University of Pretoria

An Investigation on Inefficiencies in Spare Part Management Processes in South African Power Plants

Roṋewa E. Goliada

(BSc.Eng - Wits; BEngHons – U.P.)

Student Number: 14353777

Research Supervisor: Professor J.L. Coetzee

Dissertation submitted in fulfilment of the requirements of the degree

MEng (Mechanical Engineering)

at the University of Pretoria

February 2018

ABSTRACT

Inefficiencies in spare parts management can, and do, have great repercussions for the execution of maintenance in Eskom power stations. Despite this, the sub-processes of spare parts management in power stations had not yet been subjected to rigorous analysis to identify inefficiencies. Consequently, the purpose of this research was to establish the inefficiencies that exist in the management of spare parts in South African power stations, and also to determine the causes of the inefficiencies. All this was done with the intent of recommending a solution to improve spare parts management. It was for this reason that this research was conducted in 13 Eskom coal-fired power stations in South Africa. The first phase of the research was concerned with uncovering and documenting the spare parts management model presently used in Eskom. The second phase included the use of a modified process failure mode and effect analysis (PFMEA) and the Delphi method to identify inefficiencies, their sources, and their significance. The research found that the inefficiencies included unsuitable maintenance and inventory management strategies, as a result of inadequate analysis of plant history. Furthermore, the study established that inadequate analysis of history was a result of poor maintenance records, incompetence, and the lack of access to computerised maintenance management systems (CMMSs). With the inefficiencies and their causes identified, the third phase of the research was then devoted to developing a methodology for improving spare parts management. This led to the development of a framework for improving spare parts management practices in power stations. The framework was validated and verified through a Delphi process. This framework was then recommended for adoption in an Eskom standard procedure for improving spare parts management practices. The research was thus successful in recommending a solution to improve the operational effectiveness and efficiency of spare parts management in South African power stations.

ACKNOWLEDGEMENTS

The author would like to acknowledge the following people:

- Professor Jasper Coetzee from the Department of Mechanical and Aeronautical Engineering at the University of Pretoria for his supervision and guidance.
- Mr. Muhammad Ali Rahiman for his guidance, insight, and assistance in the research approach.
- Ms. Elsie Mathebula, my fellow master's student, for the support, and the daily interactions, which resulted in both of us becoming better researchers. The quality of our respective reports is testament to this.
- Eskom Holdings SOC Limited colleagues who invested their time in participating in this research, and my mentor/manager Rofhiwa Nelwamondo for encouragement and support.
- Mr. Ndivhuwo Goliada for his encouragement and guidance.
- Mr. Vhutali Nelwamondo for their time spent editing the report.
- My cousin Michael Maladzhi for keeping me sane.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. CHAPTER 1: GENERAL ORIENTATION AND PROBLEM STATEMENT

1.1 INTRODUCTION

Production facilities make use of engineered systems during production. As a result, the engineered systems become susceptible to failure, and require maintenance (Fredriksson *et al.*, 2012). Particularly, maintenance is performed to restore functionality of an asset, and to improve its reliability (Moubray, 1991). In order to achieve the required reliability, organisations adopt maintenance regimes that are influenced by their business strategies and objectives (Marquez *et al.*, 2009; Coetzee, 1999).

The requisites for the execution of maintenance tasks are; spare parts, time, and labour (Ben-Daya *et al.*, 2016). Obviously, these requisites should be managed, and their management is referred to as maintenance logistics (Ben-Daya *et al.*, 2016). Ultimately, the effectiveness of maintenance logistics determines the success of the execution of the maintenance function (Blanchard, 2014).

The present research focuses on the management of spare parts. As a result, this chapter discusses the background of spare parts management and also presents the problem statement. Furthermore, the chapter presents the purpose of the research, and the objectives of the research. Next, the research questions, whose answers will ensure that the objectives of the research are met, are presented. This is followed by a discussion on the importance of the research. The chapter further presents a brief discussion on the methodology that was followed during the research. Finally, the scope of the research is discussed and the structure of the entire dissertation is presented.

1.2 BACKGROUND

The function of spare parts management, for managing maintenance stock in production facilities, is to ensure that the correct spare parts, in their required quantities, are available during the execution of maintenance tasks (Wallace, 2007). Spare parts management is thus important because the availability of spare parts has a significant impact on the performance of the maintenance function (Augustine *et al*., 2013; Wagner *et al.*, 2012). Furthermore, Wagner *et al.* (2012) suggested that optimal management of spare parts improves the profits of an organisation, and ensures that the organisation is providing great service to its customers. Consequently, this research will focus on spare parts management. The subsections below introduce the basic concepts in spare parts management.

1.2.1 Inventory Control

Inventory control is concerned with ensuring that adequate stock is maintained by a business, in order to meet demand while keeping the holding costs to a minimum (Toomey, 2000). Some of the basic concepts in inventory control are presented below: (Chase *et al.*, 2013; Coetzee, 1997; Walsh *et al.*, 2014)

- Inventory/stock – the goods and materials that a business holds for the purpose of utilisation.
- Cost of items – the total cost of acquiring an item. This is also known as the acquisition cost.
- Cost of ordering – this encompasses all the associated costs of placing an order.
- Holding cost – this is the cost of keeping spare parts in the stores. This includes the maintenance cost of the unused spares, space occupied, and other logistics costs such as insurance costs.
- Demand – this is defined as the rate at which spare parts are required for the execution of maintenance tasks.
- Ordering cycle – this is the time between orders placed.
- Lead time – this is the time from when an order is placed, to the time when the item is received on site.

1.2.2 Business Processes

Spare parts management in a production environment takes place as a result of the operation of a number of business processes (Susanto *et al.*, 2006). Shtub *et al.* (2010) defines a business process as a set of logically related tasks performed to achieve a defined business outcome. This outcome has expectants and these are the customers of such business processes (Shtub *et al.*, 2010). Obviously, inefficiencies within a business process affect the customer experience (Davenport *et al.*, 1990). Similarly, the existence of inefficiencies in the spare parts management business processes would affect the customers of spare parts management who are the executors of maintenance tasks (Susanto *et al.*, 2006).

Anton *et al.* (1994) stated that when a business process is being optimised, the entire process must be looked at instead of optimising individual tasks within the process. Further, Dohmen *et al.* (2010) stated that some of the business processes in organisations have never been subjected to rigorous analysis, and therefore the drivers of inefficiency in such processes are not known (Dohmen *et al.*, 2010). As a result, such processes operate based on the decisions made by the functional units without taking into consideration the overall effectiveness of the process (Dohmen *et al.*, 2010; Davenport *et al.*, 1990).

Rigorous analysis of business processes would result in the development of solutions that address any inefficiency that may exist (Davenport *et al.*, 1990; Dohmen *et al.*, 2010). Therefore, the result of such analysis would be (Davenport *et al.*, 1990):

- Cost reduction
- Time reduction
- Quality of the output of the process

As already stated, spare parts management is important in a business, and so are the business processes involved in spare parts management. However, Wagner *et al.* (2012) found that there is limited effort in production environments to ensure the optimal operation of spare parts management business processes. Inefficiencies in spare parts management result in the following:

- Increased downtime. The unavailability of material results in maintenance tasks waiting (Augustine *et al.*, 2013). The increased downtime translates to production losses.
- Low maintenance efficiency. Maintenance efficiency is a measure of the maintenance effort required to deliver required performance levels from the production system (Poling, 2017). The downtime incurred, where there is poor management of spare parts, would not translate into improved performance of an asset (Kumar *et al.*, 2014).
- Poor plant reliability as a result of utilising unsuitable spare parts (Baltimore, 2016).
- Proliferation of spare parts as a result of duplication of work (Davenport *et al.*, 1990). There may be multiple orders of the same spare parts.
- High maintenance costs (Poling, 2017)
- Postponement of maintenance due to unavailability of spare parts.

In light of the above, there is a need to ensure optimal operation of the business processes that are concerned with spare parts management.

1.3 PROBLEM STATEMENT

The research problem was that inefficiencies in spare parts management can have great repercussions for the execution of maintenance in power stations. However, the sub-processes of spare parts management had yet to be subjected to rigorous analysis. Therefore, inefficiencies that exist in these sub-processes had not been identified, and solutions to address such inefficiencies had not been developed.

1.4 THE PURPOSE OF THE RESEARCH

This research aims to establish the inefficiencies that exist in spare parts management processes in South African power stations, and the causes of the inefficiencies, with the purpose of seeking solutions for such deficiencies. Consequently, the research was conducted in coal-fired power stations in South Africa, belonging to Eskom SOC Holdings Limited (hereinafter referred to as Eskom). These power stations are representative of other power stations in South Africa.

1.5 OBJECTIVES OF THE RESEARCH

The objectives of the research are:

1. To establish the nature of inefficiencies in spare parts management processes in South African power stations.
2. To ascertain the significance of the inefficiencies.
3. To determine the causes of the inefficiencies.
4. To make recommendations to improve the efficiency and the effectiveness of spare parts management in South African power stations.

1.6 THE RESEARCH QUESTIONS

Figure 1.1 below is a flow chart that indicates how the research questions were used to achieve the objectives of the research.

The overall objective of the research was to establish the inefficiencies that exist in spare parts management processes of power plants in South Africa, and their causes, with the purpose of seeking solutions for such deficiencies. If the research had determined that such inefficiencies do not exist, then this research effort would have served to indicate that there is not be merit in investigating deficiencies in spare parts management. However, when inefficiencies in spare parts management were identified, then the first objective of the research was achieved. Statistical analysis was used to validate research results; this is discussed in detail in Chapters 3 and 4.

Since the existence of inefficiencies was confirmed in the fulfilment of the first objective, further effort was undertaken to determine the significance of each of the inefficiencies. The results of this effort were also subjected to statistical tests to confirm their validity. If the research had determined that the inefficiencies were not significant to the overall operation of spare parts management, this research would have served to demonstrate that there is not be merit in managing any inefficiencies that exist in spare parts management because they are not of significant consequence. However, when it was determined that there were inefficiencies that have significant impact on the overall functioning of spare parts management, further effort was undertaken to establish the impact of those inefficiencies. When the significance of the inefficiencies was established, the second objective of the research was achieved. Consequently, further effort was undertaken to determine the causes of those inefficiencies. When the causes of the inefficiencies were identified, the third objective of the research was achieved.

The study identified the inefficiencies in power station spare parts management, their significance, and their causes, in its fulfilment of objectives 1, 2 and 3. The study was therefore in a position to make recommendations to improve spare parts management. Further effort was then undertaken to determine what could be done to improve spare parts management, in light of the identified inefficiencies. If the study had established that nothing could be practically done to improve spare parts management, then this research effort would have served to demonstrate that spare parts management in South African power stations was operating at the highest possible efficiency and effectiveness, and that there is no merit in improving its practices. However, when the research was able to propose a systematic way of improving the spare parts management practices, the fourth research objective was achieved.

The research questions follow:

1. What are the inefficiencies in the sub-processes of spare parts management in power stations?
2. What is the significance of the inefficiencies on the overall functioning of spare parts management, if inefficiencies exist?
3. What are the causes of the inefficiency in spare parts management, if any inefficiency exists?
4. How can spare parts management in South African power stations be improved?

This space is left empty intentionally,

Please go to the next page

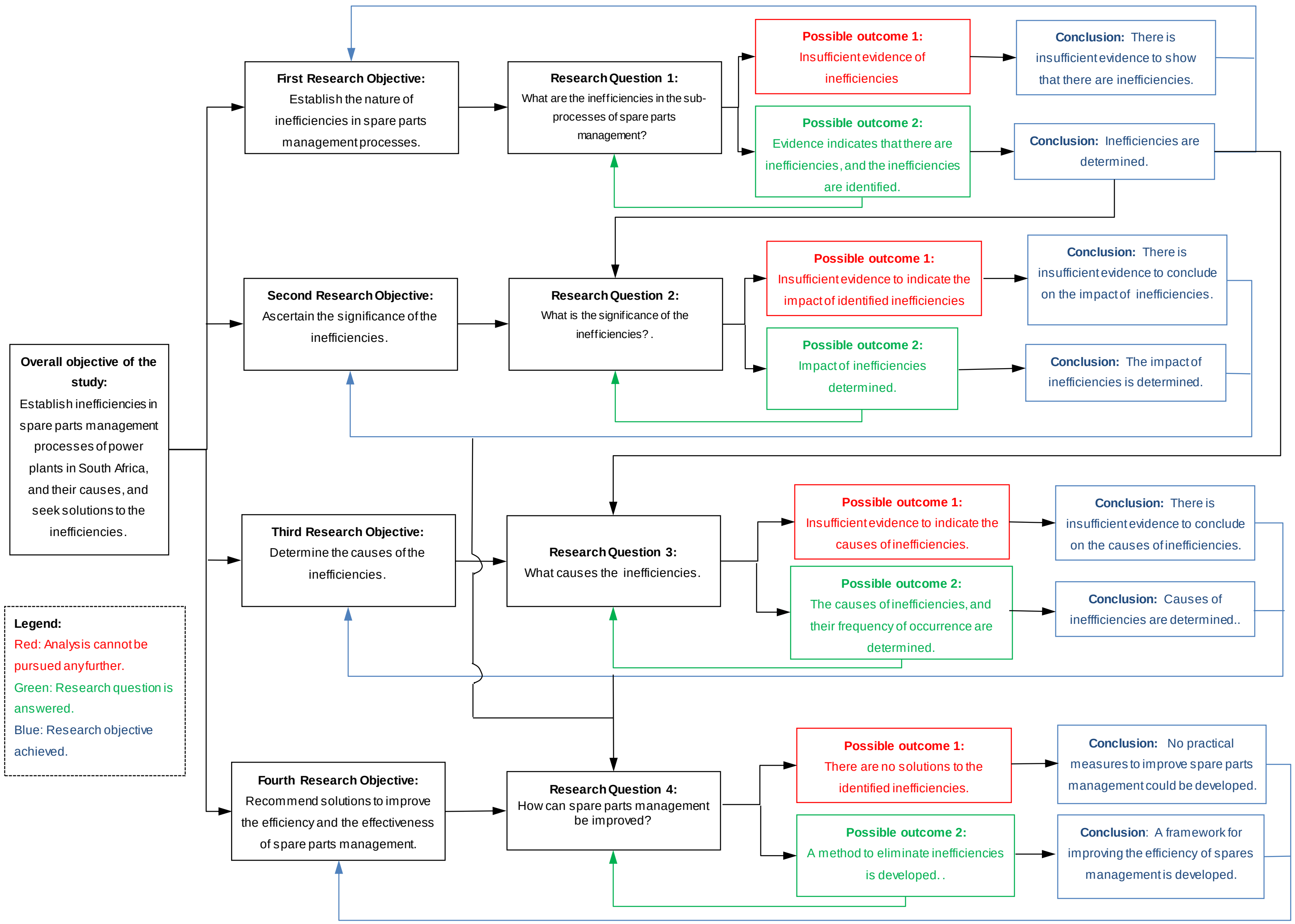


Figure 1.1: Plan for achievement of research objectives

1.7 IMPORTANCE OF THE RESEARCH

The main power utility in South Africa, Eskom, invests significant amounts of capital into the maintenance of its power plants. In the 2013-2014 financial year, the power utility spent R7,763Million on the execution of maintenance (Eskom Integrated Report, 2014). Obviously, Eskom expects a return on investment on the capital that is spent on the maintenance of power stations, and this return should be in the form of the improved reliability of the power stations (Koo *et al.*, 2016).

The production loss in an older power station can be as high as R1Million per day per production unit (Eskom Tariffs and Charges, 2016; Kenny, 2013). Likewise, on newer power plants that have higher capacity, the production loss can be as high as R4Million per day per production unit (Eskom Tariffs and Charges, 2016; Kenny, 2013). Undoubtedly, improved reliability of the power stations would result in significant savings as a result of the avoidance of production losses.

The optimal management of spare parts inventory thus becomes important to the organisation as it ensures that there is effective execution of the maintenance function, which results in improved reliability of the power plants (Koo *et al.*, 2016).

However, the effort that is aimed at the optimal operation of spare parts management process is fragmented, and this is evident in the different streams of research by researchers such as Rego *et al.* (2011), Gu (2013) and Garg (2013) who focus on optimising the inventory control models using mathematical modelling, and researchers such as Masten *et al.* (2015), Sajadieh *et al.* (2015), and Choy *et al.* (2007) who focus on the optimisation of supply chains. This then further contrasts the need for research that investigates all the business processes that are concerned with spare parts management, with the intention of optimising spare parts management. However, such a research has never been undertaken in a South African production facility, and consequently that will be the focus of the current research.

The outcomes of the research will serve as a foundation for optimal management of spare parts in power stations. Furthermore, the results of the research will be used in future research in the fields of business processes, inventory management, and supply chain management.

1.8 METHOD OVERVIEW

In paragraph 1.4, it was stated that the current research sought to determine inefficiencies and causes of inefficiencies in spare parts management, in order to optimise the management of spare parts in South African power stations. It was for this reason that the focus of the research was the fifteen (15) coal-fired power plants that belong to Eskom, which are representative of all power stations in South Africa. However, the experiences of two of the 15 power stations, Medupi and Kusile, were not sought since the stations were still under commissioning. Therefore, the research only considered thirteen (13) power stations, and these were; Hendrina, Arnot, Duvha, Komati, Camden, Matla, Kriel, Kendal, Grootvlei, Lethabo, Majuba, Tutuka, and Matimba. Data were collected from employees of these power stations.

The research was designed such that it could provide answers to the research questions, and this is highlighted in the brief discussion in the subsections below; more detailed descriptions of the research design and the research methodology can be found in Chapters 3 and 4.

1.8.1 Research Question 1

Research question 1 is reprinted below:

> What are the inefficiencies in the sub-processes of spare parts management in power stations?

Research question 1 was answered by subjecting the sub-processes of spare parts management to rigorous analysis. During the analysis, the sub-processes were subjected to process failure mode and effect analysis (PFMEA) (McDermott *et al.*, 2008; Ookalkar *et al.*, 2009). Firstly, the business processes were broken down into their elements, and all the failures that could happen at each element were identified. Secondly, the data were distilled and verified using a Delphi process, where there were several rounds of surveys, until there was convergence of the results (Skulmoski *et al.*, 2007).
In order to obtain credible results, the opinion and insight of experienced individuals was sought. Consequently, purposive sampling was used when selecting the research participants (Battaglia, 2011). This sample that was also used in the discovery of answers to research questions 2 and 3. Furthermore, the data were subjected to statistical analysis to confirm the reliability of the results.

1.8.2 Research Question 2

Research question 2 is reprinted below:

> What is the significance of the inefficiencies on the overall functioning of spare parts management, if inefficiencies exist?

Research question 2 was answered by establishing the significance of the inefficiencies, through the consideration of the severity of the effect of the failure, the frequency of occurrence of the failure, and the effectiveness of the existing strategies of managing the inefficiency. Similar to the development of answers to research question 1, failure mode and effect analysis and the Delphi process were used to develop the answers to the research question (Skulmoski *et al.*, 2007).

1.8.3 Research Question 3

Research question 3 is reprinted below:

> What are the causes of the inefficiency in spare parts management, if any inefficiency exists?

Research question 3 was answered by determining all possible causes of inefficiencies in spare parts management. Further, the research question was answered by determining the likelihood of occurrence of the different failure causes.
Similar to the development of answers to research questions 1 and 2, the data were collected using failure mode and effect analysis, over several rounds of the Delphi process. Furthermore, the data were subjected to statistical analysis to give credence to the results.

1.8.4 Research Question 4

Research question 4 is reprinted below:

> How can spare parts management in South African power stations be improved?

Research question 4 was answered by recommending a solution to improve spare parts management. This was done by developing a method to address the identified inefficiencies. After the inefficiencies and their causes were identified and classified according to significance, the study made use of a framework to present a method of improving the management of spare parts (Soni *et al.*, 2013). This framework was tested and verified to confirm its suitability to address the highlighted inefficiencies, through the use of purposive sampling and the Delphi process (Battaglia, 2011; Skulmoski *et al.*, 2007).

1.9 SCOPE AND LIMITATIONS OF THE RESEARCH

In paragraph 1.3, it was stated that inefficiencies in spare parts management can have great consequences for the execution of maintenance. Further, it was stated that the business processes in spare parts management had not been subjected to rigorous analysis to identify inefficiencies. Consequently, the scope of the current research was the rigorous analysis of spare parts business processes in coal-fired power stations, in order to identify inefficiencies and their sources.

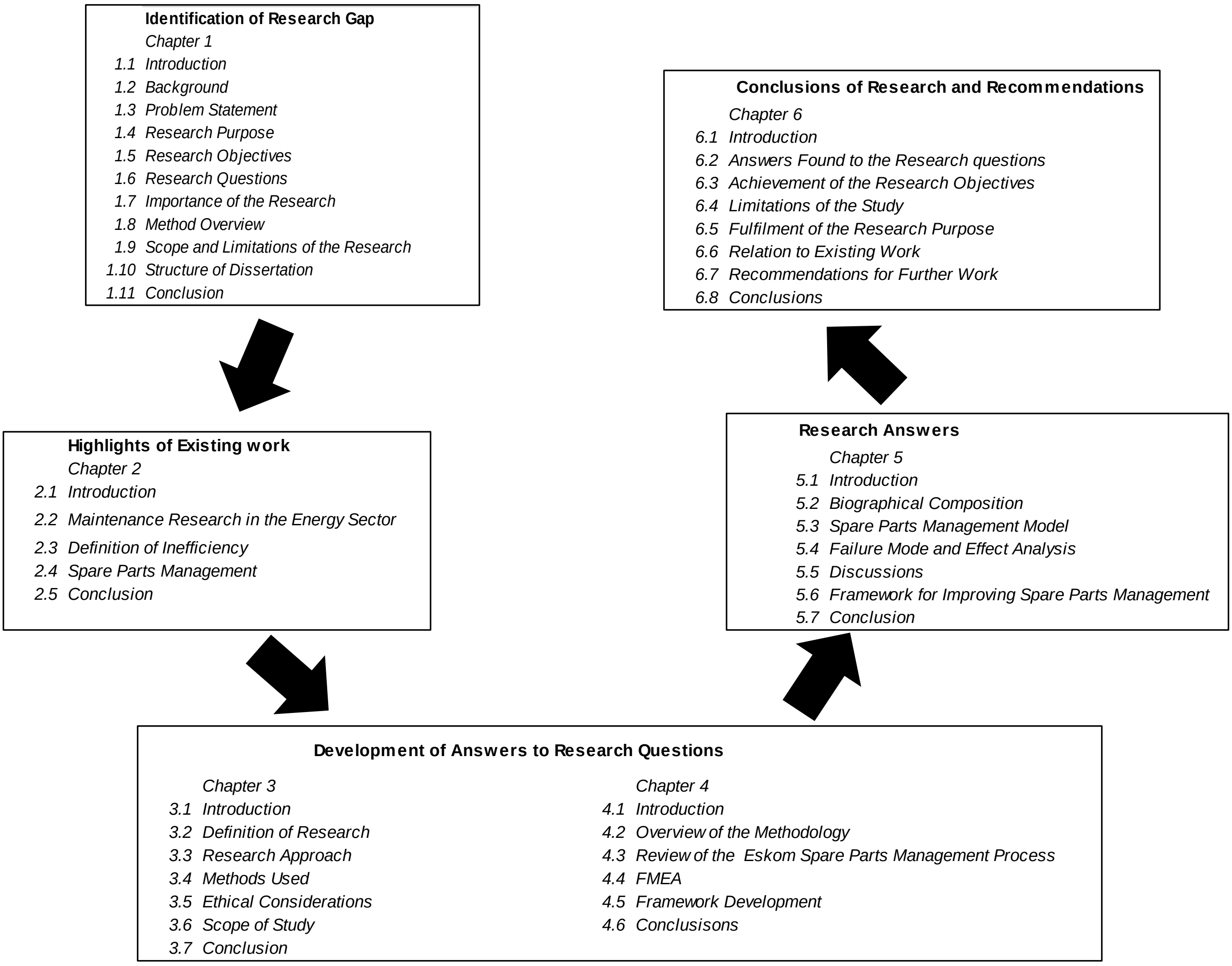
It was anticipated that the limitations and the research imperfections below could affect the fulfilment of the research purpose:

- The research participants could wrongly understand and incorrectly interpret some of the concepts related to inventory management. This could distort the results.
- The researcher was an employee at one of the power stations where the research was conducted. This could influence the interpretation of certain results of the research.
- The research was conducted at 13 of Eskom's coal-fired power stations. The applicability of the research findings may thus be limited to Eskom coal-fired power stations.
- The researcher could not have access to all the records in the power stations. Therefore the significance of the spare parts management process, and the severity of the inefficiencies, could only be inferred from the experience of the research participants.
- The target sample of the research was 26 participants who work at the power stations. It was expected that there could be unwillingness to participate by some of the maintenance stakeholders, and therefore their experiences would not influence the outcomes of this research.

This space is left empty intentionally.

Please go to the next page

1.10 STRUCTURE OF THE DISSERTATION



1.11 CONCLUSION

There are great costs associated with the execution of the maintenance function, and the production losses that are incurred as a result of ineffective execution of maintenance in power stations (Eskom, 2016; Eskom, 2014; Sitienei *et al.*, 2015). Consequently, there should be effort to improve the efficiency and the effectiveness of spare parts management as they affect the performance of maintenance. However, a preliminary literature review revealed a limitation. The limitation was that business processes in spare parts management in power stations had not been rigorously analysed to identify inefficiencies that may exist. Consequently, the focus of the current research was the rigorous analysis of these business processes in order to identify inefficiencies, and therefore provide a basis for the improvement of spare parts management, which will subsequently improve the effectiveness of maintenance.

Chapter 2 expands on the review of existing literature in the disciplines concerned with spare parts management.

2. CHAPTER 2: THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 INTRODUCTION

The preceding chapter highlighted the research problem and the research objectives. In short, the research sought to identify inefficiencies in spare parts management, in order to recommend a solution to improve spare parts management. Consequently, this chapter reviews existing literature in the subject of spare parts management, and related fields.

The chapter begins by reviewing related research that has been conducted at Eskom. Next, the chapter explores the definition of inefficiency in order to define inefficiency in the context of spare parts management. This is followed by an extensive review of spare parts management and the sub-disciplines that are involved in spare parts management. Finally, a conclusion of matters that arose is presented.

2.2 MAINTENANCE RESEARCH IN THE ENERGY SECTOR

The research sought to explore existing literature pertaining to the management of maintenance in Eskom. In order to explore the existing body of knowledge, the Eskom Information Centre and Google Scholar were searched for specific keywords, as shown in Table 2.1 below. The highest number of results in the search on Google Scholar was 2540 results. The Eskom Information Centre had a total of 128 dissertations and conference papers. The results of the search were reviewed, and research that was found to be relevant to the current research is critically analysed and discussed in the subsections below.

This space is left empty intentionally.

Please go to the next page

Table 2.1: Results of the literature search

Database	Keywords	Number of results	Relevant work
Google Scholar	Eskom spare parts management; Eskom spare parts; inventory management at Eskom; spare parts logistics Eskom	2540	Mutloane (2009); Brand *et al.* (2016); Wara *et al.* (2008); Madonsela *et al.* (2003); Ratau (2015); Hedges (2009); Mamabolo (2012); Budeli (2015); Mtembi *et al.* (2015); Murugan *et al.* (2015); Ewulum (2008).
Eskom Information Centre	Spare parts; inventory management; maintenance; asset management; spare parts logistics	128	Mortlock *et al.* (2014); Molopo (2014); Wallace (2006); Scheepers *et al.* (2014); Diamond *et al.* (2014); Booysen *et al.* (2014); Sibanda (2016); Sithole (2013); Mpofu (2010).

2.2.1 Maintenance Operations

Research pertaining to the operation of maintenance in the power stations is discussed.

The daily activities in production facilities are governed by business processes, and this is also the case in Eskom power stations (Budeli, 2015; Wallace, 2006; Wara *et al.*, 2008). However, it was found that the business processes in Eskom plants are prone to inefficiencies (Madonsela *et al*., 2003). One of the causes of such inefficiency was found to be inaccurate maintenance instructions that result in inadequate planning prior to a maintenance outage (Madonsela *et al*., 2003). Furthermore, the fragmentation of the maintenance effort was identified as one of the causes of inefficiency. In their study, Madonsela *et al*. (2003) found that there were two departments involved in maintenance at Eskom; a department for normal maintenance and another department responsible for bigger maintenance projects such as refurbishment. Evidently, because of this, the "silo effect" existed, depriving the maintenance function of the benefits of teamwork (Bevc *et al*. 2015; Root, 2016). The "silo effect" was made more evident by the procurement strategies that required for procurement to be handled by the Commercial Department only, which results in omission of important technical considerations (Madonsela *et al*., 2003); for clarity, it needs to be noted that procurement here specifically refers to the procurement of spare parts in preparation for an outage.

There are a number of initiatives that are aimed at improving the reliability of the plants in Eskom (Mutloane, 2009). However, there are multiple initiatives that are not well-coordinated and they pose a challenge when it comes to implementation and follow-up (Sibanda, 2016). In their study, Sibanda (2016) found that Eskom does not fully benefit from the advantages presented by modern strategies such as reliability centred maintenance (RCM), as a result of having a myriad of these unstructured initiatives that run concurrently. Consequently, there are a number of missed opportunities to address critical challenges such as inventory management. Importantly, Mutloane (2009) found that maintenance initiatives in the organisation fail as a result of lack of employee involvement. Their study found that Eskom experiences "initiative fatigue", where the mentality of the employees is that each initiative is a "flavour of the month" and it too shall pass (Goetsch *et al.*, 2014).

The lack of employee engagement is due to the organisational culture that has been created, as noted by Molopo (2014). Molopo (2014) found that the fulfilment of tasks by employees relies on the organisational culture. In particular, this culture does not reward the involvement of employees in organisational initiatives, as there will normally be a new initiative before the current one is completed (Goetsch *et al.*, 2014). As a result, employees in the organisation do not fully engage with maintenance initiatives, and the results of that is the development of business strategies that are not suited to the plant's needs and that take little cognisance of the abilities of the executors of the maintenance tasks (Murugan *et al.*, 2015; Ratau, 2015). This is evident from the study conducted by Ratau (2015), where supervisors were not familiar with basic concepts of asset management, despite asset management initiatives that had been operational for years in the organisation. It is therefore a common occurrence for the organisation to adopt philosophies and strategies, at corporate level, that are not cascaded to the functional level (Budeli, 2015). In their study, Budeli (2015) found that there was compliance to ISO 9001 at organisational level, but not at the functional level during the execution of daily maintenance activities.

