DURBAN UNIVERSITY OF TECHNOLOGY

OPTIMISING CORRECTIVE MAINTENANCE BACKLOG USING QUALITY TOOLS AND QUALITY PRINCIPLES AT A SELECTED POWER GENERATION PLANT IN SOUTH AFRICA

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APRIL 2022

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Submitted in fulfilment of the requirements for the Master of Philosophy in Quality Management degree in the Faculty of Management Sciences at the Durban University of Technology

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APRIL 2022

Supervisor: Dr M Ramchander **Signature:** **Date:** 11/04/22

Abstract

This study is located within a power generation plant based in the Free state province of South Africa. Corrective maintenance is a challenge in the power generation plant which created corrective maintenance backlog. This emerged as a significant challenge for the power generation to address. According to previous studies, there has been minimal improvements in the coal-fired power generation plants in South Africa. This has created an environment where power generation is through aged infrastructure with high maintenance. South Africa, with its current power generation challenges, has a direct negative impact on global investors. It is critical to meet electricity demand to power the current and future economic needs of the country. The aim of the study is to optimise the corrective maintenance backlog at a selected power generation plant.

In this study, a combination of qualitative and quantitative research methods were applied. A questionnaire was sent to the power generation plant employees. Top management was interviewed, and secondary data on corrective maintenance and documentation was analysed.

This study looked at integrating essential quality tools and ISO 9001:2015 Quality Management Principles to optimise the corrective maintenance backlog. This integration brought about a practical and implementable framework that the power generation plant can apply to improve the execution of maintenance activities and thus reduce the corrective maintenance backlog.

Key words

Corrective maintenance, quality management, quality tools, quality principles, optimisation.

Dedication

I dedicate this research to my wife (Jennifer), my son (Sean), and my daughter (Jazmine) for allowing me the time to work on this research.

Acknowledgement

I would like to thank my colleagues at work who assisted me in reviewing my work and giving thoughtful feedback. Thank you to all who took the time to fill in the research survey questionnaire amid their busy schedule. Thank you to the management of the PGP for allowing me to conduct my study at the PGP. Most importantly, I would like to thank my Supervisor, Dr Manduth Ramchander, for his guidance and patience throughout my research.

Declaration

I, Moses Matshidiso Maseola, the **undersigned**, declare that this research is solely my work, and I did not use someone else's work and make it my own. I further advise that this dissertation has not been submitted for any degree at another tertiary institution. I recognise that plagiarism is wrong, and as a result, I have referenced other people's work accordingly.

Sign: ………Date: 11 April 2022………

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List of abbreviations and acronyms

AP/AU	Awaiting plant / awaiting unit
BAUX	Boiler auxiliary section
BCM	Business centred maintenance
C&I U1-3	Control and Instrumentation for units 1-3 section
C&I U4-6	Control and Instrumentation for units 4-6 section
Capex	Capital expenditure
CFI	Comparative fit index
CM	Corrective maintenance
CMMS	Computerised maintenance management system
CMIN/DF	Chi-square fit statistics/degree of freedom.
CO_2	Carbon dioxide
CoM	Condition-based maintenance
COSP	Control and Instrumentation outside plant
CPU	Central processing unit
DF	Degree of freedom
DMADV	Define, Measure, Analyse, Design, Validate
DMAIC	Define, Measure, Analyse, Improve, Control
DoM	Design-out maintenance
EFA	Exploratory factor analysis
EMS U1-3	Electrical maintenance section for units 1-3
EMS U4-6	Electrical maintenance section for units 4-6
EOSP	Electrical outside plant section
GDP	Gross domestic product
GHG	Greenhouse gas
IFI	Incremental fit index
ILS	Integrated logistics support
ISO	International organisation for standardisation
JIT	Just in time
KMO	Kaiser-Meyer-Olkin
LCC/LCP	Life of cost/profit

MBNQA	Malcolm Baldridge National Quality Award
MDT	Mean downing time
MILLS	Milling section
MMSDUST	Dust plant maintenance management section
MMSLUB	Lubrication maintenance management section
MRT	Mean repair time
MS	Microsoft
MTBDE	Mean time between downing events
MTBM	Mean time between maintenance
MTTF	Mean time to failure
MTTR	Mean time to repair
MW	Megawatt
MWTP	Maintenance water treatment plant section
NFI	Normed Fit Index
OCLN	Outside plant cleaning section
Opex	Operational expenditure
PCFI	Parsimony Normed Fit Index
PDCA	Plan, Do, Check, Act
PESTLE	Political, Economic, Social, Technological, Legal, Environment,
PGP	Power generation plant
PM	Preventive maintenance
QMS	Quality management system
RAM	Reliability, availability, maintainability
RCM	Reliability centered maintenance
RMSEA	Root Mean Square Error of Approximation
RQ	Research question
SEM	Structural equation modelling
SPC	Statistical process control
SPSS	Statistical package for the social sciences
TLI	Tucker Lewis index

TPM	Total Productive Maintenance
TQM	Total Quality Management

Terms and Definitions

Terms	**Definition**
Backlog	Defects that can be executed but on a waiting list
Capex	Capital expenditure (organisational budget used to maintain infrastructure)
Defects awaiting spares	Defects that cannot be executed due to the unavailability of spares
Defects awaiting unit/plant	Defects that cannot be executed due to the unavailability of the plant.
G/S – Level	Non-Technical professional within PGP
Hit squad	Several members of a team or organisation that mastermind specific attacks in a networked operation and are also used as an organisational adaption (Hwang, Panggabean and Fauzi 2013: 759)
M – Level	Management position within the PGP
Opex	Operational expenditure (Organisational budget used for operational processes)
Otter.ai	The software for transcription
Outstanding documentation	Executed defects but awaiting the submission of paperwork.
P – Level	Professional engineer position within the PGP
T – Level -	Technician position within the PGP

List of appendices

CHAPTER 1: INTRODUCTION

1.1 Introduction

More than 85% of South Africa's electricity is generated from coal-fired power plants. Very few design improvements have been undertaken at these power plants between the 1990s and 2000s to resolve the growing electricity margin shortages (Muhammad and Muhammad 2017: 531). Monyei and Adewumi (2017: 2). inform that Eskom is South Africa's main electricity provider, producing over 95% of South Africa's electricity and 45% of Africa's electricity. They further inform that electricity transmitted and distributed by Eskom directly to residential is 5.6%, to the mining is 14.4%, to industrial is 22.3%, commercial & agricultural is 7%, rail is 1.4%, with a further 5.6% of international exports and lastly 42.7%. to municipalities. As electricity demand grew, no capacity was added to the electricity sector. The electricity system reliability was allowed to deteriorate unchecked, worsening the decreasing electricity reserve margin that culminated in nationwide blackouts in 2005, 2007, and 2014 (Muhammad and Muhammad 2017: 531).

The South African economy depends on the steady supply of electricity. In recent years, South Africa has experienced challenges maintaining a constant electricity supply to meet the required demand, resulting in load shedding (Goldberg 2015:6). The mandate of the power utility (Eskom) is to provide a stable electricity supply sustainably and efficiently to assist in lowering the cost of doing business in South Africa to enable economic growth (Eskom 2020: 9). In response, the utility has implemented proactive maintenance programs at existing power stations to mitigate load shedding (Eskom 2020: 9). The ageing infrastructure, which leads to ever-increasing routine maintenance, threatens the energy security and reliability of the electricity supply (Goldberg (2015:7). Furthermore, the increase in population, urbanisation and income brackets drive up electricity demand and put more strain on the already insufficient generating capacity resulting in devastating economic impact on regional, national and global levels (Ouedraogo 2017: 1047).

The researcher's view is that the continued viability of the electricity sector is crucial to support South Africa's economic growth to make a vital contribution to job creation, socio-economic development, and attract global investors. Thus, the focus of this study was to understand how best to incorporate quality tools and principles to optimise maintenance performance at a selected coal-fired power generation plant (PGP) in South Africa. The chapter commences by presenting the context of the study that summarises the power generation landscape in South Africa. The research problem is then presented, and the objectives for the study are set out. The methodology is summarised, and the scope of the survey alludes. The conceptual framework that underpins the study is elucidated, and the chapter concludes with an explication of the contents of the chapters constituting this study.

The research is built around the following constructs, which in turn are research questions:

- The extent to which quality tools are embedded in the maintenance practices.
- The extent to which ISO9000:2015 Quality Management Principles are embedded in the maintenance practices.
- The factors that contribute to the corrective maintenance backlog.
- The gaps and limitations in the maintenance documentation.
- The extent to which external service providers contribute to the corrective maintenance backlog.

1.2 Background and context of the research

Electricity supply utility (Eskom) is a state-owned organisation established in 1923 to supply affordable and reliable electricity in South Africa and some neighbouring countries (Eskom 2019: 1). Eskom drives the South African economy by providing 95% of the electricity needs in the country and is deemed to be the largest producer of electricity in Africa and is ranked in the top seven in the world for its generation capacity (Eskom 2019: 1). As the South African economy grew, so did electricity consumption.

The observation is that inconsistencies in government policies and delay in building additional power stations to compensate for increasing population and growing economic activities, the power utility resorted to implement load shedding to balance supply deficits and prevent grid breakdown. (Monyei and Adewumi 2017: 2). The warning from An and Mikhaylov (2020: 59) is that by 2021 the country will face further severe energy deficiency problem aggravated by the need to reduce the coal-based power generation plants by 2030 according to Paris Climate Agreement signed by South Africa, otherwise it faces significant fines.
According to Goldberg (2015: 2), load shedding remains with minor signs of abatement in the near future, thus deterring global investment into the South African economy. A different view from An and Mikhaylov (2020: 59) is, South Africa is one of the most promising markets for countries like Russia to invest in the medium and long terms to implement new technologies. They further inform that, the most effective solution to the problems of South African energy crisis is the construction of nuclear power plants with the view that nuclear energy is capable of not only providing surplus electricity in South Africa, but also contribute to a "soft" transition from coal-fired power plants to environmentally friendly green technology.

The selected PGP is one of the fifteen coal-fired power stations contributing to the utility's total power generating capacity of 44 034 megawatts (Eskom, 2017: 139). According to (Mashosho 2019: 20), the PGP's April 2019 maintenance performance report reflected that corrective maintenance peaked at its highest for the six months, ending April 2019, as depicted in Table 1.1.

Table 1.1: Six-month maintenance performing report

Year	Month	Number of defects
2018	November	1650
2018	December	1635
2019	January	1680
2019	February	1535
2019	March	1741
2019	April	2000

Source: Adapted from Mashosho (2019: 20)

The increasing trend reflects the challenge within the PGP's maintenance scope to deal with high levels of plant defects, thus having a negative impact on plant reliability and availability. Therefore, this study focused on the selected PGP to influence maintenance policies and strategies to optimise maintenance performance by incorporating quality tools and principles in maintenance processes. More specifically, the study aimed to optimise corrective maintenance backlog by using quality tools and quality principles. √

1.3 Research Problem, Aims and Objectives

1.3.1 Research problem

Corrective maintenance (CM) is an approach that is reactive and has a negative impact on preventive maintenance (PM). Organisations constantly find themselves in the "firefighting" mode of CM, mainly due to time and resources dedicated to executing CM (Ab-Samat and Kamarunddin 2014: 112). Furthermore, if PM is not performed effectively, the rate of CM increases resulting in a backlog, as is the case with the selected PGP. CM/PM's engineering maintenance standard ratio of CM/PM is 20%/80% (Runeyi and Sardini, 2015: 3), whilst the percentage of CM/PM at the PGP was 43%/57% respectively (Mashosho, 2019: 19).

