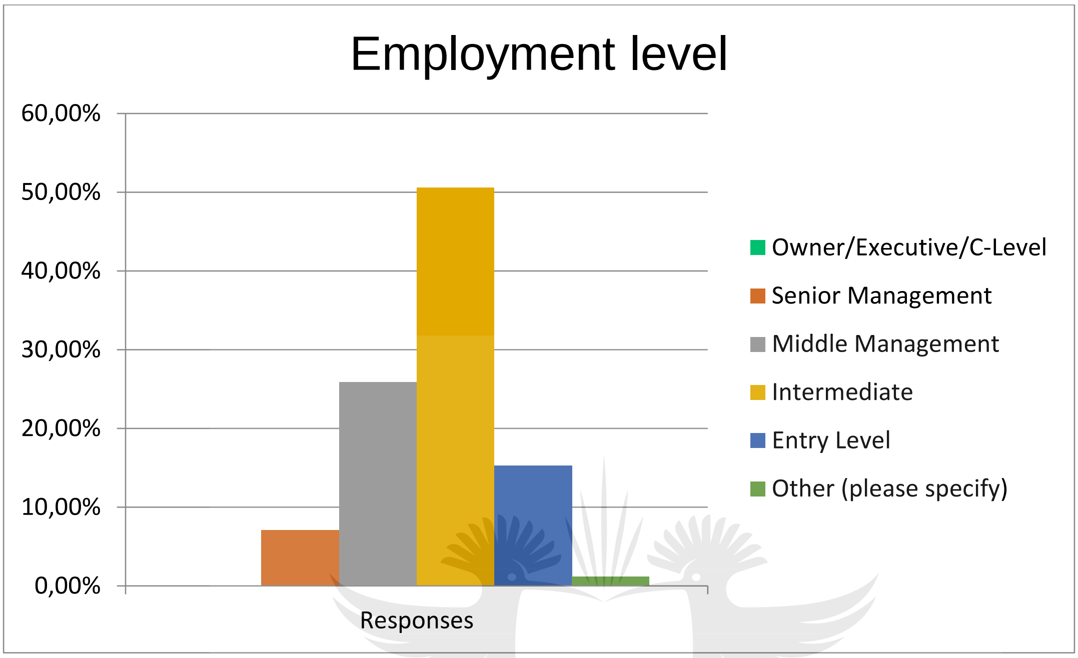

Figure 4. 15: Employment level

Table 4. 8: Question 2 - Which of the following best describes your current job level?

Answer Choices	**Responses**	
Owner/Executive/C-Level	0%	0
Senior Management	7%	6
Middle Management	26%	22
Intermediate	51%	43
Entry Level	15%	13
Other (please specify)	1%	1
	Total Respondents	**85**

In Figure 4.16 results are all based on processing plant and indicate the percentage of responses from various industries. The respondents work as follows;

- 39% chemical plant environment.
- 18% Power plant
- 11% Food industry

- 9% Oil refineries
- 11% Mineral processing
- 5% Waste-water treatment
- 8% Services

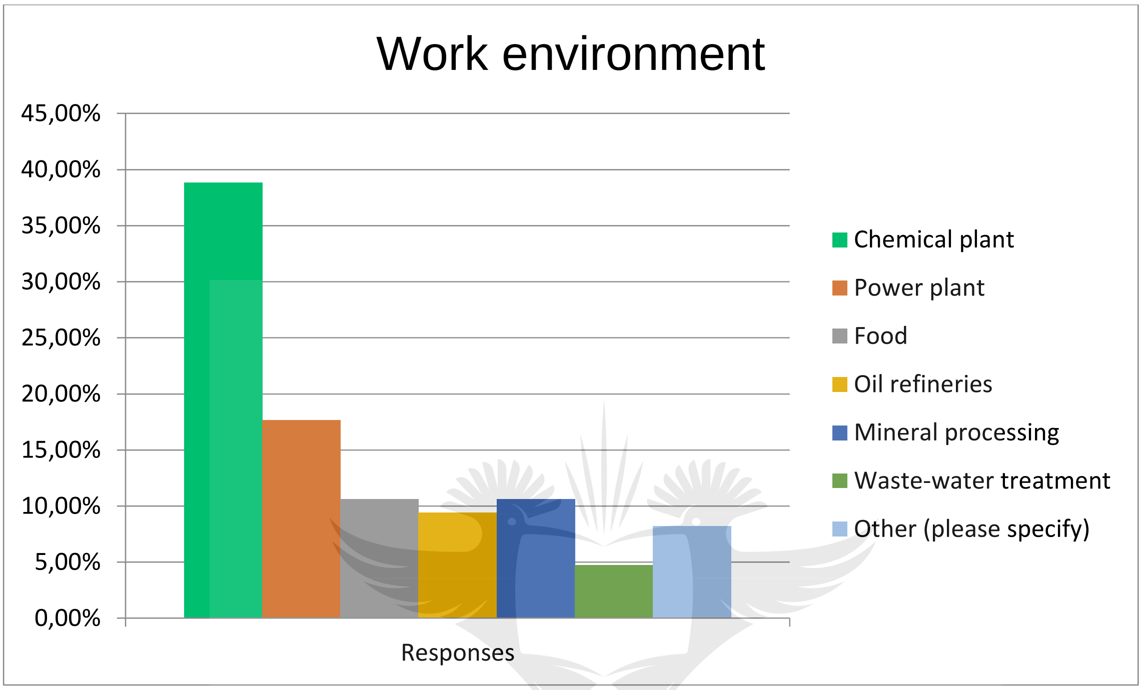

Figure 4. 16: Question 3 - Which process best describes your working environment?

4.7.2 Computerised Maintenance Management System

Selecting the right CMMS is an important business decision, thus it is recommended for an organisation to carry out research on the reliability management system most suitable for their business needs. The observed results, Figure 4.17 show that majority of the organisations were influenced by the CMMS multiple functionality/ capability (at about 75%) when purchasing the CMMS package, rather than being influenced by the CMMS package/annual subscription cost (43%) and CMMS implementation process and support provided (37%). This result reflected that most organisations do not initially only consider the cost factor when selecting a reliability management system, rather they focus more on the functions and capability the system can offer.

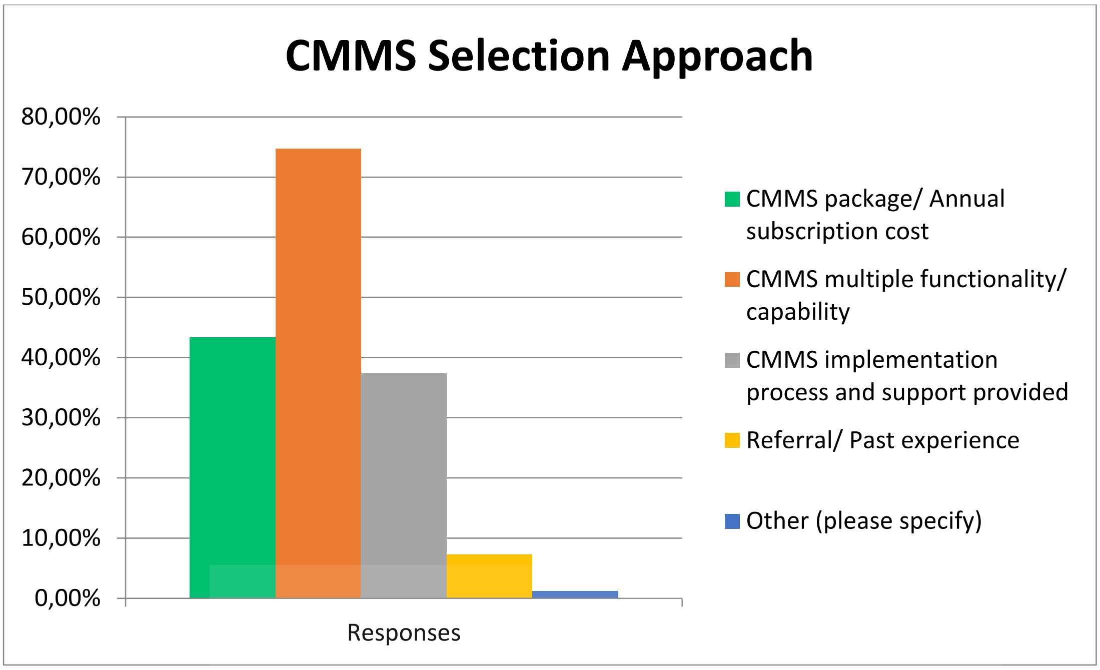

Figure 4. 8: Question 5 - Which of the following approach, if any influenced the organisation to select their CMMS package?

The online survey showed a positive response, because 98% of the respondents make made use of the CMMS and only 70% indicated that they always use CMMS to assist them in keeping track of equipment and inventory in their stores.

4.7.3 Maintenance Management

In Figure 4.18 most respondents strongly agree (60%) and 33% agree that they have a maintenance strategic plan in place within their organisation. This is further validated in Figure 4.19 by 50.00% of the respondents that strongly agree and 30% that agree to the fact that management set goals or targets for maintenance levels for future performance.

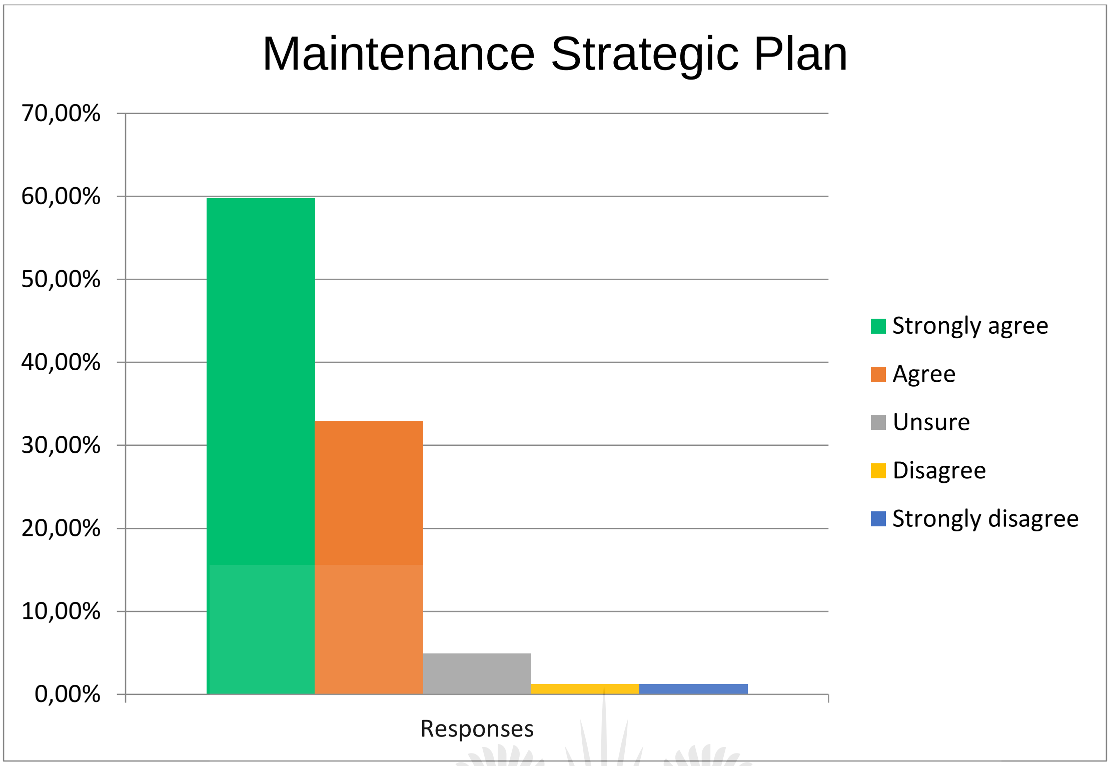

Figure 4. 9: Question 7 - Does your organisation have a maintenance strategic plan in place?

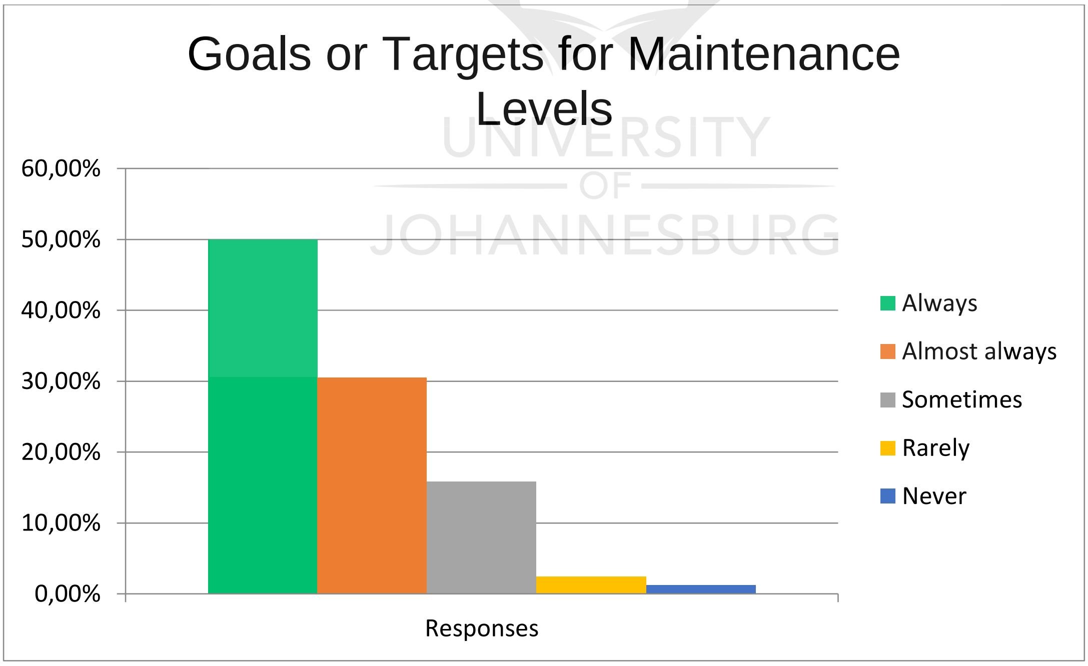

Figure 4. 19: Question 8 - How often does management set goals or targets for maintenance levels for future performance?