2.2.2 Plant Life Estimation and Maintenance Scheduling

The estimation of the useful life of components is an important aspect in maintenance as it ensures that there is adequate planning for when maintenance will be required (Hedges, 2009). Obviously, such planning would include the spare parts requirements. Brand *et al.*

(2016) looked at the development of a plant health index indicator for Eskom distribution substations. The aim of their work was to determine the right time for maintenance intervention, since the existing detection method was not effective. Their work, which was based on plant history and mathematical modelling, yielded a functional plant health indicator which indicates the right time to conduct preventive maintenance, so as to prevent the high consumption of spare parts during corrective maintenance. Similarly, Hedges (2009) developed a model to determine the right time to conduct maintenance on transformers. However, their model failed to consider the constraints that are placed on the maintenance schedule by business needs and the maintenance needs of other plant areas.

In their study, Mortlock *et al.* (2014) also looked at developing a model that determines the optimum time to conduct refurbishment on boiler feedwater pumps in power stations. The research problem came about as a result of observed deteriorating pump efficiency. The study used the recorded plant history to model the wear behaviour of the pump components throughout the pump's life cycle. Subsequently, the model provided the basis for the planning of maintenance resources that will be required throughout the life cycle of the pump, and this included the spare parts needs. Similar work was also done in the turbine machinery plant by Scheepers *et al*. (2014); Diamond *et al.* (2014); and Booysen *et al.* (2014). These studies sought to predict the life of components in the turbine plant, in order to develop suitable maintenance plans and schedules.

2.2.3 Maintenance Projects

The asset management in the energy sector has different levels of intervention as presented by Madonsela *et al.* (2003) in paragraph 2.2.1. Typically, a higher level of intervention requires a maintenance project. This is normally referred to as an outage in the energy sector. Mamabolo (2012) investigated the effectiveness of planned maintenance in power stations. The study sought to establish a relationship between planned maintenance and reliability of the plants. The study made use of questionnaires and interviews with practitioners of maintenance in Eskom power stations, and it was able to establish a positive relationship between the execution of planned maintenance and the improved reliability of the plants. Mtembi *et al.* (2015) conducted a similar study, where they used a Turbine and Generator Maintenance company as a case study. Their study found that delays in the procurement process were the main barrier to successful execution of maintenance during a maintenance project.

Similarly, Sithole (2013) investigated the success factors and barriers during the implementation of projects in power stations. Their study was able to determine the biggest factor in ensuring success; effective management. This is supported by Mpofu (2010), who found that projects in state-owned companies fail due to the absence of strategic leadership.

2.2.4 Research Gap

The literature study found that there is limited research in the subject of spare parts management in Eskom power stations. Particularly, there was no research that was done to optimise the management of spare parts by reviewing sub-processes of spare parts management. Therefore, there was a need for research that seeks to improve the management of spare parts at Eskom power stations, by rigorously analysing the sub-processes of spare parts management to identify inefficiencies and provide recommendations on how to improve spare parts management.

For this reason, the literature study was then expanded to look at spare parts management in other industries and also in other countries. The databases that were searched were, Elsevier, Emerald and JSTOR. The searches were done using specific keywords, in order to gain insight on particular topics within the subject of spare parts management. This is reflected by the Bibliography.

2.3 DEFINITION OF INEFFICIENCY

The current study seeks to determine the existence of inefficiencies and the sources of such inefficiencies in spare parts management. The Oxford Dictionary defines the word inefficiency as the state of not achieving maximum productivity; the failure to make best use of available time or resources (English Oxford Living Dictionaries, 2016). Inefficiency can also be thought of as the quality or state of being inefficient; where the word inefficient is defined as, not efficient, such as not producing the effect intended or desired (Merriam-Webster, 2016). Inefficiency can also be characterised as the lack of efficiency; where efficiency is defined as the ability to accomplish a job with a minimum expenditure of time and effort (Dictionary.Com, 2016). It is worth noting that some of the synonyms of efficiency are ability, capability, competence, performance and productivity, to name a few (Dictionary.Com, 2016); therefore, inefficiency would be the absence of these. Thus a study on inefficiencies would be concerned with identifying any inability, incapability, wastefulness, disorganization, incompetence, etc. (Merriam-Webster, 2016; Dictionary.Com, 2016; English Oxford Living Dictionaries, 2016).

In paragraph 1.2 it was stated that the function of the spare parts management is to ensure that the correct spare parts, in the required quantities, are available during the execution of maintenance tasks (Wallace, 2007). Furthermore, the spare parts management processes should ensure that this is being fulfilled in the most economical way (Handfield, 2012). Therefore, inefficiencies in spare parts management would be any inability, incapability, wastefulness, disorganization, incompetence, etc. that results in unavailability of spares, inadequate quantities of spare parts, delays in availing spare parts to the maintenance executors, and high costs of maintaining spare parts inventory (Wagner *et al.*, 2012; Merriam-Webster, 2016; Dictionary.Com, 2016; English Oxford Living Dictionaries, 2016).

In conclusion, *inefficiencies in spare parts management* are thus inadequacies in spare parts management that result in spare parts management not fulfilling its intended function, in the intended way.

2.4 SPARE PARTS MANAGEMENT

The spare parts management process is one of the main components of the maintenance infrastructure (U.S. DoD, 2000). As already stated, the objective of the spare parts management is to ensure that the correct spare parts, in their required quantities, are available during the execution of maintenance tasks (Wallace, 2007). Furthermore, this must be fulfilled in the most economical way (Handfield, 2012), by reducing the organisation's total cost of ownership of an asset. Therefore, spare parts management should (U.S. DoD, 2000):

- Ensure interoperability of maintenance programmes and systems.
- Enhance the interchangeability, reliability and availability of spare parts.
- Minimize the risk of obsolescence.
- Stop the proliferation of spare parts.

2.4.1 Management of Spare Parts in Production Facilities

Inefficiencies in spare parts management negatively affect the profitability of an organisation (Wagner *et al.*, 2012). Eloff *et al.* (2013) assessed the approach to the management of maintenance inventory in a South African cement manufacturer. The method used to conduct the study was a mixed approach; it included a survey of the employees of the company, and separate interviews that were meant to provide additional information on the results of the survey. Eloff *et al.* (2013) were able to establish the shortcomings in the approach to maintenance inventory. They found that the following factors contributed to the shortcomings; lack of appreciation of inventory control methods by senior management, lack of integration between departments, no measure of holding cost, and disregard of spare parts classification during stocking of spares. The research design of this study left room for omissions, and as such its results cannot be assumed to be universally true. The study was based on one round of surveys of 17 employees of the cement manufacturer, followed by one round of interviews. Similarly, Guajardo *et al.* (2012) evaluated inventory management of spare parts in an oil and gas company. They found that one of the biggest inefficiencies was the lack of uniformity in the application of stock level parameters. The work of Guajardo *et al.* (2012) further focused on establishing the stock level parameters that will be used throughout the company to minimise inefficiencies. The method that was used was computational experiments. The results indicated a reduction of stock that is held by the company, and that would translate to a cost saving of 13%.

Bounu *et al.* (2017) investigated the random nature of problems in the management of spare parts. The work of Bounu *et al.* (2017) focused on integrating the work done by previous researchers on the models of spare parts inventory control. Their study was able to highlight the different existing methods for spare parts identification, control, and estimation of spare parts demand. Finally, their study presented probabilistic models that were aimed at minimising the risk of spare parts shortages.

2.4.2 Inventory Control Models

The subsections below present existing research work, in relation to different inventory control models.

1) ABC analysis

The optimisation of inventory in an organisation requires significant effort (Mitra *et al.*, 2013). It is therefore not practical to optimise the management of all the spare parts in inventory. Hence, the aim of the ABC analysis of inventory is to focus maintenance resources on the most important items (Holstein *et al.*, 2006). The model is based on the Pareto principle that separates the vital few items from the trivial many items (Coetzee, 1997; Ravinder *et al.*, 2014). Naturally, it is the discretion of organisations to specify their criteria for significance.

ABC analysis can classify inventory based on the value of the annual consumption of an item. In such a case, the items found in category 'A' would constitute 10 to 15% of the total inventory but contribute 60-70% of the total consumption value. Further, the category 'B' items would constitute 20-25% of the total inventory and account for 20-30% value. Lastly, category C items would constitute 60-70% of the inventory, but only account for 10-15% of the consumption value. It is therefore important that ABC analysis is conducted correctly, and in accordance with the criteria set by the maintenance organisation, as it could lead to serious inventory management issues in an organisation (Dhoka *et al.*, 2013a).

ABC analysis can also classify inventory based on the unit price of the items (Chase *et al.*, 2013). In this case, the spares under this analysis would be classified according to high price items, medium price items, and low price items (Chase *et al.*, 2013). The cut-off prices for the different categories would be determined by the management of the maintenance organisation. This analysis helps to determine the storage requirements and the security requirements for the spare parts. Also, the procurement processes and skills for items in different price categories may differ (Mitra *et al.*, 2013).

ABC analysis is also capable of classifying spare parts according to the inventory value of spare parts already purchased by the organisation (Dhoka *et al.*, 2013b). The inventory value is determined by multiplying the quantity in stock by the cost of item. In this case, the spare parts would be classified according to these three categories; high inventory value, moderate inventory value and low inventory value (Dhoka *et al.*, 2013b). The objective of the analysis would be to ensure that there is total control over the inventory with the highest stock value (Dhoka *et al.*, 2013b).

ABC analysis is often criticised for classifying inventory according to a single criterion (Ravinder *et al.*, 2014). Mitra *et al.* (2013) argued that the use of a single-criterion analysis would not always result in the most economic control of inventory. This supported the work of Grondys (2009) and Baccheti *et al.* (2010) who presented that the criteria for classification of inventory should take cognisance of factors such as lead time, budget, supply, demand, inventory holding capacity, and safety stock. Baccheti *et al.* (2010) further illustrated that subjective weighting and rating can be applied during the inventory analysis in order to correctly exert the influence of each factor on the criticality of each item in inventory. Taking all the above into cognisance, the resulting inventory control model would surely result in an optimal business decision.

2) Economic Order Quantity (EOQ) Model

The reorder point is the level of inventory that necessitates that an order to replenish the inventory is generated (Mekel *et al.*, 2014). In an ideal case, the replenishment of spare parts would be instant; the reorder point would then be when the inventory level reaches zero. This however does not represent the actual condition in production environments because the supply of most spare parts has a significant lead time. As a result, the reorder point is determined by the forecast of the spare parts demand during the lead time plus the safety stock (Chase *et al.*, 2013). The economic order quantity (EOQ) model and the stochastic (r,q) model are kinds of reorder point inventory models.

The two factors to consider when dealing with the replenishment of inventory are; the amount stock to be ordered, and the timing of the order (Chase *et al.*, 2013). The EOQ model is used to determine the order quantity that will make the most economic sense, by doing cost tradeoffs between the procurement cost and the cost of holding inventory (Roach, 2005). The result of the EOQ analysis gives the quantity of spare to be ordered such that it will optimise the total cost of inventory (Chase *et al.*, 2013). This concept is illustrated graphically in Figure 2.1 below (Howitz, 2014).

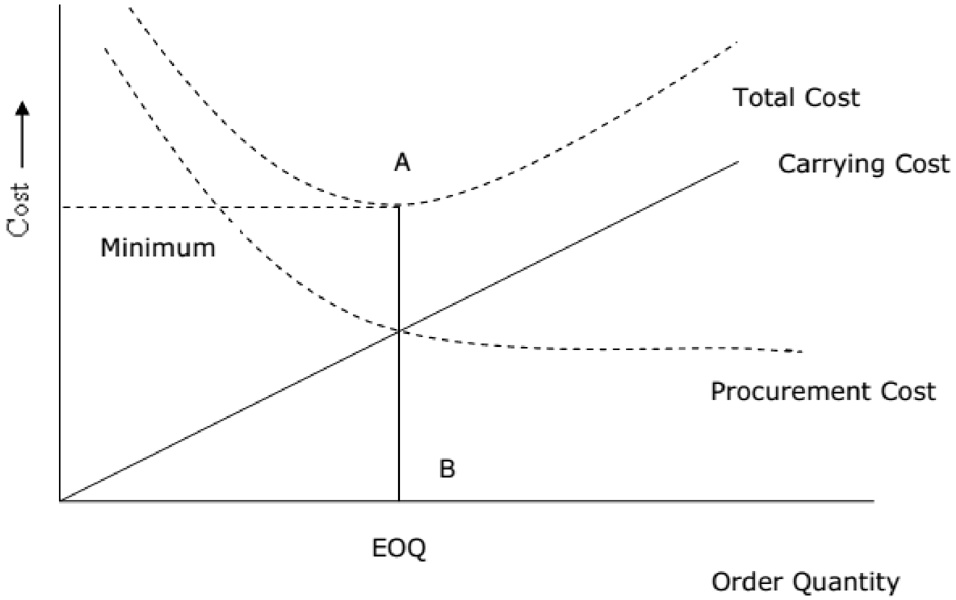


Figure 2.1: Economic Order Quantity (Howitz, 2014)

The economic order quantity (Coetzee, 1997) is given by:

$$EOQ = \sqrt{\frac{2K\beta}{h}}$$

Where *K* is the cost of an inventory item

β is the constant rate of demand of the inventory item

h is the holding cost of such item,

The model further determines the reorder point (Coetzee, 1997), and this is given by:

$$R = (\beta \times lead\ time) + safety\ stock$$

There are limitations associated to the EOQ model, and these include the fact that the model is used where the demand of the spare part can be assumed to be constant and continuous, and where there are no quantity constraints when orders are placed (Roach, 2005; Zhu *et al.*, 2015). In reality however, the demand of spare parts is not constant, and there may be minimum ordering quantities (MOQ) per batch that suppliers may insist on (Zhu *et al.*, 2015). The EOQ model would thus need to be extended in order to effectively model and control the inventory.

It is assumed when determining the optimal quantity, that the holding cost and the cost of procurement are known with certainty (Appadoo *et al.*, 2012). It is also assumed that there is a single supplier. This is mostly not the practice in maintenance organisations, as it is possible for a plant component to have multiple possible suppliers. Consequently, Appadoo *et al.* (2012) developed an EOQ model that takes into account uncertainty in the ordering cost and the holding cost. Furthermore, Parikh *et al.* (1999) applied the EOQ model with the assumption of two suppliers, who supply a component either simultaneously, or one after the other. As an extension of the work by Parikh *et al.* (1999), Erdem *et al.* (2006) developed an EOQ model that handles multiple suppliers. Surely, the results of any further work in this line of research would be result in a more realistic model that would be useful in an environment where there are many likely suppliers, and where the cost is not the only criterion for supplier selection. Kharde *et al.* (2012) and Wu *et al.* (2006) also found that the EOQ model can be extended to include safety stock to reduce the likelihood of stock-outs.

3) Stochastic Inventory Control Models

The rate of demand of spare parts in a maintenance organisation is not constant. Similarly, the supply of the spare parts, represented by the lead time to deliver, is not constant. As established already, the demand of spare parts and the supply lead time are factors that determine the reorder point, and the ordering quantity (Simchi-Levi, 2002). However, a deterministic model, such as the EOQ model, cannot be suitable to manage the inventory in a setting where the uncertainty in the demand is high and the supply lead time is variable (Sarbijt *et al.*, 2011). There is therefore a need for a probabilistic inventory control model that closely resembles the real world situation, and that is the stochastic inventory control model (Levi *et al.*, 2005). There are a number of mathematical models that were developed to emulate the behaviour of stochastic demand (You *et al.*, 2009; Browne *et al.*, 1991). The premise of the control model is that, whenever the stock level drops below point R, the reorder point, an order of quantity, Q, must be placed. However, the analysis of these models may prove to be cumbersome, and should therefore be done using computers (Coetzee, 1997). Consequently, stochastic models form the basis for computerised maintenance management systems (CMMSs). The assumption that is made when stochastic models are applied is that, even if the demand of the spare parts may be uncertain, the probability distribution of the demand is known (Hillier *et al.*, 2001).

4) JIT Model

Any maintenance organisation relies on its supply chain to ensure that the required spare parts are available when needed (Masten *et al.*, 2015). Traditionally, the maintenance organisation would hold high quantities of spare parts to ensure their availability when needed (Cirello, 1992). However, the “just-in-time” (JIT) model states that spare parts will arrive on site just as they are needed, not before and not after. This philosophy is based on inventory reduction, the improvement of processes, and elimination of waste (Kootanaee *et al.*, 2013). The aim of JIT is thus to reduce the cost of holding inventory and to eliminate the costs associated with inefficient process and waste (Cirello, 1992). The popularity of the philosophy is due to the realisation by organisations of the increased competition in the market, and the potential for reducing operational costs through optimal inventory management (Cirello, 1992).

However, the utilization of the JIT model in a maintenance organisation can result in frequent purchasing orders being placed, and this would result in increased logistics costs (Banerjee *et al.*, 1995). Consequently, Banerjee *et al.* (1995) developed an integrated JIT model that takes into account the costs that are associated with placing multiple orders. This resulted in a model that calls for keeping safety stock, and higher than needed stock levels. Evidently, this is in contrast with the principles of the JIT.

An important requirement of the JIT inventory model is accurate forecasting of spare parts demand, and this is done through mathematical models and CMMSs (Silva *et al.*, 2014). In such a case, it is therefore beneficial to automate the inventory replenishment in order to ensure that the low levels of inventory are detected quickly and purchasing orders are placed on time, to prevent stock-out (Silva *et al.*, 2014). Clearly, this requires transparency in all the parties involved in a JIT inventory model. Therefore, suppliers would have access to information about stock levels in the maintenance organisation. This allows the suppliers to prepare better for replenishment of stock.

There are risks involved with applying the JIT inventory model. The forecasting of spare parts demand often depends on known failure behaviour of the organisation's assets and also known preventive maintenance schedules. Therefore, any changes that occur in the demand of spare parts can result in stock-out. Also any deviations in the supplier's distribution systems may result in the maintenance organisation experiencing stock-out. This means that there might be postponement of preventive maintenance, or the organisation may be exposed to production losses as a result of spare parts unavailability. The way to avoid stock-outs is for the organisation to have a built-in safety net by stocking more spare parts than required, to protect the organisation from stock-outs. However, this can result in higher inventory costs, defeating the purpose of the JIT inventory control system.

5) JIT Model versus EOQ Model

The JIT model is often compared to the EOQ model due to the contrast between them. The EOQ model proposes the ordering of significant quantities of spare parts (Howitz, 2014), while the JIT model proposes the ordering of minimal stock (Cirello, 1992). The two models seem to oppose each other. As a result, Fazel (1997) reviewed the two models, and they concluded that the EOQ inventory model would be more suitable than the JIT model for an environment where there is a high annual consumption.

This was disputed by Schniederjans *et al.* (2001) who introduced a few of the cost benefits of the JIT model to the comparison. In their research, Schniederjans *et al.* (2001) concluded that the JIT model would still be the more cost effective model under all circumstances due to the plant space reduction advantage that JIT possesses. However, this assertion was disputed by Wu *et al.* (2006), who argued that the model by Schniederjans *et al.* (2001) did not take into account the cost of stock-out that may occur as a result of variations in the demand, or due to disruptions in the supply chain. Furthermore, they argue that, in such a case, the EOQ model would prove to be superior due to its ability to handle unexpected demand (Min *et al.*, 2007). As an example, there are cases where a relatively non-expensive component can result in a production loss of great consequence. In such a case, the production loss would be far greater than the holding cost (Min *et al.*, 2007).

6) Material Requirements Planning (MRP)

A significant amount of maintenance work is done during planned plant shutdowns. The scope of the work performed during such outages is significant and so would be the number of spare parts required. As a result, it would not be practical for the stores in the maintenance organisation to normally keep the levels of stock that are required during these shutdowns. Therefore, the materials management process required for this would be different from the inventory control process used for everyday maintenance.

Material requirements planning (MRP) is used in production environments for planning, scheduling and as an inventory management strategy (Cooper *et al.*, 1989). MRP works hand-in-hand with a master production schedule (MPS), which is a time-phased plan which indicates which tasks will be executed and when (Chase *et al.*, 2013).

MRP reduces the maintenance and the holding costs in an organisation by using the future demand of spare parts components in order to determine the appropriate timing and amount of spare parts to purchase (Dinesh *et al.*, 2014). This is different to other inventory models that make use of the historical usage of the components in order to determine the reorder point and reorder quantities.

An MRP system is software based. However, the computation can be done manually as it is simple mathematics (Abuhila *et al.*, 2006). In the computation, the required information is the lead time, the number of stock in hand, the safety stock, and the ordering quantity. After the computation, the MRP record for each spare part would contain the following information: (Chase *et al.*, 2013)

- Gross requirements – this is the total amount of spare parts required to perform a particular maintenance task
- Scheduled receipts – these are orders that are already placed, and are scheduled to arrive on site at the beginning of the execution of the maintenance task.
- Projected available balance – this is the amount of inventory that is expected to be available when the execution of the maintenance task begins. This is determined by looking at the sum of the stock in hand and the planned order receipts and subtracting the sum of the gross spare parts requirements and the safety stock.

There are challenges when it comes to the implementation of MRP in production facilities, and as a result not much success has been obtained from using this system (Plenert, 1999). In their study, Plenert (1999) found that uncertainty in lead times was a source of great inefficiency when MRP is utilised; this was also supported by a study by Jha (2012). It was also found that MRP requires constant re-adjustment, and this has proven to be cumbersome in big production facilities (Cooper *et al.*, 1989). Consequently, MRP is recommended for use in smaller production facilities (Hassan, 2013).

2.4.3 Supply Chains

A supply chain is defined as a sequence of processes in the production and distribution of commodities (Masten *et al.*, 2015). Similarly, a spare parts supply chain is a sequence of processes involved in the production and distribution of spare parts. Wagner *et al.* (2012) proposed that strategic and well executed spare parts logistics can improve the profits of an organisation, and ensure that the organisation is providing great service to its customers.

There are many mechanisms that exist that are designed to ensure optimal performance of the spare parts supply chain (Wagner *et al.*, 2012). Some of the mechanisms are found in the maintenance and procurement policies of the maintenance organisations themselves. However, there is little implementation of these mechanisms. In their study of mechanisms to improve the performance of supply chains, Masten *et al.* (2015) concluded that the existing knowledge is compartmented in supply chain coordination on the one hand, and supply chain integration on the other hand. Consequently, Masten *et al.* (2015) developed a model that was aimed at merging the knowledge from both streams in order to improve the performance of spare parts supply chains. Similarly, Arts (2013) developed a framework from which the planning and the control of spare parts supply chains can be done. This included all possible steps in the supply chain, and the relevant decisions. The aim of the framework was to reduce any inefficiency in the process.

The management of supply chains is a complex task. Consequently, there are maintenance organisations that have opted for outsourcing the materials management function (Murthy *et al.*, 2015). Surely, the competitiveness of a maintenance organisation can be improved by outsourcing; that is if the outsourcing is part of the overall strategy of the maintenance organisation, and it is well-managed. (Momme *et al.*, 2002)

In a spare parts supply chain there are a number of role players. Role players include a raw material supplier, a manufacturer, a supplier, and the buyer from a maintenance organisation (Ottesen *et al.*, 2012). However, the supplier may not always be able to supply the required spare parts to the maintenance organisation due to upsets upstream in the supply chain (Ottesen *et al.*, 2012). In their study, Ottesen *et al.* (2002) concluded that suppliers still try to meet the needs of the maintenance organisation by either trying to predict the supply upstream, or by trying to offer an alternative product. The offering of alternative products can be a source of problems in the inventory management systems. To illustrate, the alternative spare parts may be of lower quality and may come at a higher cost. Also, some of the alternative spare parts may not get used, in the case when the correct spare parts become available later on. This would result in reduced holding capacity of the store.

The demand for spare parts is what drives the operation of the supply chain, and if this demand is not monitored, the spare parts supply chain will not perform optimally (Sajadieh *et al.*, 2015). As discussed in paragraph 2.4.2, the demand of certain components is stochastic. Consequently, Sajadieh *et al.* (2015) studied coordinated supply chains and how they can be used in an environment where the demand is stochastic. The model developed by them could be applied in a spare parts supply chain, in that it will monitor the demand of a particular spare part within the maintenance organisation, and this information will be used to determine the production rate at the suppliers' workshops. This results in minimised overall costs in the spare parts supply chain.

A strategic relationship should exist between maintenance organisations and spare parts suppliers, and this relationship should be enforced through a contract (Goetsch *et al.*, 2014). O'Toole *et al.* (2002) argued that these relationships should be assessed regularly to determine if they are adding value to the performance of the supply chain. This assessment should be done against set criteria, known by all parties (Choy *et al.*, 2007).

2.4.4 Computerised Maintenance Management Systems (CMMSs)

Improved technology in recent years has resulted in Information Technology playing a role in maintenance (Tovia *et al.* 2011). This has resulted in the development of computerised maintenance management systems (CMMSs). The CMMSs help maintenance teams keep a record of all the assets they are responsible for, schedule and track maintenance tasks, and keep a historical record of the work they perform (Tovia *et al.*, 2011). Furthermore, the CMMSs allow for levels of spares to be monitored remotely and also for tracking of usage of specific spare parts. Other advanced systems place orders automatically when the re-ordering point is reached (Silva *et al.*, 2014).

The foundation of excellent computerised maintenance management systems (CMMSs) should include mathematical modelling (Jalil *et al.*, 2009; Tovia *et al.*, 2011). The mathematical models which are developed to fully optimise the execution of the maintenance function include one developed by Tovia *et al.* (2011). The CMMSs makes use of data that has been collected and recorded on the database of the organisation. Holstein *et al.* (2006) stated that data-driven methods should be used in CMMSs as they would minimise costs that are associated with overestimation or underestimation of spare parts demand. In support of this, Jalil *et al*., (2009) concluded that existing data can be used to forecast spare parts demand. However, Ackay (2013) cautioned that the use of existing data without verifying the accuracy of the data, results in inventory control that is not optimal.

In an environment where the inventory is well managed, the available resources would be used optimally, as the assignment of maintenance tasks, confirmation of spare part availability, and booking-out of spare parts can be done through the CMMSs (Tovia *et al.*, 2011).

2.4.5 Business Processes

Inefficiency in processes and systems represents the deficiencies that exist is such systems and processes (Shang *et al.*, 2007). Deficiencies in systems limit the capability of those systems to perform their intended functions. Spare parts management is a business process, and any inefficiencies that may exist in this business process result in system deficiency.

Consequently, the discussion below focuses on studies that were concerned with uncovering deficiencies in business processes, and the sources of the deficiencies. Furthermore, the discussion focuses on the methods that were used during the different studies.

Shang *et al.* (2007) studied deficiencies in process changes during the implementation of enterprise systems. The methods used during the study were in-depth interviews with employees of four different firms that have experienced process changes. Their study went further to determine the sources of such deficiencies during the implementation of process changes. The findings of this initial study were subjected to verification by seeking confirmation from process managers from a wide range of industries. The results could then be used during the second phase of the implementation process, to increase efficiency.

Svensson (2003) studied deficiencies in the process of theory generation in the field of supply chains management. The research approach was a review of previous studies. The deficiency in the process was found to be the narrow focus of research to a specific supply chain context, as opposed to a holistic approach to the study of supply chain management. This research saw the integration of concepts and frameworks from the marketing field to help address some of the deficiencies.

Longenecker *et al.* (2013a and 2013b) successfully identified deficiencies in the transformation processes of companies, and their sources, using multisource feedback methodology to conduct research. Kusumasari *et al.* (2010) investigated and identified resource capability deficiencies in a government institution, with regard to their operations during a natural disaster. The research approach was synthesis of information from various publications and the views of academics and experts. Using a similar research approach, Lee *et al.* (2005) was able to determine common deficiencies in potable water distribution systems, by reviewing available studies from developing countries. In their study, Myers (1971) had concluded that a significant number of deficiencies in business processes can be attributed to human involvement.

Maenetlja (2009) evaluated the communication integration process in a state-owned organisation to determine if there are deficiencies that exist. The study followed a qualitative approach, which included questionnaires and interviews, the use of a focus group, and content analysis. The study was able to meet its objective which was to identify the main deficiency in the integration of communication within the organization. Similarly, Tshibubudze (2013) conducted a critical assessment of the negotiating processes during procurement at

Eskom. Their study used content analysis as a research approach, and it was able to establish inefficiencies that existed in the negotiation processes.

2.5 CONCLUSION

It was evident in literature that the effort aimed at optimizing the operation of spare parts management was fragmented, with more research focused on the optimization of inventory control models using mathematical models (Rego *et al*., 2011 Gu, 2013 and Garg, 2013) and the optimization of supply chains (Masten *et al*., 2015; Sajadieh *et al*., 2015; and Choy *et al*., 2007). However, there was no existing research that had looked at inefficiencies in internal business processes in production facilities that result in the inefficiency of spare parts management. Such a study had never been undertaken in a South African production facility, and as a consequent, that became the focus of this research. The outcomes of this research will serve as a foundation for improving spare parts management practices in South African power stations. The results of the study will also be used in further research in the fields of power station asset management, business processes, inventory management, and supply chain management. In short, this chapter established that the answers to the research questions did not yet exist in the body of knowledge. Consequently, Chapter 3 presents the methods that were used in the development of the research methodology.

This space is left empty intentionally.

Please go to the next page

3. CHAPTER 3: RESEARCH DESIGN

3.1 INTRODUCTION

As already discussed in the preceding chapters, the focus of this research is the inefficiencies that exist in spare parts management. Consequently, this chapter presents elements of the research design that will be used to develop the methodology for discovering answers to the research questions. First, the chapter looks at the definition of research, and also the different research approaches. Secondly, the chapter presents the methods that were used in developing the research methodology. Furthermore, ethical considerations and the scope of the study are discussed. Finally, a conclusion to the discussions in the chapter is presented.

3.2 DEFINITION OF RESEARCH

Research is a logical and systematic search for new and useful information on a particular topic (Rajasekar *et al.*, 2013). Particularly, the aim of research is to find solutions to scientific and social problems. Thus, research is conducted through objective and systematic analysis. Consequently, this systematic way of solving problems is called research methodology (Saunders, 2009).

This research was aimed at solving an existing practical challenge. The study thus falls under the category of applied research (Krueger *et al.*, 2014), which can be either quantitative, qualitative or a mixture of both. Patently, quantitative research is concerned with the measurement of quantities, and its results are typically numbers and graphs. In contrast, qualitative research is non-numerical, it applies reasoning, and it is descriptive (Bowen, 2005; Allwood, 2011). Consequently, the results of an instance of qualitative research include the meaning, the feeling and the description of the situation (Saunders *et al.*, 2009).

3.3 RESEARCH APPROACH

The current study hopes to provide answers to the research questions presented in paragraph 1.6.

The research questions are reprinted below for easy reference.

1. What are the inefficiencies in the sub-processes of spare parts management in power stations?
2. What is the significance of the inefficiencies on the overall functioning of spare parts management, if inefficiencies exist?
3. What are the causes of the inefficiency in spare parts management, if any inefficiency exists?