According to Sarkar et al. (2011: 140), any deviation from the optimal PM/CM ratio affects plant reliability and availability, which leads to high maintenance costs. Vishnu and Regikumar (2016: 1082) posit that maintenance costs can range between 20-30% of the total operating costs and can even go up to 40% in larger plants. Furthermore, Mostafa, Dumrak and Soltan (2015: 435) highlight that the total operational costs average up to 30% of the total costs associated with product or service. Such high costs can lead to the final product or service being sold at a higher price to recoup the costs involved in the operations and maintenance of the plant.

The costs of maintenance activities for the financial year 2018/19 in the selected PGP was 42% of the total operating costs (Tsoaeli 2019: 5). More focussed maintenance policies are needed to determine the most effective and efficient maintenance strategies to execute the maintenance activities at the lowest possible costs (Do, Scarf and Lung 2015: 946). The reduction in both operating and maintenance expenses leads to the financial sustainability of the organisation.

Vilarinho, Lopes and Oliveira (2017: 1170) posit that to achieve optimal maintenance solutions, organisations must develop strategies that maximise the benefits of maintenance strategies in addressing both CM and PM activities. Erkoyuncu et al. (2017: 54-55) emphasises the need for an optimum balance between CM and PM, as an essential part of maintenance strategy, with the thrust being on reducing the levels of CM and improving on PM to attain maintenance effectiveness. Given both the unfavourable CM/PM ratio and the increasing number of defects, this study is considered imperative at the selected PGP.

Management strategies that can maximise the benefits of maintenance strategies in addressing CM and PM are quality management principles which are in line with current managerial theory and practice, these principles were translated into international standards` requirements and guidelines suitable for implementing established approaches to determine, measure, accomplish and improve operational objectives. (Luburic 2015: 119). Aligned to management strategies, is the quality tools which are used to improve the quality of products in any industry, this includes different methods and tools by which organization can keep check on quality (Gadre et al. 2015: 59).

1.3.2 Research aims

The study aimed is to optimise the corrective maintenance backlog at a selected PGP in South Africa

1.3.3 Research questions

The questions that this study sought to answer are:

i. What is the extent to which quality tools are embedded in the maintenance practices? (RQ1)
ii. What is the extent to which ISO 9000: 2015 Quality Management Principles are embedded in the maintenance practices? (RQ2)
iii. What are the factors that contribute to the corrective maintenance backlog? (RQ3)
iv. What are the gaps and limitations in the maintenance documentation? (RQ4)
v. To what extent do the external service providers contribute to the corrective maintenance backlog? (RQ5)
vi. What is management's perception of the practices of quality tools in maintenance? (RQ6)
vii. What is management's perception of the techniques of ISO 9000: 2015 Quality Management Principles in maintenance? (RQ7)
viii. What type of practical and implementable framework can be adopted to reduce corrective maintenance backlog? (RQ8)

1.3.4 Research objectives

The objectives of this study were:

i. To ascertain the extent to which quality tools are embedded in the maintenance practices.
ii. To ascertain the extent to which ISO 9000: 2015 Quality Management Principles are embedded in maintenance practices of the PGP.
iii. To ascertain the factors that are contributing to the corrective maintenance backlog.
iv. To evaluate the extent to which the maintenance documentation aligns to ISO 9001: 2015 requirements.
v. To determine the extent to which external service providers contribute to corrective maintenance backlog.
vi. To ascertain management's perception of the practices of quality tools in the maintenance
vii. To capture management's perceptions on how much ISO 9000: 2015 Quality Management Principles are practised in the maintenance department.
viii. To develop a practical and implementable framework to be adopted to optimise corrective maintenance backlog.

1.4 Research Methodology

The approach followed in this research is illustrated in Figure 1.1, which starts with the literature review and end with conclusion and recommendations.

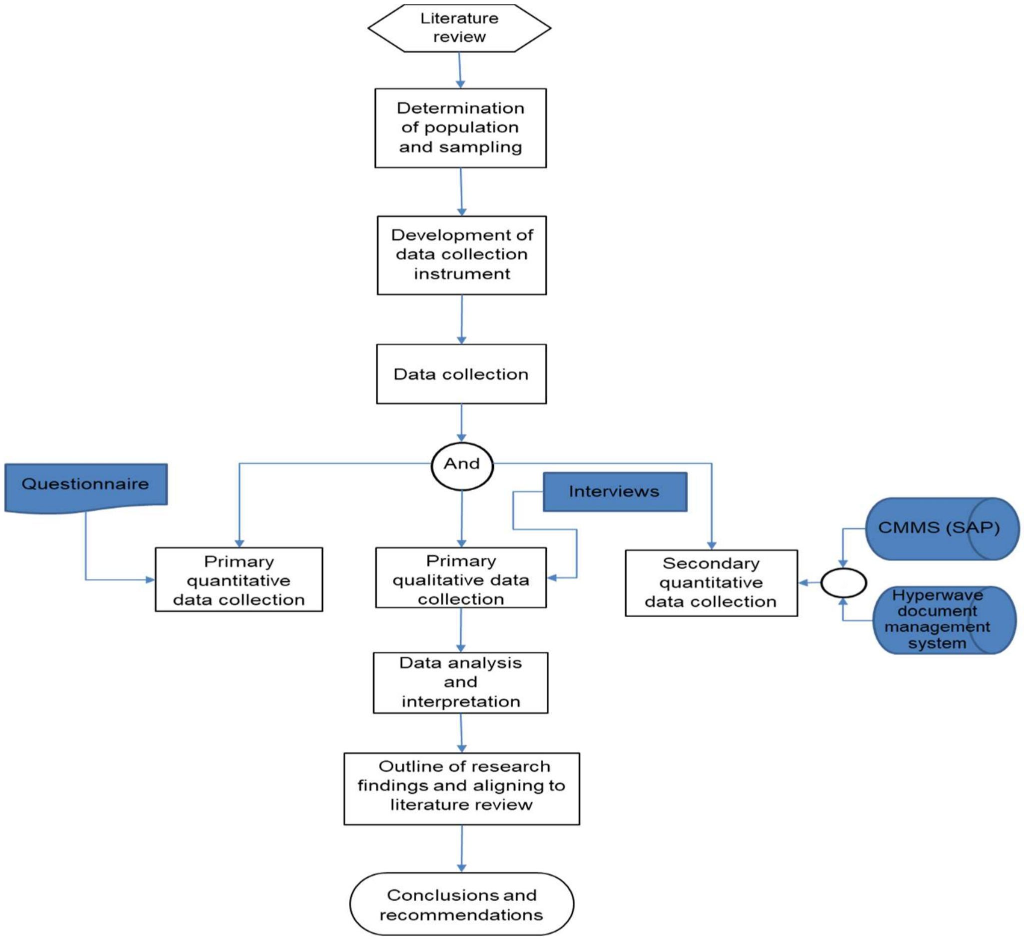


Figure 1.1: Research methodology
Source: Author's construction

As indicated in the first step of the process flow chart (Figure 1.1), a literature review was conducted to provide the foundation and understanding of the research topic by consulting already published work. The literature review guided the approach used to guide the research population and sampling. Thereafter a collection instrument was developed, and data was collected in the field. Three streams of data collection were used, namely, primary quantitative data collection, primary qualitative data collection and secondary quantitative data collection√. A questionnaire was used for primary quantitative data collection, and interviews were conducted for primary qualitative data collection. For secondary quantitative data collection, CMMS (SAP) and Hyperwave document management systems were used for data extraction.

1.5 Rationale and significance of the study

The study intended to contribute to optimising maintenance strategies to improve plant health by exploring how best to reduce the rate of CM to prevent a backlog of defects identified within the selected PGP. The basis for the study was to demonstrate what Erkoyuncu et al. (2017: 54-55) emphasised when they say the optimum balance between CM and PM is an essential part of maintenance strategy, with the target CM/PM ratio being 20%/80%. Maintenance scheduling is critical as there is an urgent need to raise and improve the capacity of the power sector in Africa as a whole. (Ouedraogo 2017: 1047). Accurately scheduled PGP maintenance plans will enhance precise forecasting of electricity supply in Africa, whereby forecasting is an essential component of power system management. (Ouedraogo 2017: 1048)

Muhammad and Muhammad (2017:531) estimated that the problems in the electricity sector had cost the South African economy around 10% of GDP. They further reported that South Africa's record of greenhouse gas (GHG) emissions concerns, with a 20% increase since 2000, making it one of the largest emitters of CO_2 in the world. South Africa is directly responsible for almost half of the CO_2 emissions for the entire African continent, and the energy sector is deemed the most significant contributor (Muhammad and Muhammad 2017: 53).

In recent years, the power utility has experienced major financial, operational and structural challenges that led to poor performance, impacting vital national priorities such as economic growth, job creation, and efforts to combat poverty in South Africa (Eskom 2020: 9). The interest of the study lies in its value to enhance the useful life of the fixed assets by improving maintenance activities on the power generation plant. It is anticipated that proper PGP maintenance would reduce GHG emissions and support local and global economic growth.

1.6 Scope and delimitations of the study

The research was limited to the selected PGP out of fifteen power generation plants within the generation division. It only focused on the coal-fired plant and not the hydropower generation plant. The PGP is situated in the Free State province of South Africa and is one of the fifteen coal-fired power stations contributing to the power utility's total power generating capacity of 44 034-megawatt, MW (Eskom, 2017: 139).

The study investigated maintenance processes within the PGP to bring about the necessary improvement. Maintenance strategies of interest were corrective and preventive maintenance. A further focus was on applying statistical quality tools and ISO 9000: 2015 Quality Management Principles (QMP) to optimise maintenance processes. The target population was professional-level employees, and it excluded contracted employees, students and utility workers.

1.7 Conceptual framework

The conceptual framework adopted for this study is illustrated in Figure 1.2

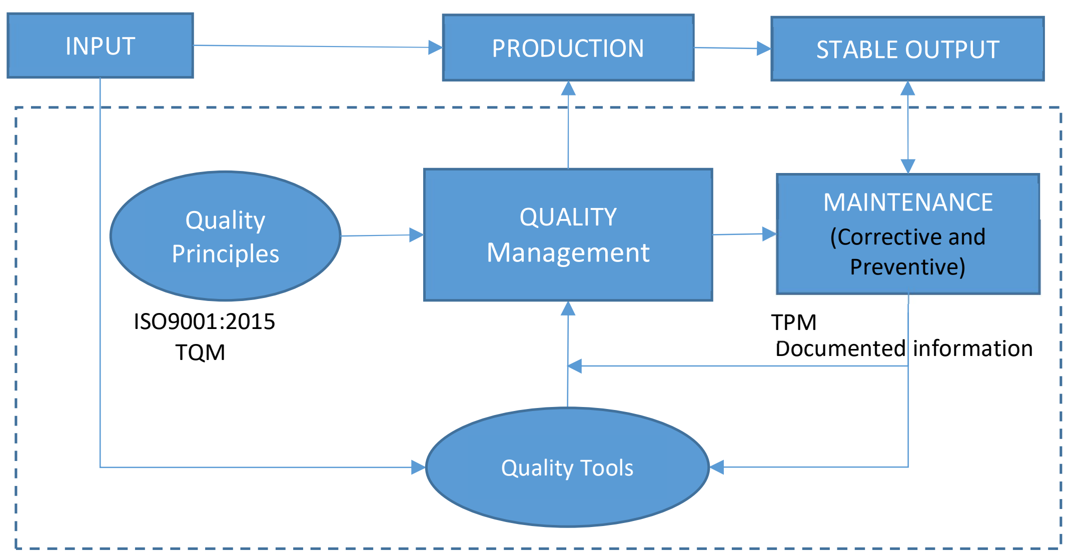


Figure 1.2: The Conceptual Framework of the study
Source: Author's construction

The approach demonstrated by the framework indicates that corrective and preventive maintenance performance is influenced by quality management. The study focused on the tools and techniques within the quality management spectrum. The quality principles and the quality tools are the key pillars influencing the effectiveness of quality management, which in turn impacts the maintenance to stabilise the corrective and preventive maintenance outputs. The conceptional framework highlighted that critical pillars of the maintenance process are corrective maintenance, preventative maintenance, total productive maintenance, and documented information. The framework of the study is contained within the dotted line, whilst the elements outside the dotted line depict the process flow for the sake of completeness.