The maintenance strategic plan establishes the maintenance objectives and therefore is aligned with the organisation's mission and goals. It assists in determining the maintenance resources that are required to perform maintenance activities. The plant maintenance objectives in this case can be considered as plant availability, reliability, quality and delivery. To successfully implement a maintenance strategic plan, it is important for management to always perform maintenance forecasting, so as to estimate and predict maintenance activities. This involves scheduled, planned and breakdown maintenance. Organisations also make use of KPIs to evaluate the organisation's success at reaching targets. Positive feedback on KPI improves on the performance measurements of maintenance in general. KPI's are continuously measured to identify current and future maintenance performances, although management should consider employees' benefits when setting the KPIs and not as a tool for managerial control. This is simply because it can lead to a negative environment resulting in employee's distrust and lowered employee commitment.

The weighted average as a result of plant availability is 5.73, therefore the respondent views the maintenance process within their organisation effective with regards to plant availability. This is generally influenced by how effectively the reliability management system and maintenance processes were implemented and are managed in the organisation. It is important to note that most of the respondents who regarded their maintenance process as ineffective did not have a maintenance strategic plan in place.

4.7.4 Preventive Maintenance

The results in Figure 4.20 show that 58% of respondents always, and 32% almost always make use of work orders when performing maintenance activities. Only 10% of respondents sometimes make use of work orders. This is an indication of how reliability plant maintenance proves inadequate in most companies. They implement CMMS, but still do not utilize its functions to assist them to monitor the plant activities. Rather they still resort to paper-based work orders which prove inefficient. Poor record keeping also has a negative effect on maintenance activities and thus lead to inefficient maintenance processes. Yet, it remains advisable for maintenance employees to include more information on their observations on the work orders, which can be populated into a report in future. This equipment report will assist maintenance employees to monitor the failures and track their history to determine equipment irregularities.

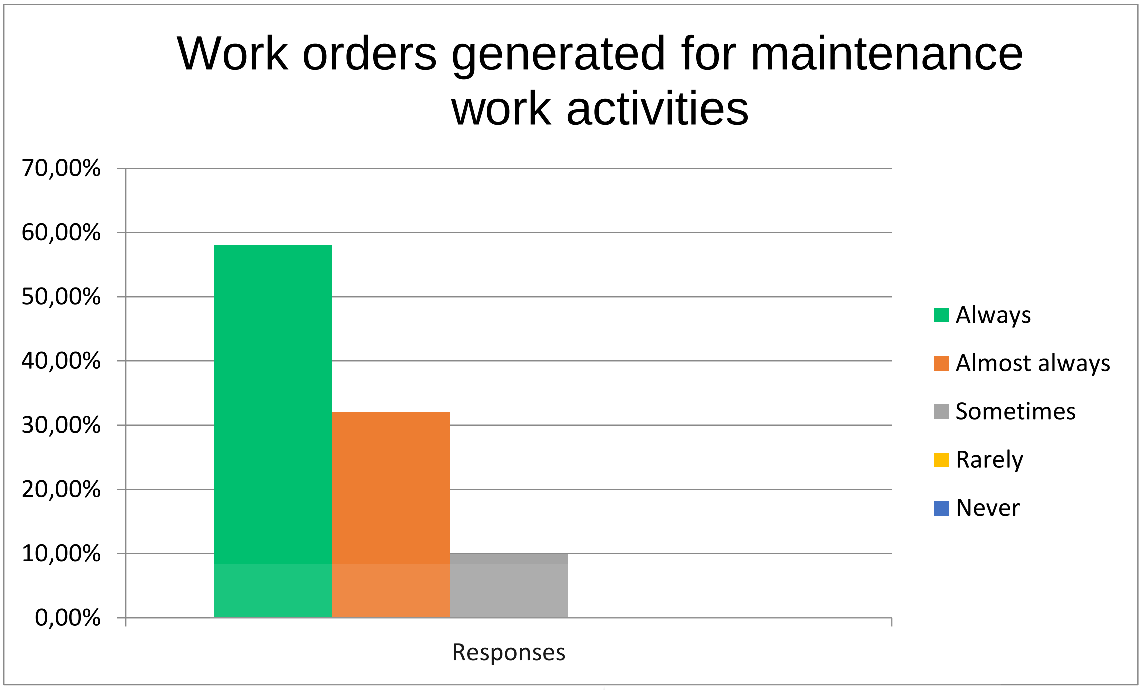

Figure 4. 10: Question 16 - How often does your organisation use work orders for maintenance work activities?

The CMMS helps establish an efficient communication process, because it makes it more convenient to send work orders. It is important that the labour hours and resources used to complete maintenance are documented on the work order, since this will assist in tracking all maintenance stock, equipment failure rates and expenses. Work orders assist organisations to stay up-to-date with labour, projects and resources.

In Figure 4.21 almost all respondents (98%) agree or strongly agree that RCM is considered when equipment failures could cause injuries, the equipment is critical or has high downtime costs. RCM is a long-term process, which if used effectively can result in the enhancement of the plant and equipment reliability. RCM yields benefits over a few years and facilitates improvements in operations and maintenance activities. (IAEA, 2007) RCM determines the type of maintenance that needs to be performed e.g. repair, testing and inspections to support the maintenance strategy. Performing RCM analysis can result in changes to existing equipment preventive maintenance tasks. Therefore, establishing the root cause of the constant equipment failures is important and to achieve these maintenance employees always must refer back into equipment past reports. This will assist to increase the plant's MTBF and reduce the organisation's overall maintenance expenditures.

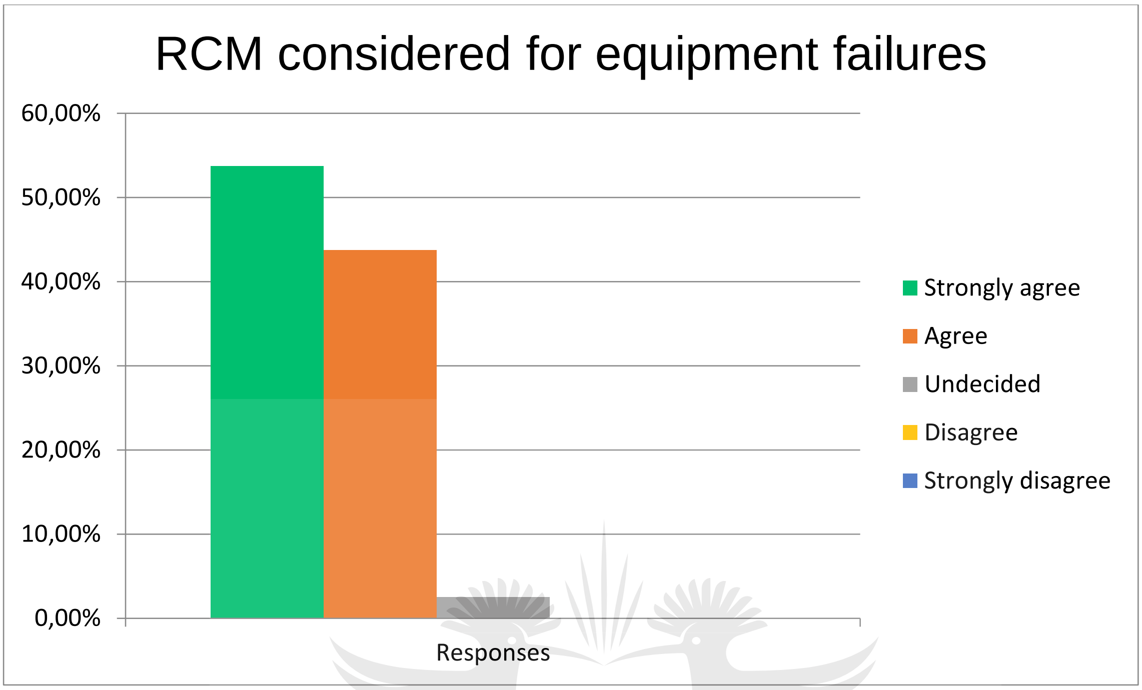

Figure 4. 11: Question 17 - Is Reliability Centered maintenance (RCM) considered when equipment failures could cause injuries, the equipment is critical or has high downtime costs?

Having the acquired skillset is necessary for effective maintenance. The survey results indicate that maintenance employees are well skilled in performing their jobs. Regardless of employees' qualifications, organisations should annually perform a skills audit to identify the skill gap. This will assist them to implement a skills development plan for their employees in order to keep them up to speed with the industry trends and technological development. Although 22% of respondents are dissatisfied with the skill development within the organisation overall, 69% are satisfied with the training their organisation offers for skills development.

It is practical for operators to assist with PM tasks in the plant, as they are in the frontline of plant production. The survey results reflect that operators in most organisations do assist with minor PMs, such as cleaning, lubricating, adjusting and inspecting. Productivity can be increased by enabling operators to expand their span of control, this will reduce operations and maintenance costs.

The results shown in Figure 4.22 reflect that 81% consider LCC when selecting equipment. The LCC approach allows effective maintenance management of the plant equipment and for the organisation to easily keep track of the maintenance expenses. Thus, to keep track of the LCC of equipment it is essential always to record equipment purchasing and maintenance costs in the CMMS. This assists management in deriving the life cycle costs to determine when equipment is critical or due for an upgrade.

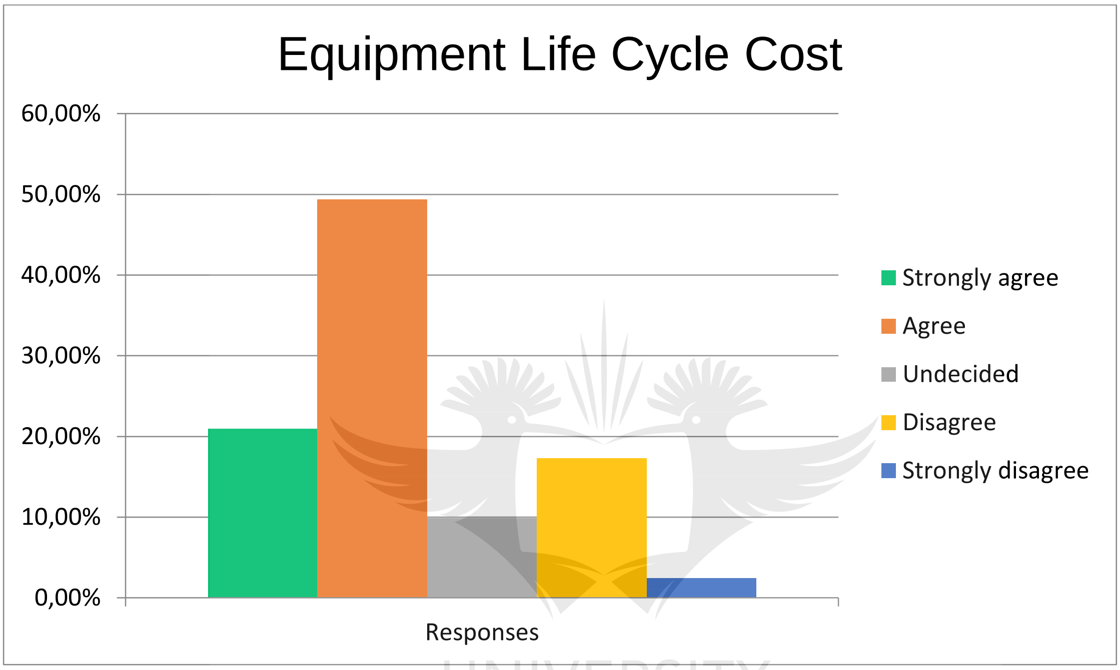

Figure 4. 12: Question 22 - Overall, would you say that the organisation keeps track of the LCC to maintain equipment?

Figure 4.23 illustrates that about 94% (41% strongly agree and 53% agree) of the respondents agree that employees follow the safety policies and procedures while performing maintenance. Most organisations have safety policies and procedures for maintenance in place that are being effectively followed. Injuries usually happen during maintenance when the procedures and policies in place are not followed.