4. How can spare parts management in South African power stations be improved?

This research is concerned with establishing the inefficiencies in the spare parts management processes in power stations in South Africa. Furthermore, the research is concerned with determining the causes of such inefficiency, and the impact of the inefficiencies on the provision of spare parts. Therefore, the desired outcome of the study is not only numerical; it is also descriptive. Therefore, this research benefits from the use of both qualitative and quantitative study methods; this was shown to be beneficial by Niglas (2000) and Bowen (2005). Consequently, this approach is known as the mixed method approach and it is the systematic integration of the quantitative and qualitative methods (Bryman, 2006; Wisdom *et al.*, 2013).

The use of the mixed method approach is justified in this research for these reasons; "complementarity" and "development" (Greene *et al.*, 1989), as the research will provide explanations to complement the numerical results. Therefore, the mixed approach ensures that the interpretation of data is grounded on the experiences of the participants, instead of the discretion of the researcher (Wisdom *et al.*, 2013; Niglas, 2000).

The data collection in the study was that of a sequential design (Driscoll *et al.*, 2007; Bryman, 2006). This was due to the fact that the study took place in three phases, where the first phase of the research was a qualitative approach which was used to identify, review and verify the business processes involved in spare parts management. The second phase of the study was both quantitative and qualitative study, where the identified business processes were analysed rigorously using reliability centred maintenance (RCM) tools, to identify inefficiencies and their sources. The third phase of the study focused on the development of a framework to improve spare parts management practices in South African power stations.

3.4 METHODS TO BE USED IN DEVELOPING THE RESEARCH METHODOLOGY

This paragraph lists, justifies, and clarifies the methods used in the design of the research methodology (chapter 4).

3.4.1 Sources

The scope of the study is the spare parts management in the 15 coal-fired power plants that belong to Eskom. However, the experiences of 2 of the 15 power stations, Medupi and Kusile, were not sought because the stations are still under commissioning. Therefore, the study only considered the operations in 13 power stations, and these are Hendrina, Arnot, Duvha, Komati, Camden, Matla, Kriel, Kendal, Grootvlei, Lethabo, Majuba, Tutuka, and

Matimba. Particularly, the data were collected from employees at these power stations, Eskom information centre, and from literature.

3.4.2 Population

The population considered were all employees that had a role, either as practitioners in, or as customers of, the spare parts management processes in Eskom coal-fired power stations. As a result, the population was comprised of employees from the following departments; senior management, engineering, maintenance department, outages management, procurement, materials management, and the production department.

3.4.3 Sample

All the role players in the management of spare parts in South African coal-fired stations organisation were of great importance to the study. However, it was unnecessary to include the whole population in the study. Therefore the data were collected from a selected sub-group, which represented the whole population.

There are two methods of sampling, namely probability sampling and non-probability sampling (Saunders *et al.*, 2009). Particularly, non-probability sampling allows researchers to select elements from the population that they are interested in studying (Saunders *et al.*, 2009). Herein, the subjective judgement of the researcher is used when selecting elements of interest to the study (Battaglia, 2011). Naturally, the judgement would be based on past experiences of the researcher, and knowledge gained from literature (Armoogum *et al.*, 2015). Therefore, purposive sampling becomes important as it allows for selection of units that provide more data, and allow for further analysis (Armoogum *et al.*, 2015).

The current research made use of purposive sampling when determining the sample for the study. This was due to the fact that the study was aimed at capturing the experiences of the maintenance role players in Eskom coal-fired power stations, as only they could offer insight into the operations of spare parts management processes.

Phung *et al.* (2015) stated that sampling errors can be minimised by selecting the correct sampling methods and the correct sample size. They further warned that there may be errors which can still occur despite the correct sample being selected. These errors arise from the conditions under which the data collection takes place. They argued that the person conducting the study must be able to relate to the participants; for example, by using the preferred language of the participants, as this can positively influence the mutual trust between the researcher and the participant. It is clear that the relationship between the interviewer and the participant will influence the response of the participant.

In this study, prior arrangement was made with the senior management of the utility to conduct the study and engage with the employees.
The researcher aimed to reach at least two (2) participants per power plant, which would amount to twenty-six (26) participants.

3.4.4 Measuring Instrument

The research is concerned with rigorous analysis of business processes involved in spare parts management in order to determine the sources of inefficiency. Below, the different tools that are used to conduct rigorous analysis of business processes are discussed. The method that is preferred for the present study is also discussed.

1) Flowchart

A flowchart is a diagram that represents a process. The process steps are depicted sequentially with arrows, indicating the inputs and outputs of each process step. The arrows indicate the flow of the process. Flowcharting was shown to be a useful tool in analysing business processes by Harrington (1991) and Aguilar-Saven (2004).

In their study, Budeli (2015) made use of flowcharting to model the quality management system followed during the maintenance and operation of conveyor belts in a power station. Ewulum (2008) used flowcharting in the development of a new maintenance strategy that was aimed at improving the availability of the plant in a power utility. Walker (2006) used flowcharting to model the supply chain in the supply of capital goods in South African state-owned companies. Their study was successful in determining the key constraints in realizing the intended goals of investments by state-owned enterprises in the capital goods sector. Mathobela (2009) used flowcharting in their study on the suitability of the existing technology in a power utility for procurement and inventory management.

Flowcharting is also used extensively in information systems when building programmes, to help with the visualisation of the process, debugging, and modification (Parsons *et al.*, 2015). Debugging refers to the identification and removal of errors from computer hardware and software (Technopedia, 2017). Therefore, flowcharting is a proven tool for reviewing and identifying deficiencies in processes.

2) Failure Mode and Effect Analysis (FMEA)

Reliability centred maintenance (RCM) analysis is used mostly on mechanical/physical systems. RCM is a methodology used to determine what needs to be done to ensure that a system continues to do whatever its users want it to do in its present operating context (Moubray, 1991). RCM is used to identify the policies that must be implemented to manage the failure modes that could cause the functional failure of a physical asset or a system in a given operating context (Smith *et al*., 2004).

RCM applies failure mode and effect analysis (FMEA) in order to determine the system boundaries, the interfaces, failure mode and criticality (McDermott *et al.*, 2008). In order to be effective, FMEA must be applied under normal conditions, abnormal conditions and emergency conditions (McDermott *et al.*, 2008). The function of FMEA is to identify process and product errors before they occur (Smith, 2016). The identification of the potential failures leads to the development of action plans to prevent these failures (Pascu *et al.*, 2016).

The application of FMEA is no longer limited to the analysis of physical systems and assets. FMEA is now applied to the process to identify errors and deficiencies, and it is called process FMEA (PFMEA). Aguiar *et al.* (2015) presented a structured way for defining the attributes of a process FMEA after studying the difference between the implementation of FMEA and the approach defined by ISO 9001.

Ookalkar *et al.* (2009) applied process FMEA in the medical field to improve the quality of a medical purification procedure. The analysis identified the requirements, causes of process failures and quantified the risk of each cause. This led to the development of actions that resulted in reduced process errors.

Similarly, Pascu *et al.* (2016) studied the assembly process of steel structures. The study was successful in identifying the causes of defects during assembly. The study further proposed improvements to the process and this included the provision of specific compliance welding. In their study, Parsana *et al.* (2014) reviewed and studied the manufacturing industry using process FMEA to enhance quality and efficiency. Puvanasvaran *et al.* (2014) also conducted a similar study in the manufacturing industry. Sanchez-Izquierdo-Riera *et al.* (2016) made use of process FMEA to identify deficiencies in a clinical process and use the results to improve the safety of patients.

Therefore, process failure mode and effect analysis is a proven method for the identification of potential failures in processes, the determination of the causes of the failure, the determination of the impact of the failures, and the development of solutions aimed at preventing such failures. This earned the method great respect in the medical field, where it is applied to improve medical processes (Sobral *et al.*, 2017)

3) Delphi Method

The Delphi method makes use of a panel of experts to solicit their opinions on specific issues (Hsu *et al.*, 2007). The facilitator of the study summarises the results of the different opinions and develop an anonymous report. Another round of the solicitation of the experts' opinions takes place, and the experts are encouraged to revise their earlier positions. The study is brought to a halt when there is convergence in the opinions of the experts, or after a predetermined number of rounds (Dalkey *et al.*, 1963; Delbecq *et al.*, 1975).The anonymity of the participants ensures that the opinion of some prominent participants does not outweigh the opinion of other participants. The facilitator also ensures that only important information is passed on to the next round.

The Delphi method is mostly used in instances of uncertainties. In such a case, the expert opinion is used to gain insight on issues in that particular field (Gordon, 2009). The Delphi method has become an accepted method of gathering data from respondents within their field of expertise. The aim of the method is to get convergence of opinion on a specific issue (Hsu *et al.*, 2007). The method improves the reliability of the research results by ensuring that far reaching conclusions are not drawn from results of a single survey. There is then confidence that if the study was to be repeated, consistent results would be obtained (Gordon, 2009).

There are no set limits on the number of iterations that should be done during a Delphi study (Skulmoski *et al.*, 2007). However, the experience of researchers shows that as little as three iterations may be enough to give consistent results (Gordon, 2009; Hsu *et al.*, 2007). During the first round of the Delphi study, an open ended questionnaire is used to solicit information from participants. The researcher then converts the results into an anonymous report, and develops a new questionnaire that will be used during the following Delphi round. Open-ended questions ensure the issue at hand is looked at from all the angles, especially in areas where there is limited literature or previous studies (Dalkey *et al.*, 1963).

In the second round of the Delphi study, the items from the first round of the study are listed. The items are then ranked according to their significance. Areas where there is agreement and areas of disagreement are noted. The experts who are part of the panel may be requested to provide reasons for their ranking of issues. In the third round, participants are encouraged to revise their positions in light of reasons highlighted by other panellists, or specify reasons why they are staying with their choices. Further clarification may be sought. If there is convergence of opinion, the study may be stopped (Dalkey *et al.*, 1963; Delbecq *et al.*, 1975).

The Delphi method is not only a data gathering method; it also distils the information that is being collected. The Delphi method ensures that only the essential meaning and the most important aspects are extracted from the experts (Skulmoski *et al.*, 2007). The Delphi method is appropriate where the problem does not lend itself to a precise analytical technique. Such a problem would benefit from the subjective judgement of experts in the particular field, as it would ensure that the most reliable consensus of opinion is obtained (Dalkey *et al.*, 1963; Delbecq *et al.*, 1975). Southard *et al.* (2011) presented a modified Delphi method that is used when conducting failure mode and effect analysis.

The number of participants that should form part of panel is not prescribed. However, it was determined that 10 to 15 participants are sufficient (Skulmoski *et al.*, 2007). It is believed that 45 days are sufficient to conduct the study (Skulmoski *et al.*, 2007). The background and the experience of the participants are of great importance during the selection of the panel (Gordon, 2009; Hsu *et al.*, 2007).

4) Preferred Instruments

This study made use of flowcharting and the Delphi method to identify, review and verify the business processes involved in the management of spare parts. The resulting model of spare parts management was presented as a flowchart, and the business processes were depicted in sequential order. All the inputs and outputs were highlighted on the flow chart. The model was then subjected to failure mode and effect analysis. The Delphi approach was used in this phase of the study.

3.4.5 Data Collection and Data Analysis

The failure mode and effect analysis was conducted iteratively over several rounds using the Delphi method. The initial FMEA was conducted by the researcher. A workbook containing the results of the initial FMEA was presented to the participants. The participants were requested to review the potential failures listed, and they were encouraged to add or remove what is not applicable. Furthermore, the participants were requested to input scores for severity of the impact of failures, occurrence of the causes of the failure, and the effectiveness of detection methods, as per the FMEA workbook provided. Finally, the participants were requested to add or remove any information in the FMEA workbook. The data from that round of the study was analysed by the researcher, and the workbook was updated accordingly. The revised workbook, which summarised the responses from the previous round, was sent out to the participants again. The process was repeated until there was convergence of responses or stability of the results from the research participants (Holey *et al.*, 2007). The process that was followed during the study is depicted graphically on the diagram in Figure 3.1 below. The results of the analysis were all potential failures in the business processes of spare parts management, the causes of the failures, and their ranking in terms of impact on the functioning of the spare parts management.

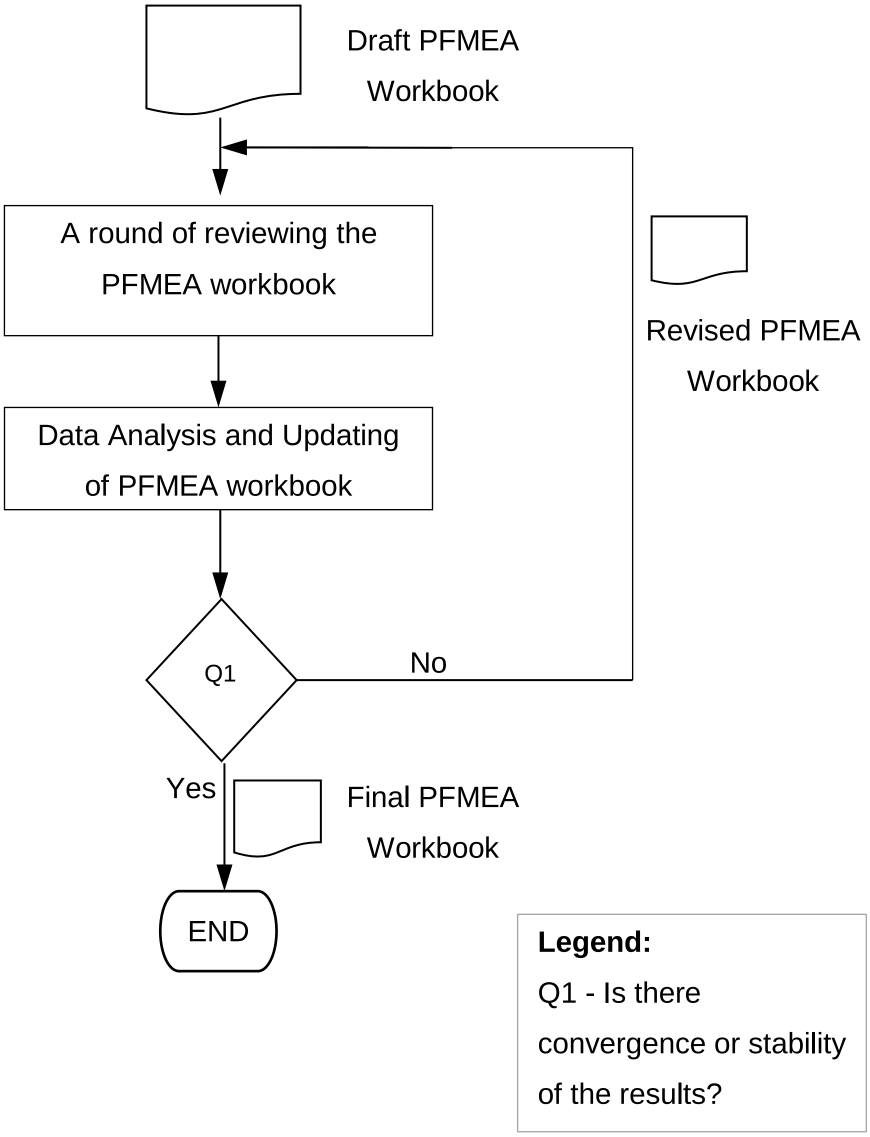


Figure 3.1: The Delphi rounds of analysis

3.4.6 Statistical Analysis

Due to the research approach, the data were collected over several rounds of the Delphi study. After each round of the Delphi study, the data were subjected to statistical analysis. The statistical analysis that was carried out is discussed in detail in the subsections below.

1) Measures of Central Tendency

Mean

To draw conclusions from data, it is useful to calculate averages. An average indicates the typical value of a set of data (Dekking *et al.*, 2005; Montgomery *et al.*, 2003). The mean is given by:

$$\bar{x} = \frac{\sum x_i}{N}$$

Where x_i is the value of the i^{th} member of the dataset

N total number of values

Median

The median divides a set of ordered data into two halves. The median is the middle number. To find the median number (Soong, 2004; Montgomery *et al.*, 2003):

- Put all the numbers in numerical order.
- If there is an odd number of numbers, the median is the middle number.
- If there is an even number of results, the median will be the mean of the two central numbers.

Given a set of n-ordered numbers, the median is thus given by (Soong, 2004; Montgomery *et al.*, 2003):

$$Median = \frac{(n+1)^{th}}{2} \quad value$$

Mode

The mode is the number which occurs most often in a set of data (Ross, 2004; Soong, 2004)

2) Measures of Spread Variability

Range

The range is the difference between the largest and the smallest observed values in a data set (Montgomery *et al.*, 2003).

Standard Deviation

The standard deviation is a quantity that shows by how much, the results differ from the mean. The standard deviation is given by (Dekking *et al.*, 2005):

$$\sigma = \sqrt{\frac{1}{N}\sum(x_i - \bar{x})^2}$$

Where x_i is the value of the i[th] member of the dataset

$\bar{x}$ is the mean

N is the total number of results

Semi-Interquartile Range

The interquartile range is given by the difference between the upper and lower quartiles (Q_3–Q_1) (Soong, 2004; Montgomery *et al.*, 2003). The interquartile range spans over half of a dataset, and it eliminates the influence of outliers because it removes the highest and the lowest quarters (Soong, 2004). Therefore, the semi-quartile range is a good measure of spread (Montgomery *et al.*, 2003). The formula for semi-quartile range is given by (Soong, 2004; Montgomery *et al.*, 2003):

$$SIQR = \frac{(Q_3 - Q_1)}{2}$$

Where Q_3 is the third quartile

Q_1 is the first quartile

3) Consensus and Stability Analysis

The Delphi study is stopped when there is convergence in the opinions of the experts, or after a predetermined number of rounds (Dalkey *et al.*, 1963; Delbecq *et al.*, 1975). Holey *et al.* (2007) presented the descriptive statistics and Kappa calculations that can be used to establish a move towards convergence and stability of the results in a Delphi study. The work of Holey *et al.* (2007) assists in determining when to terminate a Delphi study. The data analysis that must take place after each Delphi round includes the following (Holey *et al.*, 2007; Holloway *et al.*, 2002):

- Percentage response rates.
- Percentages for each level of agreement for each statement.
- Median and the semi-interquartile range.
- Mean and the standard deviation.
- Cohen's Kappa (K) values to compare chance-eliminated agreement between rounds.

Cohen's Kappa is given by (Cohen, 1960):

$$K = \frac{P_o - P_e}{1 - P_e}$$

Where P_o is the observed agreement

P_e is the chance agreement

After each round of the Delphi study, in order to establish a move towards consensus, the following should be observed (Holey *et al.*, 2007; Cohen, 1960):

- Increase in the Cohen's Kappa value.
- Convergence of range.

When the above has been observed, a Delphi study can be terminated.

3.4.7 Framework for Improving Spare Parts Management Practice

The Merriam-Webster dictionary defines a framework as the basic structure of something, or a set of ideas or facts that provide support for something. A framework can also be defined as a prescriptive set of activities to be done (Soni *et al.*, 2013). There is reasonable confusion between a model and a framework. However, a framework differs from a model in that a model represents something (Carroll, 1979), and it is an answer to the question "what is", while a framework represents a methodology to be followed to achieve a clear objective (Yusof *et al.*, 2000). Therefore, a framework provides an answer to the question 'how to" (Yusof *et al.*, 2000; Popper *et al*., 1994).

Frameworks have been used extensively to provide guidance in dealing with identified inefficiencies (Kathawala *et al*., 2003). In their study, Kathawala *et al.* (2003) investigated the performance of branches of a big firm, and identified inefficiencies. They then presented a framework that was aimed at increasing the effectiveness of the branches by improving the quality of the service rendered, while reducing the cost of operation. Similarly, Cavalieri *et al.* (2008) identified inefficiencies in the management of maintenance operations, and developed a framework to assist maintenance managers in decision-making.

It is evident that frameworks are a valid tool to provide guidance in the development of solutions to identified challenges. It is for this reason that a framework was used in the discovery of answers to Research question 4.

The framework that was developed was subjected to a review before it could be accepted as the final framework. In their study, Soni *et al.* (2013) maintain that a framework must meet the following criteria before it is considered a suitable framework:

- It must depict the complete structure of relationships between elements of the system under study and not just suggest elements comprising the system.
- It must describe steps/stages/sequence of activities which are required to be used for the designated purpose.
- It must describe the activities involved, which connects various elements of the framework.

Soni *et al.* (2003) further emphasised the importance of the verification of the suitability of the developed framework. For this purpose, the current research made use of purposive sampling to select a few representatives from the original sample to verify and validate the framework (Armoogum *et al.*, 2015).

3.5 ETHICAL CONSIDERATIONS

The following ethical considerations were applicable to the study:

- Written permission to conduct the study was obtained from the management of the power utility.
- The right to full disclosure about the research (informed consent). The purpose of the research was indicated and explained to each of the research participants.
- Participation in the research was totally voluntary. The participants were not forced in whatever way to participate in the research.
- The right to anonymity and confidentiality. Information about the participants was not mentioned in this study. The participants were addressed using a code (i.e. participant 1, 2, etc.)
- The right not to be harmed in any manner (physically, psychologically or emotionally). Research questions and purpose of the study were communicated to the research participants, and participants could choose to stop their participation in the study at any given time. The participants were free to not answer questions that they were not comfortable with.

The researcher confirms and agrees that the above considerations were adhered to during the research. The researcher also confirmed that the information gathered during the research would not be used outside of the University of Pretoria, and it would not be used for anything else other than research purposes.

3.6 SCOPE OF THE STUDY

The study was conducted primarily at 13 of Eskom's coal-fired power stations. The study was aimed at establishing the inefficiencies that exist in spare parts management processes of power plants in South Africa, and the causes of the inefficiencies, with the purpose of seeking solutions for such deficiencies. The study was conducted in coal-fired power plants in South Africa, belonging to Eskom, which are representative of all power plants in South Africa.

Below, the limitations of the study and the imperfections of the research itself are highlighted:

- The research participants might have wrongly understood and incorrectly interpreted some of the concepts related to spare parts management. This could distort the results.
- The researcher is an employee at one of the power plants where the research was conducted. This might have negatively or positively influenced the interpretation of certain results of the study.
- The study was conducted at 13 of Eskom owned coal-fired power stations. The applicability of the research findings may thus be limited to Eskom coal-fired power stations.
- The researcher did not have access to financial reports of the power plants which would give accurate costs associated with the management of spare parts. Therefore, the significance of the spare parts management process, and the severity of the inefficiencies, could only be inferred from the experiences of the research participants and from literature.
- The target sample of the study was 26 participants who work at the power stations. There could have been unwillingness to participate by some of the maintenance stakeholders, and therefore their experiences would not influence the outcomes of the study.

3.7 CONCLUSION

The chapter introduced the different approaches to research. It was established that this study intended to analyse the spare parts management process and to determine inefficiencies that exist in the process. It was concluded that a mixed approach would be more suitable for the study. This entailed the use of flowcharting, the Delphi method and failure mode and effect analysis. Statistical analysis was also conducted to confirm the validity of the results. Purposive sampling was used to determine the sample, in order to provide the study with relevant results. The study benefited from the approach by having quantified results and detailed explanations for the occurrences of phenomena.

4. CHAPTER 4: RESEARCH METHODOLOGY

4.1 INTRODUCTION

The preceding chapters elucidated that the current research is concerned with uncovering inefficiencies that exist in spare parts management, and the causes of these inefficiencies. This is done so that recommendations on how to improve spare parts management can be made. It is for these reasons that Chapter 3 presented elements of the study design that were used to develop the methodology for discovering answers to the research questions. This methodology is presented in detail in this chapter. The chapter starts by presenting an overview of the methodology. This is followed by detailed descriptions of the different phases of the methodology, which are; the development of the spare parts management model, the failure mode and effect analysis, and the development of a framework to improve spare parts management. The chapter is finally brought to a close with a conclusion.

4.2 OVERVIEW OF THE METHODOLOGY

In order to meet all the objectives of the research, the data collection and analysis was done in three phases. Figure 4.1 below shows the overview of the methodology. The subsequent paragraphs 4.3, 4.4 and 4.5, discuss in detail the activities in each phase of the study.

This space is left empty intentionally.

Please go to the next page

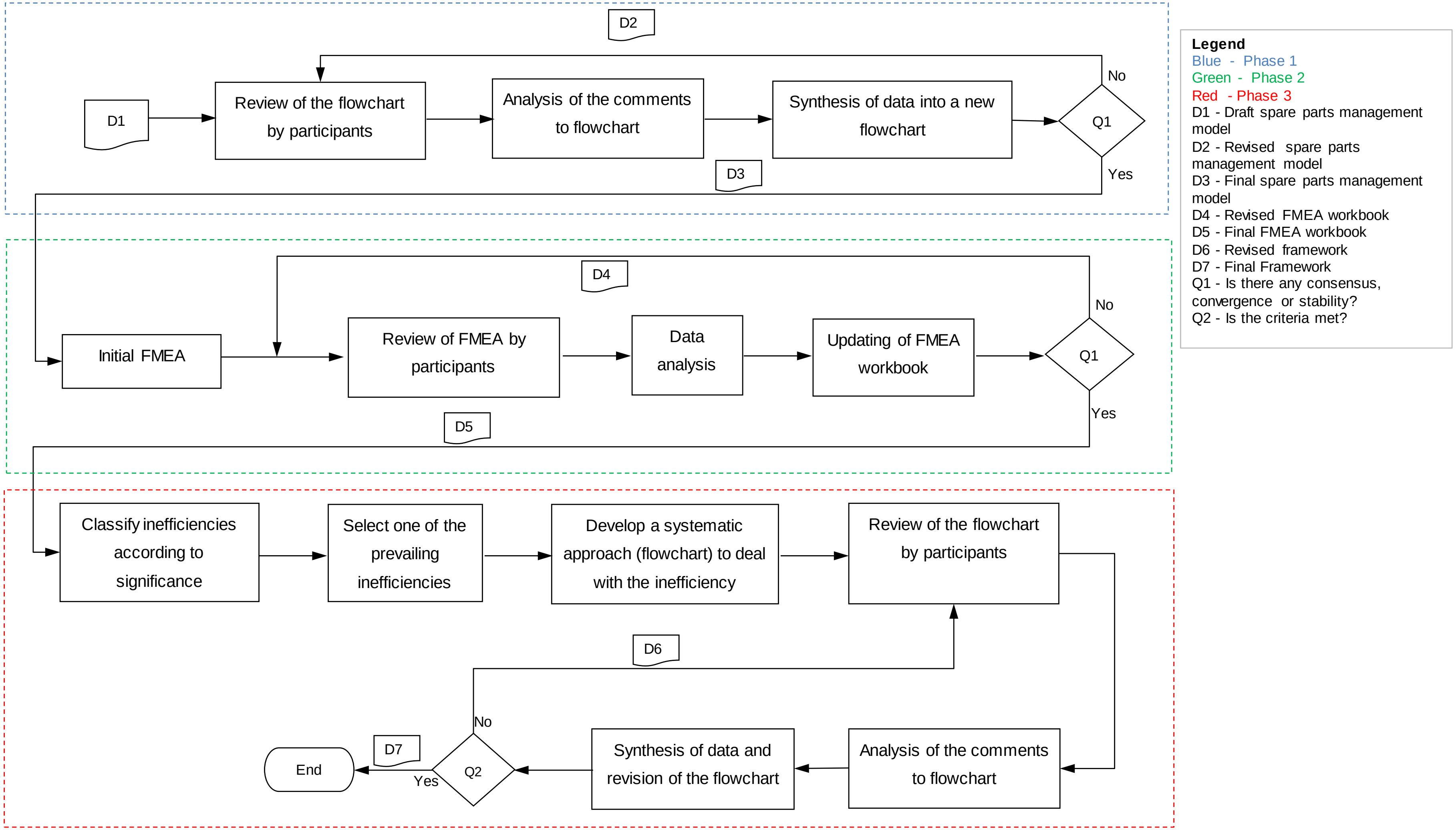


Figure 4.1: Overview of the research methodology

4.3 REVIEW OF THE ESKOM SPARE PARTS MANAGEMENT PROCESS

The steps below were followed when reviewing the present spare parts management process in Eskom power stations to identify the internal business processes involved:

1. The researcher developed the initial flow chart based on observation, literature, and Eskom manuals. This is shown in Appendix B.
2. The flow chart was given to the research participants, and they were encouraged to add or remove sub-processes steps in the flowchart, and to change the sequencing of the sub-processes.
3. The results were received from the participants, and they were reviewed and then synthesised into a new flowchart by the researcher.
4. The new flowchart was sent to participants again, and they were encouraged to add or remove sub-processes in the model, and to change the sequencing of the business processes. The participants were also requested to provide reasons for either making changes to the flow chart, or not making changes.
5. The results were again received by the researcher, and they were analysed and synthesized into a new flowchart.
6. The study was terminated when the results showed convergence or stability. The resulting flowchart was then adopted as the spare parts management model.
   In contrast, steps 1 to 5 were repeated where the results did not show convergence or stability.

4.4 PROCESS FAILURE MODE AND EFFECT ANALYSIS

The spare parts management model that was agreed upon using the process expounded in paragraph 4.2 was subjected to the modified process failure mode and effect analysis (PFMEA) over several Delphi rounds. Below is the thinking behind the modification of the standard FMEA for use in the analysis of the business processes:

4.4.1 Initial Analysis

The following steps were followed by the researcher during the initial analysis of the spare parts management model:

1. Consider business process X.(process X is the sub-process of spare parts management under review)
2. Identify all the elements and activities involved during the execution of business process X. Consult literature, and Eskom manuals and procedures.
3. Identify the different ways in which each element can fail.
4. Identify the effect of the failure of each element.

5. Identify the possible causes of each failure in each element.
6. Identify the possible control measures to prevent each of the causes.
7. Group the effects of failures into categories. These categories will then be captured as the failure modes of business process X in the FMEA workbook.
8. Group the causes of failures into categories. These categories will then be captured as the potential causes of failures of business process X in the FMEA workbook.
9. Group the control measures for the causes of failures into categories. These categories will then be captured as the process control measures of business process X in the FMEA workbook. This initial workbook is shown in Appendix C.
10. Repeat steps 1 to 9 for all sub-processes of spare parts management.