1.8 Ethical consideration

The Faculty approved the research proposal for this study of the Management Science Research Ethics committee at the Durban University of Technology (Appendix B). The appropriate research ethics training was undertaken by the researcher (Appendix C). All the necessary research protocols concerning anonymity and confidentiality strictly adhered to.

1.9 Structure of the dissertation

The structure of the dissertation is informed by the framework recommended by Maree (2007:43) and is outlined as follows:

- **Chapter 1:** Introduction – Introducing background to the problem, aims, objectives, rationale and scope of the study. This chapter provides an overview of the rest of the survey.
- **Chapter 2:** Literature review – This chapter constitutes the literature review that contextualises the study, unpacks the variable of interest, the theoretical underpinning and previous empirical studies related to this study.
- **Chapter 3:** Research methodology – In this chapter, the research design is expounded, the population is identified, the sampling strategy is detailed, and data gathering and tools for data analysis are explicated.

- **Chapter 4:** Research results - restatement of the objectives, presentation of the analysis of data, presentation of sampling compliance and presentation of research demographics
- **Chapter 5:** Findings and discussion – Discussion of the data results and how the findings link to the objectives are delineated in this chapter. In this area, the researcher unpacks the reality as presented by the study.
- **Chapter 6:** Conclusion and recommendations – Restatement of the problem, description of processes followed, acceptance or rejection of the findings, and the recommendations.
- **Acknowledgement:** Recognising the support provided during the research. Most things were made possible by the people involved; otherwise, the study would not have been a success.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The previous chapter presented the research problem and provided the outline for the study. This chapter contextualises the analysis further to bring the issue into greater focus. It unpacks variables of interest of the research and presents the theoretical position from within which the study can be explored. This section provides the context of the study, theory on the planned and corrective maintenance, quality management system in maintenance, quality tools and quality management principles, factors contributing to the corrective maintenance backlog, gaps and limitations in maintenance documentation, the impact of external service providers on the corrective maintenance backlog and lastly the ppractical and implementable framework to reduce the corrective maintenance backlog and conclusion.

2.2 Context of the study

The engineering maintenance standard ratio is 20% of corrective maintenance and 80% of preventive maintenance (Runeyi and Sardini, 2015: 3). The percentage of CM/PM that this study aimed to optimise was 43% CM and 57% PM (Mashosho 2019: 19). The research aimed to optimise corrective maintenance backlog using quality tools and quality principles at a selected power generation plant in South Africa

The financial obligation of managing the PGP is onerous, comprising of capital expenditure (Capex) and operational expenditure (Opex). In the selected PGP, the Capex budget for 2018/19 was R1 037, 8 million, and the corresponding Opex budget was R 1 423, 5 million (Tsoaeli, 2019:13-15). The interest of the study lies in its value to enhance the useful life of the fixed assets by improving maintenance activities on the power generation plant. These maintenance activities are executed under the Capex budget and the operational activities under the Opex budget. Capital maintenance activities related to the replacement of existing components and other assets in the current PGP.

Fumagalli et al. (2017: 13978) posit that an optimal balance between planned CM and planned PM maintenance policies are key to maintaining performance.

The power output of the selected PGP established in 1980 is 3558 MW providing 8% of the total power on the electricity grid (Govinden 2019: 2). Similar to other industry production plants, maintenance activities in a PGP are carried out under different strategies to ensure maximum output. Doostparast et al. (2014: 98) and Kasirye and van Waveren (2018: 2) categorise maintenance activities into corrective and preventive maintenance.

Previous studies indicate that different types of production equipment operate under different conditions depending on the industry involved. Some industry conditions are more severe on equipment than others, and this brings about unfamiliar equipment failures. As a result, different maintenance strategies need to be researched to combat these emerging conditions. In the study conducted by Oliveira and Lopes (2020: 575), manufacturing plants are characterised by old and outdated machines that have undergone adaptations, improvements, and retrofits, which makes the availability of spare parts difficult. Therefore, it is essential to investigate other techniques that can support the performance of maintenance strategies to bring about the necessary improvement.

This study is underpinned by applying a Quality Management System (QMS) to support and enhance technical processes relating to maintenance policies and procedures. It shows how the statistical quality tools and the practice of ISO 9000: 2015 QMP were explored to bring about the necessary improvement of the CM/PM ratio.

2.3 Planned vs corrective maintenance theory

Corrective maintenance and preventive maintenance were the key areas of the research study. According to Sakar et al. (2011: 130), CM is when an equipment failure occurs, and PM is more inspection related. According to

Erkoyuncu et al. (2017: 55), CM follows the principle of a run to failure and can incur high costs, including loss of production incurred due to equipment downtime (Vilarinho et al. 2017: 1170). Chen et al*. (*2017: 495) caution that CM is a high-risk strategy leading to increased machine downtime and property damage; hence the PM is the counteracting strategy to reduce the risks associated with the CM. The advantage of PM is that it maintains equipment's health condition by preventing equipment deterioration through routine maintenance, periodic inspections, equipment diagnosis and repair to restore equipment condition (Pandey et al. 2014: 2). The PM strategy minimises failure costs and machine downtime, which lead to improved productivity (Kasirye and van Waveren 2018: 2).

The study conducted by Doostparast, Kolahan and Doostparast (2014: 102) demonstrated the convergence curve for the procedure performed during the optimisation process as indicated in Figure 2.1. They further show that the system converges towards the final solution after approximately thousands of run times, with no improvement observed after that. Given sufficient run time, the system determines the best maintenance action for each component to minimise the total PM cost.

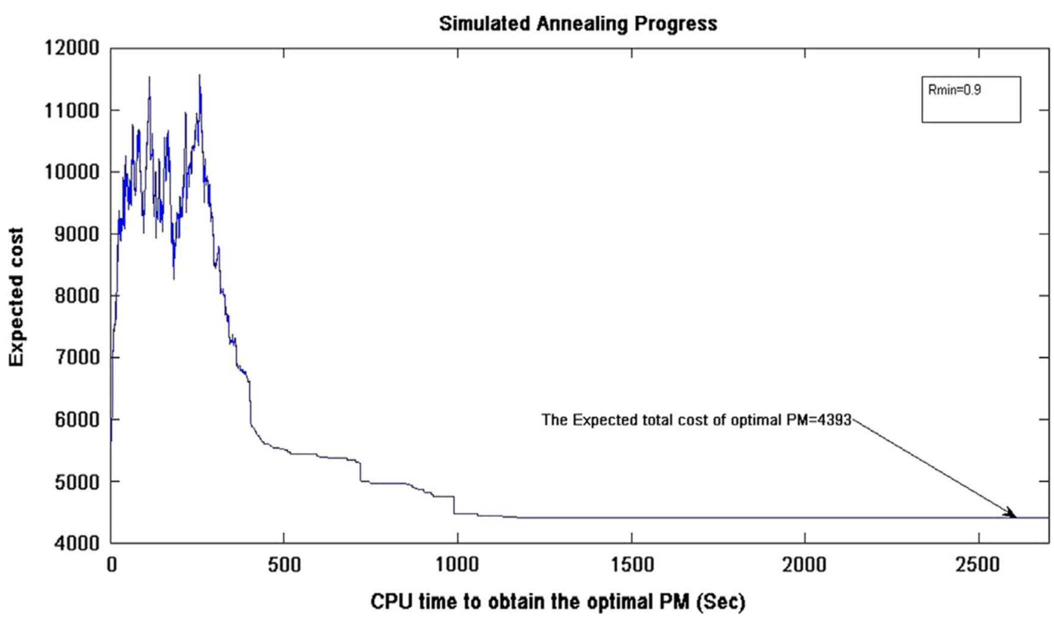


Figure 2.1: Convergence curve for the total PM cost improvement.
Source: Doostparast, Kolahan and Doostparast (2014: 102)

The PM schedule for 24 months in the study of Doostparast, Kolahan and Doostparast (2014: 102) is presented in Figure 2.2, in which the results reveal that under the optimal schedule, the types and frequencies of the PM actions differ from component to component, meaning that each element will need its specific PM schedule to minimise CM.

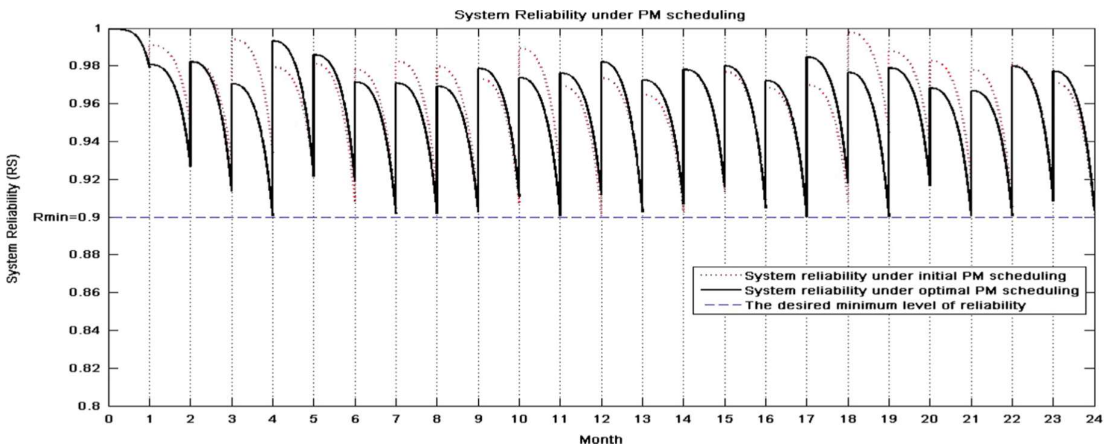


Figure 2.2: Reliability of the series-parallel system
Source: Doostparast, Kolahan and Doostparast (2014: 102)

To evaluate the effects of the minimum reliability requirements on the PM-related costs, the study of Doostparast, Kolahan and Doostparast (2014: 102) derived prices of the optimal PM schedules for some selected values of reliability system per minute ($R^{(s)}_{min}$) as presented in Figure 2.3. From their results, it may be noticed that the total cost of the optimal PM schedule increases dramatically for ($R^{(s)}_{min}$) > 0,9. The overview of the graph demonstrates that total cost encapsulates PM cost, failure cost and downtime cost. Effective and efficient PM execution is critical to keep the failure cost, CM, to a minimum.