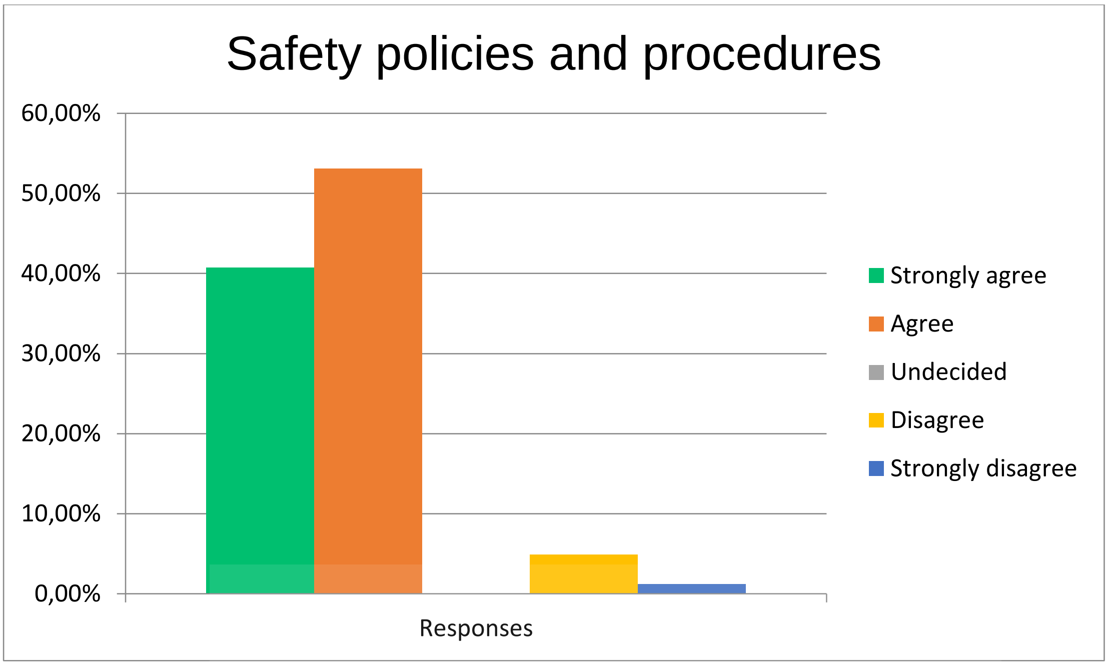

Figure 4. 13: Question 23 - The maintenance employees follow the safety policies and procedures, while performing maintenance?

Risk assessment should initially be performed to help identify the precautions that are necessary to carry out the work safely. Employees should always comply with the organisation's policies to ensure a safe working environment. Procedures help maintenance employees to be aware of their responsibilities to work and act safely by following safety instructions.

4.7.5 Planning and Scheduling

Respondents agree that priorities are set for maintenance jobs and those maintenance employees are assigned to job tasks based on their specialised knowledge and abilities. It is poor management not to have a maintenance planner as there would be no one to plan for a job in advance and make sure all the required equipment is ready. Careful consideration should be made when scheduling maintenance, because in some cases over half of the typical maintenance activities are found to be unnecessary. Activities such as routine equipment checks, and preventive maintenance is done on equipment that doesn't need it. Whereas, incorrect maintenance such as re-assembly, incorrect tightening, misalignment, etc. can reduce equipment reliability.

Although it is important to service and repair equipment before it enters the wear-out zone, maintenance should initially determine when the wear-out zone occurs as illustrated in Figure 4.24. This approach is usually found to be misinterpreted and therefore estimated, resulting in uncertainty and preventive maintenance schedules being conservative. Preventive maintenance effort is actually wasted, because it is performed too soon.

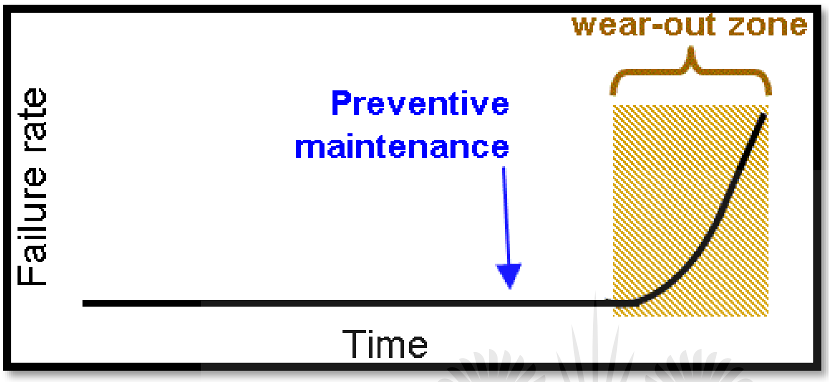

Figure 4. 14: Preventive Maintenance - Wear-out zone

The results in Figure 4.25 reflect a 4.37 average of outsourced maintenance to contractors. This shows that less than 50% of most companies' maintenance is internal. This raises concern, since managing external management can elevate maintenance process issues. Thus, management needs to ensure that contractors comply with the organisation's policies and procedures.

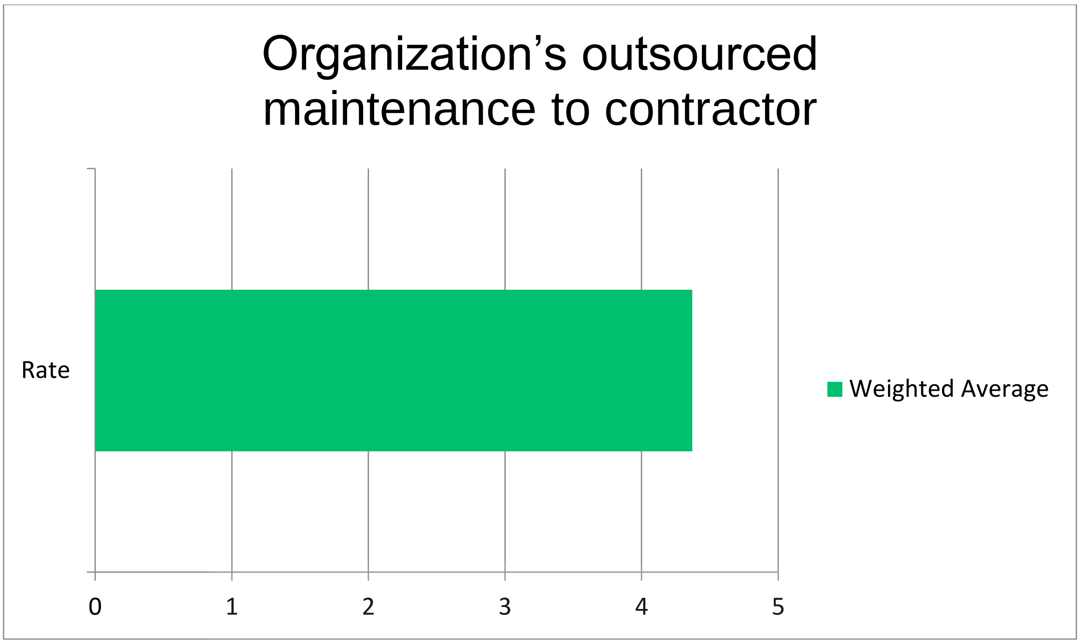

Figure 4. 15: Question 27 – How would you rate the level of the organisation’s outsourced maintenance to contactors?

The results in Figure 4.26 shows that 70% of the companies plan their shutdowns and major repairs. Effective shutdown management is critical for plant productivity as this reduces the overall downtime costs. Shutdowns have a serious impact on the plant’s profitability and thus form a major part of the organisational annual budget. Maintenance shutdown costs can be reduced, and improvements can occur without sacrificing any work or cancelling any scheduled maintenance downtime (see Table 4.9).

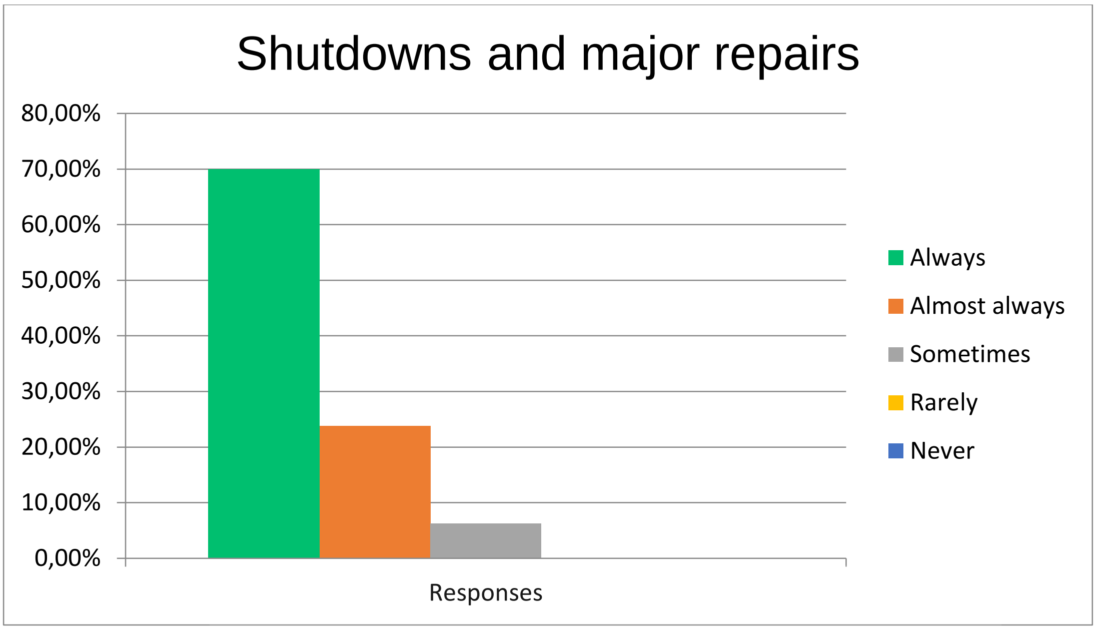

Figure 4. 16: Question 28 - Shutdowns and major repairs are planned in advance

Table 4.9 illustrates how savings from shutdown management are a result of good planning and scheduling. It demonstrates the philosophy of quality shutdown vs poor shutdown management. Shutdown management serves as a tool to effectively reduce costs and increase plant productivity.

Table 4. 9: Shutdown management (Krings, 2002)

	Quality Shutdown Management	**Poor Shutdown Management**
1	Control work list	Unlimited work list
2	Controlled overtime	Unlimited overtime
3	Contractors used only if special skills required	Contractors used to execute routine work
4	Routine work done on straight time (later)	Routine work done on overtime
5	Materials obtained at best value	Materials must be expedited
6	Little need for express shipping	Express shipping used liberally
7	Parts kitted and staged near work site	Parts scattered all over, or non-existent
8	All work planned in advance	Some work is planned, most is not
9	The schedule is extremely accurate	The schedule is a rough guess
10	Crafts are prepared with work packages	Crafts spendtime gathering information
11	Add-on work is rare	Add-on work is common
12	Planned, scheduled jobs get priority	Planned, scheduled jobs get cancelled
13	Inspection-driven focus (Preventive and Predictive maintenance)	Repair-driven focus
14	The budget is based on reality	The budget is based on the past
15	Left over parts are returned for credit	Left over parts are retained
16	Work is documented after execution	Work is not documented after execution
17	Post-outage critique meeting captures learnings	No post-outage critique meeting

4.8 Findings

In this study the triangulation method was used, as illustrated in Figure 4.27. The triangulation method included a literature review, case study and observation of the organisation, interview with management, employee questionnaires, CMMS data analysis and online survey. The main purpose of triangulation in a study is to increase the credibility and validity of the results where if a single data source can be counterbalanced by the other (Carugi, 2014).