4.4.2 FMEA using the Delphi Approach

The steps that were followed during the Delphi study are presented below:

1. The FMEA workbook from paragraph 4.4.1 was sent to the research participants and the participants were requested to input the following information:
    a. List all potential effects of each failure mode. Participants can add other failure modes that were not identified in paragraph 4.4.1.
    b. Assign a severity ranking for each effect. The scale of severity is from 1 to 10, where (Juran, 2017):
        - 1 – insignificant
        - 10 – catastrophic
    c. For all the potential root causes identified in paragraph 4.4.1, assign an occurrence ranking for each cause. Participants can add other causes that were not identified in 4.4.1. The following scale of likelihood is from 1 to 10, where (Juran, 2017):
        - 1 – highly unlikely
        - 10 – inevitable
    d. For all the process controls identified in paragraph 4.4.1, assign a detection ranking for control. This estimates how well the controls detect the cause or the failure mode, before the whole system fails. Participants can add other controls that were not identified in paragraph 4.4.1. The scale for detection is from 1 to 10, where (Juran, 2017):
        - 1 – The controls will detect the cause or the failure mode with certainty
        - 10 – there are no effective controls
2. The data was analysed using statistics. The following statistics was determined:
    - Mean

- Median
- Standard deviation
- Semi-interquartile range
- Cohen's Kappa value (only applicable after the second Delphi round)

3. The data was synthesized and was summarised in a revised workbook.
4. The workbook was sent out to participants again, for input of information requested in 1 a. to 1 d. The participants were encouraged to revise their earlier rankings, and to provide reasons for their choices.
5. When convergence of results was observed, or stability of the results between Delphi rounds was observed, this phase of the research was terminated, and the determined statistical values were taken as the final results. When there was no convergence or stability of the results, the steps were repeated from 1 to 4.
6. The risk priority number (RPN) was then determined. The RPN was given by (McDermott *et al.*, 2008):

$$RPN = Mean\ Severity \times Mean\ Occurrence \times Mean\ Detection$$

4.5 DEVELOPMENT OF A FRAMEWORK FOR IMPROVING SPARE PARTS MANAGEMENT PRACTICE

This section presents the method that was used in the development of the framework for improving the management of spare parts. The following steps were followed during the development of the framework:

1. Study the identified inefficiencies of the spare parts management processes.
2. Select process X, where process X is a sub-process of spare parts management, with identified inefficiencies and causes.
3. Use a flowchart to show how the identified inefficiencies can be managed; through elimination of root cause, detection of cause/failure, and minimization of impact.
4. Circulate the flowchart to a selected group from the original research sample, and ask them to review the flow chart using the framework criteria adapted from Soni *et al*. (2013); the criteria being as follows:
   a. Does the flowchart describe all the elements of improving spare parts management?
   b. Does the flowchart indicate the relationship between all the elements involved in the improvement of spare parts management?
   c. Is the process described by the flowchart practical?

When all the above questions are answered satisfactorily, then the flowchart can be considered to be suitable, otherwise, take note of the comments from the research participants, and modify the flowchart to ensure that all concerns are addressed. Circulate the flowchart to the same group again, for them to review. Repeat step 4 until there are no further concerns from the participants.

5. When all the concerns raised by the selected sample are addressed, present the final flowchart as the framework, and briefly describe the individual elements.

4.6 CONCLUSION

The chapter presented in detail the steps that were followed in the discovery of answers to the research questions. The purpose of the chapter was to ensure that the research problem is well-understood, and the overall purpose of the study is also well-understood, by presenting a detailed methodology that will be able to bring about the answers to the research questions. The presented methodology ensures that all the sub-processes of spare parts management are subjected to rigorous analysis. In doing this, the methodology ensures that all possible inefficiencies in the sub-processes are identified. Furthermore, the methodology classifies the inefficiencies according to significance in order to guide any effort that may be taken towards improving spare parts management. Finally, the methodology considers a systematic approach towards improving spare parts management. Thus in summary, the methodology ensures that the study meets its objectives. Chapter 5 presents the findings of the study that was undertaken under strict adherence to the methodology presented in this chapter.

This space is left empty intentionally.
Please go to the next page.

5. CHAPTER 5: RESEARCH RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

The end-goal of this research was to make recommendations to improve spare parts management in South African power stations. In order to achieve this, the study first embarked on a process of reviewing the spare parts management in the stations to determine the inefficiencies that exist and their sources. Furthermore, the study embarked on a process of developing a solution to improve spare parts management, in light of the inefficiencies that were identified. The methodology that was followed was presented in Chapters 3 and 4. The purpose of the current chapter is thus then to explain and discuss the findings of the study.

The chapter first presents the biographical composition of the sample. Secondly, the spare parts management model which shows, in high level, the business processes (sub-processes) involved in spare parts management is presented. Next, the results of the failure mode and effect analysis are presented. This is followed by a discussion of the most important findings from the failure mode and effect analysis. Further, the chapter presents the framework for improving spare parts management practices. Finally, a conclusion to the matters arose in the chapter is presented

5.2 BIOGRAPHICAL COMPOSITION

The study was conducted at 13 of Eskom’s coal-fired power stations. Permission to conduct the study was sought, and it was granted as shown by an example for one power station in Appendix A. The biographical composition in the study shows the power stations where the participants are stationed, departments where the participants work, their designations, and the number of years of experience.

As discussed in paragraph 3.4.3, purposive sampling was used when determining the sample of the research. This means that the sample was selected such that there is relatively equal representation per power station, department, designation, and experience group.

5.2.1 Power Station

Below, the distribution of the sample of participants according to the power plant where the participants are stationed is discussed. See Figure 5.1 for the graphical representation of the composition of the sample.

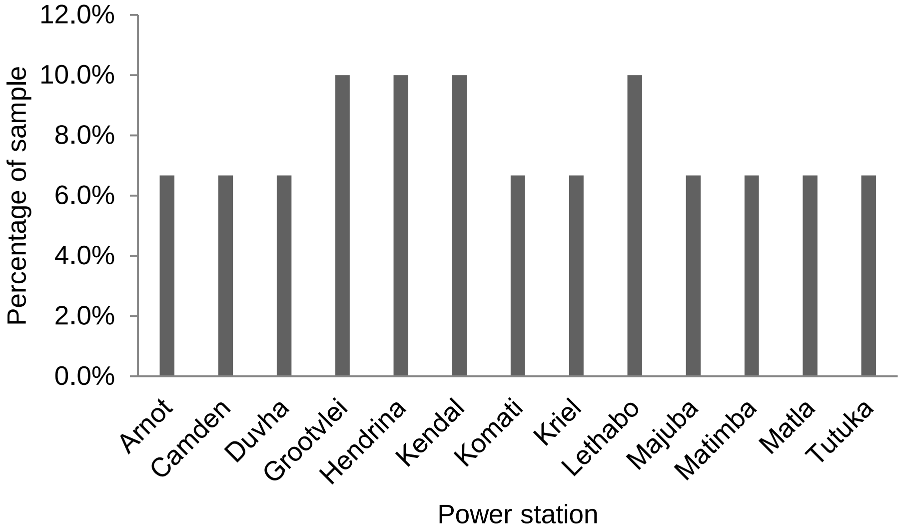


Figure 5.1: Distribution of the sample participants according to power station

A total of 30 participants took part in the study. The average number of participants per power station was 2.3. The number of participants per station ranged between 2 and 3. From Figure 5.1, it can be seen that 9 out of 13 power stations had 6.7% representation each, while 4 out of 13 had 10% representation each.

5.2.2 Department

The distribution of the sample according to departments where the participants worked is discussed below. See Figure 5.2 for the graphical depiction of the distribution.

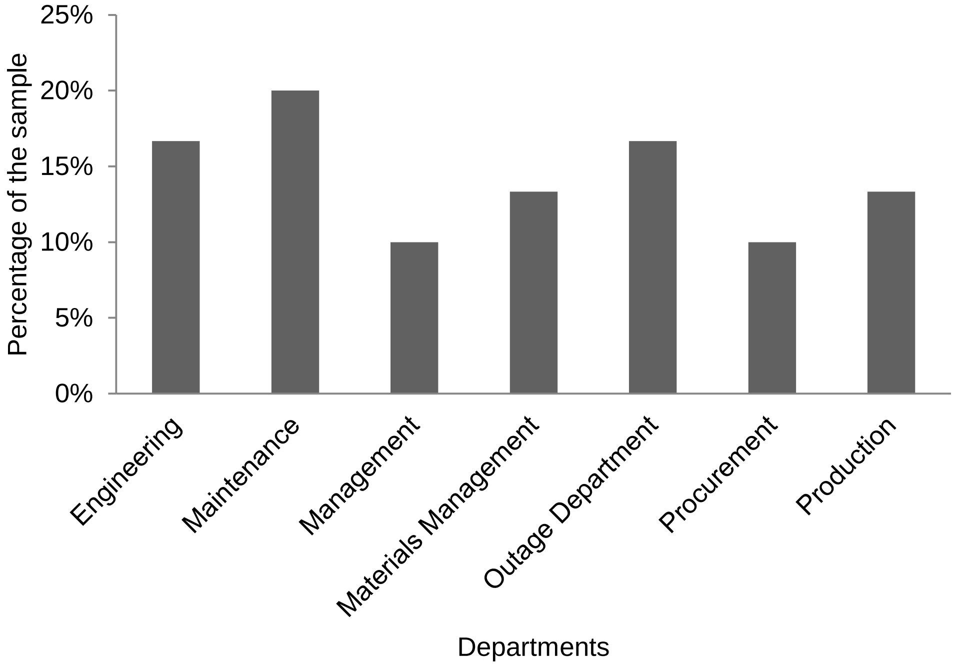


Figure 5.2: Distribution of sample of participants per department

A total of 30 participants took part in the study. The average number of participants per department plant was 4.3. The number of participants ranged between 3 and 6. From Figure 5.2, it can be seen the maintenance department had the most representation, at 20%, followed by the engineering and the outage departments with a representation of 16.7% each. The production and the materials management departments contributed to 13.3% of the participants each, while the procurement department and senior management had the least representation, at 10% contribution each.

5.2.3 Designation

The composition of the research participants according to the designation of participants is discussed below. This distribution is shown graphically in Figure 5.3.

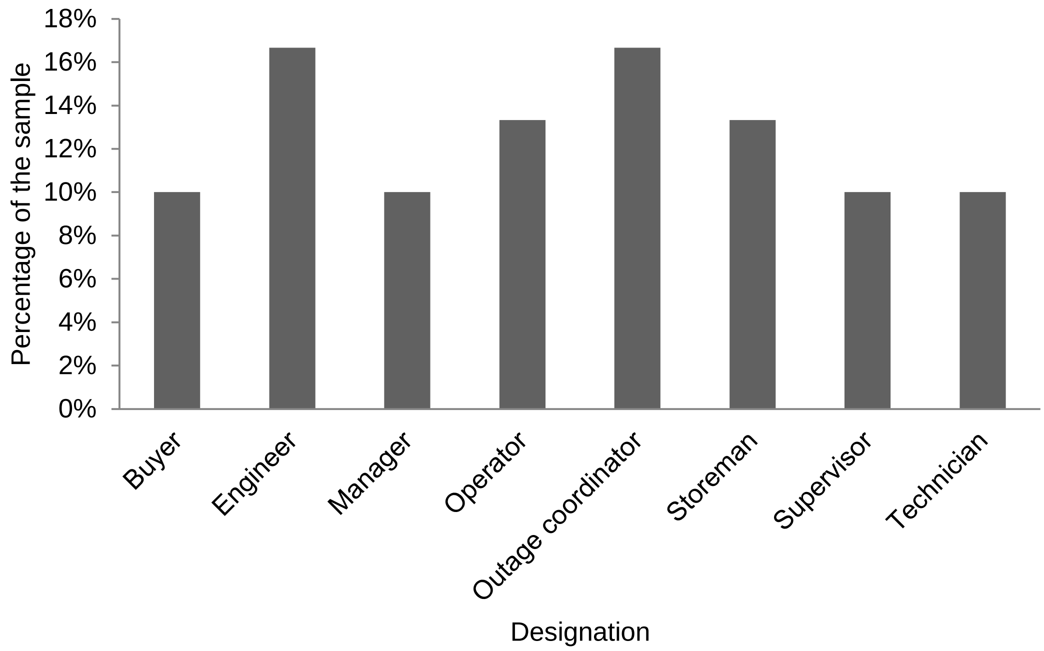


Figure 5.3: Distribution of sample of participants by designation

A total of 30 participants took part in the study. The average number of participants per designation was 3.75. The number of participants ranged between 3 and 5. From Figure 5.3, it can be seen that engineers and outage coordinators had the biggest representation, at 16.7% each, followed by storemen and operators at 13.3% representation each. Buyers, managers, supervisors and technicians had 10% representation each.

5.2.4 Years of Experience

The composition of the sample according to the years of experience is discussed below. Figure 5.4 depicts the distribution of the sample graphically.

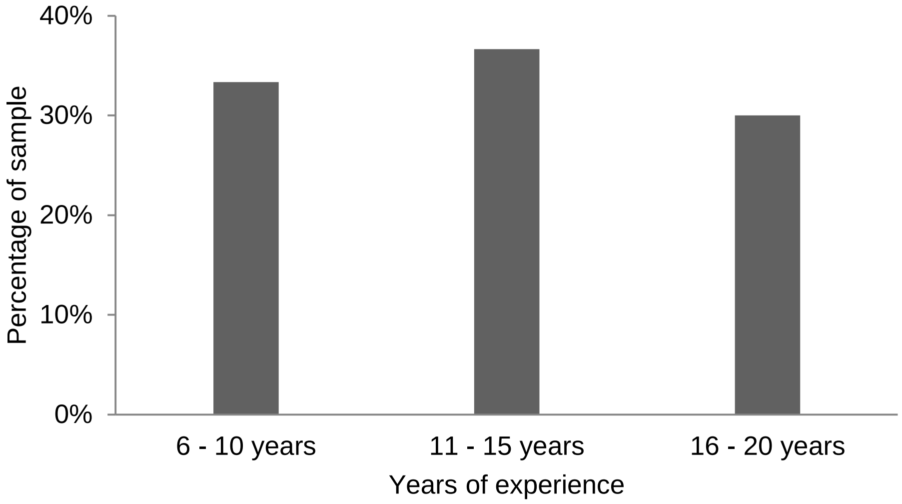


Figure 5.4: Distribution of sample of participants according to years of experience

In order to get insight on the inefficiencies that exist in spare parts management, participants with more than 5 years of experience in power plants were actively sought (Armoogum *et al.*, 2015). The years of experience were divided into three groups; 6 to 10 years of experience, 11 to 15 years of experience, and 16 to 20 years of experience. A total of 30 participants took part in the study. Thus, the average number of participants per experience group was 10. The experience group with the most representation was the 11 to 15 years group, with 11 participants, which contributed to 36.7% of the participants. The 6 to 10 years of experience group had 33% representation, while the 16 to 20 years of experience group had 30% representation.

5.3 SPARE PARTS MANAGEMENT MODEL

The first step of the study was to review spare parts management in power stations to establish convergence of expert opinion on the business processes involved in spare parts management. The study followed a Delphi process which was discussed in paragraph 4.2.1. An initial spare parts management model was developed (see Appendix B), and the model was subjected to rounds of the Delphi method, for review and verification. Convergence on the sequencing of the business processes was achieved after three rounds of the Delphi process. The model was sent to participants for the fourth round, and stability of the results was observed by noting the absence of comments or changes on the flowchart that was submitted in this round. Figure 5.5 depicts the spare parts management model.

In the model, two main branches can be observed, and these are the maintenance branch, and the outage branch. The results revealed that the execution of maintenance in power stations took place under two different settings. There is day-to-day preventive and corrective maintenance, and there is maintenance that takes place when a unit is put on outage. The maintenance branch is for management of spare parts for day-to-day preventive and corrective maintenance, while the outage branch is for the management of spare parts for major shutdowns.

The model consisted of high level sub-processes of spare parts management. However, during the analysis, the sub-processes were broken into their elementary activities in order to determine any inefficiency that may exist. Thus the rigorous analysis went to granular details of each sub-process, and this is illustrated in paragraph 5.4.1 below.

This space is left empty intentionally.

Please go to the next page.

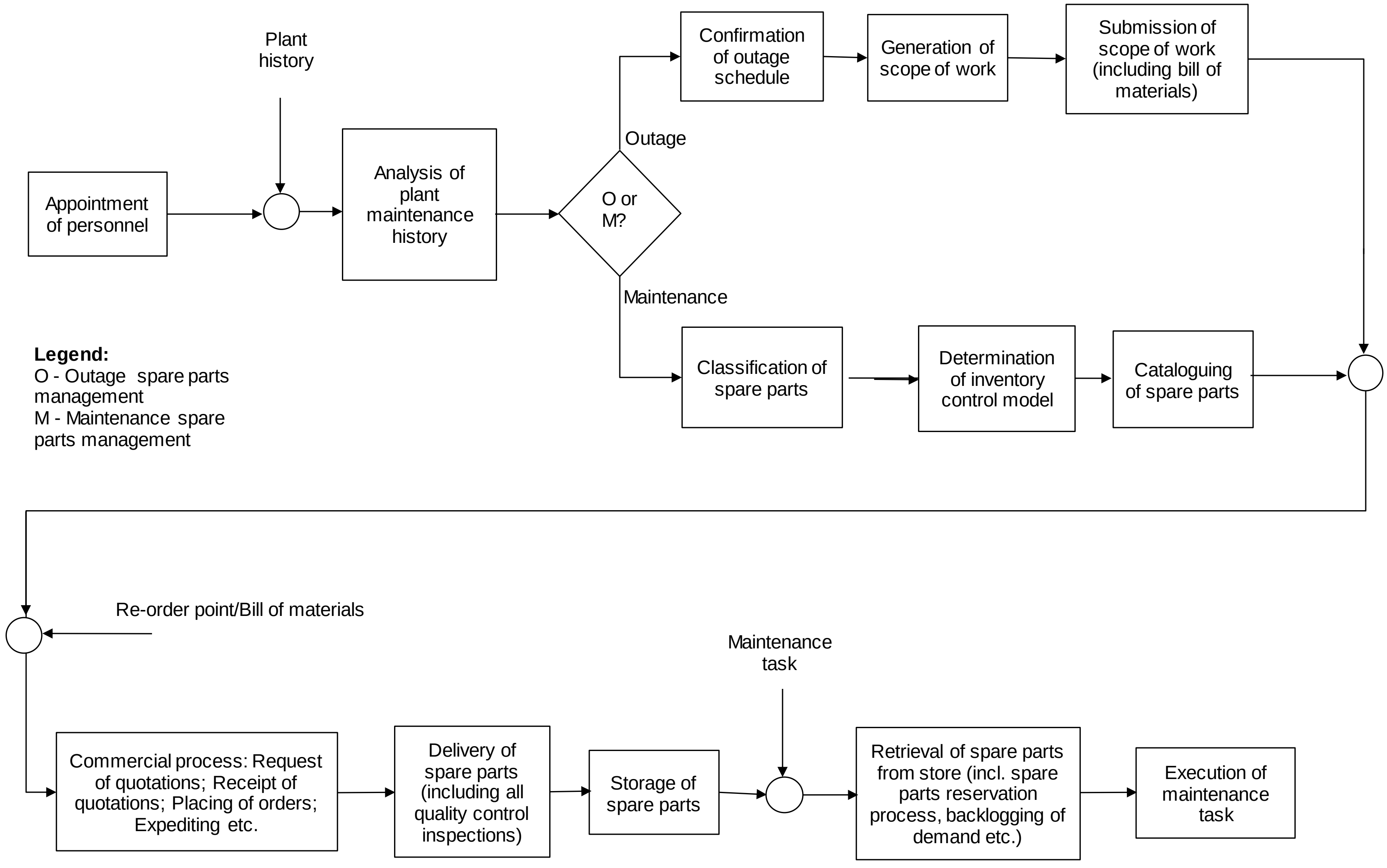


Figure 5.5: High level spare parts management model

5.4 FAILURE MODE AND EFFECT ANALYSIS

The spare parts management model was subjected to failure mode and effect analysis, through three rounds of the Delphi method. In paragraph 2.3 it was stated that the function of the spare parts management system is to ensure that the correct spare parts, in the required quantities, are available during the execution of maintenance tasks. This was to be done in a cost-effective manner. Therefore the functional failures of spare parts management are related to:

- Unavailability of spare parts
- Proliferation of spare parts
- Poor quality of spare parts
- High inventory management costs

The analysis of the sub-process of spare parts management was thus focused on inefficiencies that lead to the above functional failures. The subsections below summarise the results of the failure mode and effect analysis.

5.4.1 Sample Analysis – Appointment of Personnel

The spare parts management model is comprised of thirteen sub-processes. This section shows how the business processes were analysed by discussing in detail the analysis of one business process.

The first sub-process in spare parts management is concerned with the appointment of relevant stakeholders to positions within maintenance. In order to determine the basic activities that constitute this sub-process, the Eskom Information Centre and literature databases mentioned in Chapter 2 were searched for recruitment procedures and related literature. As a result, the activities that were considered in the analysis of this sub-process were informed by procedures and literature such as that by Mashaba *et al.* (2017), Panday *et al.* (2014), Miles *et al.* (1984), Bartlett *et al.* (2002), and Berman *et al.* (2013). These activities were rigorously analysed in order to determine the impact of their performance on the successful operation of the ‘appointment of personnel’ business process. Table 5.1 shows the detail of the sub-process.

This space is left empty intentionally.

Please go to the next page.

Table 5.1: Details of the ‘appointment of personnel’ sub-process.

Steps	Activities	Effect of Failure	Causes
Need identification	Review of organogram; Identification of open gaps.	No appointment; Delays in appointment.	Human involvement; Non-adherence to procedure.
Sourcing	Advertise post / Consultation of agencies / Review of bursar list.	Delays in appointment; No appointment	Budget constraints; Non-adherence to procedure.
Screening	Review of CVs; Shortlisting	Appointment of unsuitable candidate; Delays in appointment; No appointment	Inadequate procedures; Incompetence; Human involvement.
Evaluation	Interviews; Candidate selection	Delays in appointment; Appointment of unsuitable person.	Human involvement; Non-adherence to procedure
Joining	Induction; Briefing; Handover of previous work; Access to relevant tools	Unpreparedness of new employee	Non-adherence to procedure; Poor talent management; Lack of procedures

The effects of failure at each process step on the successful operation of the sub-process ‘appointment of personnel’ are:

- Delays in appointment.
- No appointment.
- Appointment of unsuitable candidates.
- Unpreparedness of new employee.

These effects were then considered as the failure modes of the sub-process, when the sub-process was subjected to failure mode and effect analysis (FMEA). Further rigorous analysis of the sub-process ensured that the effects of each of these failure modes on the overall spare parts management are determined, and also that the causes of the failures, and the existing control measures are determined. The quantification of the severity of effect, the frequency of occurrence of the failure cause, and the effectiveness of the existing control measures, was done through three Delphi rounds. In order to establish a move towards convergence, the range of the results and Cohen’s kappa values were monitored, as per Holey *et al.* (2007). Hence the standard deviation, the semi-interquartile range, and Cohen’s Kappa values were determined in each round. As discussed in paragraph 3.4.6, Cohen’s

Kappa values were determined by comparing data between two Delphi rounds. A move towards convergence was established by noting a decrease in the standard deviation and the semi-interquartile range from round 1 to round 3. Furthermore, an increase of Cohen's kappa value was observed through the Delphi rounds. See Figure 5.6 below for an illustration of the evolution of consensus, which indicates the evolution of consensus for the severity of impact of the failure effect 'no execution of work'.

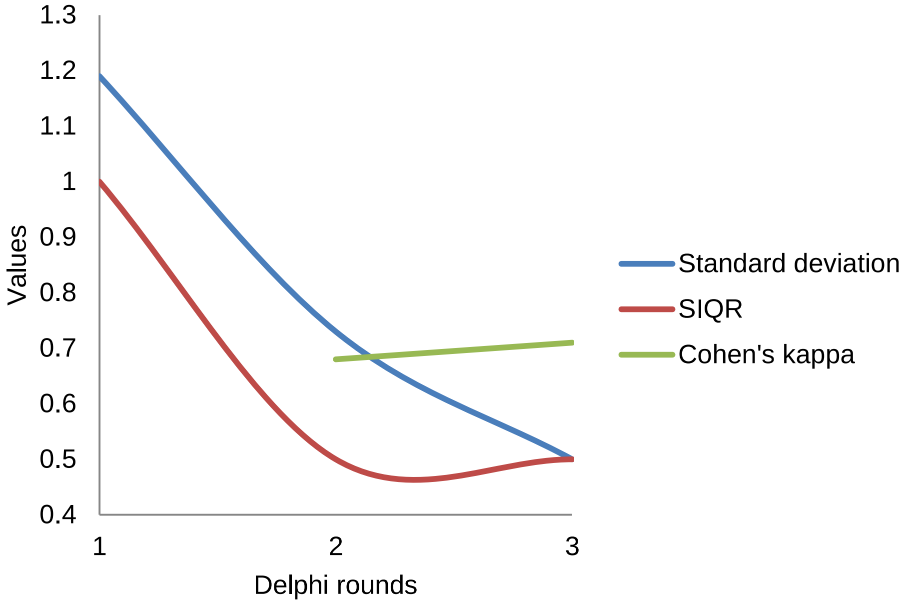


Figure 5.6: The evolution of consensus - severity of 'no execution of work'

The data from the third round were thus accepted as the final results of the analysis of this sub-process. The risk priority number of each of the potential failure modes was then determined. Table 5.2 shows the full results of the rigorous analysis of the 'appointment of personnel' sub-process. This analysis was repeated for all the sub-processes in the spare parts management model. Accordingly, the results of the analysis are shown in Appendix D.

This space is left empty intentionally.

Please go to the next page.

Table 5.2: FMEA - Appointment of personnel.

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Appointment of personnel	No Appointments	No execution of work	1	8.80	9	1.19	1.00		Inadequate management procedures	5.23	5	1.19	0.50		None	10.00	10	0.00	0.00		461
			2	9.23	9	0.73	0.50	0.68		5.27	5	0.83	0.50	0.54		10.00	10	0.00	0.00	1.00	486
			3	9.40	9	0.50	0.50	0.71		5.37	5	0.72	0.50	0.82		10.00	10	0.00	0.00	-	504
			1	8.80	9	1.19	1.00		Budget constraints	5.23	5	1.19	0.50		None	10.00	10	0.00	0.00		461
			2	9.23	9	0.73	0.50	0.68		5.30	5	0.84	0.50	0.58		10.00	10	0.00	0.00	1.00	489
			3	9.40	9	0.50	0.50	0.71		5.40	5	0.72	0.50	0.83		10.00	10	0.00	0.00	-	508
	Delays in appointment	Delays in the execution of work	1	8.20	8	0.76	0.50		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		234
			2	8.43	8	0.50	0.50	0.67		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	210
			3	8.40	8	0.50	0.50	0.93		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	188
			1	8.20	8	0.76	0.50		Non-adherence to procedures	5.27	5	1.05	0.50		None	10.00	10	0.00	0.00		432
			2	8.43	8	0.50	0.50	0.67		5.27	5	0.83	0.50	0.58		10.00	10	0.00	0.00	1.00	444
			3	8.40	8	0.50	0.50	0.93		5.30	5	0.79	0.50	0.94		10.00	10	0.00	0.00	-	445
	Appointment of unsuitable candidates	Ineffectiveness in the execution of maintenance work	1	8.80	9	1.19	1.00		Non-adherence to recruitment process procedures	5.27	5	1.05	0.50		None	10.00	10	0.00	0.00		463
			2	9.23	9	0.73	0.50	0.68		5.27	5	0.83	0.50	0.58		10.00	10	0.00	0.00	1.00	486
			3	9.37	9	0.56	0.50	0.77		5.30	5	0.79	0.50	0.94		10.00	10	0.00	0.00	-	496
	Unpreparedness of new appointees.	Poor execution of work	1	8.20	8	0.76	0.50		Non-adherence to recruitment process procedures	5.27	5	1.05	0.50		None	10.00	10	0.00	0.00		432
			2	8.47	8	0.51	0.50	0.67		5.27	5	0.83	0.50	0.58		10.00	10	0.00	0.00	1.00	446
			3	8.50	9	0.51	0.50	0.93		5.30	5	0.79	0.50	0.94		10.00	10	0.00	0.00	-	451

Legend:

SEV = Severity of the effect

OCC = Frequency of occurrence of the cause

DET = Effectiveness of the specific process control to detect failure/cause

S.D. = Standard deviation

SIQR = Semi-interquartile range

5.4.2 Failure Modes

The analysis of the spare parts management model identified 36 prevalent failure modes. The results of the failure mode and effect analysis recognised the top failure modes depending on severity rate, and frequency of occurrence of their causes. The top ten failure modes according to severity and frequency are shown in Figures 5.7 and 5.8, respectively. The failure to generate outage scope of work, and the failure to submit scopes of work were identified as the top failure modes according to the severity of their impact on spare parts management. The lack of delivery, and delayed deliveries of spare parts were identified as the top failure modes in terms of the frequency occurrence of their causes.