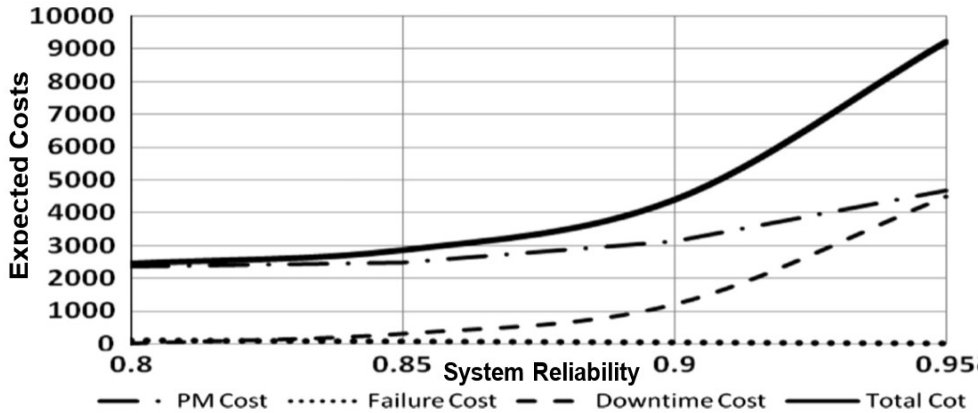


Figure 2.3: Reliability requirements on the PM-related costs
Source: Doostparast, Kolahan and Doostparast (2014: 102)

Doostparast et al. (2014: 105) advises that the optimum PM schedule should be determined. The decision should involve determining the best set of PM actions for every inspection period concerning the total costs, available resources, and reliability requirements.

Equipment reliability, availability and maintainability (RAM) depends on the number of interventions at the planning stages of maintenance activities, such as human factors that influence the system RAM when the planned interventions are executed (Fumagalli et al. 2017: 13976). Additional factors contributing to maintenance challenges include equipment breakdowns, equipment setup and adjustments, equipment defects and reworks (Pandey et al. 2014: 170). Mostafa et al. (2015: 435 & 440) highlights the types of waste found in maintenance processes that need to be eradicated, namely, unproductive maintenance activities, waiting for resources, poor inventory management, unnecessary personnel motion, poor artistry, ineffective data management and under-utilisation of resources.

Vishnu and Regikumar (2016: 1080) list the maintenance performance indicators used in various strategies as mean time to failure (MTTF); mean time to repair (MTTR); mean time between downing events (MTBDE); mean down time (MDT); mean time between maintenance (MTBM); mean repair time (MRT) and availability of the system (A_0). Kasirye and van Waveren (2018: 2) list the following as the common maintenance strategies; total productive maintenance (TPM), business centred maintenance (BCM) terotechnology, capital asset management integrated logistics support (ILS) and life of cost/profit (LCC/LCP) to be monitored by indicators mentioned above.

2.4 Quality management systems in maintenance

According to ISO 9000 (2015: 2) QMS comprises activities by which the organization identifies its objectives, processes and resources required to achieve organisational output, through managing the interacting processes and resources to deliver value to relevant interested parties. QMS further enables organisational management to optimise the use of resources via effective decision making. The quality management principles give the organisation the ability to overcome challenges presented by environment different from the past decades (ISO 9000 2015: 1).

Although ISO 9001 certification is not a compulsory and legal requirement for organisations, it has a significant role in maintaining business relationships worldwide (Fonseca and Domingues 2016: 149). The ISO 9001 certification is not used to measure quality directly, but it indicates a systematic approach to improving quality (Hallberg et al. 2018: 486). Awadh and Saad (2013: 168) believe that quality helps in improving organisation and employee development, which in turn strengthens the business relationship. Psomas and Antony (2015: 2091) highlight that resistance to change among employees creates a significant problem in advancing the Quality Management System (QMS) and its effectiveness. Hence, cultural change of employees and managers is necessary to implement the QMS (Maletic et al. 2014: 1749). To enhance the required quality culture, Gharakhani et al. (2013: 46) highlight that the goal is to get everyone involved in the QMS implementation.

The impact of quality extends beyond customer satisfaction. Any deficiency could be detrimental to an organisations' reputation; hence quality principles have been developed to guide organisations in implementing Total Quality

Management (TQM) (ISO 9000: 2015: 1). The seven quality principles outlined in ISO 9000: 2015 include Customer Focus, Leadership, Engagement of People, Process Approach, Improvement, Evidence-based decision making and Relationship management (Fonseca 2015: 55). According to Maletic et al. (2014: 1749), a strong foundation on quality management orientation within the maintenance department effectively improves maintenance performance in an organisation. The philosophy used to guide organisations to implement TQM in maintenance processes is Total Productive Maintenance (TPM) (Pandey et al. 2014: 169 and 177). Bartz, Siluk and Bartz (2013: 5) describe TPM as a continuous improvement methodology to improve confidence in equipment and increase management efficiency by involving people, production activities, maintenance, and engineering. TPM is a strategy used to implement quality management in the maintenance environment. Similarly, ISO 9001 is used to implement the TQM philosophy throughout the organisation (Maletic et al. 2014: 1749). This study explored ISO 9000: 2015 Quality Management Principles as a backdrop to enhance maintenance performance.

The international standard, ISO/CD 55000 Asset management — Overview, principles and terminology, encourages organisations to develop processes that monitor, measure, and manage asset performance to compare performance against maintenance objectives during the corrective and preventive maintenance execution (ISO/CD 55000.2:2012: 6). In this regard, TQM serves as a link between an organisation's strategies and operational plans (Al-Ibrahim 2014: 124). However, Fonseca (2015: 54) points out that not all the reported cases of QMS implementation have been successful. Tenji and Foley (2018: 401) reiterated that the success of the QMS is linked to the organisational culture and the way the standard is interpreted and implemented. Leavengood et al. (2014: 3) criticised the TQM philosophy as lacking the practical elements that organisations can use to implement the philosophy, and therefore other frameworks such as Malcolm Baldrige National Quality Award (MBNQA), ISO 9001 and TPM, are used to define these critical practices. This study used ISO 9000: 2015 Quality Management Principles to contextualise the boundaries of TQM. √

2.5 Quality tools and Quality Management Principles

This section elaborates more on quality tools and quality management principles used in this study.

2.5.1 Quality tools

The TQM philosophy is quality tool for continuous improvement, referred to as the seven essential quality control tools. According to Muhammad (2015: 32), these quality tools were established independently, even though they are grouped as crucial tools. They are called crucial tools because of their simplicity and no formal training needed (Muhammad 2015: 32).

Erkoyuncu et al. (2017: 20) describes quality tools and techniques as practical methods, skills, means and mechanisms applied on a particular task to facilitate positive changes and improvement. Furthermore, Gadre et al. (2015: 59) state that quality tools are simple statistical tools used to solve problems. Essential quality tools are listed by many authors as; flow chart, Pareto diagram, check sheet, control chart, histogram, scatter diagram and cause-and-effect diagram (Sokovic et al. 2009: 1, Singh et al. 2012: 854, Magar and Shinde 2014: 364, Fonseca et al. 2015: 607, Muhammad 2015: 31, Gadre et al. 2015: 59 and Erkoyuncu et al. 2017: 20). Quality tools are essential pillars within business processes and critical instruments for the success of an organisation's quality program (Sokovic et al. 2009: 1). Fotopoulos and Psomas (2008: 565) recommend using quality tools and quality techniques to ensure the effectiveness of the QMS, with the emphasis being on the implementation of quality tools and techniques to improve the overall business results.

The significance of essential quality tools within the QMS cannot be underestimated, as the successful application of these quality tools provides an advantage to the organisation (Magar and Shinde 2014: 370 and Sokovic et al. 2009: 3). The view of Ahmed and Hassan (2002: 796) is that a QMS cannot be effectively and objectively practised without using a set of tools and techniques. Quality has become an integral part of day-to-day activities in which quality tools and techniques have evolved with time to positively impact organisational performance (Pandey et al. 2014: 2347). The use of quality tools in a QMSis essential to any successful improvement (Singh et al. 2012: 858), which provide a systematic and structured quality management approach (Ahmed and Hassan 2002: 796). Fonseca and Domingues (2017: 2101) insight is that quality tools and techniques are used mainly within the automotive industry.

An understanding from Sokovic et al. (2009: 1) is that quality tools cannot be expected to solve every quality problem; instead, they can undoubtedly provide a direction of how to remedy the situation. Some quality tools do not work precisely as intended by the organisations applying them because they lack understanding regarding when, where and how to use them (Fotopoulos and Psomas 2008: 566). A further emphasis by Fotopoulos and Psomas (2008: 566) is that organisations mistake applying quality tools individually instead of combining them with other tools and techniques. The concurrent views between Singh et al. (2012: 858) and Fotopoulos and Psomas (2015: 609) allude that quality tools can only be beneficial if proper training is provided to the workforce to understand the use of these tools. The challenge highlighted by Ras and Visser (2015: 192) is that, even though quality tools and techniques are available for use by all organisations, the interpretation and application of these tools and techniques differ from person-to-person, organisation-to-organisation, industry-to-industry and situation-to-situation.

According to the study of Fonseca et al. (2015: 616), about 22% of Portuguese ISO 9001 certified organisations are not using the essential quality tools. Aichouni (2012: 32) states that quality professionals can use the critical quality tools to identify procedures, ideas, effectiveness and efficiencies relating to the organisations. For the organisation to move from a static to dynamic improvement status, Erkoyuncu et al. (2017: 32) suggest using the essential quality tools in process identification, data acquisition and analysis. In his work, Muhammad (2012: 34) attest that major defect root causes were identified after implementing essential quality tools, leading to the removal of defects from the manufacturing process. Another point from Raghuraman et al. (2012: 1012) is that where the quality tools and techniques are built within a process, the management and employees understand the cost of wastage caused by rejected work. A good understanding of quality tools enhances the motivation of the workforce. Gadre et al. (2015: 59) claims that continuous use of quality tools affects people involved positively, enhances their thinking ability, advance their generation of ideas, and improves their planning abilities. Manzini et al. (2018: 3) indicate that organisations that use quality tools, techniques, and knowledge to advance organisational performance have a greater chance of survival. The essential quality tools are elaborated further in Table 2.1.

Table 2.1: Basic quality tools

#	Name of quality tool	Brief description of the quality tool	Authors
1	Flow chart	Shows the steps in a process that visually illustrates the sequence of operations required to complete a task.	Gadre et al. (2015: 59); Fonseca et al. (2015: 608)
2	Pareto diagram	Identify few (20%) items that cause the maximum (80%) influence within the process.	Magar and Shinde (2014: 368); Gadre et al. (2015: 60); Fonseca et al. (2015: 608).
3	Check sheet	A structured, uncomplicated and systematic form is used to collect specific data.	Gadre et al. (2015: 59); Magar and Shinde (2014: 370); Muhammed (2015: 31); Fonseca et al. (2015: 608).
4	Control charts	Provide an insight into how a process changes over time so that action can be taken.	Gadre et al. (2015: 61); Magar and Shinde (2014: 368); Muhammad (2015: 34); Fonseca et al. (2015: 608)
5	Histogram	Provide a graphical presentation of how often a set of different data occurs.	Gadre et al. (2015: 60); Muhammad (2015: 32); Fonseca et al. (2015: 608).
6	Scatter diagram	It identifies the relationship between two variables, where one variable is on the x-axis and the other variable on the y-axis.	Fonseca et al. (2015: 608); Gadre et al. (2015: 60); Magar and Shinde (2014: 59); Muhammad (2015: 33)
7	Cause-and-effect diagram	Identify many possible causes for a problem and sorts them into useful categories to get the root cause of the problem.	Gadre et al. (2015: 60); Magar and Shinde (2014: 365) Muhammad (2015: 33); Fonseca et al. (2015: 608)

Source: Adapted from Fonseca (2015: 608)

2.5.2 Quality Management Principles

Quality management principles (QMPs) are a set of fundamental beliefs, norms, rules and values that are accepted as true and can be used as a basis for quality management, QMPs can be used as a foundation to guide an organization's performance improvement (ISO 9000 2015: 3).