Triangulation

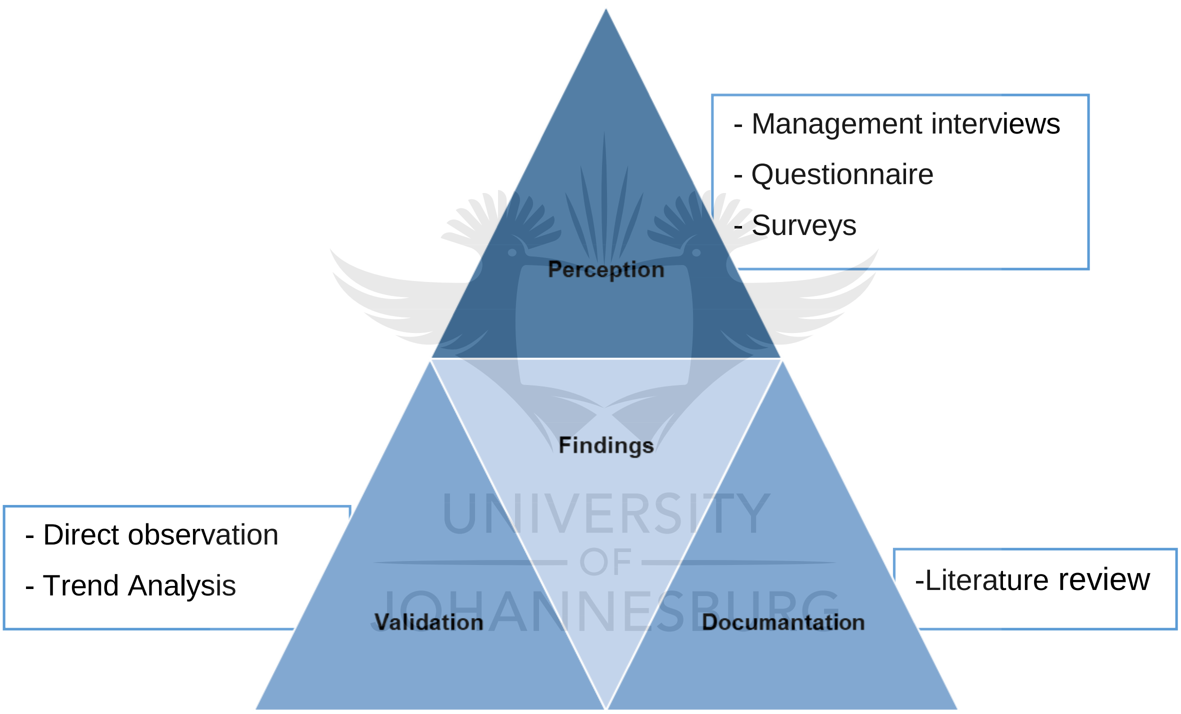

Figure 4. 17: Triangulation Method (Carugi, 2014)

Table 4.10 illustrates the study’s summary of findings through the triangulation method. Triangulation enabled the author to compare the consistency of findings obtained from the data collected through the different methods.

Table 4. 10: Summary of findings

CMMS	The observations show that maintenance technicians are not aware of the usefulness of CMMS and employees do not actively participate in maintenance or improvement strategies, which is further supported by the questionnaires. The questionnaires highlight that there is no regular communication between management and employees' involvement with CMMS. Management insists that although the plant experiences regular breakdown incidences, planned maintenance is still practiced, and they would not really regard the process as being reactive. Some managers feel that the CMMS implemented is working effectively, whereas others feel that improvements should be implemented, and more planning is required. Although the system does assist in the day-to-day running of the maintenance department, it is not fully utilised. Data analysis indicates that planned maintenance continues to be performed, whereas due to constant breakdowns there are often delays. Only in 2015 preventive maintenance is 14%, this concludes that continuous improvement is absent and management should consider implementing it to ensure plant efficiency and reduce plant failure.
Procedure and safety policies	Observation, Management and Survey show that organisations have procedures and safety policies in place. Observation and Management in Company A indicates that the procedures are not being followed and the workspace safety checklist during maintenance is not always performed. Questionnaires and surveys both highlight that RCM is considered when equipment failure could cause injuries.
Spares	The author observed that there is an inadequate budgetary control in the maintenance and duplication of spares. Management suggest that there is a critical spares list and those are the spares which are readily available. The other spares are ordered as and when required. There is no record kept for spare purchase and no tracking process in place. This also highlights the issue on the duplication of spares, therefore increasing maintenance costs.
Strategic Plan	Observations highlighted that there seems to be a limited connection between maintenance strategy and business strategy, since the maintenance management is not as effective and unnecessary costs are acquired. Management has no developed maintenance KPI process in place, thus maintenance efficiency is not evaluated and there is no set goal. Management does not have a strategic maintenance plan for the maintenance budget purposes with top management. The project manager assists the maintenance team to plan maintenance shutdowns and is also in charge of production plant process improvement strategies. The critical spares list is only documented on an excel document in the database and is not updated in the CMMS. A budget is provided monthly. Management does not have a structured process on which they manage their budget, but only make sure they do not go over the allocated budget.

Strategic Plan	Data analysis shows that management plans the plant shutdown schedule at the beginning of the year, after receiving the company's annual productivity performance figures. The highest maintenance expenditures were experienced during 2015. Online survey shows that most organisations agree to have a maintenance strategic plan in place, that is aligned with the organisation's mission and goals. To successfully implement a maintenance strategic plan, it is important for management to always perform maintenance forecasting, so as to estimate and predict maintenance activities. Organisations also make use of KPIs to evaluate the organisation's success at reaching targets. It is important to note that most of the respondents who regarded their maintenance process as ineffective, did not have a maintenance strategic plan in place.
Work Practice	The questionnaires suggest that the employees support the implementation of Reliably Management however, work orders are not costed for labour, parts and other cost. The employee also suggests that the repeated failure report does automatically trigger an investigation to find the root cause. Online survey indicates that only 58% of respondents always make use of work orders, this is an indication of how reliability plant maintenance proves inadequate in most organisations.

4.9 Summary

This chapter provides the results of the study, which assisted in establishing the outcomes of the subject. The author's observations were described and validated by management and employees' interviews. The response from the survey questionnaires were interpreted and discussed. The findings from the different instruments were correlated through the triangulation method.

Chapter 5: Conclusions and Recommendation

This is the last chapter of the research study. This chapter presents the highlight of the research areas such as the problem statement, the research objectives and the research questions. The author further draws a conclusion for the study based on the research findings; the author suggests several recommendations, including possible areas for further study.

5.1 Conclusion

Effective plant reliability in Company A cannot occur without proper maintenance management. Maintenance remains the most important part of the chemical processing plant, because of the associated production costs and specialised tasks involved in maintenance.

Maintenance enhances equipment reliability and helps to minimize the failure rate. Keeping productivity high and maintenance costs low remain the bottom line for organisations. Reliability and safety are critical in achieving production uptime and plant profitability. Thus, it is important for equipment to be well maintained and be fully functional at various operating conditions. Product standards, the quality management system and continuous improvement methods help improve the company's productivity and hence, place it in a more competitive position.

The literature study acknowledges the worldwide best practice of maintenance management experience to enhance plant performance. Full reliability cannot happen if CMMS is not fully operational in Company A, and this will be measured by productivity improvement. Proper maintenance management will help any organisation like Company A in planning, scheduling, and managing work requirements and maintenance tasks that are critical for production. Daily, recurring, preventive and predictive maintenance work can therefore be enhanced, resulting in improved operational performance.

The empirical study conducted with Company A's employees (mainly from the maintenance and operators' departments) identified possible blunders, which transpired during the reliability management system implementation phase. The study also found issues regarding the lack of communication between management and employees, which led to lack of employees' involvement. Thus it appears that management does not always update employees on the plant reliability management issues.

Maintenance is not measured. Therefore no KPI's are conducted, because there is lack of planning within the production and maintenance teams. Management needs to sit down and start planning the maintenance process to allow plant availability during the high demand season. Currently, the production team does not have a demand planning schedule in place to assist in plant availability. Thus, maintenance could be better scheduled so as not to interfere with production. Maintenance management needs to be committed and more involved in the production.

Maintenance often takes place while business goes on as usual. Poor communication between production and maintenance staff may lead to a safety risk because production and other workers will be uninformed of the severity of maintenance taking place. While it might always look better to buy new equipment, what builds long-term production income at a low budget is through the maintenance of all equipment. Maintenance is not daily routine work, as the working environment or situation changes per breakdown. Time pressure is a major maintenance problem, and maintenance workers are under pressure when a breakdown occurs and the production plant must be stopped. Such pressure can lead to a safety risk that could escalate new hazards. Working with subcontractors, however, also presents a safety challenge. Successful application of the root cause analysis helps to eliminate a pesistant maintenance problem.

It is important that the spare parts are available for maintenance of equipment to ensure that it performs as expected when commissioned. It is also important to ensure that all spares are stored appropriately in the storeroom. The lack of standard work practices and a scheduled preventive maintenance program in the storeroom might also be affecting the plant performance. All plant equipment is captured on the CMMS, and new installed equipment is updated. Work orders are developed on a weekly basis, but not effectively followed. The maintenance breakdown reporting structure is ineffective and not followed. The maintenance administrator requires advanced training. A more advanced version of CMMS is required.

Based on the online survey findings it can be concluded that most organisations in South Africa have successfully implemented CMMS within their maintenance department to facilitate their maintenance activities. With the implementation of CMMS, the maintenance process has become more effective, and the quality of maintenance has improved. The results indicate CMMS to have a positive impact on the overall maintenance processes and productivity. Maintenance employees are well skilled in performing their jobs. Respondents highlight that priorities are set for maintenance jobs, and that maintenance employees are assigned to job tasks based on their specialised knowledge and abilities. Although most organisations offer training for skills development, in this study only 22% of respondents were dissatisfied with the skill development within the organisation.

The online survey also confirms the majority of organisations to have safety policies and procedures for maintenance in place and are being effectively followed within organisations. Injuries usually happen during maintenance when the procedures and policies in place are not followed. Risk Assessment should initially be performed, to help identify the precautions that are necessary to carry out the work safely. Shutdowns and major repairs are planned and should be included in the annual organisational budget. A proactive approach to shutdowns helps to reduce maintenance costs.

5.2. Research Question

The author made use of different methods to obtain key findings to answer the research questions.

Question 1: What effects does the implementation of reliability management have on the quality of maintenance within the organisation?

The study assisted Company A to identify the effects of implementing reliability management to improve the company’s quality of maintenance. Based on the findings, the maintenance improvements should be achieved due to organisational learning. The study will assist the company to identify Company A deficiency with the reliability management processes and therefore rectify this to improve on the quality of maintenance and ensure that the plant experiences less downtime. It is essential for management to infuse quality and performance improvement initiatives in all aspects of production and maintenance. The reliability management system currently in place can be more efficient if advanced software is used. The organisation needs to look into adopting other functions within the CMMS, such as linking spares with the purchasing department and making use of a scoreboard. The company has no equipment spares control in place. Implementing the RCM analysis approach will assist the company in creating scheduled maintenance plans, which is an important aspect of an effective asset management program.

TQM is the instrument used to measure quality management and assess the plant's reliability. TQM requires all employees to participate in improving the company's processes, products, services and working culture. The maintenance department needs to implement a strategic plan to ensure maintenance measures or controls are performed. Equipment activities are measured by availability and operational reliability. The company's maintenance management is under-developed, and management feels they have no time to focus on planning because they fear to disrupt production. The maintenance manager must focus more on planning, scheduling and analysing maintenance, rather than reacting to solving problems. The maintenance manager needs to carry out proper maintenance problem analysis for failing equipment frequently. The day-to-day and decision-making activities tend to distract management from focusing on executing continuous improvement activities in maintenance. Management needs to be more involved to foster maintenance improvement programs.

Question 2: What are the costs associated with the maintenance engineering system and maintaining such a system?

Failure of CMMS implementation is a continuing problem and researching the appropriate maintenance management system for the company needs to be highly prioritised by management during the decision-making process. This assists management to evaluate the CMMS modules determining the costs and benefits. Company A did not invest in the full CMMS package, which is currently only used to record, manage, and communicate their day-to-day maintenance operations. The organisation downloaded the standard version of Cworks online, with the manual and there was no external training carried out to operate the software. The system can also provide reports that can be used to manage the organisation's resources, prepare key performance indicators (KPIs)/metrics to evaluate the effectiveness of current operations and make future organisational decisions. However, since the company did not invest in the advanced software, they do not have access to this function, and thus they cannot measure the KPI, thus making it challenging to set continuous improvement processes. Preventive maintenance requires management to implement a plan for the manpower and financial resources to assist better cost control.

The reliability management strategy is essential for achieving high levels of equipment reliability and maintainability and therefore resulting in plant availability. Reliability plays a key role in the cost-effectiveness of systems. Thus failing to perform maintenance to maintain the dependability of a system can be costly. The company has no in-house maintenance costs budget plan in place. As part of the maintenance strategy, the company outsource some of their maintenance activities such as servicing equipment, to minimise operating costs. The costs incurred by the organisation are frequently due to system downtime, cost of spares, repair equipment, personnel and the cost of warranty claims.

To achieve effective maintenance management life cycle costs (LCC) is a requirement. The concept of LCC is not well practised in many organisations, because their focus is on short-term cost reductions rather then what drives the costs. It is important for the maintenance department to consider LCC when selecting equipment. The right equipment might cost more, but the cost of ownership will be lower.

5.3 Achievement of the objective

From the study's problem statement, research objectives were formulated. The research objectives of this study were achieved by conducting the following:

- A case study on the company
- Interview with management
- Survey questionnaire with employees
- Online survey questionnaire

Reliability is a strategic initiative in improving plant productivity. Reliability management plays a significant role in the maintenance process, it influences production and directly affects maintenance costs. Company A implemented the CMMS to assist them in improving their maintenance. The company has successfully captured all the plant assets within the system, and there is scheduled maintenance in place, which assisted the company to perform preventive maintenance within the plant.

When referring to the online survey questionnaire, the participants agree to the fact that implementing a CMMS has helped improve their maintenance process and further enhance productivity.