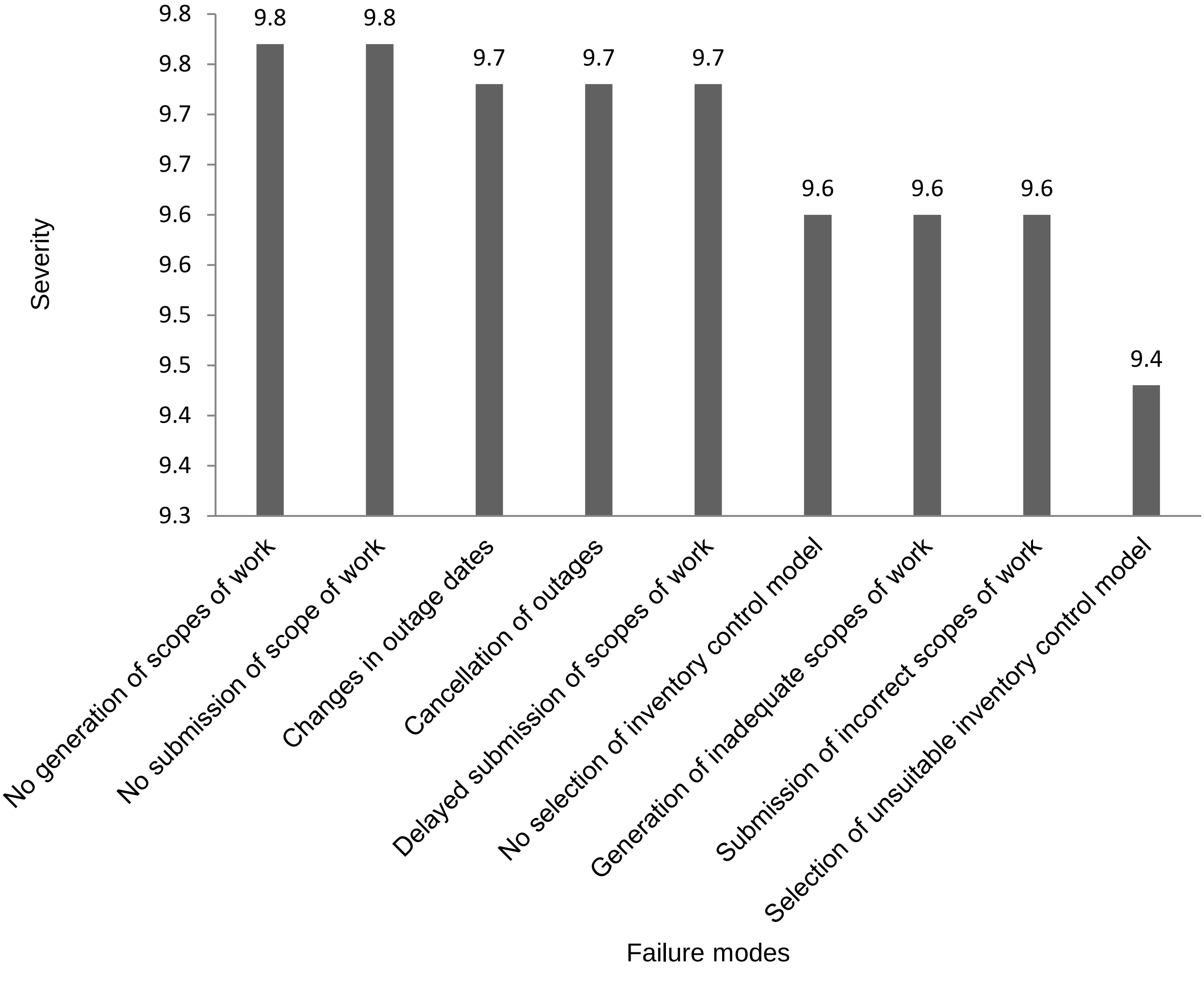


Figure 5.7: Graph of top 10 failure modes according to severity

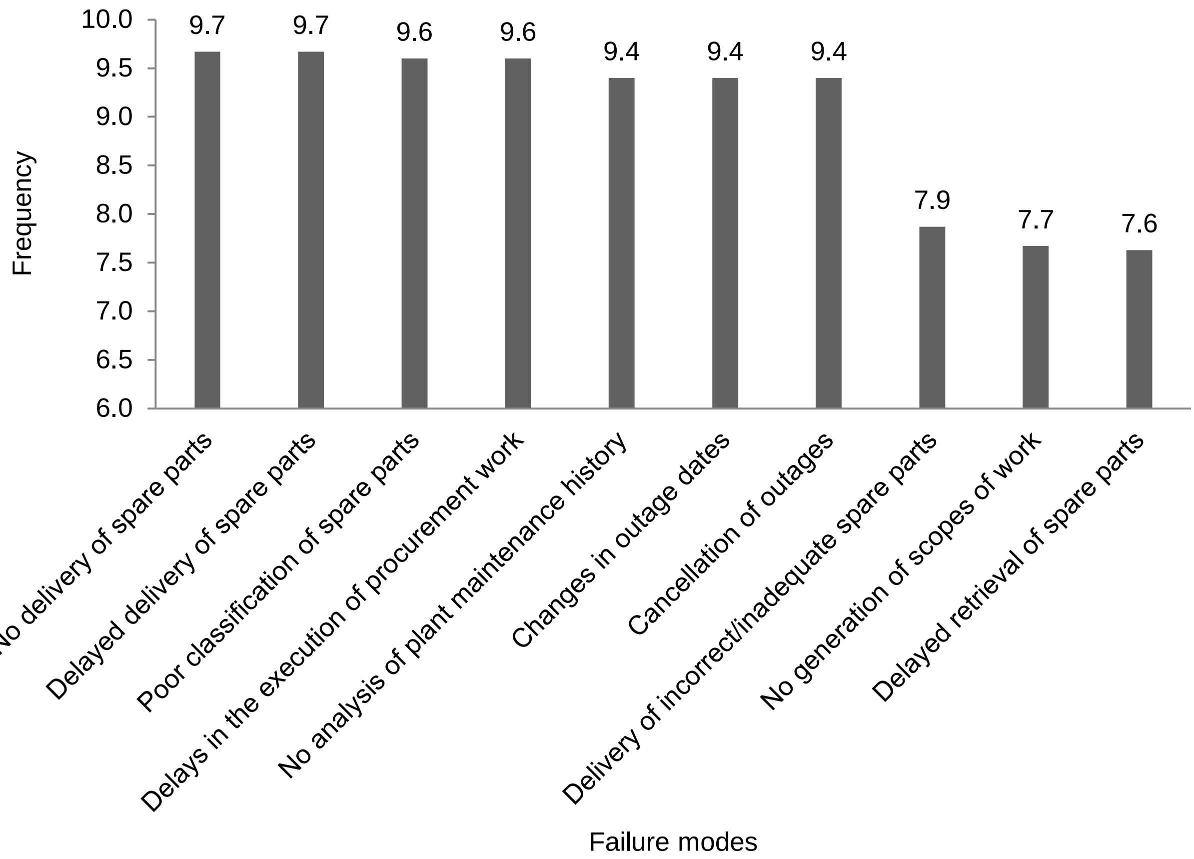


Figure 5.8: Graph of top 10 failure modes according to frequency

The top failure modes were also classified according to the effectiveness of the existing control measures to detect or prevent the cause of the failure. This was taken into account by determining the risk priority number (RPN). Accordingly, Figure 5.9 shows the top ten failure modes according to their risk rating. Markedly, the failure to analyse maintenance history was identified as the top failure mode. The remainder of the failure modes are shown in FMEA tables in Appendix D.

This space is left empty intentionally.

Please go to the next page.

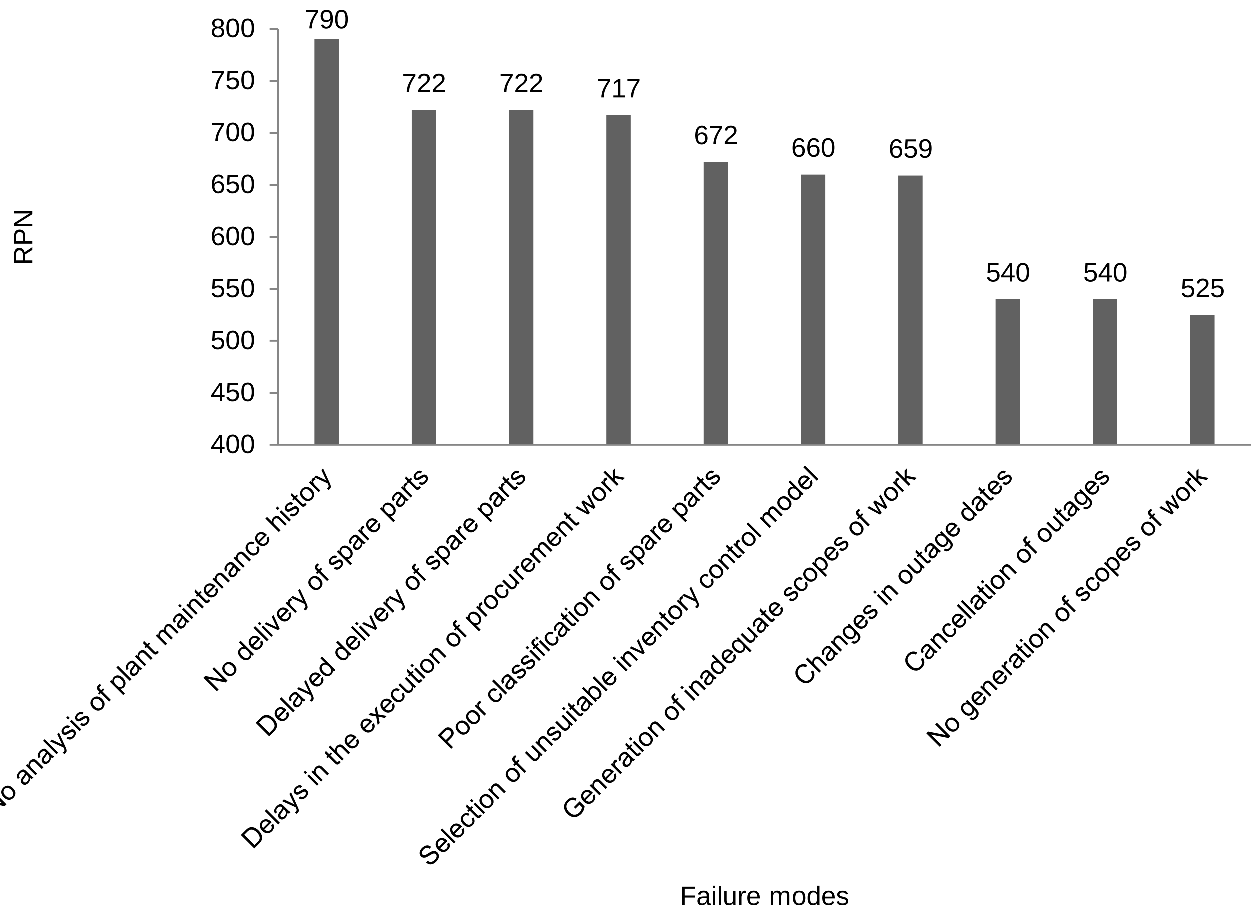


Figure 5.9: Graph of top failure mode according to RPN

5.4.3 Failure Causes

The analysis of the spare parts management model identified 26 unique causes of failure in the sub-processes. As a result, thematic analysis (Anderson *et al.*, 2015) was used to group similar causes together. These causes were then classified according to the frequency of their occurrence. Accordingly, the top ten failure causes are shown in Figure 5.10 below. Noticeably, the inadequacy of the contracts between power stations and suppliers was identified as a top failure cause according to the frequency of occurrence.

This space is left empty intentionally.

Please go to the next page.

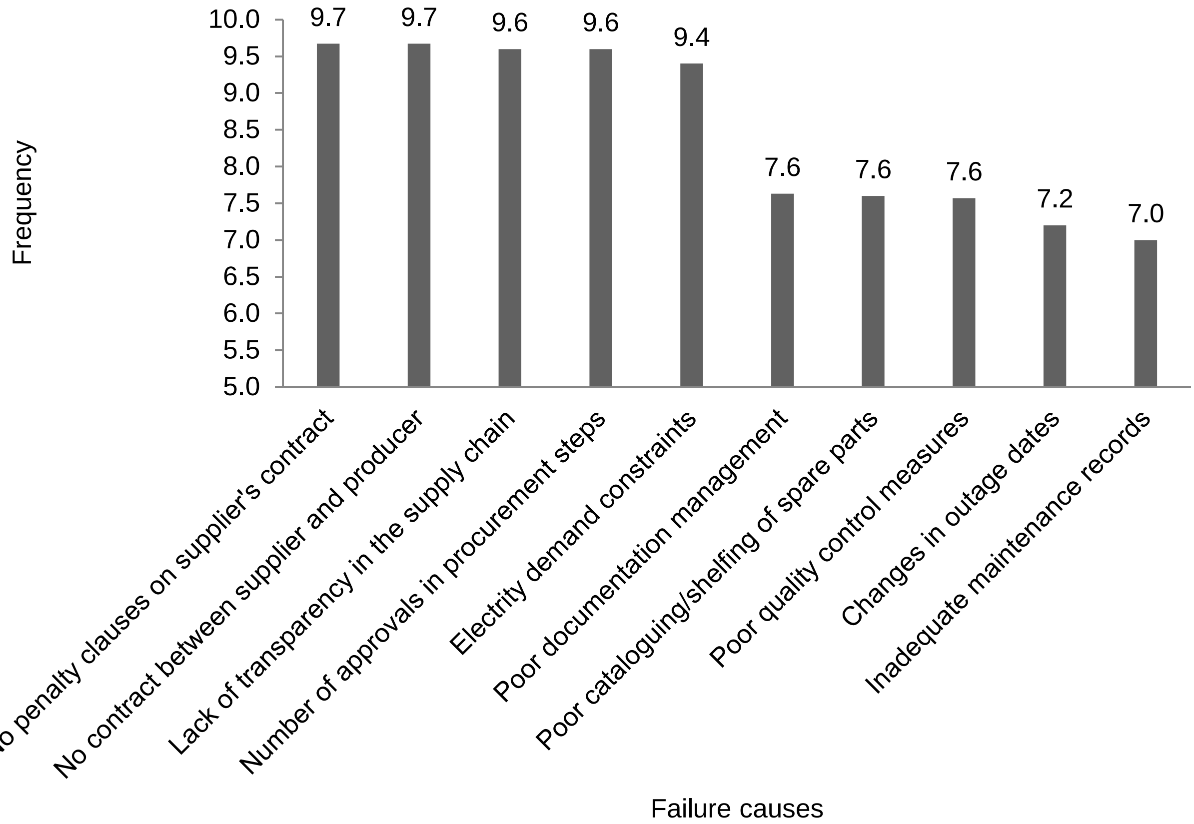


Figure 5.10: Graph of top failure causes according to frequency

5.5 DISCUSSIONS

In Chapter 2, *inefficiencies in spare parts management* were defined as inadequacies in spare parts management that would result in spare parts management not fulfilling its intended function, in the intended way. In light of this definition, this section discusses the top failure modes in spare parts management that result in it not meeting its intended function in the intended way.

The risk priority number (RPN) is a numeric representation of risk associated with a failure mode. Importantly, this number takes into consideration the likelihood of occurrence, likelihood of detection, and severity of impact of failure. Consequently, the business processes from which the top ten failure modes, according to RPN, occur are discussed in detail. Figure 5.10 shows the spare parts management model highlighting the business processes affected by the top ten failure modes, resulting in the overall inefficiency of the spare parts management.

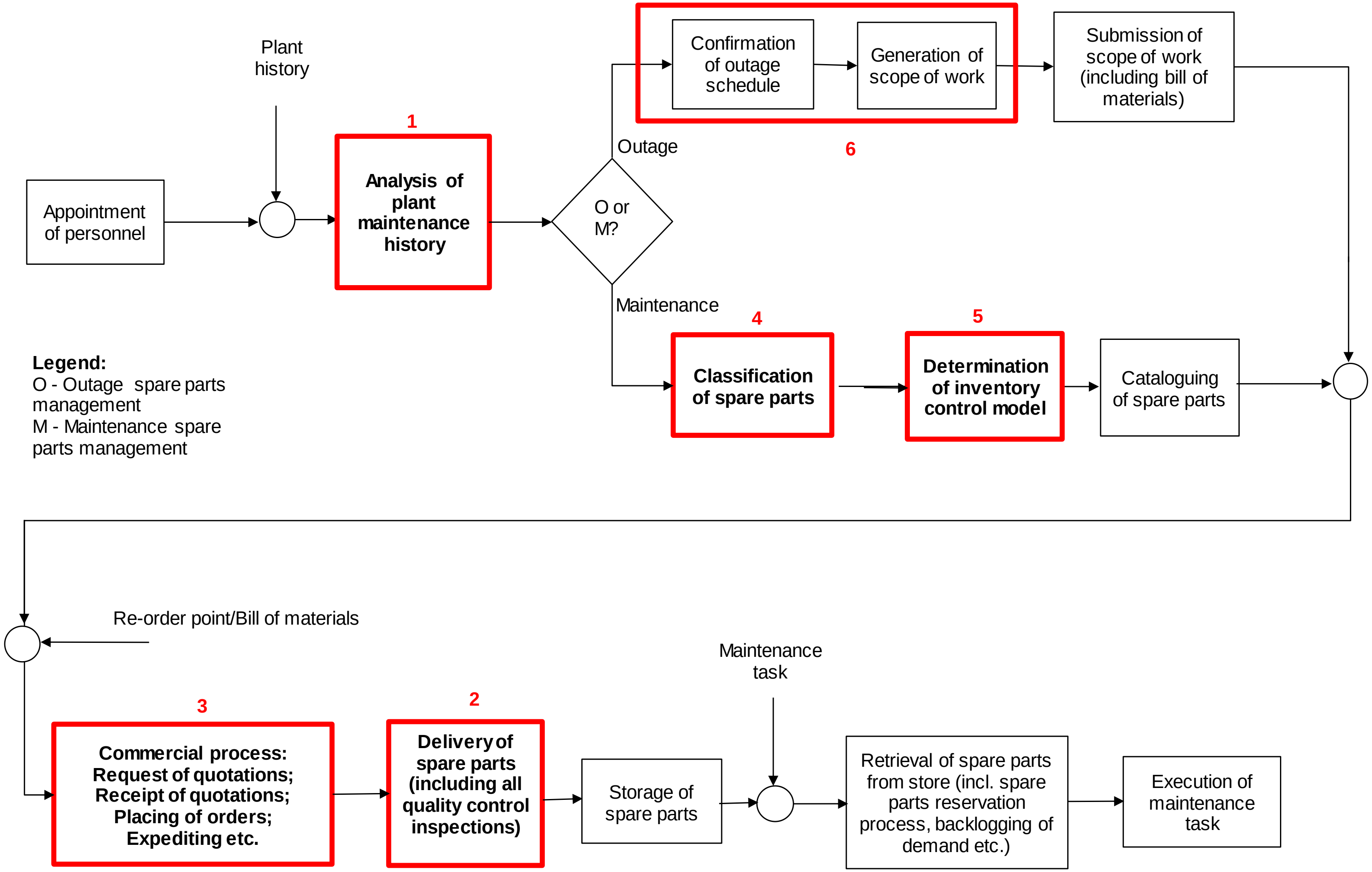


Figure 5.11: Inefficiencies in spare parts management

5.5.1 Analysis of Plant History

The lack of analysis of maintenance history was recognised as a top failure mode. This failure results in inadequate maintenance and inventory management strategies. In the absence of suitable inventory control models, the inventory control will be done according to a generic min-max inventory control model (Scarf, 1957). This effect has the highest severity on spare parts management. Furthermore, maintenance strategies that do not get reviewed to suit the behaviour of the plant would result in non-optimal maintenance, which would lead to an unnecessary demand for spare parts. As a result of inadequate maintenance strategies, failures occur frequently, leading to higher consumption of spare parts. In contrast, certain components are subjected to more than required maintenance interventions which translate to unnecessary consumption of spare parts.

The results revealed that inadequate analysis of maintenance history was due to the lack of recording of maintenance data, lack of access to computerised maintenance management systems (CMMSs), and incompetence of personnel. Supervision was identified as the existing control measure to counter the lack of recording of maintenance data, and also to counter incompetence.

The top inefficiencies that exist in spare parts management are therefore the non-optimal management of spare parts as a result of the use of the generic inventory control model, and the higher depletion of spare parts as a result of inadequate maintenance strategies.

5.5.2 Delivery of Spare Parts

No delivery of spare parts and delayed deliveries were also identified as top failure modes in spare parts management. These failure modes result in the unavailability of spare parts during the execution of maintenance tasks. As a result, maintenance activities get cancelled or postponed. Furthermore, the results revealed that these failures were a result of unsuitable suppliers, the unavailability of spare parts in the local market, and inadequate contracts between the role players in the spare parts supply chain.

The study also determined that the procurement procedures, in their current form, are not effective in preventing the selection of unsuitable suppliers. These procedures have a detection ranking of 5.9. Also, the study found that the current government policies do not ensure that spare parts get manufactured in the country to ensure their speedy availability to the power stations. Furthermore, the results revealed that existing contracts between the stations and suppliers do not have penalty clauses that would assist in ensuring that the suppliers adhere to the committed supply schedules. The analysis also established that the power stations are only involved partially in the spare parts supply chain; that is, the power stations only interact with their immediate suppliers. Therefore, the power stations are not able to influence the performance of the supply chain because they do not have relationships with all the role players.

5.5.3 Commercial Processes

Delays in the execution of commercial work were also noted as one of the top failure modes in spare parts management. The study found that delays in the commercial process result in delayed deliveries of spare parts, and as discussed in 5.5.2, this results in postponement or the cancellation of maintenance tasks.

The delays occur as a result of incompetence of procurement personnel, the number of approvals at each step in the commercial process, and lack of clarity in some procurement procedures. The lack of clarity in procedures results in delays in the execution of procurement work while clarity is being sought from a higher office. Furthermore, re-work is experienced in instances where wrong procurement processes were followed. The study also found that there were no existing control measures that were aimed at reducing the number of steps and approvals in the procurement processes.
Supervisors and managers are expected to manage any incompetence from their subordinates.

5.5.4 Classification of Spare Parts

Poor classification of spare parts was also identified as a top failure mode in spare parts management. The poor classification of spare parts leads to inventory management strategies that are not suited to the spare parts demand behaviour in the stations. Inadequate inventory control will result in either maintaining higher than necessary levels of stock, or unavailability of spare parts. The causes of inadequate classification were found to be; inadequate maintenance records and the lack of transparency in the spare parts supply chains. The analysis found that there are no existing controls to counter the identified failure causes.

5.5.5 Determination of Inventory Control Model

The study found that the selection of unsuitable inventory control models resulted in inadequate control over spare parts. This can lead to maintaining higher than required levels of stock, or it can lead to unavailability of spare parts. The causes of the selection of unsuitable inventory control models were found to be inadequate analysis of plant history, inadequate maintenance records, and incompetence. Incompetence in this instance entailed the use of incorrect methods during the analysis of maintenance history. This incompetence could be addressed through strategic management and effective supervision.

5.5.6 Outages

The study found that inadequate outage maintenance instructions (scope of work) were identified as a top failure mode in the spare parts management model, ranked 7th. The study also identified the absence of a scope of work was also a top failure mode, ranked 10th. The study found that inadequate scope of work result in the ordering inadequate spare parts, and this would result in inadequate maintenance of the plant. In the case where no scope of work is submitted, there would be no planning of spare parts for any maintenance. This lack of maintenance later results in higher demand of spare parts due to frequent failures.

The causes of inadequate scope of work were found to be inadequate analysis of plant history and human factors. The absence of an outage scope of work is caused by human related factors and changes in outage dates. Supervision and monitoring of progress in departmental meetings were identified as the existing controls to prevent the occurrence human induced failures.

The analysis established that changes in outages are due to budget constraints and electricity demand constraints. The cancellation of outage dates and the changing of outage schedules were identified as top failure modes, ranked 8th and 9th, with a risk rating of 540. These failure modes result in inefficiencies in spare parts management, and these are; the proliferation of spare parts due to the unused spare parts in the case of cancelled outages, and inadequate planning for spare parts in the case outage dates that are brought forward. Financial management procedures and integrated demand procedures were identified as the existing controls to prevent changes in outage schedules, and they were found to be not effective.

5.6 FRAMEWORK FOR THE IMPROVEMENT OF SPARE PARTS MANAGEMENT

In paragraph 5.4, the research identified inefficiencies and the causes of the inefficiencies in spare parts management. Furthermore, the inefficiencies have been ranked according to their significance on spare parts management, as discussed in paragraph 5.5. Therefore, the study is in a good position to make recommendations to the power stations, on how to improve the management of spare parts. Consequently, flowcharting and the Delphi method were used to develop a method to address the highlighted inefficiencies. An initial flowchart was drawn, and it was presented to a purposively selected group of research participants; see Table 5.3. The initial flowchart is shown in Appendix E. The flowchart went through three

Delphi rounds, where changes were made to the flowchart after each round, in accordance to the comments from the research participants. The detailed methodology is found in paragraph 4.5.

Table 5.3: Biographical information of the sample

Department	Frequency	Years of experience
Engineering	1	7
Maintenance	1	11
Management	1	14
Outage Department	1	9
Procurement	1	11

Figure 5.12 shows the final flowchart, which incorporated the comments from the industry experts with regard to the robustness of the framework. The methodology depicted in Figure 5.12 was thus accepted the framework for improving spare parts management practices. The elements of this framework are discussed briefly below.

1) Identification of knowledgeable stakeholders

This process involves the assembling of a knowledgeable team that will review the spare parts management. Purposive sampling can be used in the assembly of the team. It is recommended that the team should have representation from all parties that are role-players in spare parts management. Furthermore, experienced individuals with appropriate qualifications should make-up the team, as per the criteria that would be set by the power station management.

2) Selection of sub-processes to be reviewed.

This process involves selecting a sub-process from either the original spare parts management model, or the revised spare parts management model. The process will ensure that the sub-processes that have not been reviewed are selected for review. Colour-coding or placing a mark next to a reviewed sub-process can assist in ensuring that no sub-process is overlooked.

3) Perform FMEA on new sub-process.

This process is only applicable in the event that there is consensus by the team that the sub-process, in its current form, is not the best possible way to achieve the desired result, and should be subsequently changed. The new sub-process should thus be subjected to failure mode and effect analysis, and any inefficiency in the sub-process should be identified.

4) Update the spare parts management model

In the event that the sub-process under review has been modified, changed or eliminated, the spare parts management model must be updated to reflect this change. Thus this process ensures that further review of spare parts management is cognisant of the changes.

5) Elimination of failure causes

This process involves the development of strategies that are aimed at eliminating the causes of failure in the sub-process. Therefore, the team will brainstorm the practical methods and strategies of eliminating the causes of failure. In the event that the elimination of the causes is not practical, the team will focus on the detection of occurrence and minimization of impact. However, if the brainstorming session yields a workable way of eliminating the causes of failure, then the focus will shift to the next sub-process.

6) Detection of failure

This process involves the review of existing process control measures that govern the sub-process under review. In the event that there are no existing controls, the team will seek to establish if there are practical ways of detecting impending failure or controlling the causes of failure. In the event that the team establishes that potential control measures for the sub-process under review are not practical, the focus will shift to the minimization of impact of failure. However, if the team establishes that the failures can be practically detected or controlled, the team will focus on developing the strategies and methods for detection.

In the event that there are existing process control measures, the team will assess if the controls are effective. This can be done by reviewing the detection score from the FMEA results. If the team finds that the existing controls are effective, the focus will shift to the next sub-process. However, if the existing controls are not effective, the team will look at either improving the effectiveness of existing controls, or the development of new detection and control methods.

7) Response to impending failure

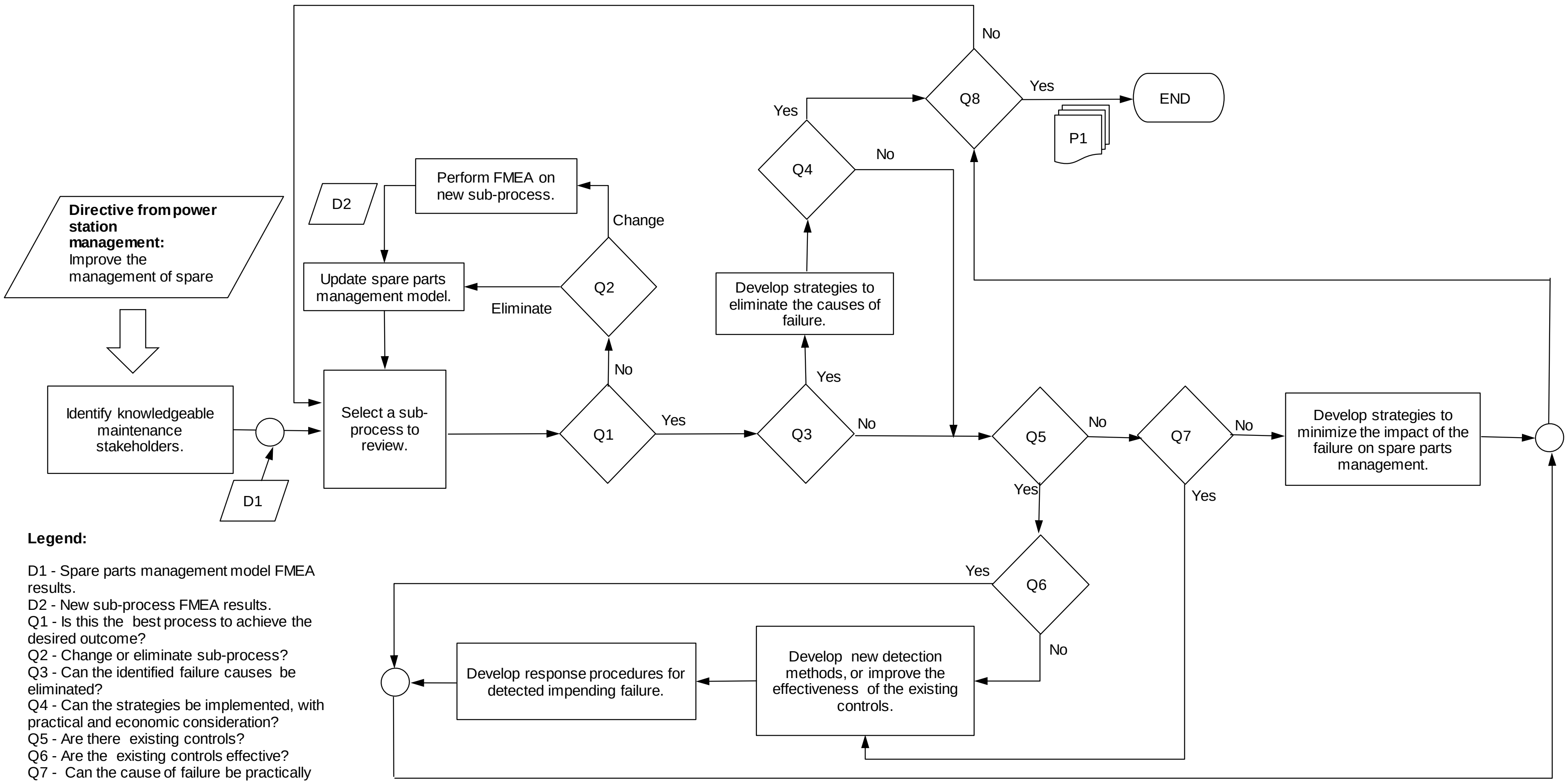
This process will involve the development of response procedures when failure has been detected. In the event that failure has been detected, there should be a detailed procedure that indicates which remedial actions should be taken. The actions may be aimed at delaying the occurrence of failure where the cause of the failure has been detected, or to correct the failure before it impacts spare parts management. Furthermore, the response actions may include continuous monitoring of the failure to determine the right time to act. This process may also include the creation of an alternative sub-process that can be used when failure has been detected on the sub-process under review.

8) Minimization of impact of failure

This process is concerned with developing strategies that will ensure that the impact of the failure of the sub-process is minimised. As an example, this may include the development of emergency procedures that would allow for speedier expediting of spare parts when normal processes have failed. Also, this may include development of strategic agreements with suppliers that would allow for suppliers to retain certain levels of specific stock in hand for the power stations, in case of emergency. The power stations may also opt to include safety stock in their inventory control models in order to reduce the impact of failure in the sub-processes.

This space is left empty intentionally.

Please go to the next page.



Legend:

D1 - Spare parts management model FMEA results.
D2 - New sub-process FMEA results.
Q1 - Is this the best process to achieve the desired outcome?
Q2 - Change or eliminate sub-process?
Q3 - Can the identified failure causes be eliminated?
Q4 - Can the strategies be implemented, with practical and economic consideration?
Q5 - Are there existing controls?
Q6 - Are the existing controls effective?
Q7 - Can the cause of failure be practically controlled or detected?
Q8 - Are all the sub-processes reviewed?
P1 - Optimised spare parts management model with effective control measures.