The ISO 9001:2015 standard was designed as a framework for organisations seeking to improve their operations and achieve certification (Sitnikov and Bocean 2015: 1010). The certification of ISO 9001 is a voluntary act by organisations, meaning there are no legal requirements forcing organisations to become certified (Hallberg et al. 2018: 486). There are two motives behind the organisation's ISO 9001 certification: to improve product and process quality or to use it as a marketing tool (Psomas and Antony 2014: 2090). Fonseca (2015: 54) argues that not all organisations implementing ISO 9001 QMS successfully attribute the failure to lack the required quality culture. Maletic et al. (2014: 1744) emphasises that treating quality as a cultural phenomenon encourages quality to be approached as a set of values, general orientation, and organisational ideology. Singh et al. (2016: 1408) view culture as a vital element in successfully implementing quality improvement programs. The organisational culture is seen as a significant differentiating factor between organisations that implement quality management practices.

According to Tenji and Foley (2018: 401), TQM is a holistic approach throughout an organisation that consists of "hard aspects" such as tools, techniques, practices and systems and "soft aspects" such as behavioural and cultural elements. Zeng et al. (2015: 217) refer to "hard QM" and "soft QM" in which the complex QM aspects involves a range of production techniques such as statistical process control (SPC) and quality function deployment. Zeng et al. (2015: 217) further describe "soft QM" aspects as establishing customer awareness and the management of the workforce. The workforce's knowledge and skills are enhanced when employees are strengthened in quality improvement initiatives, significantly where TQM changes the organisation's culture towards quality (Durana et al. 2014: 69). For quality management philosophies to be successfully implemented, specific support structures need to be in place to integrate practices into employee lifestyles (Phogat and Gupta 2016: 190).

Organisations striving to achieve lasting continuous improvement and customer satisfaction should embrace the Quality Management System (Magar and Shinde 2014: 370). ISO 9001: 2015 is based on Fonseca and Domingues's seven Quality Management Principles (2016: 152) and ISO 9000 (2015: 3-8).

2.5.2.1. Quality Management Principle 1: "**customer focus",** aims to meet current and future customer requirements and strive to exceed customer expectations (Fonseca and Domingues, 2016: 152 and ISO 9000: 2015: 3). Maletic et al. (2014: 1748) states that customer orientation emphasises how the organisation is performing as seen by customers based on time, quality, cost and performance. Elshaer and Augustyn (2014: 1289) assert that customer focus enables organisations to effectively respond to the changing customer requirements that may lead to customer satisfaction.

2.5.2.2 Quality Management Principle 2:, **"leadership",** described by Fonseca and Domingues (2016: 15) and ISO 9000 (2015: 4), states that leaders establish unity of purpose and direction at all levels that provide an environment in which people can achieve organisational objectives by engaging with each other. Leadership is a key element of quality performance; it does drive not only an organisation's quality strategy but also guides innovation (El Manzani et al. 2018: 6).

2.5.2.3 Quality Management Principle 3: Engagement of people is the **third** Quality Management Principle that encourages people's competency, empowerment, and engagement at all levels within an organisation. The capability to create and deliver value can be enhanced

(Fonseca and Domingues, 2016: 152 and ISO 9000: 2015: 5). The workforce's knowledge and skills benefit more when the employees are strengthened in the quality improvement practices (Durana et al. 2014: 68).

2.5.2.4 Quality Management Principle 4:, **"process approach,"** is the philosophy that believes that interrelated processes function as a coherent system to achieve consistent and predictable results effectively and efficiently (Fonseca and Domingues, 2016: 152 and ISO 9000: 2015: 6). Elshaer and Augustyn (2014: 1290) add that process management may create an organisational culture that reduces process duplication and variance.

2.5.2.5 Quality Management Principle 5: Improvement allows organisations to succeed and sustain themselves by ongoing improvement (Fonseca and Domingues, 2016: 152 and ISO 9000: 2015: 5-6). According to Sokovic (2009: 3), quality tools enhance the realisation of continuous improvement. Leavengood et al. (2014: 4) observed that continuous improvement of processes leads to achievement and sustenance of high-quality output.

2.5.2.6 Quality Management Principle 1: "evidence-based decision making", encourages an analytical approach where desired results are more likely to come from decisions supported by analysing and evaluating related information data (Fonseca and Domingues, 2016: 152 and ISO 9000: 2015: 7-8). The appreciation of statistical methods should promote more informed business problems and permit more effective decision-making (Wegner 2001: 3).

2.5.2.7 Quality Management Principle 1: "relationship management", emphasises the importance of establishing a good relationship with relevant stakeholders such as service providers for the common understanding of organisational objectives (Fonseca and Domingues, 2016: 152 and ISO 9000: 2015: 7-8). Elshaer and Augustyn (2016: 1290) also view effective supplier management as a vital factor that nurtures inter-organisational business relationships. According to Hallberg et al. (2018: 486), suppliers emulate the quality systems their customers have implemented, implying an upstream adoption of practices between organisations. Duran et al. (2014: 65) highlight that organisational information is also valuable to nourish the business relationship. A good relationship between organisations and interested parties such as service providers and customers ensure sustained success (Fonseca and Domingues 2016: 152). Quality management scholars agree that supplier management encourages the development and maintenance of active long-time relationships with suppliers (Wagner 2006: 3). Improving supplier quality includes certifying suppliers on the Quality Management System and providing the necessary support (Al-Abdallah et al. 2014: 193). Through mutually beneficial commitments with suppliers, organisations can innovate by proactively developing new products (El Manzani et al. 2018: 7).

2.6 Management impact on quality tools and quality principles

Quality tools and techniques require management support and commitment to ensure success (Fotopoulos and Psomas 2008: 566). Organisational management is encouraged to use quality management in their improvement activities and decision-making (Fonseca et al., 2015:606 and Sokovic et al., 2009: 1). Promotion of quality tools usage by management can encourage employees to use them (Singh et al. 2012: 858). Managers of labour-intensive organisations are committed and devoted to improving the labour productivity of the workforce by implementing Quality Management Principles (Belay et al. 2012: 90).

Castello, Castro and Marimon (2019: 85) believe that managers should understand that the quality of a product also depends on the quality of management systems that use essential quality tools and techniques. Furthermore, management must ensure a conducive atmosphere and the resources and training required for continuous improvement programs that promote quality tools and techniques. Implementation of a technical system such as statistical process control (SPC) was complex due to lack of resources, management support and lack of statistical knowledge, as highlighted in the work of Ahmed and Hassan (2003: 822).

The extent of the use of the full range of quality tools was found to be relatively low according to the research conducted by Ismyrlis (2017: 684) in Greek companies. Ismyrlis (2017: 684) also found that quality tools and techniques most often used are check sheets, graphics, flowchart, brainstorming, and benchmarking, highlighting that this can be attributed mainly to tools mentioned being easiest to use due to them being less complex. Soković et al. (2009: 09) highlight the importance of turning the passive status of using quality tools, techniques, and related methods into proactive status, which is another way to affirm a continuous improvement process further. However, for the tools to be effective, they should cover various applications such as problem identification, data analysis, process analysis, decision making, planning, quality control and statistical process control, as demonstrated by Namibian municipalities in the research of Silombela, Mutingi and Chakraborty (2017: 18). According to their findings, municipalities that recruited maintenance managers with an engineering background and knowledge in quality management tools performed much better than maintenance managers with no engineering background and little knowledge in QM tools and techniques.

Tenji and Foley (2018: 401) suggest that intangible leadership factors such as people management and partnership must be changed to create a new organisational quality culture to support continuous improvement. Top management leadership is expected to drive effective quality management implementation to create an environment for continuous improvement by developing goals, policies, values, and systems to develop quality culture (Elshaer and Augustyn (2014: 1288). The warning from Malitic et al. (2014: 1750) is that management's primary responsibility is to provide the commitment to ensure the employees are stimulated to improve process performance by providing the necessary support.

According to Vishnu and Regikumar (2016: 1081), the primary organisational objective of plant maintenance is to achieve minimum breakdown and keep the plant in good working condition at the lowest possible cost. Doostparast (2014: 98) states that management must maintain a certain level of reliability with minimal total maintenance-related cost. In this regard, Fumagalli et al. (2017: 13981) assert that the objective should be to determine the optimum maintenance interval that balances the system failure repair costs and the cost of maintenance. While ccorrective maintenance can cause the costs to spiral to exorbitant amounts, it can also, at the same time, lead to production losses and thus creating the need for it to be counterbalanced by an appropriate level of preventive maintenance (Valarinho et al. 2017: 1171-2). √

2.7 Factors contributing to the corrective maintenance backlog

Fumagalli et al. (2017: 1398) contends that the system reliability depends on the number of possible interventions in the planning horizon (the time window in which the maintenance is being planned). The interventions can be constrained by several factors, including but not limited to:

(i) A declining pool of maintenance workforce whereby experienced technicians go on retirement and new skilled technicians get job opportunities in other industries (Koornneef and Curran 2017: 161);

(ii) The inefficient integration of social practices deteriorates the effectiveness of technical procedures and vice versa (El Manzani et al. 2018: 23). The social and technical aspects of QMS (ISO 9001) are interdependent. They must be designed jointly without taking a logical superiority over each other, meaning that both the socially oriented common practices and the technically oriented basic TQM, JIT and TPM techniques are necessary to achieve performance. (El Manzani et al. 2018: 24).

(iii) Resistance to change among employees (Psomas and Antony 2014: 2091) becomes a barrier to the successful implementation of total productive maintenance (TPM) (Maletič et al. 2014: 1745).

(iv) The human factor influences system reliability, where personnel do not perform the maintenance intervention correctly, resulting in a partial or even null system reliability improvement (Fumagalli et al. 2017: 13981).

(v) Difficulty in changing attitudes and work culture within specific job environments due to workers' low level of skill (Pandey 2014: 172).

(vi) Many companies still do not use advanced quality tools in the world of intense global competition (Fonsenca 2015: 616).

Furthermore, maintenance interventions could be delayed due to the following factors, as alluded to by (Erkoyuncu 2017: 56):

(i) The time taken to complete paperwork.

(ii) The time of waiting for the workforce.

(iii) The time of waiting for spares, tools, test equipment, and non-availability of major critical equipment for maintenance.

Chen et al. (2017: 495) adds that travelling time, workload balancing, visiting time window violation and overworking time affect maintenance intervention. A critical point that Erkoyuncu (2017: 56) emphasises is that administrative delays and costs that are ignored at the design stage are the ones that drive the level of operational availability and which usually has a more significant effect than the execution of maintenance.

Vishnu and Regikumar (2016: 1081) conclude that an improperly maintained or neglected plant eventually requires expensive and frequent repair because all machines or other facilities wear out over time. Hence, maintenance models may include the need to consider stochastic or structural dependence in condition-based maintenance (CBM) to achieve maintenance optimisation (Do et al. 2015: 946).

Lean maintenance seeks to eliminate all forms of waste and every waste category defined for production processes related to maintenance according to Jasiulewicz – Kaczmarek (2014: 4472) and Mostafa (2015: 434), are listed as:

i. Unproductive work – efficiently doing work that does not increase equipment reliability.
ii. Delays in motion – waiting for production equipment to be available to carry out preventive maintenance.
iii. Unnecessary motion – unnecessary travel, trips to parts stores and looking for tools required to do a job.
iv. Poor management of inventory – not having an adequate amount of the right parts at the right time.
v. Rework – having to repeat tasks due to poor quality.
vi. Under-utilization of resources – maximising resources available and harnessing the skill sets of the maintenance teams.
vii. Ineffective data management – collecting data that is not useful or failure to collect data that is important.
viii. Misapplication of machinery – incorrect operation or deliberate operational strategies leading to maintenance work being done when it needed not to be.