To answer the research objectives, the following can be drawn from the study:

1. To determine the barriers to implementing a reliability management system.
Barriers to implementing a reliability management system are technical, economic, managerial, organisational and cultural environmental. However, without a plan or process to manage reliability and maintenance management systems, culture change is impossible, hindering continuous improvement. The proactive strategies for implementing a reliability management system become compromised because the organisation focus on keeping the plant running. Maintenance management's lack of involvement in tracking production losses and critical equipment costs leads to escalating costs, which in turn diminishes the most critical return opportunities. The condition of maintenance workshops and stores also pose a real barrier to efficient maintenance practices.

The study also identified the barriers to the implementation of maintenance systems in industries to be lack of top management support, lack of overall equipment effectiveness (OEE) measurement and lack of strategic planning. The following highlights the barriers:

- **Lack of top management support towards employees' skill development.** Employees who do not receive adequate training may have difficulty meeting performance requirements. Management needs to identify where employees' skills are lacking, and budget and implement a training plan. Skills training will reduce the cost associated with sending the equipment back to the supplier every time failure occurs, thus enabling the equipment to be maintained in-house. Companies investing in employees' skill development can reap the benefit of a motivated workforce, contributing to strengthening the growth of the company. Regardless of employees' qualifications, organisations should annually perform a skills audit to identify the skill gap. This will assist them in implementing a skills development plan for their employees to keep them up to speed with the industry trends and technological development.

- **Lack of strategic planning**. The company has a limited connection between maintenance strategy and business strategy; this can cause maintenance management to be ineffective and to acquire unnecessary costs. There is inadequate budgetary control in maintenance. Management becomes too involved in the day-to-day maintenance and has less time to spend on improving and strategising the maintenance process. There is insufficient practice in maintenance efficiency measurement and long-term planning. Management has no developed maintenance KPI process in place. Thus maintenance efficiency is not evaluated, and there is no set goal.

2. To establish possible causes that lead maintenance improvement initiatives failing to deliver expected results.

Implementing reliability management has helped the organisation to improve the quality of maintenance. The downfall is the fact that they are not entirely utilising the reliability management system. The organisation has implemented a preventive maintenance strategy, but the rate of reactive maintenance is not decreasing. The following issues were established to be causes leading maintenance improvement initiatives failing to deliver expected results:

- Management needs to understand how CMMS helps them to obtain metrics and reports that can improve their decision-making processes. For the CMMS to be successful, it has more to do with the attitude of the organisation rather than the quality of the software.

- Maintenance technicians are not aware of the usefulness of CMMS. However, it is important for the CMMS users to understand how the system will help their equipment to get prompt and effective maintenance. The maintenance technicians must view CMMS as a tool that will assist them in their daily tasks.

- The maintenance department only has a few procedures, which are currently not being followed. The study has helped to reveal that it is important to have procedures in place to save maintenance time and to ensure the correct maintenance is always carried out to ensure equipment availability and utilization. Management needs to focus on fixing the current process to improve their maintenance effectively.

- Operators usually choose to address the need to prevent breakdowns in production by creating extensive spare parts stockpiles. Unmonitored inventory purchases can lead to spare parts exceeding their shelf life and thus introducing a high probability of failure. The maintenance team should consider developing a well-structured inventory system to reduce waste and inefficiencies. Having an inventory management system in place will enable spares to be effectively managed and reduce premature failure of equipment within the plant.

- There is no annual physical inventory review of all parts in stock or to update them on the stock on hand reorder point. To run a great maintenance department, proper planning is essential to ensure that high priority jobs are evaluated. Thus, proper planning and scheduling will save execution time. It is always important for the team's scope of work to be noted and the required spare parts to be available before starting the job.

- Part of management feels that the CMMS implemented at present should be improved and that more planning is required. There is no structured long-term planning process in place to improve the quality and reduce the cost of maintenance.

- When management does not involve the employees when making critical decisions, they create a barrier with the employees. The employees often feel they are unimportant and are reluctant to participate when changes or improvements are implemented. This leads the employees to be demotivated to assist and improve the maintenance processes. Thus, it is important for management to involve employees when making decisions.

- A budget is provided monthly. Management does not have a structured process on which they manage their budget, but only ensure that they do not go over the allocated budget. The maintenance department does not keep records for purchased spares, and there is no tracking process in place. The general spares are bought as and when required. The budgeting processes are short-term projections and will have a negative effect on the organisation in future if not controlled and modified.

- The critical spares list is only documented in an excel document in the database and is not updated in the CMMS. Thus the work orders do not contain the critical spares required for the specific maintenance. Management does not conduct an economic analysis of each new item of equipment to determine the ROI.

- Management only has some working procedure in place, which the employees do not utilise. Although the procedures are made available, once employees feel they are familiar with fixing equipment they stop following the work procedures and take shortcuts, which leads to a safety issue. Moreover, the safety checklist is often omitted. Although employees have the skills to repair equipment, it is important for them to follow the procedures when they carry out a maintenance task.

- To achieve efficiency, manufacturing organisations need to treat maintenance as a strategic subject. Maintenance should be recognised as an integral part of the plant strategy by accounting its proper contribution to profits, productivity and quality (Maletic, et al., 2012). The central aspect of the maintenance strategy is to determine the maintenance objective, dependent on the business plan. The maintenance objective enables the organisation to evaluate the effectiveness of the proposed maintenance strategy succeeding implementation and assists in minimising indirect maintenance costs.

- However, maintenance techniques continue to change due to the increasing variety of equipment complexity and automation (Lee Cooke, 2003). Frequently, processing industries replace malfunctioning or dated equipment with the latest technology, rather than performing a critical evaluation of their maintenance plans. Replacement of equipment with new technology does not enable an inefficient maintenance program to be any more efficient. However, the goal of maintenance and reliability system is to deliver a proper balance of maintenance activities, primarily those aimed at identifying impending failures to allow for timely corrective actions.

- An organisation needs to examine first the scheduled maintenance activities currently being performed, to ensure a viable maintenance strategy (Armitage, 2015). It then needs to make sure that there is an appropriate balance of conditional inspections, preventive replacements, monitoring technology applications, and run-to-failure strategies based on observed assets behaviour.

- The organisation should consider being results-oriented because this approach improves equipment reliability performance, which drives manufacturing cost down. Whereas, organisations focusing solely on cutting maintenance costs may suffer the consequences of maintenance costs drastically increasing in the future, due to reliability decrease (Jonsson & Lesshamma, 1999).

- During the maintenance management implementation process, management needs to ensure that there are proper skill levels, proper work preparation, suitable tools and schedule within the department. These facilitate the maintenance management system's efficiency and help reduce direct costs incurred by unnecessary labour and maintenance resources which are not used continuously and just stored for several years (Márquez, et al., 2009; Salonen, 2009). The reduction of inventory buffers in the plant process put more pressure on the maintenance system. The practical approach to maintenance management within an organisation diminishes maintenance pressures.

3. To determine and eliminate the primary causes of plant downtime that negatively impact the production output.

Although downtime seems to be reduced by implementing CMMS, maintenance still poses a challenge within the company. The company has the potential for large production capacity, but due to the constant reactive maintenance performed the company is often led to the low end of the manufacturing scale, thus decreasing the company's competitiveness within the market. The main objective of the maintenance system remains to improve overall plant productivity and profitability.

Company A should develop and implement an effective reliability program plan to achieve an improved reliability process. Poor maintenance planning and record keeping has a negative effect on maintenance activities and thus leads to inefficient maintenance processes. Shutdowns have a serious impact on the plant's profitability and should be a major part of the annual organisational budget. Consequently, planned shutdowns should not consume the savings they can generate. Hence, effective shutdown management is critical for plant productivity and reduces the overall downtime costs. Unreliable equipment availability caused by excessive system downtime reduces production quality, increases inventory and leads to reduced plant performance (Ahuja & Khamba, 2008).

Capital assets are essential to the operational process, and the downtime of the assets needs to be minimised. Unavailability of the required spares usually causes extension of downtime. The downtime of capital assets immediately affects the primary processes. Thus, implementing planned maintenance on capital assets is vital (Von Petersdorf, 2013).

Planning is the most important advantage of preventative maintenance over less complex strategies. Unplanned, reactive maintenance consist of overhead costs that can be avoided during the planning process (Mobley, 2014). Maintenance employees should consider replacing parts which are worn or damaged to reduce the time spent on maintaining equipment. For this reason, effectively predicting the equipment preventive maintenance time-point is essential.

4. To establish the effects of the reliability management system on employee's performance and management's decision making.

Management has failed to implement the CMMS within maintenance successfully. First of all, they do not have a maintenance strategy in place to help guide them. Thus the implementation of the CMMS has had less effect on plant improvement. There are also no measures performed to monitor and control maintenance. There is no proper stock control process and storage to manage spares. Initially, management failed to conduct a study to assist them in determining the best suitable CMMS program for the organisation's maintenance department before implementation. They only considered the cost-effectiveness of the C-work software that is currently being used. Conducting this research assisted management to identify the pitfalls during the CMMS implementation phase and therefore this can further assist them to implement continuous improvements. Although performing preventive maintenance has helped keep the plant running and improved on the company's maintenance, the consequence of not using all the necessary capabilities incorporated in the software has led maintenance to experience drawbacks within the maintenance processes.

Management continues to realise the need to build its maintenance capability to ensure reliability and cost-effectiveness of its operation. However, for management to successfully improve the quality of maintenance by implementing reliability management, performance measurement remains a fundamental principle. Performance measurement is important because it identifies performance gaps between current and desired performance.

Reliability engineering assists in tracking production losses and extremely high maintenance cost of equipment. This allows management to make informed decisions to reduce those losses or high costs. Management achieves this by prioritising and focusing efforts on the most critical opportunities (Blanchard, 2016). However, the financial benefits of maintenance can be realised when planned maintenance is being practised (Lee Cooke, 2003). Important factors to consider during maintenance are to ensure: reliability is measured; standard operating procedures (SOP) are in place and followed; planned or scheduled maintenance is performed (Maletic, et al., 2012).

High reliability and availability of well-maintained equipment enhance the morale of personnel, whereas constant equipment breakdowns can be seriously frustrating (Lee Cooke, 2003). Although investments are made on maintenance to have a favourable effect on unit costs, production still takes the credit. These become quite a challenge for the maintenance employees because of the expected increase in productivity and trying to gain more by reducing the very same maintenance time that produced the advantage.

5. To determine the extent to which reliability measures performed on equipment's life-cycle assist to achieve reliability maintenance goals.

The literature study acknowledges worldwide best practices of maintenance management experience, which enhances the plant performance. However, full reliability management cannot happen if CMMS is not fully operational in Company A, which will be measured by productivity improvement. Proper maintenance management will help any organisation like Company A in planning, scheduling, managing work requirements and maintenance tasks that are critical for production. Maintenance management monitors the progress of corrective and preventive maintenance activities to make timely decisions on available resources, such as man-hours. Daily, recurring, preventive and predictive maintenance work can, therefore, be enhanced, resulting in improved operational performance.

Maintenance metrics and benchmarking of industrial operations are conducted by maintenance management to evaluate the effectiveness of the current maintenance strategy, for future improvement purposes. The KPI measures the level and rate of achieving the objective. It can also be used to measure the effectiveness of the changes or actions taken or to determine if they are showing any improvements. Typical key performance indicators for manufacturing include operating cost; asset availability, lost time injuries, number of environmental incidents, OEE and asset utilisation.

6. To suggest recommendations on how to improve the quality of maintenance through effective reliability management.

Possible improvement recommendations will be provided based on the implemented maintenance process results obtained from previous chapters in the study.

Management should consider the following weighting process to determine the KPI; usage of consumption; the cost of failure or loss of production; reliability; and availability of equipment in the market.

6.1. Due to the quick development of technologies and reliability maintenance importance within an organisation, it is important to ensure that proper maintenance is performed to ensure the production rate is not negatively affected by constant preventable breakdowns. Management needs to adopt employee skills and abilities to changing requirements continually. Management is currently faced with ongoing challenges when it comes to maintenance employees' effectiveness, because of failure to advance skills and competences levels. Management needs to implement a training and development schedule for employees, to ensure they are better prepared to assist the organisation to achieve their maintenance goals. This will also ensure that the employees are more productive and require less supervision.

Organisations are exposed to changes, which do not only require updates and upgrades of technology, processes, and procedures within the organisation but also changes for employees working in that organisation. Management can achieve this by performing a training needs analysis (TNA). A TNA is an assessment of needs for employee development within the organisation. It considers the skills, knowledge and behaviours that employees need, and how to develop them effectively.

The organisational TNA is ideally undertaken in 3 levels:

- Organisational level – Involves the review of the organisation's strategic and operational plans by performing an organisational SWOT analysis. The SWOT is a tool that identifies and presents the strengths, weaknesses, opportunities and threats facing an organisation.
- Team/departmental level – Involves reviewing the necessary skills needs within the team to accomplish the team's objectives. The analysis considers both the needs of individuals and also anything that can help the team to work together more effectively.
- Individual-level - Appraisal and supervision meetings allow individuals to reflect on their own learning needs about their work objectives.