Figure 5.12: Spare parts management improvement framework

5.7 CONCLUSION

The chapter presented the results from the study. The study began by presenting the spare parts management model. Subsequent to that, the model was subjected to failure mode and effect analysis that was applied through the use of the Delphi process. The study was successful in determining the failures, and causes of the failures in the sub-processes of spare parts management. These failures were then classified according to their significance. In light of the identified failures, the study then developed a framework that was aimed at improving spare parts management by reengineering the spare parts management model, developing strategies for eliminating failure causes, developing strategies for detecting failure and developing strategies for minimizing the impact that the failures have on spare parts management. Chapter 6 presents a conclusion to the research questions, and the overall conclusion to the study.

This space is left empty intentionally.

Please go to the next page.

6. CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In Chapter 1, it was stated that the purpose of the study was to establish the inefficiencies that exist in spare parts management in South African power stations. Furthermore, the research sought to identify the sources of such inefficiencies in order to make recommendations to improve spare parts management practices. In order to meet this overall objective of the research, four questions were developed (see Figure 1.1 for a flowchart indicating how the research questions were used to achieve the research objective). Justifiably, the existing literature was reviewed to determine if answers to the research questions already existed. However, it was concluded that the answers to the research questions were yet to be in the body of knowledge. Consequently, Chapters 3 and 4 presented the study design and the methodology that was used to discover answers to the research questions. This methodology was implemented, and in Chapter 5, the research questions were answered. This affirmed the suitability of the methodology used.

In this chapter, the answers that were found to the research questions are presented and elucidated. Following this, the study considers whether the research objectives were achieved. Limitations found during the study are also considered. Furthermore, the study finally considers if it has served its purpose within the context of the broader body of literature. Recommendations for further work are presented, and conclusions are drawn.

6.2 ANSWERS FOUND TO THE RESEARCH QUESTIONS

In this section, the research questions are considered, in light of the answers found.

6.2.1 Inefficiencies in the Sub-processes

Research question 1 is restated below for ease of reference:

> What are the inefficiencies in the sub-processes of spare parts management in power stations?

The purpose of this research question was to achieve the first objective of the research, which was to establish the nature of inefficiencies in spare parts management in South African power stations. In the process of discovering answers to this research question, flowcharting and the Delphi method were used to develop a conceptual model of spare parts management. This was followed by failure mode and effect analysis, which was administered through the Delphi method, to identify the failures that occur in the operation of the sub-process in the spare parts management model. The answer to the research question was found through the identification of the most prevalent failure modes and their causes in paragraph 5.4 and the quantification of the inefficiencies that exist in paragraph 5.5.

6.2.2 The Significance of the Inefficiencies

Research question 2 is restated below for ease of reference:

> What is the significance of the inefficiencies on the overall functioning of spare parts management, if inefficiencies exist?

The aim of this research question was to achieve the second objective of the research which was to ascertain the significance of the inefficiencies. At this stage, the answer to the first research question had confirmed that inefficiencies exist in spare parts management. As a result, the study used failure mode and effect analysis and the Delphi process to determine the effect of the failures as well as the severity of those effects. The answer to the research question was arrived to in Chapter 5, paragraph 5.4.2, where the different failures were ranked according to the significance of their impact on spare parts management.

6.2.3 The Causes of Inefficiencies

Research question 3 is restated below for ease of reference:

> What are the causes of the inefficiency in spare parts management, if any inefficiency exists?

The aim of this research question was to achieve the third objective of the research which was to determine the causes of the inefficiencies. At this stage, the answers to the first and second research questions had confirmed the existence of significant inefficiencies in spare parts management. In the process of discovering answers to this research question, the study once again used failure mode and effect analysis and the Delphi method, to determine and establish consensus on the causes of failures. Furthermore, the study established the likelihood of the occurrence of these causes. Therefore, the answer to the research question was the identified causes of failures in spare parts sub-processes, such as inadequate contracts between spare parts suppliers and power stations. This answer was arrived to in Chapter 5, and was discussed in paragraphs 5.4.3 and 5.5.

6.2.4 The Framework for Improving Spare Parts Management

Research question 4 is restated below for ease of reference:

> How can spare parts management in South African power stations be improved?

The aim of this research question was to achieve the fourth objective of the research which was to recommend a solution to improve the efficiency and the effectiveness of spare parts management. The answers to the first three research questions confirmed the existence of significant inefficiencies in spare parts management, and also determined the sources of the inefficiencies. This further emphasized the significance of this research question. Now, in order to answer this research question, the study used flowcharting to develop a methodology to improve spare parts management. Furthermore, the study made use of the Delphi process to modify and validate the methodology. Consequently, the answer to the research question was arrived at in Chapter 5, and was presented and discussed as the framework for improving spare parts management practices in paragraph 5.6. The framework calls for the optimisation of spare parts management through the elimination or modification of poor sub-processes. Further, where practical, the framework ensures that failure causes in the sub-processes are eliminated. In addition, the methodology ensures that there is development of strategies to detect and control failures, and strategies to minimize the impact of the failures.

6.3 ACHIEVEMENT OF THE RESEARCH OBJECTIVES

In this section, the achievement of the research objectives is considered.

6.3.1 Establishment of the Nature of Inefficiencies

The first objective of the study is restated for ease of reference:

> To establish the nature of inefficiencies in spare parts management processes in South African power stations.

In Chapter 1, it was stated that the first objective of the study would be met when the inefficiencies in spare parts management are identified. The study used flowcharting to verify all the business processes that are involved in spare parts management. By using failure mode and effect analysis and the Delphi method, all the elements of the business processes in spare parts management were considered, and all potential failures and their effect on spare parts management were determined. In light of the answer to research question 1, the first objective of the study was achieved.

6.3.2 Ascertainment of the Criticality of the Inefficiencies

The second objective of the study is restated for ease of reference:

> To ascertain the significance of the inefficiencies.

In Chapter 1, it was stated that the second objective of the study would be met when the significance of the inefficiencies has been established. The study used failure mode and effect analysis and the Delphi method to determine the severity of the effect of the failures. Furthermore, the study determined the risk priority ranking of the failures by considering the severity of the failures, the frequency of occurrence of their causes, and the effectiveness of the current process controls to detect the causes of failure. The failures were then ranked according to their risk rating. In light of the answer to research question 2, the second objective of the study was achieved.

6.3.3 Determination of the Root Causes

The third objective of the study is restated for ease of reference:

> To determine the causes of the inefficiencies.

In Chapter 1, it was stated that the third objective of the study would be met when the causes of the inefficiencies in spare parts management have been identified. By using failure mode and effect analysis and the Delphi method, all the elements of the business processes were considered, and all potential failures were determined. The study then determined the causes of the failures, and the frequency of occurrence of their causes. In light of the answer to research question 3, the third objective of the study was achieved.

6.3.4 Improvement of Spare Parts Management

The fourth objective of the study is restated for ease of reference:

> To make recommendations to improve the efficiency and the effectiveness of spare parts management in South African power stations.

In Chapter 1, it was stated that the fourth objective would be met when the study has determined what should be done to improve the management of spare parts. The study through the use of a framework developed a methodology to: reengineer the spare parts management in the power stations; develop strategies to eliminate failure causes, develop strategies to detect and control failure; and to develop strategies to minimize the impact of the failures. Surely, the optimised spare parts management processes, and the reduction of inefficiencies and their impact, would result in improved spare parts management in the power stations. Therefore, spare parts management would perform its intended function with improved quality, and with less effort required; this translates to improved effectiveness and improved efficiency. This framework will be taken up in an Eskom standard procedure, to improve spare parts management practices. In light of the answer to the research question 4, the fourth objective of the research was met.

6.4 LIMITATIONS

The following limitations were found during the research:

- The research was conducted in 13 coal-fired power stations belonging to a single company. Thus, the applicability of the research findings may be limited to Eskom coal-fired power stations.
- The researcher is an employee at one of the power stations where the research was conducted, and this might have influenced the interpretation of certain results of the study.
- The developed framework has only been tested and validated for business processes in Eskom power stations only.

6.5 FULFILMENT OF THE RESEARCH PURPOSE

The purpose of the study was to establish the inefficiencies that exist in spare parts management processes of power plants in South Africa, and the causes of the inefficiencies, with the purpose of seeking solutions for such deficiencies. The study determined the inefficiencies that exist in spare parts management business processes. In doing so, the study was able to meet its first objective. The study then determined the significance of the failures, and in doing so, achieved the second objective of the study. Furthermore, the study determined the causes of the inefficiencies and their frequency of occurrence. This ensured that the third objective of the research was met. In light of the identified inefficiencies and their sources, the study developed a framework from which the operational effectiveness and efficiency of spare parts management could be improved. This ensured that the fourth objective of the research was met, as the research was able to recommend a solution to improve spare parts management practices. In meeting the objectives of the study, the study was able to serve its purpose.

6.6 RELATION TO EXISTING WORK

In Chapter 2, a research gap was identified. The research gap was that the business processes in spare parts management were yet to be subjected to rigorous analysis, and a result, solutions to inefficiencies that may exist in these processes had yet to be developed. The objectives of this study were achieved, and as a result, the following was added to the relevant body of knowledge:

- A general process for the rigorous analysis of internal business processes.
- Results of an example of rigorous analysis of internal business processes in spare parts management.
- A systematic way of improving spare parts management in South African power stations.
- A general framework for improvement of business processes.

6.7 RECOMMENDATIONS FOR FURTHER WORK

This study was conducted in power stations belonging to a single company. It is recommended that further similar studies are conducted in other companies to give credence to the universal applicability of the conclusions reached in this study.

The current research also yielded a framework to improve sub-processes of spare parts management. Further research can be done to test the suitability of this framework for business processes that are outside of spare parts management. The results of such a study would either give more credence to the framework from this research, or would result in improvements to the framework that will ensure its universal applicability.

6.8 CONCLUSIONS

The research problem was that inefficiencies in spare parts management in power stations can have great repercussions for the execution of the maintenance. However, the business processes in spare parts management were yet to be subjected to rigorous analysis. The purpose of the study was derived from this research problem, and it was to establish the inefficiencies that exist in spare parts management, and the causes of these inefficiencies. This was done with the intent to recommend a solution to the identified deficiency. The objectives of the study were derived from the research purpose, and they were: to establish the nature of inefficiencies and their sources in spare parts management, to establish the significance of the inefficiencies, and to make recommendations to improve the efficiency and effectiveness of spare parts management.

This study was able to achieve these objectives, in that it has managed to determine the particular inefficiencies in spare parts management, and it has also determined the significance of the inefficiencies and the causes of such inefficiencies. Furthermore, the study recommended a workable solution to improve spare parts management practices in South African power stations.

This study was designed so that its conclusions could have universal applicability. Moreover, the study was designed such that its results can be immediately used in power stations to improve spare parts management. In addition, the study was able to contribute to the body of knowledge, as discussed in paragraph 6.6. However, there are limitations to the applicability of the study as discussed in paragraph 6.4, and as a result, recommendations for future work were made. The key conclusions of the research are:

- The sub-processes of spare parts management were subjected to rigorous analysis - this has filled a specific research gap that existed.
- There are significant inefficiencies in the management of spare parts in South African power stations, and they result in cycles of high spare parts consumption due to inadequate maintenance, and cycles of high proliferation of spare parts due to unsuitable inventory control strategies.
- Inefficiencies in power station spare parts management result in high costs of managing spare parts.
- Failures in the sub-processes of spare parts management are the source of inefficiency in spare parts management. These failures were identified and discussed in detail in Chapter 5, paragraph 5.4.2.
- The root causes of the inefficiencies are tangible. These root causes were identified and are discussed in detail in Chapter 5, paragraph 5.4.3.
- The effectiveness and efficiency of spare parts management in power stations can be improved; a framework was developed to this effect. The development of this framework has filled a specific research gap that existed.
- The framework for improving spare parts management practices in South African power stations has been recommended for adoption in an Eskom standard procedure.

BIBLIOGRAPHY

Abuhila, L., Rabadi, G., Souza-Poza, A. 2006. Supply Chain Inventory Control: A comparison among JIT, MRP, and MRP with Information Sharing Using Simulation. *Engineering Management Journal* 18, 2, 51-57.

Ackay, A.E.,2013. Statistical Estimation Problems in Inventory Management (PhD Thesis). Carnegie Mellon University, Pittsburgh, Pennsylvania.

Aguiar D.C, Salomon V.A.P, Mello C.H.P. 2015. An ISO 9001 Based Approach for the Implementation of Process FMEA in the Brazilian Automotive Industry. *International Journal of Quality & Reliability Management* 32, 6, 589 – 602.

Aguilar-Savén, R.S. 2004. Business process modelling: Review and framework. *International Journal of Production Economics* 90, 2, 129-149.

Allwood, C.M. 2011. The Distinction Between Qualitative and Quantitative Research Methods is Problematic. *Quality and Quantity Journal* 46, 1417-1429.

Anderson, D., Lees, B., and Avery, B. 2015. Reviewing the Literature using the Thematic Analysis Grid. *European Conference on Research Methodology (ECRM) for Business and Management Studies* 14. Valletta, Malta

Anton, A.I., McCracken, W.M., Potts, C. 1994. Goal Decomposition and Scenario Analysis in Business Process Reengineering. Advanced Information Systems Engineering Lecture Notes in Computer Science 811. Springer, Berlin, Heidelberg

Appadoo, S.S., Bector, C.R., Bhatt, S.K. 2012. Fuzzy EOQ Model using Possibilistic Approach. *Journal of Advances in Management Research* 9, 1, 139 – 164.

Armoogum, J., Dill, J. 2015. Workshop Synthesis: Sampling Issues, Data Quality and Data Protection. 10th International Conference on Transport Survey Methods. *Transportation Research Procedia* 11, 60-65.

Arts, J. J. 2013. Spare Parts Planning and Control for Maintenance Operations. Eindhoven: Technische Universiteit Eindhoven DOI: 10.6100/IR760116

Augustine, A., Agu, A. 2013. Effect of Inventory Management on Organisational Effectiveness. *Information and Knowledge Management Journal* 3, 8.

Baccheti, A., Plabani, F., Saccani, N., Syntetos, A.A. 2010. Spare Parts Classification and Inventory Management: A Case Study. Salford Business School, University of Salford, Manchester.

Baltimore Aircoil Europe. 2016. 7 Risks of Not Choosing BAC Spare Parts. Retrieved from https://www.baltimoreaircoil.eu. Date retrieved: 22 July 2016.

Banerjee, A., Kim, S. 1995. An Integrated JIT Inventory Model. *International Journal of Operations & Production Management* 15, 9, 237 – 244.

Bartlett, C.A. Ghoshal, S. 2002. Building Competitive Advantage through People. *MIT Sloan Management Review* 43, 2, 34-41.

Battaglia, M.P. 2011. Nonprobability Sampling, Encyclopaedia of Survey Research Methods. SAGE publications.

Ben-Daya, M., Kumar, U., Murthy, D.N.P. 2016. Maintenance Logistics, in Introduction Maintenance Engineering: Modelling, Optimization and Management. John Wiley & Sons, Ltd, Chichester, UK.

Berman, E.M., Bowman, J.S., West, J.P, Wart, M.R. 2013. Human Resource Management in Public Service, 4th Edition. SAGE Publications.

Bevc, C.A., Retrum, J.H., Varda, D.M. 2015. New Perspectives on the "Silo Effect": Initial Comparisons of Network Structures across Public Health Collaboratives. *American Journal of Public Health* 105, 2, 230-235.

Blanchard, B.S. 2014. Logistics Engineering and Management, 14th Edition. Prentice-Hall.

Booysen, C., Heyns, S., Scheepers, R. 2014. Fatigue Life Estimation of a Low Pressure Steam Turbine Blade during Resonant Conditions Applying Probabilistic Concepts. *Eskom Power Plant Engineering Institute Student Conference* 1, 73-75.

Bounou, O., El Barkany A., El Biyaali, A. 2017. Inventory Models for Spare Parts Management: A Review. *International Journal of Engineering Research in Africa* 28, 182-198.

Bowen, G.A. 2005. Preparing a Qualitative Research-Based Dissertation: Lessons Learned. *The Qualitative Report* 10, 2, 208-222.

Brand, E., Fritz, W., Minnar, U. 2016. *Development of a Plant Health Index for Eskom Distribution Substations*, Eskom Distribution, Eskom ERID and Cape Peninsula University of Technology. Retrieved from http://nersa.org.za. Date retrieved: 20 March 2016.

Browne, S., Zipkin, P. 1991. Inventory Models with Continuous, Stochastic Demands. *The Annals of Applied Probability* 1, 3, 419-435.

Bryman, A. 2006. Integrating Quantitative and Qualitative Research: How Is It Done? *Qualitative Research* 6, 1, 97-113.

Budeli, L. 2015. Quality management system to improve conveyor system performance: Lethabo Power Station as case study (Master's Thesis). North-West University, South Africa.

Carroll, A.B. 1979. A Three-Dimensional Conceptual Model of Corporate Performance. *Academy of Management Review* 4, 4, 497-505.

Cavalieri, S., Garetti, M., Macchi, M. 2008. A Decision-Making Framework for Managing Maintenance Spare Parts. *Production Planning and Control* 19, 4.

Chase, R., Jacobs, F.R., 2013. Operations and Supply Chain Management, 13th Edition. McGraw-Hill.

Choy, K.L., Chow, H., Lee, W., Chan, F.T.S. 2007. Development of Performance Measurement System in Managing Supplier Relationship for Maintenance Logistics Providers. *Benchmarking: An International Journal* 14, 3, 352 – 368.

Cirello, D.J. 1992. Application of Just-in-Time Production Methods in the Defense Industrial Base. Department of the Air Force USA, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio.

Coetzee, J.L. 1997, Maintenance. Maintenance Publishers.

Coetzee, J.L. 1999. A Holistic Approach to the Maintenance "Problem". *Journal of Quality in Maintenance Engineering* 5, 276-280.

Cohen, J. 1960. A Coefficient of Agreement for Nominal Scales. *Educational and Psychological Measurement* 20, 1, 37–46.

Cooper, R.B., Zmud, R.W. 1989. Material Requirements Planning System Infusion. *International Journal of Management Science* 17, 5, 471-481.

Dalkey, N., Helmer, O. 1963. An Experimental Application of the Delphi Method to the Use of Experts. *Management Science* 9, 3, 458-467.

Davenport, T.H., Short, J.E. 1990. The New Industrial Engineering: Information Technology and Business Process Design. *Massachusetts Institute of Technology (MIT) Sloan Management Review*. Retrieved from https://sloanreview.mit.edu. Date retrieved: 03 November 2016.

Dekking F.M., Kraaikamp, C., Lopuhaa, H.P., Meester, L.E. 2005. A Modern Introduction to Probability and Statistics: Understanding Why and How. Springer. The Netherlands.

Delbecq, A. L., Van de Ven, A. H., & Gustafson, D. H. 1975. Group Techniques for Program Planning. Glenview, IL: Scott, Foresman, and Co.

Dhoka, D., Choudary, Y.L. 2013a. ABC Classification for Inventory Optimization. *IOSR Journal of Business and Management* 15, 1, 38-41.

Dhoka, D., Choudary, Y.L. 2013b. XYZ Inventory Classification and Challenges. *IOSR Journal of Economics and Finance* 2, 2, 23-26.

Diamond, D.H., Heyns, S., Oberholster, A.J. 2014. A Novel Technique for Estimating Synchronous Turbomachinery Blade Vibration from Blade Tip Timing Data. *Eskom Power Plant Engineering Institute Student Conference* 1, 71-72.

Dictionary.Com.2016. Inefficiency. Retrieved from http://www.dictionary.com/browse/inefficiency. Date retrieved: 11 January 2016.

Dinesh, E.D., Arun, A.P., Pranav, R. 2014. Material Requirement Planning for Automobile service Plant. *International Journal of Innovative Research in Science, Engineering and Technology* 3, 3, 1171 – 1175.

Dohmen A., Moormann J. 2010. Identifying Drivers of Inefficiency in Business Processes: A DEA and Data Mining Perspective. Enterprise, Business-Process and Information Systems Modelling. Lecture Notes in Business Information Processing, Springer, Berlin, Heidelberg.

Driscoll, D.L., Appiah-Yeboah, A., Salib, P., Rupert, D.J. 2007. Merging Qualitative and Quantitative data in Mixed Methods Research: How To and Why Not, *Ecological and Environmental Anthropology* 3, 1, 19-28.

Eloff, M., Carstens, S. 2013. Managing the Maintenance Inventory of a Cement Manufacturer. *Journal of Transport and Supply Chain Management* 7, 1.

English Oxford Living Dictionaries. 2016. Inefficiency. Retrieved from https://en.oxforddictionaries.com/definition/inefficiency. Date retrieved: 11 January 2016.

Erdem, A. S., Fadiloǧlu, M. M. and Özekici, S. 2006. An EOQ model with Multiple Suppliers and Random Capacity. *Naval Research Logistics* 53, 101–114.

Eskom. 2014, *Eskom Generation Supplementary and Divisional Report*. Retrieved from http://intergratedreport.eskom.co.za. Date retrieved: 03 November 2016.

Eskom. 2016, *Tariffs and Charges*. Retrieved from www.eskom.co.za/customercare. Date retrieved: 03 November 2016.

Ewulum, O.K. 2008. A New Maintenance Strategy for Power Holding Company Nigeria to Contest the Current Power Demand Problem (Master's Thesis). North-West University, South Africa.

Fazel, F. 1997. A comparative analysis of inventory costs of JIT and EOQ purchasing. *International Journal of Physical Distribution & Logistics* 27, 8, 496-504.

Feili, H.R., Akar, N., Lotfizadeh, H., Bairampour, M., Nasiri, S. 2013. Risk Analysis of Geothermal Power Plants using FMEA Technique. *Energy Conversion and Management* 72, 69-76.

Fredriksson, G., Larsson, H. 2012. An Analysis of Maintenance Strategies and Development Of A Model For Strategy Formulation. Department Of Product And Production Development, Division Of Production Systems, Chalmers University Of Technology. Göteborg, Sweden.

Garg, J. 2013. Maintenance: Spare Parts Optimization (Master's Thesis). Ecole Centrale Paris, France.

Goetsch, D.L., Davis, S. 2014. Quality Management for Organizational Excellence: Introduction to Total Quality, Seventh Edition. Pearson Education Limited.

Gordon, T.J. 2009. The Delphi Method. *Futures Research Methodology* 3.

Greene, J.C., Caracelli, V.J., Graham, W.F. 1989. Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis* 11, 3, 255-274.

Grondys, K., 2009. ABC Analysis in Spare Parts Warehouse. *Advanced Logistic Systems* 3, 147-156.

Gu, J. 2013. Proactive and Efficient Spare Parts Inventory Management Policies Considering Reliability Issues (Master's Thesis). University of Windsor, Canada.

Handfield, R. 2011. Role of Procurement within an Organization. North Carolina State University. Retrieved from: https://scm.ncsu.edu. Date retrieved: 10 September 2016.

Harrington, H.J. 1991. Business Process Improvement: The Breakthrough Strategy for Total Quality, Productivity, and Competitiveness. McGraw-Hill.

Hassan, A. 2013. A Study on Material Requirement Planning System for Small Scale Industries. *Mechanica Confab Journal* 2, 3, 96 – 104.

Hedges, J.R. 2009. An Optimal Maintenance Scheduling Model for the Transmission Division of Eskom (Thesis). University of Pretoria, South Africa.

Hillier, F.S., Lieberman, G.J. 2001. Introduction to Operations Research. McGraw-Hill.

Holey, E. A., Feeley, J. L., Dixon, J., & Whittaker, V. J. 2007. An Exploration of the use of Simple Statistics to Measure Consensus and Stability in Delphi studies. *BMC Medical Research Methodology 7*, 52.

Holloway, I., Wheeler S. 2002. Qualitative Research in Nursing, Oxford: Blackwell Science Ltd.

Holstein, J., Olofsson, A. 2006. Inventory Control, Lund University, Department of Industrial Management and Logistics.

Howitz C. 2014. Determine Economic Order Quantity to Minimize Inventory Costs. Simcrest Technology Solutions. Retrieved from http://www.simcrest.com. Date retrieved 11 January 2016.

Hsu, C.C., Sandford, B.A. 2007. The Delphi Technique: Making Sense of Consensus, Practical Assessment. *Research and Evaluation* 12, 10.

Jalil, M., Zuidwijk, R., Fluiccheman, M., van Nunen, J. 2009. Spare Parts logistics and Installed Base Information. *Journal of Economic Literature*.

Jha, V. 2012. MRP-JIT Integrated Production System. *International Journal of Engineering Research and Applications* 2, 4, 2377-2387.

Juran, J.M. 2017. Rating Factors. Retrieved from http://juran.com. Date retrieved: 01 March 2017.

Kathawala, Y., Abdou, K. 2003. Supply Chain Evaluation in the Service Industry: A Framework Development Compared to Manufacturing. *Managerial Auditing Journal* 18, 2, 140-149.

Kenny, A. 2013. Presentation to NERSA on Eskom's Proposed Electricity Price Increases: 2013 to 2017. Retrieved from www.nersa.org.za. Date Retrieved: 03 November 2016.

Kharde, B., Patil, G., Nandurkar, K., 2012. EOQ Model for Planned Shortages by Using Equivalent holding and Shortage Cost. *International Journal of Industrial Engineering Research and Development (IJIERD)* 3, 1, 43-57.

Koo, W.L., Van Hoy, T. 2016. Determining the Economic Value of Preventive Maintenance. Jones Lang LaSalle Strategic Consulting Group.

Kootanaee, A.J., Babu, K.N., Talari, H.F. 2013. Just-in-Time Manufacturing System: From Introduction to Implement. *International Journal of Economics, Business and Finance* 1, 2, 7-25.

Krueger, R.A., Casey, M.A. 2014. Focus Groups: A practical guide to Applied Research, SAGE Publications.

Kumar, P., Bahl, R.N. 2014. The Effect of Inventory Management on Organizational Performance, *International Journal of Innovative Science*, Engineering & Technology 4.

Levi, R., Pal, M., Roundry, R., Shmoys, D.B. 2005. Approximation Algorithms for Stochastic Inventory Control Models. Cornell University.

Madonsela, M.G.B., Kachieng'a, M.O. 2003. Technology Management in the Deregulated Electricity Distribution Industry: The South African Case. *SA Journal of Industrial Engineering* 14, 2, 75-86.

Maenetja, M.J. 2009. An Evaluation of Communication Integration within a State-Owned Organisation (Unpublished Master's Thesis). Univeristy of South Africa, Pretoria, South Africa.

Mamabolo, C.M. 2012. Effectiveness of Planned Maintenance in Power Stations (Master's Thesis). University of Pretoria, South Africa

Marquez, A.C., de Leon, P.M. 2009. The Maintenance Management Framework. *Journal of Quality in Maintenance Engineering* 15.

Mashaba, H.J., Spayile B., Mdaka, T., Molabe, T. 2017. Duvha 3 Human Resource Management Plan (240-130161977). Eskom Information Centre.

Masten, K.A., Kim, S. 2015. So Many Mechanisms, So Little Action: The Case for Third Party Supply Chain Coordination. *International Journal of Production Economics* 168, 13-20.

Mathobela, T.P. 2009. Analysis and Recommendations for the Technology System used for Procurement and Inventory Management at Eskom (Honour's Thesis). University of Pretoria, South Africa.

McDermott, R.E., Mikulak, R.J., Beauregard, M.R. 2008. The Basics of FMEA, 2nd Edition. CRC Press, Taylor & Francis Group.

Mekel, C., Anantadjaya, S.P.D., Lahindah, L. 2014. Stock out Analysis: An Empirical Study on Forecasting, Re-Order Point and Safety Stock Level at PT. Combiphar, Indonesia. *Review of Integrative Business and Economics Research Journal* 3, 1, 52-64.

Merriam-Webster. 2016. Inefficiency. Retrieved from https://www.merriam-webster.com/dictionary/inefficiency. Date retrieved: 11 January 2016.

Miles R.E., Snow C.C. 1984. Designing Strategic Human Resources Systems. *Organisation Dynamics* 13, 1, 36-52.

Min, W., Pheng, L.S. 2007. Modelling Just-in-Time Purchasing in the Ready Mixed Concrete Industry. *International Journal of Production Economics* 107, 190 – 201.

Mitra, S., Pattanayak, S.K., Bhowmik, P. 2013. Inventory Control Using ABC and HML Analysis – A Case Study in a Manufacturing Industry. *International Journal of Mechanical and Industrial Engineering* 3, 1, 76-81.

Molopo, A.G. 2014. The Relationship between Organisational Culture and Assignment Fulfilment – A Case of an Energy Provider. Tshwane University of Technology, South Africa.

Momme, J., Hvolby, H. 2002. An Outsourcing Framework: Action Research in the Heavy Industry Sector. *European Journal of Purchasing and Supply Management* 8, 185-196.

Montgomery, D.C., Runger, G.C. 2003. Applied Statistics and Probability for Engineers, Third Edition. John Wiley & Sons, Inc.

Mortlock, S., Vicatos, G., v.d. Westhuizen, W. 2014. Optimum Time to Refurbish a Boiler Feed Pump (BFP) in a Fossil Fired Power Station. *Eskom Power Plant Engineering Institute Student Conference* 1, 10-11.

Moubray, J. 1991. Reliability-centred Maintenance. Butterworth-Heinemann.

Mpofu, S. 2010. Strategic Leadership Challenges in the Management of Projects in the Parastatals (PhD Thesis). University of the Witwatersrand, Johannesburg, South Africa.

Mtembi, T., Kanakana, M. G. 2015. Project Management Approach for Turbine Maintenance in Power Utility Plants: The Case of a South African Maintenance Company. *IEEE International Conference on Industrial Engineering and Engineering Management*. Singapore.1737-1741.

Murthy, D.N.P., Karim, M.R., Ahmadi A. 2015. Data Management in Maintenance Outsourcing. *Reliability Engineering and System Safety* 142, 100–110.

Murugan, R., Ramasamy, R. 2015. Failure Analysis of Power Transformer for Effective Maintenance Planning in Electric Utilities. *Engineering Failure Analysis* 55, 182-192.

Mutloane, O.E. 2009. Maintenance Management for Effective Operations Management at Matimba Power Station (Master's thesis). North-West University, South Africa.

Niglas, K. 2000. Combining Quantitative and Qualitative Approaches. European Conference on Educational Research, Edinburgh. 20-23 September 2000.

O'Toole, T., Donaldson, B. 2002. Relationship Performance Dimension of Buyer-Supplier Exchanges. *European Journal of Purchasing and Supply Management* 8, 197-207.