The evidence mentioned above is a shift away from the focus in the early days, where maintenance concentrated mainly around corrective maintenance, meaning repairs and replacements were done when needed, with no attention to optimisation and minimum awareness of the downtime (Mostafa, 2015: 434).

2.8 Gaps and limitations of maintenance documentation

Implementation of a Quality Management System (QMS) is key to the organisational development process. It must be adequately documented to provide valuable and accurate information from processes and audits (Sokovic et al., 2009: 3). Due to the complexity of an industrial environment, maintenance documentation must be properly organised and managed effectively (Valarinho et al., 2017: 71-720).

A computerised maintenance management system (CMMS) manages maintenance documentation, schedules, personnel, material and historical asset information (Mostafa et al. 2015: 441 and Valarinho et al. 2017: 72). Oliveira and Lopes (2020: 576) find that improvement actions to reach higher levels of performance involve the acquisition of an effective CMMS for the management and control of maintenance activities. Duran et al. (2014: 67) states that the knowledge put in writing creates value for the organisation. If effectively used in a quality management environment, documented knowledge can increase the success of a quality improvement initiative.

In this regard, Koornneef et al. (2017: 61) note that sometimes there is a challenge to find the required information to perform a task due to poor documentation management, which ultimately leads to the workforce wasting up to 30% of maintenance time whilst trying to access the correct information. Kajko-Mattsson (2005: 31) also asserts that corrective maintenance documentation is still neglected in most organisations. Poor and/or unavailable documentation is a significant contributor to defects in maintenance. Jerome and Emilio (2017: 392) suggest that by having established and accurate documentation within the organisation, the guesswork regarding whether a specific condition pre-existed can be avoided.

Barthelmey et al. (2014: 208) categorises technical documentation into internal and external documentation, with external documentation comprising digital and printed materials delivered with the product and internal documentation consisting of all information for machinery, plant, and product. The periodicity of maintenance interventions depends on information received with the equipment and the experience gathered throughout maintenance activities (Valarinho et al. 2017: 2), thus catching valuable information and creating new material that needs to be documented (Durana et al. 2014: 68).

It is necessary to design shared databases for different quality tools, such as customer requirements, competitors benchmarking information, product quality characteristics, part quality characteristics information, process quality characteristics and other related databases to implement quality tools consolidation. √

2.9 Impact of external service providers on the corrective maintenance backlog

Supply chain management is the management of relationships in the network of organisations, starting with the original supplier to the string of customers to deliver value to the final customer (Lambert and Enz 2017: 5). High performing suppliers are recognised as having an essential role in the performance of any organisation (Manzini, Sidmou and Cegarra 2018: 7), whereby parts and material are procured in advance in a well-planned and timely manner complete maintenance tasks (Mostafa et al. 2015: 44). The quality of the product and services produced by the organisation is influenced by both internal and external processes indicating that suppliers play a critical role in the success of organisations (Patyal and Koilakuntla, 2016: 1409).

Hallberg et al. (2018: 486) emphasise that a Quality Management System is critical in creating structures and processes to select suppliers. According to Phogat and Gupta (2016: 196), quality certification of suppliers helps in the selection of suppliers for current and future use. Wieteska (2016: 309) cautions about uncertainty brought about by external factors such as political factors, economic factors, social factors, technological factors, legal factors and environmental factors (PESTLE). According to Rhodes et al. (2014: 4), Al-Abdallah (2014: 192), and Pal et al. (2017: 1226), managing the relationship between the supplier and the client is critical in outsourced processes, where the key factors such as quality, trust, collaboration, cost and communication are given attention.

Integration of supply chain assists organisations to reconfigure the resources and capabilities both internally and externally to consolidate the supply chain as a whole to improve long term performance (Huo et al. 2014: 369). Muhammad et al. (2017: 1069) suggest, organisations must not only select suppliers with complementary resources only, but they should ensure that the necessary infrastructure is also in place. Qrunfleh and Tarafdar (2012: 9) advise that the supply chain is becoming more complex; it requires intelligent and effective management with adequate information processing. √

2.10 Practical and implementable framework to reduce the corrective maintenance backlog

Maintenance has become a vital pillar towards achieving the strategic objectives of the organisation by maintenance being necessary to guarantee high productivity, keep physical assets to acceptable operating conditions, and increase the value of reliability, availability, safety and quality of the production plant (Mostafa et al. 2015: 434). Laks and Verhagen (2017: 202) contends that optimised maintenance solutions must bring the repaired component back to an as-good-as-new state so that the reliability of given equipment should not drop below a stated threshold. Organisations committed to total quality employ quality tools and techniques associated mainly with data collection, analysing, visualising and other phases of PDCA-cycle, DMAIC, DMADV and lean six sigma (Erkoyuncu et al. 2017: 22).

Maintenance organisation models consider item reliability, evaluate and compare maintenance policies to determine how often to inspect and maintain equipment, leading to effective and efficient schedules and plans (Valarinho et al., 2017: 71). Vishnu and Formagalli (2017: 13976) speculate that the performance of the maintenance system should be measured with the three main performance measure parameters being:

i. **Reliability** – how long can equipment operate without failure
ii. **Availability** – Equipment is replaced upon failure or is preventively maintained to the equipment's ratio.
iii. **Maintainability** – The ease and rapidity with which a system or equipment can be restored to operational status.

Pandey et al. (2014: 2347) and Ab-Samat and Kamaruddin (2013: 99) identified the following four types of maintenance interventions:

i. **Preventive maintenance:** the method of maintaining the equipment's healthy conditions by preventing deterioration through routine maintenance, periodic inspection and equipment diagnosis.
ii. **Breakdown maintenance:** the approach where maintenance is applied after the breakdown has occurred.
iii. **Corrective maintenance**: is the method of maintenance in which steps for extension of equipment service life and cost reduction are considered.
iv. **Productive maintenance:** when breakdown and defects in equipment are eliminated, resulting in improved production and cost.

Regikumar (2016: 1081) group the breakdown/corrective maintenance as run-to-failure maintenance and preventive maintenance (PM)/ condition-based maintenance (COM) as preventative maintenance and add the strategy of design out maintenance (DOM) and reliability centred maintenance (RCM). Mostafa et al. (2015: 437) explains that design-out-maintenance (DOM) which, is pro-active, concentrates on the design of equipment to eliminate the causes of maintenance. Mostafa et al. highlights that DOM makes maintenance easier during the equipment's lifecycle due to the successive design corrections undertaken with the knowledge obtained from maintenance.

Another essential aspect of maintenance interventions is that it requires integration and interfaces with other internal and external systems, resulting in cooperation between maintenance and its stakeholders (Jasiulewicz-Kaczmarek 2014: 4474). Total productive maintenance (TPM) is a unique philosophy that can provide a distinctive, comprehensive equipment lifecycle management approach that minimises component failure, production defects and accidents by involving everyone in the organisation and beyond (Jasiulewicz-Kaczmarek 2014: 4475).

To improve asset performance at optimum cost, maintenance strategies such as TPM, condition-based monitoring (CBM) and reliability centred maintenance (RCM) have advanced with time (Maletic et al. 2014: 1748). Belay et al. (2012: 88) advises that it is unrealistic to have expensive equipment and large numbers of personnel at the same time. Managers of labour-intensive organisations should look for improved solutions by combining the effects of different techniques because a single approach may not bring a significant impact on all other dimensions. Manzini, Sidmou and Cegarra (2018: 22) support the idea that a system as a whole, in which the emphasis is on implementing both social and technical practices that allow the organisation to achieve the best performance, must be encouraged.

The organisation must consider the joint optimisation of both the socially-oriented standard practices and the technically oriented basic TQM, JIT, and TPM approaches, where JIT in maintenance leads to maximum yield in profitability and productivity and lessens the need for maintenance, troubleshooting and repairs (Phogat and Gupta 2016: 188). According to Phogat and Gupta (2016: 195), total productive maintenance helps improve the quality, flexibility, and cost by increasing detailed time-bound improvement action plans. Bartz, Siluk and Bartz (2013: 17) found in their research that, after initiating the implementation of the maintenance management model according to the specifications of TPM, the scrap, rework, and efficiency rates showed significant improvement positive trends. Barthelmey et al. (2014: 208) supports the concept of smart manufacturing, where components contain computers, sensors and controls that extend the features of manufacturing facilities further to enable them to capture the required information that supports maintenance interventions.

In the work of Do, Scarf and Lung. (2015: 950) a condition-based maintenance policy for a two-dependent component system is proposed. A “state dependence”, which implies that the deterioration speed of each component depends not only on its state but also on the state of other components, is demonstrated in their maintenance model. Their study further indicated that adaptive preventive maintenance and opportunistic maintenance rules must be considered to select a component or components to be preventively maintained at each regular time interval. This cost model developed by Do, Scarf and Lung (2015: 951) also considers the economic dependence between components to find the optimal value of decision parameters. In this case, they argue that combining maintenance activities of different components are cheaper than performing maintenance on individual components (Do, Scarf and Lung 2015: 946).

The work of Raghuraman et al. (2012: 1012) demonstrated that statistical process control and statistical quality control were effective in improving a process, irrespective of production or manufacturing-oriented process. Aichouni (2012: 37-38), in his research “on the use of the basic quality tools for the improvement of the construction industry,” concluded that the ISO 9001 certification procedure associated with the systematic implementation of the quality tools would be an excellent approach for quality improvement in the construction industry. He demonstrated that the statistical process control (SPC) tool, which constitutes a significant part of the basic quality tools, can be used efficiently in the construction industry to continuously improve processes by reducing variability and eliminating errors and rework in projects.

Gadre et al. (2015: 62), in their work on the “use of seven quality tools to improve quality and productivity in the industry”, concluded that the seven quality control tools are most helpful in troubleshooting issues related to quality. Their work further supports that quality tools are essential in data collecting, analysing, visualising and making sound base decisions.

A decision supporting tool has been presented by Laks and Verhagen (2018: 210-211), which identifies cost-optimal maintenance decisions for a given planning period. The device uses the failure limit policy with a generalised renewal process modelling approach to ensure maintenance action before a critical threshold. Their proposed optimal solution can be observed as a sequence of repair and replacement decisions, in the order

MMMRMRMMRMMM, with **M** representing a repair decision and **R** representing a replacement decision.

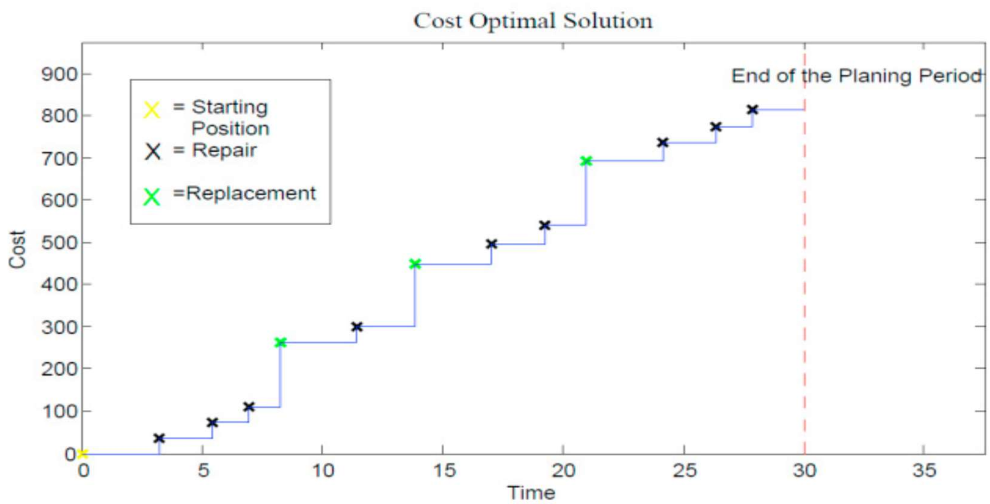


Figure 2.4: Maintenance cost-optimal solution
Source: Laks and Verhagen (2018: 210)

Figure 2.4 demonstrates how Laks and Verhagen (2018: 210) decision supporting tool works to identify the cost-optimal maintenance decision for a planned period. It further indicates the sequence of maintenance/repair (M) and replacement (R) plot against its time and cost. Laks and Verhagen (2018: 211) contend that the decision support tool can integrate various parameters linked to preventive maintenance decision making.