For the TNA to be a success, it is important for the organisation to implement:

- A strategic and organisational plan
- An appraisal system
- All employees having an up to date job description with written objectives
- A competency framework in place
- A training strategy
- Formalizing the organisational processes

The outcomes of the organisation's TNA should result in a learning and development plan, which is linked to organisational, team and individual objectives.

6.2. Management needs to implement an approach in which reliability personnel monitor critical equipment to predict potential failures or efficiency loss. The organisation should also implement a checklist of major and minor task requirements during shut-down and planned maintenance. The organisation also needs to implement cost management and execution performance reporting methods.

6.3. Maintenance needs to focus on sustainable reliability improvements. Sustainable reliability improvements occur when maintenance chase after equipment failure events, ahead of their next occurrences. To achieve this, the maintenance team need to monitor equipment during operation, maintain safe practices doing so and accurately document the results. This will assist them in establishing a failure trend. Instead of operators and maintenance team waiting for the equipment to fail, periodic predictive tasks to check assets issues is a necessity.

6.4. The reliability system currently implemented needs to be up-scaled so that more information can be captured to determine the KPI's. Increased productivity can be obtained by making full use of the reliability program (Cworks), as this will reduce the cost of massive spare expenditures and labour hours. Management needs to establish the CMMS benchmarking system that will be effective for the organisation and also determine the scoreboard for maintenance operations.

6.5. The CMMS should be linked with purchasing and stores. Management will need to employ and train someone who will be responsible at the stores and update used spares. Spare parts management is a potential area that could increase the organisation's productivity. Thus, it is important for the maintenance department to execute logistics planning and the management of spares process, to save the company money.

6.6. The organisation should perform internal maintenance audits to ensure they comply with the standards. Management should ensure planned meetings conducted on a regular basis, which involve the rest of the maintenance team so that they are well informed of the updated schedules and improvements being implemented.

6.7. The shutdown should be pre-planned and scheduled. Communication between management and employees should be maintained before, during and after shutdown. Employees should ensure the compilation and validation of worklists and individual job planning.

6.8. The company has a large production capacity and if they can look into improving the maintenance processes and implementing KPI's they can even look into expanding their production.

6.9. The organisation has to perform a skills audit to identify the skill gap annually. This will assist the maintenance department to implement a skills development plan for their employees to keep them up to speed with the industry trends and technological development.

6.10. Management should establish a reward system for employees who follow the correct process. This will ensure employees carry out the maintenance tasks correctly and automatically motivate employees to perform better on their task.

5.4 Critique of research methodology

The approach followed in the research study was a mixed method approach which comprised both qualitative and quantitative methods. The qualitative approach was performed by conducting a literature review, observing the organization's maintenance processes and performing a gap analysis. The quantitative approach included conducting surveys to collect data in the company and other related companies to establish the effects the reliability management system has on maintenance. The author analysed the collected data to draw a conclusion.

The research approach used was effective, although the author feels that the research could have yielded better results if the author had carried out case studies in two or three similar organisations and compared their maintenance systems. The research approach used does answer the research questions on the effect of implementing reliability management. However, the value of the cost associated with maintenance had to be limited to Company A only. The author thus performed a case study at one company and validated the study by further performing an online survey to collect data from other organisations.

From the conclusion, the research questions seem to be answered. The study identified barriers affecting the quality of maintenance at Company A and based on the findings; the maintenance improvements will hopefully be achieved due to organisational learning. The study will assist the company to identify their deficiency with the reliability management processes and therefore rectify it to improve on the quality of maintenance and ensure that the plant experiences less downtime.

5.5 Research contribution

The research will contribute to available knowledge because it identifies the effects of implementing reliability management and barriers that can prevent a company from improving the quality of maintenance.

5.6 Limitations of the study

The study is limited to reliability management and the necessary improvements required in achieving quality maintenance within production plant industries. A limited period of four months was provided to receive the response on the questionnaire, distributed to individuals working in a maintenance environment in organisations within South Africa. The author could not focus on the financial implications of maintenance, because the research was based on one organisation and they did not have a maintenance-focused budget.

The above study limitations should be taken into consideration when drawing conclusions from the study outcome.

5.7 Recommendation for future study

Based on the findings of this study, it is concluded that future research could broaden the investigation to identify supplementary complex measures of achieving quality maintenance within production plants. Moreover, sample size should be expanded to a larger group and compared to increase the generalisability of the results.

The research was limited to Company A, and further research can be conducted by analysing several companies and comparing their quality of maintenance. Further research can also be carried out by allowing a larger population to complete the online survey.

5.8 Summary

This concluding chapter has focused on making practical and appropriate recommendations for the successful improvement of maintenance management.

The effective implementation of reliability management in various organisations was identified through an analysis of the responses to the questionnaires. The suggestions made for each objective are essential for the successful implementation of reliability management. Furthermore, the recommendations made in this chapter present a framework on which a full action plan can be developed for an improved maintenance management system.

The study also suggested how it was possible to evaluate the nature and scope of reliability management system implementation, based on the organisational framework for employees at Company A. It is believed that the performance evaluation of the maintenance process is critical for the long term value creation and economic viability of the organization. Minimizing downtime should be performed in such a way that it has no negative impact on product quality, employee morale or jeopardizes a longer-term strategy of increasing the proportion of preventive/reactive maintenance.

This research has contributed to both the theory and practice of plant maintenance and can be used as a point of departure for further research directed at improving the maintenance system by implementing a reliability management system. In a dynamic world, however, no research can ever claim to be the last word on a specific topic. In this regard, areas for further research have been identified, and it is hoped that other students will take these up in the future.

Being human inherently implies striving for something better. History records this phenomenon in detail throughout the ages. The philosophy and principles of reliability maintenance management provide a valuable tool in the quest for institutional excellence. This thesis attempted to contribute, in general, to the understanding of improving the quality of maintenance through the implementation of reliability management and how this is to be achieved in Company A. This research is completed in the trust that the findings recorded here and the recommendations made will be useful.

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7 Appendices

7.1 Employee Survey

Questionnaire

This questionnaire is design for the purpose of the maintenance research, conducted to obtain data form maintenance and operating department

Mark the applicable answer with a cross (X)

Section A

1. Department:

Maintenance	Operating

2. Position:

Engineer	Technician	Operator	Assistance	Others

If others specify: ……………………………………………………………

3. Educational background:

University	College	Matric	No Matric

4. How long have you worked for the organization? ……… Years

<u>Section B</u>

1. Performance of CMMS

Maintenance and Operating Employees (only)						
		1	**2**	**3**	**4**	**5**
Q-No.	**How much do you agree or disagree with:**	**Strongly Disagree**	**Disagree**	**Unsure**	**Agree**	**Strongly Disagree**
1	Is RCM considered when equipment failure could cause injuries, the equipment is critical or has high downtime cost?					
2	Do you regard maintenance process as effective, with regards to plant availability?					
3	Do you have a maintenance schedule?					
4	Is there a review of slow moving items to see if they belong in stock?					
5	Is the CMMS used to make orders?					

2. Skill Development & Communication

Maintenance and Operating Employees (only)						
		1	**2**	**3**	**4**	**5**
Q-No.	**How much do you agree or disagree with:**	**Strongly Disagree**	**Disagree**	**Unsure**	**Agree**	**Strongly Agree**
1	Is the competency of maintenance employees satisfactory?					
2	Are skills & development training provided to employees?					
3	Is there regular communication between management and employees involvement with CMMS?					
4	Does management conduct meetings with employees to set priorities?					
5	Are operators trained to do routine maintenance?					

3. Work Practice

Maintenance and Operating Employees (only)						
	How much do you agree or disagree with:	1	2	3	4	5
Q-No.		Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
1	Do you support the implementation of Reliability Management?					
2	Do you always work per work order?					
3	Are all repairs classified e.g. corrective, routine, breakdown, preventive maintenance etc.?					
4	Are work orders costed for labour, parts and other cost?					
5	When deficiencies are found by inspection, are they written up as corrective work and completed in a reasonable time?					
6	Does repeated failures automatically trigger and investigation to find the root cause to correct it?					
7	Are the resources identified (labour, materials, tools, machine access and permissions) before a job is scheduled?					
8	Does the maintenance schedule consist of jobs whose resources are in-house?					

Comments

Thank you...

7.2 Online Survey

7.2.1 Survey letter

Dear Madam/Sir

You are hereby invited to participate in a research I am currently conducting for my Masters dissertation. This research is titled 'Improving the Quality of Maintenance through Reliability Management'. The main objective of the study is to evaluate the effects Reliability Management implementation has on improving the quality of maintenance within an organization.

I understand that you have a busy schedule. The survey will only take about 7minutes of your time to complete.

Please click on the link below to complete the questionnaire:

https://www.surveymonkey.com/r/6HZFR76

Your completed questionnaire is anonymous and will not ask for your name or any information that can identify you personally.

Your participation in the survey is much appreciated.

Thank you!

Yours Sincerely,

Fulufhelo Munzhelele

7.2.2 Survey Questionnaire

Survey Questionnaire

The purpose of this survey is to conduct a research to determine the effectiveness of maintenance in various plant organizations for the fulfilment of a Masters minor dissertation. Please complete the questionnaire, by reading each statement carefully and select the most applicable to your organization. All questions are multiple choice question and will only take +- 7 mins of your time to complete.

Department Identification

1. What department do you work in?

- Maintenance
- Operation
- Production
- Other (please specify)

2. Which of the following best describes your current job level?

- Owner/Executive/C-Level
- Senior Management
- Middle Management
- Intermediate
- Entry Level
- Other (please specify)

3. Which process best describes your working environment?

- Chemical plant
- Power plant
- Food
- Oil refineries
- Mineral processing
- Waste-water treatment
- Other (please specify)

Survey Questionnaire

Computerized Maintenance Management System (CMMS)

4. Does your organization use a computerized system (CMMS) for maintenance activities?

- Yes
- No

5. Selecting the right Computerized Maintenance Management System (CMMS) is an important business decision, which may require comparing different software before making a purchasing decision. This can be challenging and time consuming.

Which of the following approach, if any influenced the organization to select their CMMS package?

- [ ] CMMS package/ Annual subscription cost
- [ ] CMMS multiple functionality/ capability
- [ ] CMMS implementation process and support provided
- [ ] Referral/ Past experience
- [ ] Other (please specify)

6. How often does your organization use CMMS to assist them to keep track of equipment and inventory in stores?

- Always
- Almost always
- Sometimes
- Rarely
- Never

Survey Questionnaire

Maintenance Management

7. It is important to always have a process in place to measure and control maintenance.

Does your organization have a maintenance strategic plan in place?

- Strongly agree
- Agree
- Unsure
- Disagree
- Strongly disagree

8. How often does management set goals or targets for maintenance levels for future performance?

- Always
- Almost always
- Sometimes
- Rarely
- Never

9. How often does your organization track its total maintenance expenditures and costs?

- Always
- Almost always
- Sometimes
- Rarely
- Never

10. Do you agree or disagree that the overall structure of your maintenance department is effective?

- Strongly agree
- Agree
- Undecided
- Disagree
- Strongly disagree

11. On a scale from 1(extremely low regard) to 7(extremely high regard), please rate the maintenance process effectiveness with regards to plant availability?

1	2	3	4	5	6	7
○	○	○	○	○	○	○

12. Does your organization track machine downtime as a measure of efficiency?

- Strongly agree
- Agree
- Undecided
- Disagree
- Strongly disagree

13. How often does your organization track and record the time maintenance spend on jobs?

- Always
- Almost always
- Sometimes
- Rarely
- Never

14. Does your maintenance organization compare itself (benchmarking) against other maintenance organizations to see how well it is operating?

- Strongly agree
- Agree
- Undecided
- Disagree
- Strongly disagree

15. How involved are the maintenance employees in setting the company's objectives?

- Extremely involved
- Very involved
- Moderately involved
- Slightly involved
- Not at all involved

Survey Questionnaire

Preventive maintenance

16. How often does your organization use work orders for maintenance work activities?

- Always
- Almost always
- Sometimes
- Rarely
- Never

17. Is Reliability Centred maintenance (RCM) considered when equipment failures could cause injuries, the equipment is critical or has high downtime costs?

- Strongly agree
- Agree
- Undecided
- Disagree
- Strongly disagree

18. Generally speaking, would you say that the maintenance employees are well skilled to perform their jobs?

- Strongly agree
- Agree
- Uncertain
- Disagree
- Strongly disagree

19. Organizations should annually perform a skills audit in order to identify the skill gap. To assist them on implementing a skills development plan for their employees, to keep them up to speed with the industry trends and technological development.

Overall, are you satisfied or dissatisfied with the training your organization offers, for skills development?

- Extremely satisfied
- Satisfied
- Undecided
- Dissatisfied
- Extremely dissatisfied

20. How often do operators help with minor PMs such as cleaning, lubricating, adjusting and inspecting?

- Always
- Almost always
- Sometimes
- Rarely
- Never

21. For effective maintenance management the organization should consider (Life Cycle Costs) LCC when selecting equipment. The right equipment might cost more, but cost of ownership will be lower.

Overall, would you say that the organization keeps track of the LCC to maintain equipment?