Ookalkar, A.D., Joshi A.G., Ookalkar, D.S. 2009. Quality Improvement in Haemodialysis Process using FMEA. *International Journal of Quality & Reliability Management* 26, 8, 817 – 830.

Ottesen, G., Grønhaug, K. 2002. Market Orientation and Uncertain Supply in Upstream Markets: An Exploratory Study. *European Journal of Purchasing and Supply Management* 8, 209-219.

Panday, V. Roux, P.G., Koko, M. 2014. Eskom's Procurement and Supply Chain Management Procedure (32-1034). Eskom Information Centre.

Parikh, M., Shah, N.H., Shah, Y.K. 1999. Diversification in economic order quantities (EOQ) model. *Kybernetes*, 28, 3.

Parsana, T.S., Patel, M.T. 2014. A Case Study: A Process FMEA Tool to Enhance Quality and Efficiency of Manufacturing Industry. *Bonfring International Journal of Industrial Engineering and Management Science* 4.3, 145-152.

Parsons, D., Wood, K., Haden, P. 2015. What Are We Doing When We Assess Programming? (Conference Paper). *Australasian Computing Education Conference* 17.

Pascu, C.I, Paraschiv, D. 2016. Study about Improving the Quality Process Performance for a Steel Structures Components Assembly using FMEA Method. *Applied Mechanics & Materials* 822, 429-436.

Phung, T.D., Hardeweg, B., Praneetvatakul S., Waibel, H. 2015. Non-Sampling Error and Data Quality: What Can We Learn From Surveys To Collect Data For Vulnerability Measurements? *World Development Journal* 71, 25-25.

Plenert, G. 1999. Focusing Material Requirements Planning (MRP) towards Performance. *European Journal of Operational Research* 119, 91-99.

Poling, A. 2017. Maintenance Efficiency: Understand It to Drive It, Maintenance Technology. Retrieved from http://www.maintenancetechnology.com. Date retrieved: 20 April 2017.

Puvanasvaran, A.P., Jamibollah, N, Norazlin N., Adibah, R. 2014. Poka-Yoke Integration into Process FMEA. *Australian Journal of Basic and Applied Sciences* 8, 7, 66-73.

Rajasekar, S., Philominathan, P., Chinnathambi, V. 2013. Research Methodology. School of Physics, Bharathidasan University, India.

Ravinder, H., Misra, R.B. 2014. ABC Analysis for Inventory Management: Bridging the Gap between Research and Classroom. *American Journal of Business Education* 7, 3, 257-264.

Rego, J.B., Mesquita, M.A. 2011. Spare Parts Inventory Control. *Producao* 21, 4, 656-665.

Roach, B. 2005. Origin of the Economic Order Quantity Formula; Transcription or Transformation? *Management Decision* 43, 9, 1262 – 1268.

Root, G.N. 2016. Importance of Teamwork at Work. *Chron*.

Ross, S.M. 2004. Introduction to Probability and Statistics for Engineers and Scientists, Third Edition. Elsevier Academic Press.

Sajadieh, M.S., Larsen, C. 2015. A Coordinated Manufacturer-Retailer Model under Stochastic Demand and Production Rate. *International Journal of Production Economics* 168, 64-70.

Sanchez-Izquierdo-Riera, J.A., Molano-Alvarez, E., Saez-de la Fuente, I., Maynar-Moliner, J., Marín-Mateos, H., Chacón-Alves, S. 2016. Safety Management of a Clinical Process Using Failure Mode and Effect Analysis: Continuous Renal Replacement Therapies in Intensive Care Unit Patients. *ASAIO Journal* 62, 1, 74-79.

Sarbijt, S., Shivraj, S. 2011. Deterministic and Probabilistic EOQ Models for Products Having Power Demand Pattern. *World Congress on Engineering*, July 6-8 2011.

Saunders, M., Lewis, P., Thornhill, A. 2009. Research Methods for Business Students, Fifth edition. Pearson Education Limited.

Scarf, H.E. 1957. A Min-Max Solution of an Inventory Problem. *The Rand Corporation*, Santa Monica, California.

Scheepers, R., Heyns, S., Newby, M. 2014. A Comparative Study of Finite Element Methodologies for the Prediction of Torsional Response of Bladed Rotors. *Eskom Power Plant Engineering Institute Student Conference* 1, 68-69.

Schniederjans, M.J., Cao, Q. 2001. An Alternative Analysis of Inventory Costs of JIT and EOQ Purchasing. *International Journal of Physical Distribution & Logistics Management* 31, 2, 109 -123.

Shang, S., Seddon, P.B. 2007. Managing Process Deficiencies with Enterprise Systems. *Business Management Journal* 13, 3, 405-416.

Shtub, A., Kami, R. 2010. ERP: The Dynamics of Supply Chain and Process Management. *Springer Science and Business Media* 2.

Sibanda, R.T.J. 2016. Reliability Improvement of the Boiler-Coal Processing Plant in Eskom Using Reliability Centred Maintenance Principles. University of the Witwatersrand, Johannesburg, South Africa.

Silva, T., Saalmann, P., Cordes, A., Giacomolli, A., Pereira, C., Hellingrath, B. 2014. Integration Architecture of Intelligent Maintenance Systems and Spare Parts Supply Chain Planning, 8th International Conference on Digital Enterprise Technology, *Procedia CIRP* 25, 192-198.

Simchi-Levi, D. 2002. Introduction to Stochastic Inventory Models and Supply Contracts (Lecture Slides). Massachusets Institute of Technology (MIT).

Sithole, M. 2013. Success Factors and Barriers When Managing a Project at Power Stations in Eskom (Master's Thesis). University of Pretoria, South Africa

Sitienei, E., Memba, F. 2015. The Effect of Inventory Management on Profitability of Cement manufacturing Companies in Kenya: A Case Study of Listed Cement Manufacturing Companies in Kenya. *International Journal of Management and Commerce Innovations* 3, 111-119.

Skulmoski, G.J., Hartman F.T. 2007. The Delphi method for Graduate Research, *Journal of Information Technology Education* 6.

Smith, A.M., Hincheliffe, G.R. 2004. RCM: Gateway to World Class Maintenance. Elsevier Butterworth-Heinemann.

Smith D.L. 2016, FMEA: Preventing a Failure before Any Harm is Done. Retrieved from https://www.isixsigma.com. Date retrieved: 27 November 2016.

Sobral, J., Teixeira, D., Morais, H., Neves,M. 2017. Methodology to Assess Medical Processes Based on a Failure Mode and Effects Analysis (FMEA). *IEEE 5th Portuguese Meeting on Bioengineering (ENBENG)*, Coimbra, 1-4.

Soong, T.T. 2004. Fundamentals of Probability and Statistics for Engineers. John Wiley & Sons, Ltd.

Soni, G., Kodali, R. 2013. A critical review of supply chain management frameworks: proposed framework. *Benchmarking: An International Journal* 20, 2, 263-298.

Southard, P. Kumar, S., Southard, C.A. 2011. A Modified Delphi Methodology to Conduct an FMEA: A Patient-centric effort in a Clinical Medical Laboratory. O*perations and Supply Chain Management Faculty Publications* 1. Retrieved from http://ir.stthomas.edu. Date retrieved: 03 December 2016.

Susanto, M.B., Cook, G.R., Apte, U. 2006. Business Process Reengineering in the Inventory Management to Improve Aircraft Maintenance Operations in the Indonesian Air Force (Published Master's Thesis). Naval Postgraduate School, Monterey, California.

Technopedia, *Debugging*. Retrieved from https://www.techopedia.com. Date retrieved: 09 July 2017.

Toomey, J. 2000. Inventory Management: Principles, Concepts and Techniques. Springer Science and Business Media.

Tovia, F., Cassady, C., Brooks, R., Rossetti, M. 2011. Modelling and Analysis of Service Parts Logistics Systems. *International Journal of Operational Research* 10, 1, 60 – 81.

Tshibubudze S. 2013. A Critical Assessment of The Success of Eskom's Prevailing Procurement Negotiation Practices: A Content Analysis Study (Master's Thesis). University of Cape Town, Cape Town, South Africa.

United States of America, Department of Defense (U.S. DoD). 2000. Parts Management, Military Handbook (MIL-HDBK-512). United States of America, Department of Defense.

United States of America, Department of Defense (U.S. DoD). 2009. Diminishing Manufacturing Sources and Materials Shortage: A Guidebook of Best Practices and Tools for Implementing DMSMS Management Program. Department of Defense, Defense Standardization Program Office.

Wagner, S., Jonke, R., Eisingerich, A. 2012. A Strategic Framework for Spare Parts Logistics. *California Management Review* 54, 4, 69-92.

Walker, M. 2006. Assessing the Impact of Transnet and Eskom's Infrastructure Investment Programmes on the Capital Goods Sector and Key Constraints. *Accelerated and Shared Growth in South Africa: Determinants, Constraints and Opportunities Conference*, 18-20 October 2006.

Wallace, D. 2007. Integrated Inventory Management for Maintenance, Repair and Operations (MRO) Materials. *Reliable Plant,* July-August 2007, Life Cycle Engineering.

Wallace, T. 2006. Development and Implementation of an Automated Business Process and Maintenance and Monitoring Tool (The Distribution List Cleanup Tool) (Master's Thesis). Da Vinci Institute for the Management of Technology and Innovation, South Africa.

Walsh, K.D., Hershauer J.C., Tommelein, I.D., Walsh, T.A. 2014. Strategic Positioning of Inventory to Match Demand in a Capital Projects Supply Chain. *Journal of Construction Engineering and Management* 130, 6, 818-826.

Wara, S.T., Abayomi-AIIi, A. 2008. Facility Maintenance and Management Information System (MIS). In: *Conference Facility Maintenance and Management Information System (MIS)*. Covenant University, Nigeria.

Wisdom, J., Creswell, J.W. 2013. Mixed Methods: Integrating Quantitative and Qualitative Data Collection and Analysis While Studying Patients-Centred Medical Home Models. Rockville, MD: *Agency for Healthcare Research and Quality* 13.

Wu, M., Zhang, Y., Xu, M.Z, 2006. The Theoretical Advantage of JIT Purchasing is Probably Overstated. The CRIOCM 2006 International Symposium on Advancement of Construction Management and Real Estate.

You, F., Grossmann, I. 2009. Stochastic Inventory Management for Tactical Process Planning under Uncertainties: MINLP Models and Algorithms. Department of Chemical Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, USA

Yusof, S.M. and Aspinwall, E. 2000. Total Quality Management Implementation Frameworks: Comparison and Review. *Total Quality Management* 11, 3, 281-294.

Zhu, H., Liu, X., Chen, Y. 2015. Effective Inventory Control Policies with a Minimum Order Quantity and Batch Ordering. *International Journal of Production Economics* 168, 21-30.

A. APPENDICES

Appendix A: Permission to Conduct Research

ACCESS LETTER REQUESTING PERMISSION TO CONDUCT RESEARCH

University of Pretoria
Enquiries: Ronewa E. Goliada
Cell: +27 (0)73 599 7229
Student No: u14353777

Mr. Ashwin Rampersad
Hendrina Power Station
Impala Street, Pullenshope
Private Bag X 1003
Pullenshope
1096

16 August 2016

Dear Mr. Ashwin Rampersad

REQUEST FOR PERMISSION TO CONDUCT RESEARCH

I am a registered Master's student in the Department of Mechanical Engineering, in the Centre of Asset Integrity Management at the University of Pretoria, Hatfield Campus. My supervisor is Professor Jasper L. Coetzee.

The proposed topic of my research is: "*Causes of deficiencies in inventory management systems, and the impact of poor inventory management on the execution of maintenance*"

The objectives of the study are:

(a) To establish the existence of deficiencies in the management of spare parts in a power generating plant.
(b) To ascertain reasons for the limited effort to optimise inventory control in production facilities.
(c) To determine the contributing factors to the unavailability of spare parts during the execution of maintenance tasks.
(d) To determine the impact of shortage of spares on the effectiveness of the maintenance function

(e) To develop solutions to improve the inventory management and the spare parts procurement processes.

I am hereby seeking your consent to conduct a study by conducting a survey and in-depth interviews with employees in the following departments: Engineering, Outages, Maintenance, Procurement and Materials Management.

Should you require any further information, please do not hesitate to contact me or my supervisor. Our contact details are as follows:

Ronewa E. Goliada	RGoliada@gmail.com	+27 (0)73 599 7229
Jasper L. Coetzee	jasper.coetzee@up.ac.za	+27 (0)12 420 4746

Upon completion of the study, I undertake to provide you with a copy of the dissertation.

Your permission to conduct this study will be greatly appreciated.

Yours sincerely,

Ronewa E. Goliada

Ashwin Rampersad
Power Station Manager: Hendrina Power Station (Acting)

Permission	Granted	✓
	Denied	

Appendix B: Spare Parts Management Model Questionnaire

Survey Questions – Spare Parts Management

Good day,

My name is Ronewa E. Gollada. I am a registered Master's student in the Department of Mechanical Engineering, in the Centre of Asset Integrity Management at the University of Pretoria, Hatfield Campus. My supervisor is Professor Jasper L. Coetzee.

The proposed topic of my research is: *"Inefficiencies in Spare Part Management Processes in South African Power Plants"*.

The purpose of the study is to establish the inefficiencies that exist in spare parts management processes in South African power plants, and the causes of the inefficiencies, with the purpose of seeking solutions for such deficiencies

I am requesting your participation in this study, by reviewing the attached models of spare parts management, and comment on their correctness. Please feel free to make additions and removal of sub-processes.

Should you require any further information, please do not hesitate to contact me. My contact details are as follows:

Ronewa E. Gollada: RGollada@gmail.com,

GolladRE@eskom.co.za

+27 (0)73 599 7229 / 013 296 3220

Yours sincerely,

Ronewa E. Gollada

Date: 2017/03/06

Figure A.1: Front page of the spare parts model questionnaire

Item Name:	Spare Parts Management		Researcher: Ronewa E. Goliada
Objective of the research	To establish the inefficiencies that exist in spare parts management processes in South African power plants, and the causes of the inefficiencies		
Name (optional)			
Power Station			
Department			
Years of experience			

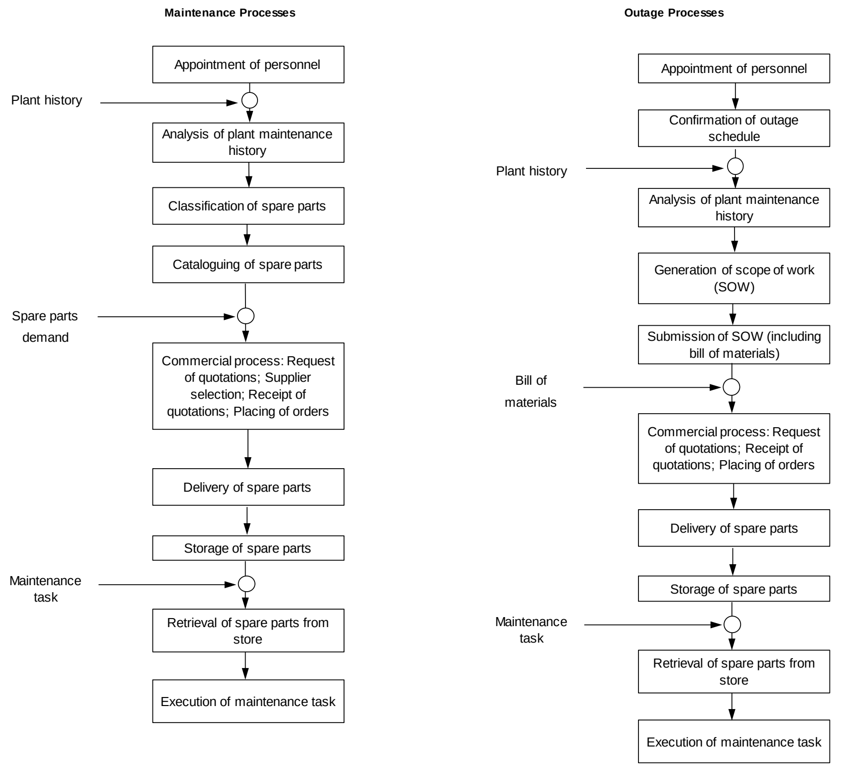


Figure A.2: Spare parts management model questionnaire

Appendix C: Questionnaire - Failure Mode and Effect Analysis

Survey Questions – Spare Parts Management

Good day,

My name is Ronewa E. Goliada. I am a registered Master's student in the Department of Mechanical Engineering, in the Centre of Asset Integrity Management at the University of Pretoria, Hatfield Campus. My supervisor is Professor Jasper L. Coetzee.

The proposed topic of my research is: *"Inefficiencies in Spare Part Management Processes in South African Power Plants"*.

The purpose of the study is to establish the inefficiencies that exist in spare parts management processes in South African power plants, and the causes of the inefficiencies, with the purpose of seeking solutions for such deficiencies

I am requesting your participation in this study, by performing failure mode and effect analysis as per the attached spreadsheet.

Should you require any further information, please do not hesitate to contact me. My contact details are as follows:

Ronewa E. Goliada: RGoliada@gmail.com,

GoliadRE@eskom.co.za

+27 (0)73 599 7229 / 013 296 3220

Yours sincerely,

Ronewa E. Goliada

Date: 2017/03/23

Figure A.3: Front page of the FMEA questionnaire

Process FMEA			
Item Name:	**Spare Parts Management**		**Researcher: Ronewa E. Goliada**
			FMEA Date (Orig): March 2017
Objective of the research	**To establish the inefficiencies that exist in spare parts management processes in South African power plants, and the causes of the inefficiencies**		
Name (optional)			
Power Station			
Department			
Years of experience			

Process Step or Variable or Key Input	Potential Failure Mode	Potential Effect on Customer Because of Defect	S E V	Potential Causes	O C C	Current Process Controls	D E T	R P N
What is the process step?	**In what ways can the Process Step, Variable, or Key Input go wrong? (chance of not meeting requirements)**	**What is the impact on the Key Output Variables (customer requirements) or internal requirements?**	**How Severe is effect to the**	**What causes the Key Input to go wrong? (How could the failure mode occur?)**	**How frequent is cause likely to**	**What are the existing controls that either prevent the failure mode from occurring or detect it should it occur?**	**How probable is Detection of cause?**	**Risk Priority # to rank order concerns**
Appointment of Relevant Stakeholders in the maintenance function	No Appointments	Maintenance work will not be executed		Management Oversight		None		
	Poor briefing	Work not being done on time because the stakeholder is not sure of the area they are supposed to cover.		Poor Management		None		
	Inadequate handover	Delays in the execution of work, as the stakeholder will not have all the works						
		Loss of experience and history						
	No training and No access to important tools (e.g. CMMSs)	Poor execution of the stakeholder's function						

Figure A.4: Snippet of the initial FMEA spreadsheet

Appendix D: Process Failure Mode and Effect Analysis Results

Table A.1: PFMEA results - Analysis of maintenance history

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Analysis of Plant Maintenance History	No analysis	The use of generic inventory control models.	1	8.20	8	0.76	0.50		No recording of plant maintenance history.	6.80	7	0.76	0.50		Supervision	8.40	8	1.04	0.50		468
			2	8.43	8	0.50	0.50	0.67		6.80	7	0.41	0.00	0.33		7.77	8	0.73	0.50	0.67	445
			3	8.47	8	0.51	0.50	0.93		7.00	7	0.64	0.00	0.58		7.47	7	0.51	0.50	0.71	443
			1	8.20	8	0.76	0.50		Lack of access to CMMS	8.80	9	0.76	0.50		None	10.00	10	0.00	0.00		722
			2	8.43	8	0.50	0.50	0.67		9.60	10	0.50	0.50	0.44		10.00	10	0.00	0.00	-	810
			3	8.47	8	0.51	0.50	0.93		9.40	9	0.50	0.50	0.62		10.00	10	0.00	0.00	-	796
			1	8.20	8	0.76	0.50		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		234
			2	8.43	8	0.50	0.50	0.67		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	210
			3	8.47	8	0.51	0.50	0.93		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	190
		High spare parts demand (due to failures that are not being analysed)	1	8.20	8	0.76	0.50		No recording of plant maintenance history.	6.80	7	0.76	0.50		Supervision	8.40	8	1.04	0.50		468
			2	8.43	8	0.50	0.50	0.67		6.80	7	0.41	0.00	0.33		7.77	8	0.73	0.50	0.67	445
			3	8.40	8	0.50	0.50	0.93		7.00	7	0.64	0.00	0.58		7.47	7	0.51	0.50	0.71	439
			1	8.20	8	0.76	0.50		Lack of access to CMMS	8.80	9	0.76	0.50		None	10.00	10	0.00	0.00		722
			2	8.43	8	0.50	0.50	0.67		9.60	10	0.50	0.50	0.44		10.00	10	0.00	0.00	-	810
			3	8.40	8	0.50	0.50	0.93		9.40	9	0.50	0.50	0.62		10.00	10	0.00	0.00	-	790
			1	8.20	8	0.76	0.50		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		234
			2	8.43	8	0.50	0.50	0.67		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	210
			3	8.40	8	0.50	0.50	0.93		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	188
	Inadequate analysis	Unsuitable inventory control models.	1	7.40	7	1.04	0.50		Inadequate recording of plant maintenance history	6.80	7	0.76	0.50		Supervision	8.40	8	1.04	0.50		423
			2	7.40	7	0.50	0.50	0.41		6.80	7	0.41	0.00	0.33		7.77	8	0.73	0.50	0.67	391
			3	7.17	7	0.38	0.00	0.46		7.00	7	0.64	0.00	0.58		7.47	7	0.51	0.50	0.71	375
			1	7.40	7	1.04	0.50		Incompetence (use of incorrect analysis methods; misintepretation of data)	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		211
			2	7.40	7	0.50	0.50	0.41		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	184
			3	7.17	7	0.38	0.00	0.46		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	161

Table A.2: PFMEA results – Classification of spare parts

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Classification of Spare parts	Wrong classification	Incorrect inventory management strategy	1	8.40	8	1.04	0.50		Poor risk/impact assessment	4.00	4	0.91	1.00		Supervision	8.40	8	1.04	0.50		282
			2	8.37	8	0.49	0.50	0.41		3.40	3	0.50	0.50	0.41		7.77	8	0.73	0.50	0.67	221
			3	8.40	8	0.50	0.50	0.93		3.20	3	0.41	0.00	0.55		7.47	7	0.51	0.50	0.71	201
			1	8.40	8	1.04	0.50		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		240
			2	8.37	8	0.49	0.50	0.41		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	208
			3	8.40	8	0.50	0.50	0.93		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	188
	Poor classfication	Inadequate inventory management strategy	1	7.40	7	1.04	0.50		Inadequate maintenance records.	6.80	7	0.76	0.50		None	10.00	10	0.00	0.00		503
			2	7.37	7	0.56	0.50	0.47		6.80	7	0.41	0.00	0.33		10.00	10	0.00	0.00	-	501
			3	7.00	7	0.74	0.75	0.62		7.00	7	0.64	0.00	0.58		10.00	10	0.00	0.00	-	490
			1	7.40	7	1.04	0.50		Lack of transparency in the supply chain	9.40	10	0.81	0.50		None	10.00	10	0.00	0.00		696
			2	7.37	7	0.56	0.50	0.47		9.60	10	0.50	0.50	0.64		10.00	10	0.00	0.00	-	707
			3	7.00	7	0.74	0.75	0.62		9.60	10	0.50	0.50	1.00		10.00	10	0.00	0.00	-	672
	Ineffective classification	Inadequate inventory management strategy	1	7.40	7	1.04	0.50		Poor classification criteria	5.00	5	0.64	0.00		Management Directives	3.53	4	0.94	0.50		131
			2	7.37	7	0.56	0.50	0.47		4.40	4	0.50	0.50	0.38		3.10	3	0.31	0.00	0.16	100
			3	7.00	7	0.74	0.75	0.62		4.17	4	0.38	0.00	0.46		2.90	3	0.31	0.00	0.47	85

Table A.3: PFMEA results – Determination of inventory control model

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Determination of inventory control model	No selection of inventory model	No control over the spare parts.	1	9.40	10	0.81	0.50		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		268
			2	9.57	10	0.50	0.50	0.59		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	238
			3	9.60	10	0.50	0.50	0.93		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	215
	Selection of unsuitable inventory control model	Inadequate control of spare parts.	1	9.40	10	0.81	0.50		Inadequate analysis of maintenance history	6.80	7	0.76	0.50		Supervision	8.40	8	1.04	0.50		537
			2	9.50	10	0.51	0.50	0.50		6.80	7	0.41	0.00	0.33		7.77	8	0.73	0.50	0.67	502
			3	9.43	9	0.50	0.50	0.87		7.00	7	0.64	0.00	0.58		7.47	7	0.51	0.50	0.71	493
			1	9.40	10	0.81	0.50		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		268
			2	9.50	10	0.51	0.50	0.50		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	236
			3	9.43	9	0.50	0.50	0.87		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	211
			1	9.40	10	0.81	0.50		Inadequate maintenance records	6.80	7	0.76	0.50		None	10.00	10	0.00	0.00		639
			2	9.50	10	0.51	0.50	0.50		6.80	7	0.41	0.00	0.33		10.00	10	0.00	0.00	-	646
			3	9.43	9	0.50	0.50	0.87		7.00	7	0.64	0.00	0.58		10.00	10	0.00	0.00	-	660

Table A.4: PFMEA results – Cataloguing of spare parts

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Cataloguing of spare parts	Omission of spare parts from database	No inventory management strategy for the spare parts	1	8.20	8	1.19	1.00		Human error	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		234
			2	8.63	8	0.85	0.50	0.46		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	215
			3	8.60	8	0.81	0.50	0.94		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	193
			1	8.20	8	1.19	1.00		CMMSs malfunction	4.40	4	1.04	0.50		Spare Parts Audit	9.50	10	0.57	0.50		343
			2	8.63	8	0.85	0.50	0.46		4.00	4	0.64	0.00	0.71		9.57	10	0.63	0.50	0.75	330
			3	8.60	8	0.81	0.50	0.94		3.60	4	0.50	0.50	0.64		9.67	10	0.61	0.38	0.79	299
	Incomplete/inaccurate capturing of spare parts specifications	Delivery of incorrect spare parts	1	8.17	8	1.21	1.00		Human error	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		233
			2	8.57	8	0.86	0.50	0.51		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	213
			3	8.50	8	0.78	0.50	0.82		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	190

Table A.5: PFMEA results – Confirmation of outage dates

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Confrimation of outage date	Changes in outgae dates	Inadequate planning for spare parts	1	9.40	10	0.81	0.50		Budget constraints	5.23	5	1.19	0.50		Financial management procedures	5.50	6	1.22	1.50		271
			2	9.50	10	0.51	0.50	0.50		5.30	5	0.84	0.50	0.58		5.90	6	0.84	1.00	0.61	297
			3	9.73	10	0.45	0.38	0.53		5.40	5	0.72	0.50	0.83		5.90	6	0.84	1.00	1.00	310
			1	9.40	10	0.81	0.50		Electricity demand constraints	8.80	9	0.76	0.50		Integrated demand management	5.50	6	1.22	1.50		455
			2	9.50	10	0.51	0.50	0.50		9.40	9	0.50	0.50	0.41		5.90	6	0.84	1.00	0.61	527
			3	9.73	10	0.45	0.38	0.53		9.40	9	0.50	0.50	1.00		5.90	6	0.84	1.00	1.00	540
	Cancellation of outages	Proliferation of spare parts	1	9.40	10	0.81	0.50		Budget constraints	5.23	5	1.19	0.50		Financial management procedures	5.50	6	1.22	1.50		271
			2	9.50	10	0.51	0.50	0.50		5.30	5	0.84	0.50	0.58		5.90	6	0.84	1.00	0.61	297
			3	9.73	10	0.45	0.38	0.53		5.40	5	0.72	0.50	0.83		5.90	6	0.84	1.00	1.00	310
			1	9.40	10	0.81	0.50		Electricity demand constraints	8.80	9	0.76	0.50		Integrated demand management	5.50	6	1.22	1.50		455
			2	9.50	10	0.51	0.50	0.50		9.40	9	0.50	0.50	0.41		5.90	6	0.84	1.00	0.61	527
			3	9.73	10	0.45	0.38	0.53		9.40	9	0.50	0.50	1.00		5.90	6	0.84	1.00	1.00	540

Table A.6: PFMEA results – Generation of scope of work

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Generation of scope of work (maintenance instructions)	Generation of inadequate maintenance instructions	Procurement of inadequate spare parts	1	9.40	10	0.81	0.50		Inadequate analysis of maintenance history	6.80	7	0.76	0.50		None	9.57	10	0.50	0.50		612
			2	9.57	10	0.50	0.50	0.59		6.80	7	0.41	0.00	0.33		9.70	10	0.47	0.50	0.72	631
			3	9.60	10	0.50	0.50	0.93		7.00	7	0.64	0.00	0.58		9.80	10	0.41	0.00	0.74	659
			1	9.40	10	0.81	0.50		Human factor related	7.20	7	1.19	1.00		Supervision/ Department Progress Feedback meetings	8.40	8	1.04	0.50		569
			2	9.57	10	0.50	0.50	0.59		7.40	7	0.50	0.50	0.25		7.77	8	0.73	0.50	0.67	550
			3	9.60	10	0.50	0.50	0.93		7.20	7	0.41	0.00	0.55		7.47	7	0.51	0.50	0.71	516
	No maintenance instructions generated	No ordering of spare parts	1	9.40	10	0.81	0.50		Changes in outage dates	6.60	6	0.81	0.50		Financial management procedures and Integraged demand procedures	5.50	6	1.22	1.50		341
			2	9.57	10	0.50	0.50	0.59		7.20	7	0.76	0.50	0.44		5.90	6	0.84	1.00	0.61	406
			3	9.77	10	0.43	0.00	0.57		7.67	8	0.61	0.50	0.68		5.90	6	0.84	1.00	1.00	442
			1	9.40	10	0.81	0.50		Human factor related	7.20	7	1.19	1.00		Supervision/ Department Progress Feedback meetings	8.40	8	1.04	0.50		569
			2	9.57	10	0.50	0.50	0.59		7.40	7	0.50	0.50	0.25		7.77	8	0.73	0.50	0.67	550
			3	9.77	10	0.43	0.00	0.57		7.20	7	0.41	0.00	0.55		7.47	7	0.51	0.50	0.71	525