In their effort to improve process machinery availability and reliability, Kasirye and Waveren (2018:19) demonstrated that the implementation of reliability analysis techniques assists in ensuring the accuracy of data collected. They result in better maintenance practices and equipment designs, improve equipment availability, reduce maintenance and production costs and thus enhance competitiveness.

In their investigation, where they propose a reliability-based maintenance optimization model, Fumagalli, Macchi and Giacomin (2017: 13980) found that the maximization of the system reliability is according to how the preventive maintenance is planned. The first innovative aspect of their model is that the system reliability is treated as a signal, so both the average and minimum system reliability are considered. A second creative aspect of the model is introducing the concept of balance between preventive and corrective maintenance policies. The model only considers perfect preventive maintenance interventions whereby a failure mode is the restoration of the reliability curve (called high-level repair). On the other hand, the proposed maintenance optimization model considers CM as not having any effect on the reliability curve.

The findings from Vilarinho, Lopes and Oliveira (2017: 1175) for the component studied, the age replacement model to obtain an optimal preventive replacement age was considered. They found that preventive replacement actions require two necessary conditions. Firstly, the cost of the corrective replacement must be greater than the preventive replacement cost, and secondly, the component hazard rate must be increasing. They concluded that minimisation of the total cost per unit time allows obtaining the optimal replacement interval resulting in the optimal preventive maintenance.

The work of Panja and Sarkar (2011: 141) found that most optimal maintenance models in the literature primarily look at minimising system maintenance cost rate but ignoring reliability performance. Therefore, they insist that optimal maintenance policy must be based on cost rate and reliability measures. The takeaway message is that minimising the maintenance cost rate for multicomponent systems may not imply maximising the system reliability measures. An optimal maintenance policy must simultaneously consider maintenance cost and reliability measures to achieve the best operating performance.

2.11 Conclusion

In this chapter, a brief introduction was provided, followed by the context of the study. The theory on planned and corrective maintenance was elucidated to provide a background on what other researchers have already done on the topic. QMS in maintenance was followed by theory on quality tools and principles concerning maintenance activities. The chapter further aligned management impact to quality tools and quality principles. It extensively looked at the factors contributing to the corrective maintenance backlog, emphasising the gaps and limitations on maintenance documentation. The chapter ends with the impact of external services providers on the PGP corrective maintenance backlog and the possible practical models already researched by other scholars.

CHAPTER 3: RESEARCH METHODOLOGY AND DESIGN

3.1 Introduction

This chapter details the research approach, research design and research methodology. It further outlines the population and sampling procedures and provides detailed information on collected and analysed data.

3.2 Research overview

The study is both quantitative and qualitative (mixed method). It used a combination of questionnaires, interviews, and the SAP system (computerised maintenance management system) to collect the necessary data during the research period. No risks to people, animals and the environment were anticipated throughout the study. The research was guided by Durban University of Technology's ethics policy and guidelines. Figure 3.1 depicts an overview of how the research was approached. Numbering in the graphical display indicates the priority and sequence in which steps were followed.

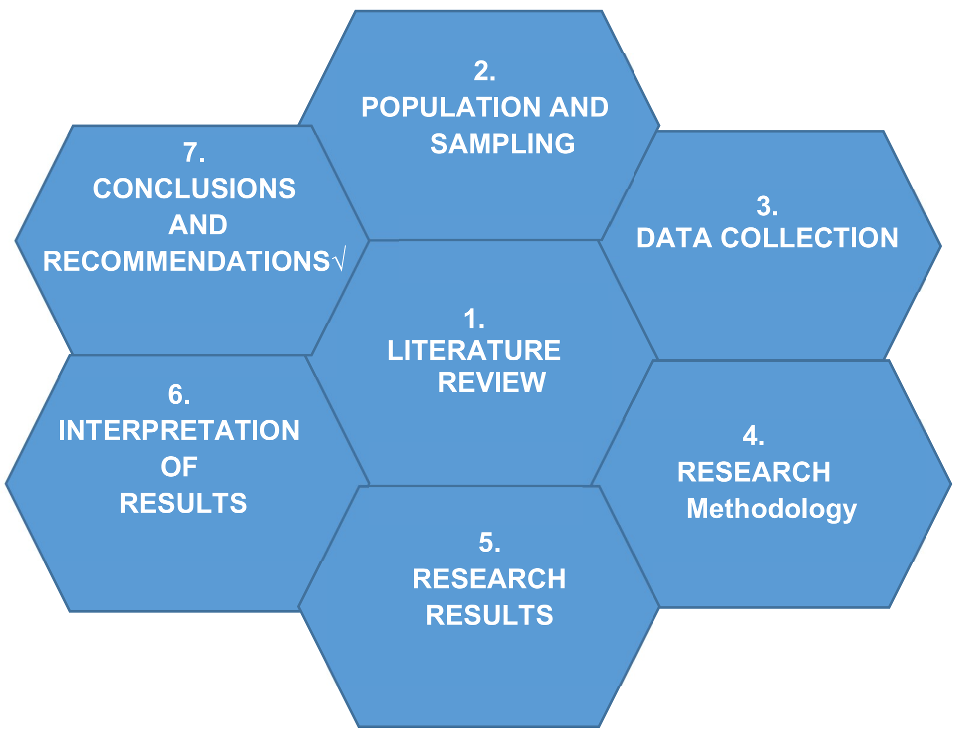


Figure 3.1: Research methodology applied
Source: Author's construction

The literature review was the first and critical step undertaken during the research process; hence it is placed in Figure 3.1. The arrangement of other stages around the literature review indicates how each research step revolves around the literature review. The numbering of each research step shows the process the research followed.

3.3 Research design and methodology

The research design (Figure 3.2) followed both qualitative and quantitative methodologies. The qualitative aspect of the study entailed maintenance documents evaluation and structured interviews that consisted of a schedule of open-ended questions. The quantitative part of the study entailed the administration of a structured questionnaire and the analysis of secondary data from the SAP system. Figure 3.2 demonstrates an overview of the research methodology followed in this study.

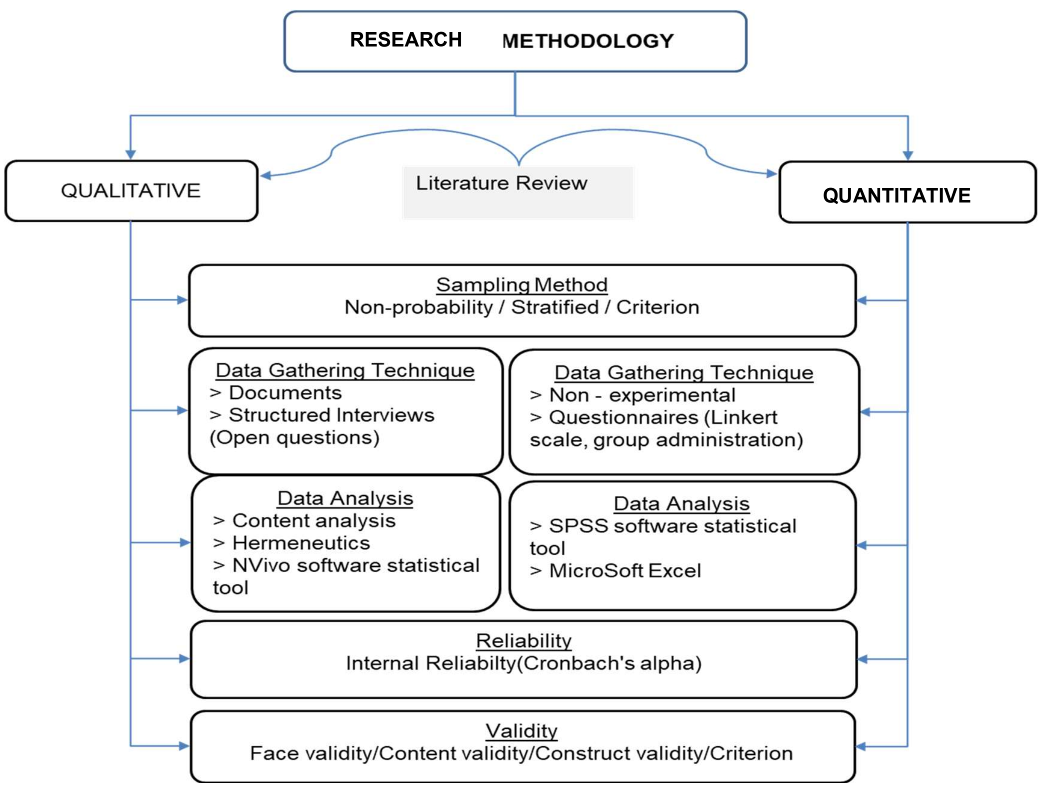


Figure 3.2: Research design

Source: Author’s construction

The information displayed in Figure 3.2 above highlights literature review on qualitative and quantitative aspects, sampling approach employed, data gathering techniques followed, demonstration of reliability and validity of the study.

Figure 3.3 below demonstrates the relationship between the data collection methods and the research questions. It shows what data was collected to answer which related research question in this study.

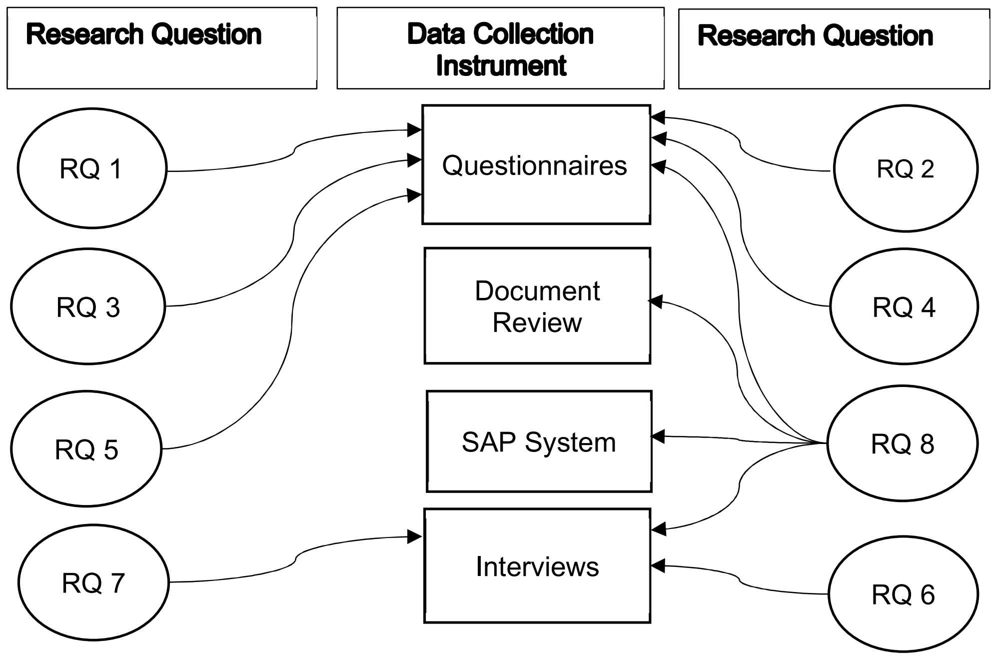


Figure 3.3: Interaction between research questions and data collection methods
Source: Author's construction

In Figure 3.3, data for RQ1, RQ2, RQ3, RQ4, RQ5 and RQ8 was collected using a questionnaire, data for RQ6, RQ7 and RQ8 was collected using interviews. Data for RQ8 was further collected through document review and the SAP system (CMMS).