- Strongly agree
- Agree
- Undecided
- Disagree
- Strongly disagree

22. The organization has safety policies and procedures for maintenance?

- Strongly agree
- Agree
- Undecided
- Disagree
- Strongly disagree

23. The maintenance employees follow the safety policies and procedures, while performing maintenance?

- Strongly agree
- Agree
- Undecided
- Disagree
- Strongly disagree

Survey Questionnaire

Planning and Scheduling

24. Are priorities set for maintenance job tasks?

- ◯ Strongly agree
- ◯ Agree
- ◯ Undecided
- ◯ Disagree
- ◯ Strongly disagree

25. Are maintenance employees assigned to job tasks based on their specialized knowledge and abilities?

- ◯ Always
- ◯ Almost always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

26. Does your organization have a maintenance planner responsible for planning and preparing scheduled maintenance such as major repairs and shutdowns?

- ◯ Strongly agree
- ◯ Agree
- ◯ Undecided
- ◯ Disagree
- ◯ Strongly disagree

27. On a scale from 1(extremely low) to 7 (extremely high). How would you rate the level of the organization's outsourced maintenance to contractors?

1	2	3	4	5	6	7
◯	◯	◯	◯	◯	◯	◯

28. Shutdowns and major repairs are planned in advance?

- ◯ Always
- ◯ Almost always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

29. How likely are inventory parts available when needed?

- Extremely likely
- Very likely
- Somewhat likely
- Not so likely
- Not at all likely

7.2.3 Online Survey Results

Description:

The accompanying pdf document shows the online survey results.

File name:

Online _survey_data.xls

7.3 Work orders Raw Data

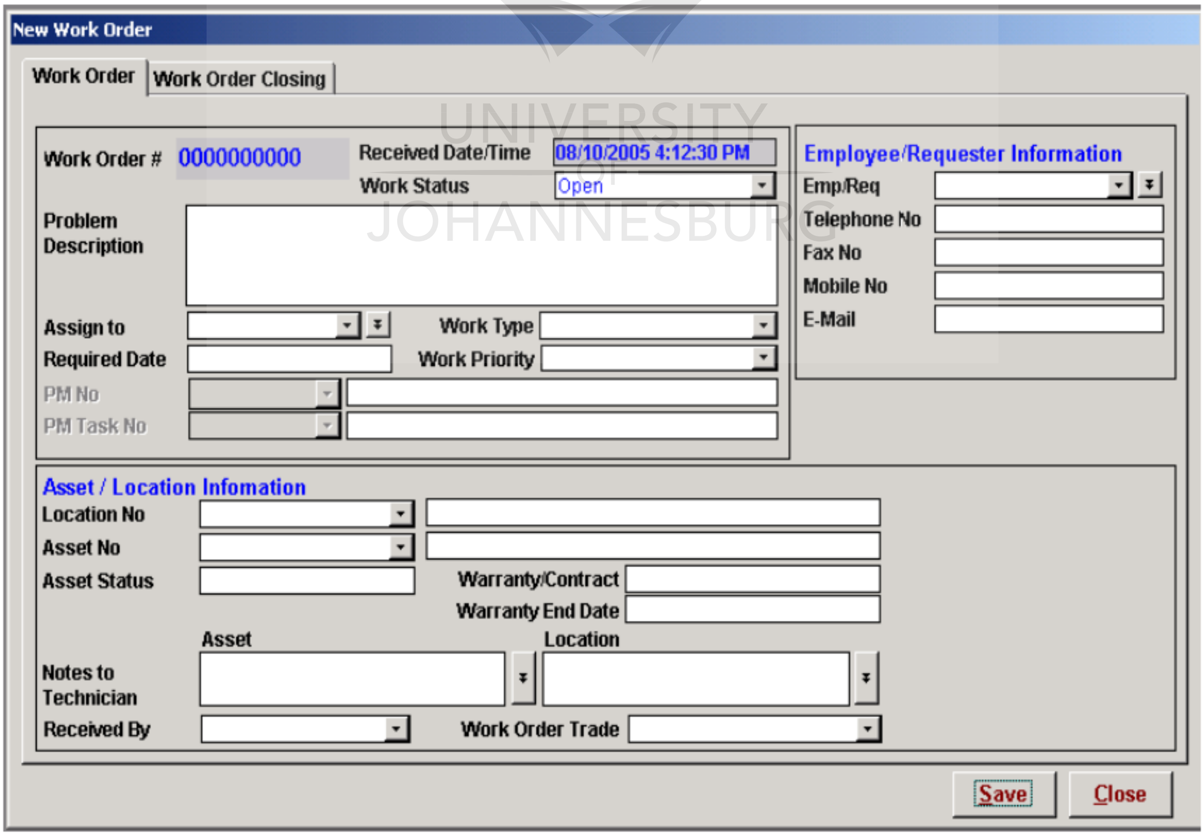
Description:

The accompanying pdf document displays the workorders raw data.

File name:

Workorders.xlsx

7.3.1 Work order Template



7.4 Maintenance Costs

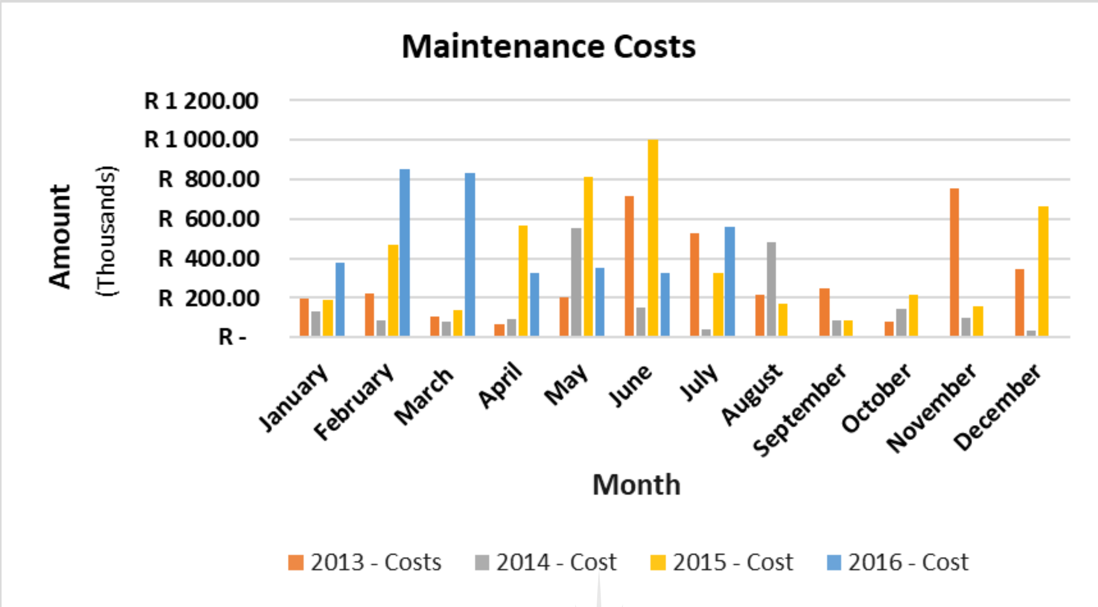


Figure 7.1: Overall Maintenance Costs

Table 3.1.2.1: Maintenance Costs - 2013

Months	Maint & Repair	New Assets	2013 - Costs
January	R99k	R96k	R195k
February	R193k	R30k	R223k
March	R52k	R56k	R108k
April	R60k	R4k	R65k
May	R34k	R171k	R204k
June	R302k	R412k	R714k
July	R78k	R452k	R530k
August	R68k	R145k	R213k
September	R35k	R215k	R250k
October	R41k	R37k	R77k
November	R22k	R732k	R754k
December	R23k	R324k	R347k

Total/year	R3 681k

Table 3.1.2.2: Maintenance Cost - 2014

Months	Maint & Repair	New Assets	2014 - Cost
January	R37k	R91k	R128k
February	R78k	R5k	R83k
March	R74k	R3k	R77k
April	R91k	R1k	R92k
May	R65k	R491k	R555k
June	R148k	-	R148k
July	R41k	-	R41k
August	R121k	R360k	R482k
September	R64k	R21k	R85k
October	R141k	-	R141k
November	R95k	-	R95k
December	R35k	-	R35k

Total/year **R1 962k**

Table 3.1.2.3: Maintenance Costs - 2015

Months	Maint & Repair	New Assets	2015 - Cost
January	R73k	R115k	R188k
February	R96k	R372k	R468k
March	R133k	R6k	R139k
April	R108k	R457k	R564k
May	R28k	R782k	R810k
June	R326k	R676k	R1002k
July	R176k	R149k	R325k
August	R42k	R126k	R167k
September	R65k	R20k	R85k
October	R119k	R99k	R218k
November	R64k	R90k	R155k
December	R85k	R581k	R666k

Total/year R4 787k

Table 3.1.2.4: Maintenance Costs - 2016

Months	Maint & Repair	New Assets	2016 - Cost
January	R44k	R332k	R376k
February	R242k	R611k	R854k
March	R108k	R727k	R834k
April	R134k	R190k	R324k
May	R84k	R271k	R355k
June	R177k	R152k	R329k
July	R49k	R510k	R560k
August	-	-	-
September	-	-	-
October	-	-	-
November	-	-	-
December	-	-	-

Total/year	R3 631k

7.5 Product Manufactured

	2009							
Month	**Product Mnfctrd Tons**	**Elect. Max. Demand KVA**	**Elect. Usage KWh**	**Diesel Usage Litres**	**Elect. Rands**	**Elect. R/Ton**	**Elect. KWh / Ton**	**Diesel Litres / Ton**
Jan	5658	1441	760k	17361	245k	43	134	3.07
Feb	6573	1464	809k	14411	258k	39	123	2.19
Mar	5425	1349	722k	16887	233k	43	133	3.11
Apr	5094	1468	658k	10759	218k	43	129	2.11
May	4755	1326	634k	13734	208k	44	133	2.89
Jun	4824	1615	626k	16995	298k	62	130	3.52
Jul	4824	1420	688k	15749	424k	88	143	3.26
Aug	5743	1365	715k	13509	427k	74	124	2.35
Sep	5234	1534	687k	14756	304k	58	131	2.82
Oct	5376	1595	714k	18523	405k	75	133	3.45
Nov	6476	1563	815k	17547	349k	54	126	2.71
Dec	5008	1403	689k	18082	302k	60	138	3.61
Total	64991	1462	8517k	188313	3670k	56	131	2.90

	2010							
Month	**Product Mnfctrd Tons**	**Elect. Max. Demand KVA**	**Elect. Usage KWh**	**Diesel Usage Litres**	**Elect. Rands**	**Elect. R/Ton**	**Elect. KWh / Ton**	**Diesel Litres / Ton**
Jan	5712	1322	739k	7530	316k	55	129	1.32
Feb	5039	1375	654k	6834	288k	57	130	1.36
Mar	5185	1316	651k	6762	286k	55	125	1.30
Apr	4545	1227	588k	20076	262k	58	129	4.42
May	3632	1057	477k	19627	217k	60	131	5.40
Jun	3864	1152	497k	22692	316k	82	129	5.87
Jul	5863	1236	699k	27048	576k	98	119	4.61
Aug	6011	1220	741k	14029	596k	99	123	2.33
Sep	5745	1283	696k	5663	389k	68	121	0.99
Oct	5851	1314	740k	5700	407k	70	127	0.97
Nov	5822	1376	730k	2051	407k	70	125	0.35
Dec	3502	1247	595k	6143	332k	95	170	1.75
Total	60770	1260	7806k	144155	4393k	72	128	2.37

	2011							
Month	**Product Mnfctrd Tons**	**Elect. Max. Demand KVA**	**Elect. Usage KWh**	**Diesel Usage Litres**	**Elect. Rands**	**Elect. R/Ton**	**Elect. KWh / Ton**	**Diesel Litres / Ton**
Jan	6211	1430	794k	2157	428k	69	128	0.35
Feb	5424	1357	720k	7964	397k	73	133	1.47
Mar	4453	1242	572k	6184	328k	74	129	1.39
Apr	4219	1271	507k	3861	296k	70	120	0.92
May	4766	1205	587k	9373	333k	70	123	1.97
Jun	4364	1197	529k	7650	448k	103	121	1.75
Jul	5149	1246	587k	8118	590k	114	114	1.58
Aug	4781	1002	547k	5017	556k	116	115	1.05
Sep	5733	1184	602k	3898	412k	72	105	0.68
Oct	5550	1143	606k	4376	410k	74	109	0.79
Nov	6141	1169	656k	7159	443k	72	107	1.17
Dec	3849	1321	470k	3949	343k	89	122	1.03
Total	60640	1231	7178k	69706	4983k	82	118	1.15