Table A.7: PFMEA results – Submission of scope of work

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Submission of scope of work (inlcuding Bill of material)	Delayed submission of SOW	Inadequate planning for spare parts	1	9.40	10	0.81	0.50		Human factor related delays	3.40	4	0.81	0.50		Supervision/ Department Progress Feedback meetings	8.40	8	1.04	0.50		268
			2	9.50	10	0.51	0.50	0.50		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	236
			3	9.73	10	0.45	0.38	0.53		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	218
	Submission of incorrect scope of work	Acquisition of incorrect/inadequate spare parts	1	9.40	10	0.81	0.50		Human error	3.40	4	0.81	0.50		Central dcumentation control by Technical support services	3.70	4	1.21	1.00		118
			2	9.57	10	0.50	0.50	0.59		3.20	3	0.76	0.50	0.69		4.00	4	0.83	1.00	0.64	122
			3	9.60	10	0.50	0.50	0.93		3.00	3	0.64	0.00	0.69		3.70	4	0.70	0.50	0.70	107
	No submission	No ordering of spare parts	1	9.40	10	0.81	0.50		Changes in outage dates	7.20	7	1.19	1.00		Supervision	8.40	8	1.04	0.50		569
			2	9.57	10	0.50	0.50	0.59		7.40	7	0.50	0.50	0.25		7.77	8	0.73	0.50	0.67	550
			3	9.77	10	0.43	0.00	0.57		7.20	7	0.41	0.00	0.55		7.47	7	0.51	0.50	0.71	525
			1	9.40	10	0.81	0.50		Non-adherence to outage management procedures	5.27	5	1.05	0.50		Non-compliance Reports	3.73	4	1.20	1.00		185
			2	9.57	10	0.50	0.50	0.59		5.27	5	0.83	0.50	0.58		3.97	4	0.81	1.00	0.60	200
			3	9.77	10	0.43	0.00	0.57		5.30	5	0.79	0.50	0.94		3.73	4	0.64	0.50	0.69	193

Table A.8: PFMEA results – Commercial processes

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Commercial processes	No execution of procurement work	No spare parts	1	7.27	7	1.41	1.38		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		208
			2	7.07	7	0.87	0.75	0.58		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	176
			3	7.47	7	0.90	0.50	0.72		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	167
			1	7.27	7	1.41	1.38		Lack of clarity on procedures	5.23	5	1.19	0.50		Supervision	8.40	8	1.04	0.50		319
			2	7.07	7	0.87	0.75	0.58		5.27	5	0.83	0.50	0.54		7.77	8	0.73	0.50	0.67	289
			3	7.47	7	0.90	0.50	0.72		5.37	5	0.72	0.50	0.82		7.47	7	0.51	0.50	0.71	299
	Delays in the execution of commercial work	Delays in the delivery of spare parts	1	7.27	7	1.41	1.38		Incompetence	3.40	4	0.81	0.50		Supervision	8.40	8	1.04	0.50		208
			2	7.07	7	0.87	0.75	0.58		3.20	3	0.76	0.50	0.69		7.77	8	0.73	0.50	0.67	176
			3	7.47	7	0.90	0.50	0.72		3.00	3	0.64	0.00	0.69		7.47	7	0.51	0.50	0.71	167
			1	7.27	7	1.41	1.38		Number of approvals at each step	8.80	9	1.19	1.00		None	10.00	10	0.00	0.00		639
			2	7.07	7	0.87	0.75	0.58		9.20	9	0.76	0.50	0.72		10.00	10	0.00	0.00	-	650
			3	7.47	7	0.90	0.50	0.72		9.60	10	0.50	0.50	0.67		10.00	10	0.00	0.00	-	717
			1	7.27	7	1.41	1.38		Lack of clarity on procedures	5.23	5	1.19	0.50		Supervision	8.40	8	1.04	0.50		319
			2	7.07	7	0.87	0.75	0.58		5.27	5	0.83	0.50	0.54		7.77	8	0.73	0.50	0.67	289
			3	7.47	7	0.90	0.50	0.72		5.37	5	0.72	0.50	0.82		7.47	7	0.51	0.50	0.71	299
	Selection of unsuitable suppliers	Delivery of incorrect/ inadequate spare parts	1	7.27	7	1.41	1.38		Poor assessment of potential suppliers	4.97	5	0.61	0.00		Procurement procedures	5.50	6	1.22	1.50		199
			2	7.07	7	0.87	0.75	0.58		4.43	4	0.50	0.50	0.40		5.90	6	0.84	1.00	0.61	185
			3	7.47	7	0.90	0.50	0.72		4.10	4	0.48	0.00	0.46		5.90	6	0.84	1.00	1.00	181

Table A.9: PFMEA results – Delivery of material

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Delivery of spare parts	No delivery	No execution of maintenance tasks	1	7.27	7	1.41	1.38		Unsuitability of the supplier for the order of spare parts	4.97	5	0.61	0.00		Procurement procedures	5.50	6	1.22	1.50		199
			2	7.07	7	0.87	0.75	0.58		4.43	4	0.50	0.50	0.40		5.90	6	0.84	1.00	0.61	185
			3	7.47	7	0.90	0.50	0.72		4.10	4	0.48	0.00	0.46		5.90	6	0.84	1.00	1.00	181
			1	7.27	7	1.41	1.38		Unavailability of spare parts locally.	5.00	5	0.64	0.00		Government policies	8.30	8	1.02	0.50		302
			2	7.07	7	0.87	0.75	0.58		5.60	6	0.50	0.50	0.38		7.73	8	0.74	0.50	0.72	306
			3	7.47	7	0.90	0.50	0.72		5.80	6	0.41	0.00	0.55		7.33	7	0.61	0.50	0.73	318
			1	7.27	7	1.41	1.38		No penalty clauses on the contract between organisation and supplier.	8.97	9.5	1.22	1.00		Contract	10.00	10	0.00	0.00		652
			2	7.07	7	0.87	0.75	0.58		9.40	10	0.77	0.50	0.69		10.00	10	0.00	0.00	-	664
			3	7.47	7	0.90	0.50	0.72		9.67	10	0.55	0.50	0.75		10.00	10	0.00	0.00	-	722
			1	7.27	7	1.41	1.38		No contract between supplier and producer.	8.83	9	1.15	1.00		None	10.00	10	0.00	0.00		642
			2	7.07	7	0.87	0.75	0.58		9.27	9	0.74	0.50	0.67		10.00	10	0.00	0.00	-	655
			3	7.47	7	0.90	0.50	0.72		9.67	10	0.48	0.50	0.60		10.00	10	0.00	0.00	-	722
	Delayed delivery	Delayed execution of maintenance tasks	1	7.27	7	1.41	1.38		Unsuitability of the supplier for the order of spare parts	4.97	5	0.61	0.00		Procurement procedures	5.50	6	1.22	1.50		199
			2	7.07	7	0.87	0.75	0.58		4.43	4	0.50	0.50	0.40		5.90	6	0.84	1.00	0.61	185
			3	7.47	7	0.90	0.50	0.72		4.10	4	0.48	0.00	0.46		5.90	6	0.84	1.00	1.00	181
			1	7.27	7	1.41	1.38		Unavailability of spare parts locally.	5.10	5	1.30	0.88		Government policies	8.30	8	1.02	0.50		308
			2	7.07	7	0.87	0.75	0.58		4.90	5	0.92	0.38	0.52		7.73	8	0.74	0.50	0.72	268
			3	7.47	7	0.90	0.50	0.72		4.87	5	0.78	0.00	0.83		7.33	7	0.61	0.50	0.73	266
			1	7.27	7	1.41	1.38		No penalty clauses on the contract between organisation and supplier.	8.97	9.5	1.22	1.00		Contract	10.00	10	0.00	0.00		652
			2	7.07	7	0.87	0.75	0.58		9.40	10	0.77	0.50	0.69		10.00	10	0.00	0.00	-	664
			3	7.47	7	0.90	0.50	0.72		9.67	10	0.55	0.50	0.75		10.00	10	0.00	0.00	-	722
			1	7.27	7	1.41	1.38		No contract between supplier and producer.	8.83	9	1.15	1.00		None	10.00	10	0.00	0.00		642
			2	7.07	7	0.87	0.75	0.58		9.27	9	0.74	0.50	0.67		10.00	10	0.00	0.00	-	655
			3	7.47	7	0.90	0.50	0.72		9.67	10	0.48	0.50	0.60		10.00	10	0.00	0.00	-	722
	Delivery of incorrect or inadequate spare parts	No execution of maintenance tasks	1	7.27	7	1.41	1.38		Poor spare parts specifications	5.40	6	0.81	0.50		Spare parts audit	9.50	10	0.57	0.50		373
			2	7.07	7	0.87	0.75	0.58		5.40	5	0.50	0.50	0.38		9.57	10	0.63	0.50	0.75	365
			3	7.47	7	0.90	0.50	0.72		5.60	6	0.50	0.50	0.62		9.67	10	0.61	0.38	0.79	404
			1	7.27	7	1.41	1.38		Non-adherence to specifications	5.27	5	1.05	0.50		Supervision	8.40	8	1.04	0.50		321
			2	7.07	7	0.87	0.75	0.58		5.27	5	0.83	0.50	0.58		7.77	8	0.73	0.50	0.67	289
			3	7.47	7	0.90	0.50	0.72		5.30	5	0.79	0.50	0.94		7.47	7	0.51	0.50	0.71	295
			1	7.27	7	1.41	1.38		Unsuitability of the supplier for the order of spare parts	4.97	5	0.61	0.00		Procurement procedures	5.50	6	1.22	1.50		199
			2	7.07	7	0.87	0.75	0.58		4.43	4	0.50	0.50	0.40		5.90	6	0.84	1.00	0.61	185
			3	7.47	7	0.90	0.50	0.72		4.10	4	0.48	0.00	0.46		5.90	6	0.84	1.00	1.00	181
			1	7.27	7	1.41	1.38		Poor quality control measures	6.80	7	1.19	1.00		Quality procedures	5.50	6	1.22	1.50		272
			2	7.07	7	0.87	0.75	0.58		7.20	8	1.00	1.00	0.41		5.90	6	0.84	1.00	0.61	300
			3	7.47	7	0.90	0.50	0.72		7.57	8	0.57	0.50	0.41		5.90	6	0.84	1.00	1.00	333

Table A.10: PFMEA results – Storage of spare parts

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Storage of spare parts	Poor preservation of spare parts	Bad condition of spare parts.	1	7.00	7	1.44	1.00		Non-adherecnce material storage procedures	5.27	5	1.05	0.50		Spare parts audit	9.50	10	0.57	0.50		350
Storage of spare parts	Poor preservation of spare parts	Bad condition of spare parts.	2	6.77	7	0.94	0.50	0.58	Non-adherecnce material storage procedures	5.27	5	0.83	0.50	0.58	Spare parts audit	9.57	10	0.63	0.50	0.75	341
Storage of spare parts	Poor preservation of spare parts	Bad condition of spare parts.	3	7.13	7	1.01	0.50	0.77	Non-adherecnce material storage procedures	5.30	5	0.79	0.50	0.94	Spare parts audit	9.67	10	0.61	0.38	0.79	365
Storage of spare parts	Poor documentation management (i.e. material certificates, etc)	Delays in the utilisation of a spare part	1	6.90	7	1.35	1.00		Non-adherecnce to quality procedures	5.27	5	1.05	0.50		Re-certification procedure	5.50	6	1.22	1.50		200
Storage of spare parts	Poor documentation management (i.e. material certificates, etc)	Delays in the utilisation of a spare part	2	6.67	7	0.84	0.50	0.57	Non-adherecnce to quality procedures	5.27	5	0.83	0.50	0.58	Re-certification procedure	5.90	6	0.84	1.00	0.61	207
Storage of spare parts	Poor documentation management (i.e. material certificates, etc)	Delays in the utilisation of a spare part	3	7.03	7	0.93	0.88	0.72	Non-adherecnce to quality procedures	5.30	5	0.79	0.50	0.94	Re-certification procedure	5.90	6	0.84	1.00	1.00	220
Storage of spare parts	Poor control over spare parts retrieval	Wastage of spare parts	1	7.07	7	1.39	1.00		Inadequate spare parts procedure	5.23	5	1.19	0.50		None	3.70	4	1.21	1.00		137
Storage of spare parts	Poor control over spare parts retrieval	Wastage of spare parts	2	6.90	7	0.76	0.50	0.53	Inadequate spare parts procedure	5.27	5	0.83	0.50	0.54	None	4.10	4	0.80	0.88	0.68	149
Storage of spare parts	Poor control over spare parts retrieval	Wastage of spare parts	3	7.20	7	0.71	0.50	0.75	Inadequate spare parts procedure	5.37	5	0.72	0.50	0.82	None	3.77	4	0.73	0.50	0.70	146
Storage of spare parts	Poor control over spare parts retrieval	Uncertainty on stock levels	1	7.07	7	1.39	1.00		Non-adherence to spare parts procedure	5.27	5	1.05	0.50		None	3.70	4	1.21	1.00		138
Storage of spare parts	Poor control over spare parts retrieval	Uncertainty on stock levels	2	6.90	7	0.76	0.50	0.53	Non-adherence to spare parts procedure	5.27	5	0.83	0.50	0.58	None	4.10	4	0.80	0.88	0.68	149
Storage of spare parts	Poor control over spare parts retrieval	Uncertainty on stock levels	3	7.33	7	0.66	0.50	0.65	Non-adherence to spare parts procedure	5.30	5	0.79	0.50	0.94	None	3.77	4	0.73	0.50	0.70	146

Table A.11: PFMEA results – Retrieval of spare parts

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Retrieval of spare parts	No retrieval	No execution of maintenance task	1	7.00	7	1.44	1.00		Non-adherecnce material storage procedures	5.27	5	1.05	0.50		Spare parts audit	9.50	10	0.57	0.50		350
			2	6.77	7	0.94	0.50	0.58		5.27	5	0.83	0.50	0.58		9.57	10	0.63	0.50	0.75	341
			3	7.13	7	1.01	0.50	0.77		5.30	5	0.79	0.50	0.94		9.67	10	0.61	0.38	0.79	365
	Delayed retrieval	Delayed execution of maintenance task	1	6.90	7	1.35	1.00		Unavailability of human resources	5.10	5	1.30	0.88		Supervision	8.40	8	1.04	0.50		296
			2	6.67	7	0.84	0.50	0.57		4.90	5	0.92	0.38	0.52		7.77	8	0.73	0.50	0.67	254
			3	7.03	7	0.93	0.88	0.72		4.87	5	0.78	0.00	0.83		7.47	7	0.51	0.50	0.71	256
		Delayed execution of maintenance task	1	6.90	7	1.35	1.00		Poor cataloguing/ shelfing of spare parts	6.60	6	0.81	0.50		Quality procedures	5.50	6	1.22	1.50		250
			2	6.67	7	0.84	0.50	0.57		7.20	7	0.76	0.50	0.44		5.90	6	0.84	1.00	0.61	283
			3	7.03	7	0.93	0.88	0.72		7.60	8	0.50	0.50	0.67		5.90	6	0.84	1.00	1.00	315
		Delayed execution of maintenance task	1	6.90	7	1.35	1.00		Poor documentation management	6.60	6	0.81	0.50		Quality procedures	5.50	6	1.22	1.50		250
			2	6.67	7	0.84	0.50	0.57		7.20	7	0.76	0.50	0.44		5.90	6	0.84	1.00	0.61	283
			3	7.03	7	0.93	0.88	0.72		7.63	8	0.56	0.50	0.67		5.90	6	0.84	1.00	1.00	317
	Failure to update stock levels	Uncertainty on stock levels	1	7.07	7	1.39	1.00		Non-adherecnce material management procedures	5.27	5	1.05	0.50		Materials management procedure	5.50	6	1.22	1.50		205
			2	6.90	7	0.76	0.50	0.53		5.27	5	0.83	0.50	0.58		5.90	6	0.84	1.00	0.61	214
			3	7.33	7	0.66	0.50	0.65		5.30	5	0.79	0.50	0.94		5.90	6	0.84	1.00	1.00	229
	Failure to book rotable and repaiarable spare parts to the store	Unnecessary increased costs of inventory	1	7.07	7	1.39	1.00		Non-adherecnce material management procedures	5.27	5	1.05	0.50		Materials management procedure	5.50	6	1.22	1.50		205
			2	6.90	7	0.76	0.50	0.53		5.27	5	0.83	0.50	0.58		5.90	6	0.84	1.00	0.61	214
			3	7.20	7	0.71	0.50	0.75		5.30	5	0.79	0.50	0.94		5.90	6	0.84	1.00	1.00	225

Table A.12: PFMEA results – Execution of maintenance task

Process Step	Potential Failure Mode	Potential Effect	Round	Mean SEV	Median	S.D.	SIQR	Kappa	Potential Causes	Mean OCC	Median	S.D.	SIQR	Kappa	Current Process Controls	Mean DET	Median	S.D.	SIQR	Kappa	RPN
Execution of maintenance task	Poor workmanship	Increased consumption of spare parts	1	7.83	8	1.15	1.00		Non-adherecnce quality procedures	5.27	5	1.05	0.50		Supervision	3.70	4	1.21	1.00		153
			2	7.23	7	0.73	0.50	0.49		5.27	5	0.83	0.50	0.58		4.10	4	0.80	0.88	0.68	156
			3	7.40	7	0.50	0.50	0.71		5.30	5	0.79	0.50	0.94		3.77	4	0.73	0.50	0.70	148
	Poor handling of spare parts	Increased consumption of spare parts	1	7.83	8	1.15	1.00		Non-adherecnce maintenance procedures	5.27	5	1.05	0.50		Supervision	3.70	4	1.21	1.00		153
			2	7.23	7	0.73	0.50	0.49		5.27	5	0.83	0.50	0.58		4.10	4	0.80	0.88	0.68	156
			3	7.40	7	0.50	0.50	0.71		5.30	5	0.79	0.50	0.94		3.77	4	0.73	0.50	0.70	148
	Poor handling of rotable components	Unnecessary increased costs of inventory	1	7.90	8	1.16	1.00		Non-adherecnce quality procedures	5.27	5	1.05	0.50		Supervision	3.70	4	1.21	1.00		154
			2	7.17	7	0.79	0.50	0.46		5.27	5	0.83	0.50	0.58		4.10	4	0.80	0.88	0.68	155
			3	7.53	8	0.57	0.50	0.68		5.30	5	0.79	0.50	0.94		3.77	4	0.73	0.50	0.70	150

Appendix E: Framework Development

Item name : **Spare parts management improvement framework**
Objective of the study :
To determine the suitability of the developed framework below in addressing the inefficiencies highlighted by the FMEA
Name (*optional*) : ____________________
Department : ____________________
Years of experience : ____________________

Brief :

The spare parts management model was subjected to failure mode and effect analysis. The analysis was able to identify the inefficiencies that exist in spare parts management in power stations, and the causes of such inefficiency . Furthermore, the study ranked the inefficiencies in terms of their significance in order to ensure that efforts aimed at improving spare parts management consider the most significant inefficiencies first.

Below is a framework that has been developed to improve the operation of the spare parts management sub-processes.
Please review the framework according to the criteria below:

1. Does the flowchart describe all the elements of improving spare parts management?
2. Does the flowchart indicate the relationship between all the elements involved in the improvement of spare parts management?
3. Is the process described by the flowchart practical?

Please comment on any inadequacies of the process shown in the flowchart below. You can also highlight with a pen on the flowchart itself.
You can use the following sub-process to test the robustness of the flowchart:

Sub-process	**Inefficiency**	**Causes**	**Controls**
Analysis of plant maintenance history	Inadequate analysis of plant maintenance history.	Inadequate maintenance records	Supervision

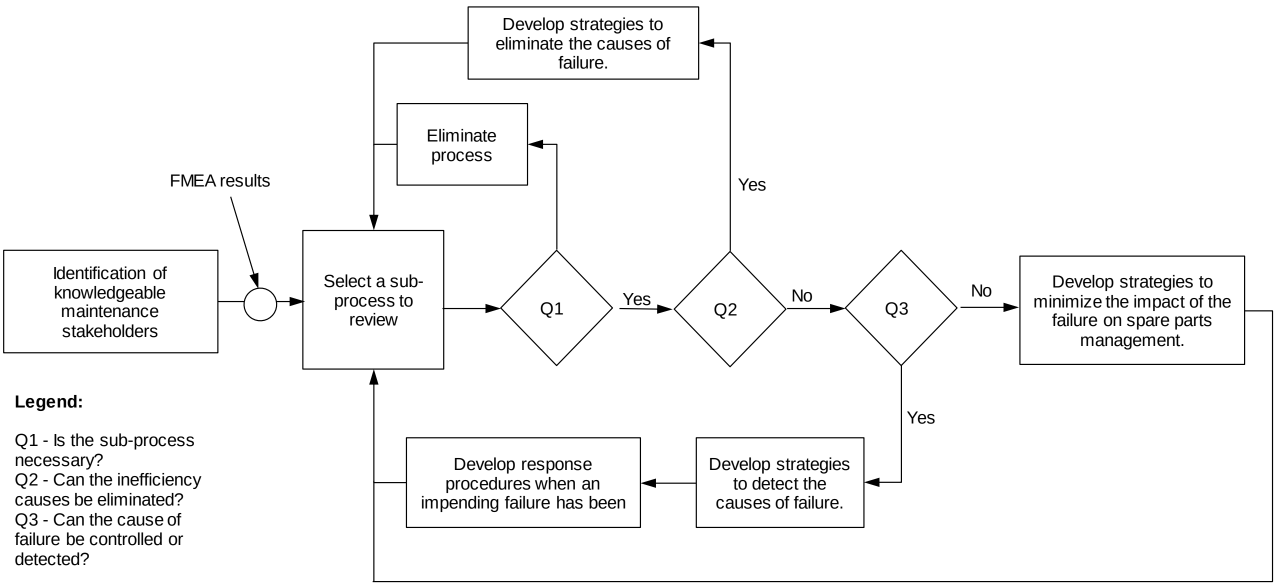
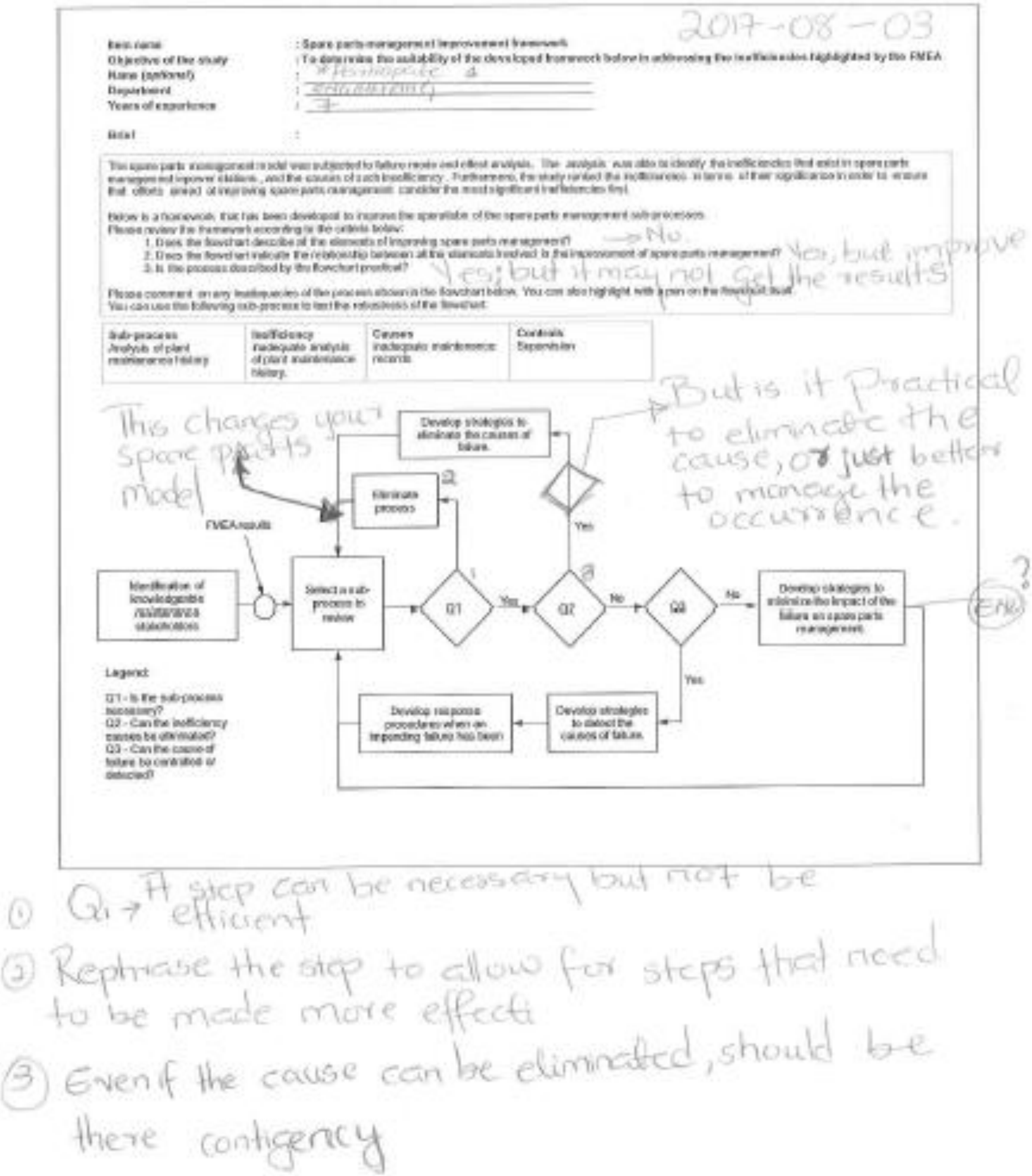


Figure A.5: Framework questionnaire round 1



2017-08-03

Item name : Spare parts management improvement framework
Objective of the study : To determine the suitability of the developed framework below in addressing the inefficiencies highlighted by the FMEA
Name (optional) : #Respondent 4
Department : Engineering
Years of experience : 7

Brief :

The spare parts management model was subjected to failure mode and effect analysis. The analysis was able to identify the inefficiencies that exist in spare parts management improvement, and the causes of such inefficiency. Furthermore, the study ranked the inefficiencies in terms of their significance in order to ensure that efforts aimed at improving spare parts management consider the most significant inefficiencies first.

Below is a framework that has been developed to improve the operation of the spare parts management sub-processes.
Please review the framework according to the criteria below:
1. Does the flowchart describe all the elements of improving spare parts management? → No.
2. Does the flowchart indicate the relationship between all the elements involved in the improvement of spare parts management? Yes, but improve
3. Is the process described by the flowchart practical? Yes; but it may not get the results

Please comment on any inadequacies of the process shown in the flowchart below. You can also highlight with a pen on the flowchart itself.
You can use the following sub-process to test the robustness of the flowchart:

Sub-process	Inefficiency	Causes	Controls
Analysis of plant maintenance history	Inadequate analysis of plant maintenance history.	Inadequate maintenance records	Supervision

① Q1 → A step can be necessary but not be efficient
② Rephrase the step to allow for steps that need to be made more effecti
③ Even if the cause can be eliminated, should be there contigency

Figure A.6: Example of results from the research participants

Round 2

Item name : **Spare parts management improvement framework**
Objective of the study : **To determine the suitability of the developed framework below in addressing the inefficiencies highlighted by the FMEA**
Name (*optional*) : ______________________
Department : ______________________
Years of experience : ______________________

Brief :

The spare parts management model was subjected to failure mode and effect analysis. The analysis was able to identify the inefficiencies that exist in spare parts management in power stations, and the causes of such inefficiency. Furthermore, the study ranked the inefficiencies in terms of their significance in order to ensure that efforts aimed at improving spare parts management consider the most significant inefficiencies first.

Below is a framework that has been developed to improve the operation of the spare parts management sub-processes.
Please review the framework according to the criteria below:

1. Does the flowchart describe all the elements of improving spare parts management?
2. Does the flowchart indicate the relationship between all the elements involved in the improvement of spare parts management?
3. Is the process described by the flowchart practical?

Please comment on any inadequacies of the process shown in the flowchart below. You can also highlight with a pen on the flowchart itself.

Sub-process	**Inefficiency**	**Causes**	**Controls**
Analysis of plant maintenance history	Inadequate analysis of plant maintenance history.	Inadeqaute maintenance records	Supervision

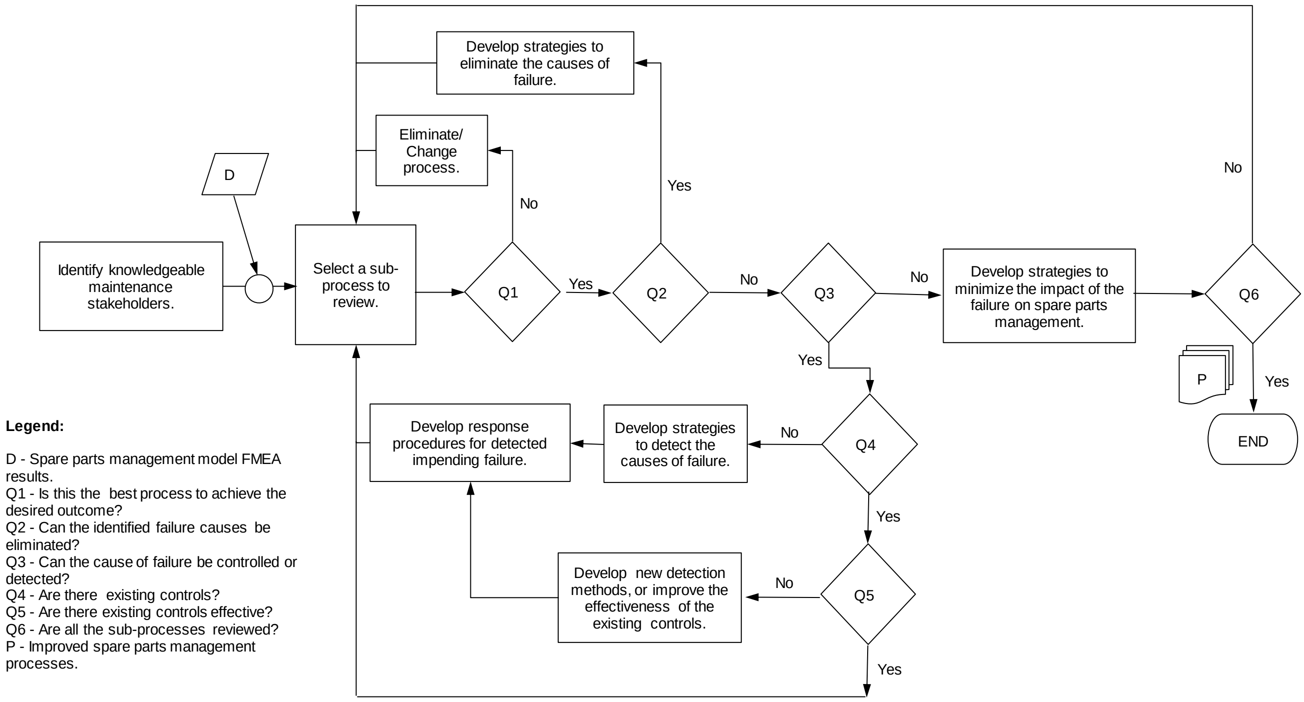


Figure A.7: Framework questionnaire round 2