	2012							
Month	**Product Mnfctrd Tons**	**Elect. Max. Demand KVA**	**Elect. Usage KWh**	**Diesel Usage Litres**	**Elect. Rands**	**Elect. R/Ton**	**Elect. KWh / Ton**	**Diesel Litres / Ton**
Jan	6335	1215	680k	3462	455k	72	107	0.55
Feb	5997	1197	622k	3814	421k	70	104	0.64
Mar	6396	1201	695k	4142	461k	72	109	0.65
Apr	5189	1145	545k	5232	374k	72	105	1.01
May	4896	1100	520k	5421	361k	74	106	1.11
Jun	6064	1268	642k	4770	612k	101	106	0.79
Jul	5751	1010	564k	7153	644k	112	98	1.24
Aug	5415	1033	550k	5829	631k	117	102	1.08
Sep	6891	1155	638k	3146	481k	70	93	0.46
Oct	5875	1089	568k	3554	440k	75	97	0.60
Nov	5754	1078	557k	3739	433k	75	97	0.65
Dec	4312	1070	458k	2354	365k	85	106	0.55
Total	68876	1130	7040k	52616	5678k	82	102	0.76

	2013							
Month	**Product Mnfctrd Tons**	**Elect. Max. Demand KVA**	**Elect. Usage KWh**	**Diesel Usage Litres**	**Elect. Rands**	**Elect. R/Ton**	**Elect. KWh / Ton**	**Diesel Litres / Ton**
Jan	5243	1097	551k	4527	428k	82	105	0.86
Feb	5555	1021	551k	5500	426k	77	99	0.99
Mar	5412	1108	551k	10134	421k	78	102	1.87
Apr	6077	1019	565k	3310	430k	71	93	0.54
May	6132	963	535k	6961	410k	67	87	1.14
Jun	3981	901	388k	12358	445k	112	98	3.10
Jul	6658	931	542k	4863	664k	100	81	0.73
Aug	5310	964	474k	7015	583k	110	89	1.32
Sep	6095	935	532k	3498	432k	71	87	0.57
Oct	6202	998	557k	3106	454k	73	90	0.50
Nov	7510	1202	661k	2610	534k	71	88	0.35
Dec	4756	1079	458k	3866	375k	79	96	0.81
Total	68931	1018	6365k	67748	5602k	81	92	0.98

	2014							
Month	**Product Mnfctrd Tons**	**Elect. Max. Demand KVA**	**Elect. Usage KWh**	**Diesel Usage Litres**	**Elect. Rands**	**Elect. R/Ton**	**Elect. KWh / Ton**	**Diesel Litres / Ton**
Jan	6494	961	572k	2087	398k	61	88	0.32
Feb	5760	1093	509k	3449	426k	74	88	0.60
Mar	5881	1006	548k	2863	446k	76	93	0.49
Apr	4983	1092	440k	11378	379k	76	88	2.28
May	6227	1011	572k	10912	460k	74	92	1.75
Jun	5409	1036	469k	5484	570k	105	87	1.01
Jul	5290	980	484k	5679	650k	123	92	1.07
Aug	5889	959	503k	8111	653k	111	85	1.38
Sep	6506	1085	573k	5017	502k	77	88	0.77
Oct	8223	1267	752k	4138	641k	78	91	0.50
Nov	7275	1255	670k	5309	574k	79	92	0.73
Dec	3487	1232	378k	5226	370k	106	108	1.50
Total	71423	1081	6471k	69653	6068k	85	91	0.98

	2015							
Month	Product Mnfctrd Tons	Elect. Max. Demand KVA	Elect. Usage KWh	Diesel Usage Litres	Elect. Rands	Elect. R/Ton	Elect. KWh / Ton	Diesel Litres / Ton
Jan	5788	1176	575k	3324	507k	88	99	0.57
Feb	6235	1096	586k	2776	513k	82	94	0.45
Mar	5789	1087	598k	4254	521k	90	103	0.73
Apr	4498	1040	436k	6976	399k	89	97	1.55
May	6318	1035	571k	4196	495k	78	90	0.66
Jun	5848	1137	540k	4930	712k	122	92	0.84
Jul	7629	1174	639k	5049	944k	124	84	0.66
Aug	7804	1118	653k	3997	912k	117	84	0.51
Sep	7811	1251	670k	12186	649k	83	86	1.56
Oct	8420	1294	728k	7445	701k	83	86	0.88
Nov	8334	1199	686k	3120	659k	79	82	0.37
Dec	5698	1255	506k	4477	514k	90	89	0.79
Total	80171	1155	7187k	62730	7525k	94	90	0.78

	2016							
Month	Product Mnfctrd Tons	Elect. Max. Demand KVA	Elect. Usage KWh	Diesel Usage Litres	Elect. Rands	Elect. R/Ton	Elect. KWh / Ton	Diesel Litres / Ton
Jan	7217	1127	620k	2449	604k	84	86	0.34
Feb	5821	1092	504k	3171	513k	88	87	0.54
Mar	6827	1235	614k	7933	603k	88	90	1.16
Apr	8107	1161	671k	3386	646k	80	83	0.42
May	8327	1170	669k	8390	639k	77	80	1.01
Jun	6732	1092	547k	7764	798k	119	81	1.15
Jul	7316	946	541k	9637	842k	115	74	1.32
Aug								
Sep								
Oct								
Nov								
Dec								
Total	50346		4167k	42730	4644k	92	83	0.85

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017
Product Mnf. Ton	65k	61k	61k	69k	69k	71k	80k	50k	
Elect. KWh/Ton	131.1	128.4	118.4	102.2	92.3	90.6	89.6	82.8	
Elect. Rands	3670k	4393k	4983k	5678k	5602k	6068k	7525k	4644k	
Elect. R/Ton	R 56.47	R 72.29	R 82.17	R 82.44	R 81.27	R 84.97	R 93.86	R 92.24	
Ave. Max Demand KVA	1462	1260	1231	1130	1018	1081	1155		
Diesel L/Ton	2.90	2.37	1.15	0.76	0.98	0.975	0.78	0.85	

7.6 Preventive Maintenance Schedule

Description:

The accompanying pdf document illustrates the organization’s annual preventive maintenance schedule.

File name:

Annual_PM_Schedule.pdf

7.7 Critical Spare List

Line								Equipment	Detail	Supplier	Model	Stock / Spare	Required	On Order		Expected Delivery	Comments
1	2	3	Cont.Neut.	RM	BT	FP	Utilities							Yes / No	Quantity		
	X	X						Bare shaft	Blower	Airgas	GM150	1					
	X	X						Motor	Blower	Zest	300 Kw	1					
X								Bare shaft	Blower	Airgas	GM90S	0					Possibility of using original blower.
X								Motor	Blower	Zest	132 Kw	1					
	X	X						Heat Exchanger	Regen Steam	Faco	1st stage P40-16 VA-8R-27T-850-2.5Pa Fe/Al	1	1				
	X	X						Heat Exchanger	Regen Water	Faco	2nd stage P40-16 AR-6R-27T-850-3.0Pa SS/Al	1	1				
	X	X						Heat Exchanger	Air Cooler Water	Faco	1st stage P40-16 AR 8R-26T-660-2.0Pa Cu/Al	1					
	X	X						Heat Exchanger	Air Cooler Glycole	Faco	2nd stage P40-16 AR 16R-26T-660-2.0Pa Cu/Al	1					
X								Heat Exchanger	Regen Steam	Faco	1st stage P60-16 VA 9R-11T-660A-2.0Pa Fe/Al	1					
X								Heat Exchanger	Regen Water	Faco	2nd stage P60-16 AR 7R-11T-660A-2.0Pa Cu/Al	1					
		X						Heat Exchanger	Waste Heat 1st stage	Faco	1st stage P40-16 AR 12R-27T-1080A-0.0Pa Fe	1					
		X						Heat Exchanger	Waste Heat 2nd stage	Faco	2nd stage P60-21 AR 10R-18T-1080A-2.5Pa Fe/Fe	1					
X								Heat Exchanger	Air Cooler Water	Faco	1st stage P60-16 AR 8R-13T-480A-2.0Pa Cu/Al	1					
X								Heat Exchanger	Air Cooler Glycole	Faco	2nd stage P60-16 AR 24R-13T-480A-2.0Pa Cu/Al	1					
X						X		Pump	Various	Denorco	R22 Rotoflo	1					
	X	X						Pump	Various	Denorco	R32 Rotoflo	1					
					X	X		Pump	Various	Denorco	R42 Rotoflo	1					
						X		Pump	Various	D	R42 Rotoflo	1					
			X					Pump	Continuos Netraliser	Denorco	R43 Rotoflo	2					
X	X	X						Pump	Homogenising pump	Prochem	MT12	1					
X	X	X						Pump	Water Dosing	Seko	TPG803 / APG803	1					
	X	X						Pump	Lauric Acid Dosing	Seko	PS1DO25C21A4000	1					
	X							Pump	LAB Dosing	Seko	1AB356210A1200	0					
		X						Pump	LAB Dosing	Seko	PS1DO38C21B4000	2					
			X					Pump	Acid Dosing	Seko	ACL602	0	1				
							X	Pump	Hot Oil Circulation	Rapid	NTT32-160	1					
							X	Pump	Sulpher Offloading	Rapid		0	1				
X								Pump	Sulpher Feed			1					
	X	X						Pump	Sulpher Feed		DOXA M/80Z x 25	2					
							X	Pump	Diesel Boiler / Truck	Meter Systems	E120 380volt	1					
			X					Pump	Caustic Dosing	Prochem	Oberdorfer Chemsteel S20716CJ	1					
			X					Pump	Water Dosing	Prochem	Oberdorfer Chemsteel S41716CJ	1					
	X	X						Sight Glass	LAB Feed / Cyclones	Glass Blowing Ind.	300mm 80od 5Tk	3					
X								Sight Glass	Reactor	Glass Blowing Ind.	500mm80od 5Tk	2					
	X	X						Sight Glass	Reactor	Glass Blowing Ind.	500mm 110od 5Tk	2					
	X	X						O-Ring	Reactor	Ballestra	Fluoraz 797 Diam.35X5.5MM (set of 120)	1					
	X	X						Nozzles	Reactor	Ballestra		5					
	X	X						Nuts	Reactor	Ballestra		10					
X								Controler	ESP	Castlet		1					
X								Cable	ESP	Geecom	Single core high tension cable	1					
X								V-Belts	Blower	BMG	XPB2650 Gates Quadpower (set of 6)	1					
	X	X						V-Belts	Blower	BMG	XPC3550 Gates Quadpower (set of 7)	2					
	X							V-Belts	After Cooler Fan	BMG	XPC3750 Gates Quadpower (set of 3)	2					
		X						V-Belts	After Cooler Fan	BMG	XPB3800 Gates Quadpower (set of 4)	1					

Line								Equipment	Detail	Supplier	Model	Stock / Spare	Required	On Order		Expected Delivery	Comments
1	2	3	Cont.Neut.	RM	BT	FP	Utilities							Yes / No	Quantity		
	X	X						V-Belts	Regen & Converter Fans	BMG	XPA2650 Gates Quadpower (set of 5)	2					
							X	Hose	Sulpher Offloading	Jachris	3"SSFHAx4m long FBE:3" S/S45deg. Nipple c/w handle	1					
X								Filter	Sulpher Feed	Dawning Filters	103/94 x 270 x 100u	1					
	X	X						Filter	Sulpher Feed	Dawning Filters	220/200 x 314 x 100u	1					
X	X	X					X	Contactor	MCC Panels	Lido	LC1 D80M7 (220 COIL)	1					
X	X	X					X	Overload	MCC Panels	Lido	GV3ME80 (56 - 80 Amp)	1					
X								Heater	Start-up			1					
	X	X						Heater	Start-up			0					
X	X							Fan	Gas cooling / Converter	Advent Industrial	Bearing assembly	1					
X	X	X	X	X	X	X	X	Motor	Various	Zest	Motor sizes up to 132 KW					24hr breakdown service	
						X	X	Motor	Various	Zest	5.5kW	4					
X	X	X					X	Motor	Various	Zest	30kW	1					
			X					Pump	Homogenising pump spares		M26 (stationary & fixed mixer, nut)	1					
X	X	X						Pump	Homogenising pump spares		MT12 (stationary & fixed mixer, nut)	2					
			X					Stator	Deairator pump	Franklin Electrics	Stator B1302 EPDM P/No.4068	2					
			X					Auger	Deairator pump	Franklin Electrics		1					
X								Shim	Reactor head	Ballestra		1					
							X	Pump	Sump pump	Franklin Electrics	Drenox model 250/10A 230Volt submersable c.w. auto f	1					
	X	X						VSD	Blower speed control	Zest	WEG VSD CFW090600T3848ESZ 330KW 380V	0					
	X	X						Sprays	Candle Filter spray nozzles	Monitor Engineering	PA140-6-37-70-SS Air Cap 303 S/Steel	12					
	X	X						Sprays	Candle Filter spray nozzles	Monitor Engineering	PF40100DF Fluid cap 303 S/Steel	6					
	X	X						Sprays	Candle Filter spray nozzles	Monitor Engineering	CP3612-TEF Gasket Teflon	30					
	X	X						Solinoid valve	Candle Filter spray nozzles	Burkert	24V DC Coil, 0 to 12Bar	6					
	X	X						Pump	LAB feed / Reactors	Prochem		1					
							X	Filter	Diesel Filter	Matsam	BT351						