3.4 Population and sampling

The target population for this study was 320 for the quantitative approach, comprising the PGP employees. The sample frame is summarised in Table 3.1, which has been constructed as guided by the population to sample ratio as espoused by Sekaran and Bougie (2010: 246). A stratified random sampling technique was employed where the population strata consisted of management level (M-level), senior advisors' level (G-level), professionals' level (P-Level) and supervisors and technicians' level (T-level). The target population consisted of professional-level employees and excluded contracted employees, students and utility workers. The target population for the qualitative approach was the PGP top management, known as the management committee (MC), which consisted of 8 members. According to the sampling table of Sekaran and Bougie (2010: 246), if the population is 10, the sample will also be 10. This means that any number below 10 will automatically be the sample size. Like in this study, the population is eight, so is the sample.

Table 3.1: Summary of the sample frame.

#	Job Grade		Population (N)		Sample (n)
1	M-Level		36		33
2	G-Level		17		16
3	P-Level		50		44
4	T - Level	T13	26		25
5		T 12	58		56
6		T11	76		47
TOTAL			263		221

Source: Author's construction

3.5 The Data collection approach

This section provides a road map of how data collection was planned, executed and analysed.

3.5.1 Primary quantitative data

In a quantitative data collection approach, a theoretical construct is put to the test to determine to what extent something is occurring or not occurring. Furthermore, the knowledge about the targeted reality is obtained through the researcher's eyes (Jonker and Pennink, 201:66). Primary quantitative data was gathered through a non-experimental approach that used questionnaires based on a 5-point Likert scale (Maree 2007: 167). A Likert scale is a psychometric scale with multiple categories respondents select to specify their opinions, attitudes, or feelings about a particular subject (Nemoto T and Beglar D (2014: 2).

3.5.1.1 Description of the instrument

The questionnaire consisted of two sections, section one aimed at collecting biographical information and section two aimed at collecting research information. Section two consisted of five main questions, which comprised of twenty-nine sub-questions. The questionnaire was based on Quality Management Principles derived from ISO 9000: 2015 Quality Management Systems – Fundamentals and vocabulary. Appendix A of this document presents the research survey questionnaire used in this study.

3.5.1.2 How the instrument was administered

The electronic system (University enterprise sub-account ©2021 QuestionPro) was used to distribute the questionnaires instead of the initial idea of physically handing them out. This was due to the COVID-19 situation, which limited access and most people had to work from home. However, the response was very low; only 43% of the feedback was received. As a result, a manual form was printed and handed out to participants after the lock-down level was eased. This was to increase the response rate. The researcher had to do constant follow-up with the participants to remind them to return the surveys. A complete record of the surveys is available for auditing purposes. See Figure 3.4. The researcher took it upon himself to capture data in the QuestionPro system. This provided certainty that the information captured was correct.

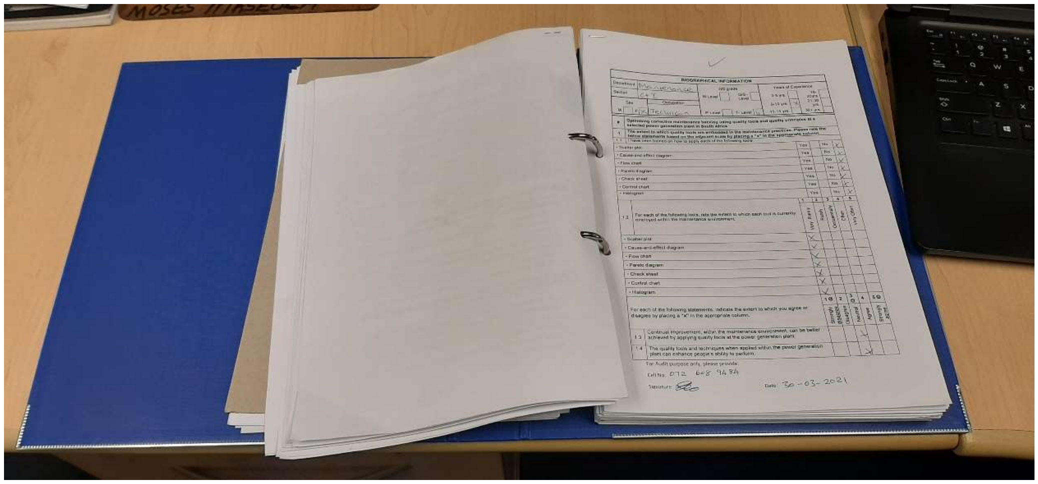


Figure 3.4: Evidence of record management

Source: Author’s picture

3.5.1.3 Reliability of data

Reliability refers to the consistency, stability and repeatability of results in the same situation on repeated occasions (Heale and Twycross (2015:66) and Mohajan (2017:14). Mohajan (2017:10) states reliability is when a researcher’s approach is consistent across different researchers and projects. The three attributes of reliability, according to Heale and Twycross (2015: 66-67), are:

i. **Homogeneity (internal consistency**) - The extent to which all the items on a scale measure one construct and instruments with questions that have more than two responses can be used in this test. Cronbach’s α is the most used test to determine the internal consistency of an instrument, with a number between 0 and 1 indicating the results. An acceptable reliability score is above 0.7.

ii. **Stability** - The consistency of results using an instrument with repeated testing.

iii. **Equivalence** - Consistency among responses of multiple users of an instrument or alternate forms of a device.

In this study, the instrument's internal consistency was tested using Cronbach's alpha to demonstrate the reliability of the data.

3.5.1.4 Validity of data

Validity is the extent to which a measuring instrument measures what it is intended to measure (Heale and Twycross (2015:66),
Taherdoost (2016: 29), Nemoto and Beglar (2014: 1) and Mohajan (2017: 14). According to Mohajan (2017: 14), validity is when the researcher uses specific procedures to check for the accuracy of the research findings.

Heale and Twycross (2015: 66) and Taherdoost (2016: 29) highlight four significant types of validity that can be considered in research, and these are:

i. **Content validity** – Checking whether the instrument adequately covers all the content it should concerning the variable (Heale and Twycross (2015:66). The degree to which items in an instrument reflect the content universe to which the tool will be generalized (Taherdoost 2016: 29).

ii. **Face validity** – Experts are asked their opinion about whether an instrument measure the concept intended (Heale and Twycross (2015: 66). The content simply looks relevant to the person taking the test (Taherdoost 2016: 29).

iii. **Construct validity** – Refers to whether you can draw inferences about test scores related to the concept being studied (Heale and Twycross (2015:66). How well a concept, idea, or behaviour that is a construct is translated or transformed into a functioning reality (Taherdoost 2016: 31).

iv. **Criterion validity** – A criterion is any other instrument that measures the same variable where correlations can be conducted to determine the degree to which the different instruments measure the same variable (Heale and Twycross (2015: 66) and the extent to which a measure is related to an outcome (Taherdoost 2016: 31).

In this research, validity was assured by conducting face validity, content validity, construct validity and criterion validity (Maree 2007: 167). The questionnaire was emailed to the environmental manager, process engineering manager, IT Manager, Technical Support Manager, IBI Specialist, IRM Officer, OE Manager, Learning Centre Senior Advisor and a DUT Statistician to review the content, structure and provide opinions. Amongst the people who reviewed the questionnaire, there were five master's graduates and one PhD graduate. Feedback was given to the researcher, and it was used to adjust the questionnaire before it was used.

3.5.1.5 Analysis of data (techniques)

The collected quantitative data was analysed using the statistical package for the social sciences (SPSS version 27) and Microsoft Excel.

3.5.1.6 Ethical consideration

QuestionPro software used for this study provided the privacy of participants as required. The research information package detailing what the research is about was sent to participants to decide whether to participate.

3.5.2 Primary qualitative data

According to (Jonker and Pennink, 201: 66), qualitative data allows the researcher to understand specific reality and its occurring phenomena from the perspective of those involved. They further confirm that, in this approach, knowledge about reality can be obtained through someone else's eyes. In this study, primary qualitative data was gathered by conducting interviews with the top management of the PGP.

3.5.2.1 How the interviews were administered

The primary qualitative data was collected through structured interviews with open-ended questions. The PGP senior managers were interviewed, and the interview took place on Microsoft MS team software. The interview sessions were recorded for ease of information retrieval.

3.5.2.2 Trustworthiness of the data

According to Nowell et al. (2017: 3), the concept of trustworthiness can be demonstrated through the criteria of credibility, transferability, dependability, and confirmability to equal the conventional quantitative assessment criteria of validity and reliability. Credibility is said to address the "fit" between respondents' views and the researcher's representation of the same ideas (Nowell et al., 2017: 3). Transferability refers to the generalisability of the findings from the study, which can be easily transferred by other researchers (Nowell et al., 2017: 3). The third criterion of trustworthiness, "dependability", looks at how documented the research process is, how logical it is and finally, is it traceable enough (Nowell et al. 2017: 3). The current study has been documented with related records being archived and can be retrieved for audit purposes. The fourth and last criterion of trustworthiness is "confirmability", which is concerned with how the researcher's findings and interpretations are connected to the data collected during the progression of the study, giving an idea of how the conclusions have been reached (Nowell et al. 2017: 3). In further elaboration, Nowell et al. (2017: 3) indicate that keeping raw data, field notes, transcripts, and a reflexive journal can help researchers systemise, relate, and cross-reference data.

Electronic files have been created to ensure an adequate audit trail for anyone wishing to verify some information collected during the progression of this study. The interview notes and audios have been filled as softcopies and are available for audit. Microsoft Excel and Word were used to document the related data and information to be analysed. Nowell et al. (2017: 7) that the Nvivo software program was used in this study to aid in the sorting and to organize the large set of data which enabled the researcher to work efficiently with complex coding schemes and large amounts of text.

Nowell et al. (2017: 2) says qualitative researchers can demonstrate how data analysis has been conducted through recording, as was done in this study, to systematise and disclose the analysis methods with enough detail to enable the reader to determine whether the process is credible. The sessions were recorded on the MS team platform to maximise content retrieval and trustworthiness of data. The transcription of the interviews was done using **Otter.ai** software. After that, the researcher reviewed the content of the transcripted material in line with the audio to ensure that it was aligned accordingly. Interpretation of data was made possible using Nvivo software version 12. Data review was done by sending transcripted interviews back to the interviewees to get their feedback and issues of concern.

3.5.3 SAP CMMS secondary quantitative data

The secondary quantitative data was obtained from a Computerised Maintenance Management System (CMMS) called SAP. The data collected was more of live data because it reflected the exact status of the plant at the time of analysis.

3.5.3.1 The process to extract secondary quantitative sap data

Secondary quantitative data was collected from CMMS (SAP system) and exported to an excel spreadsheet for statistical manipulation. The data was supplied by the planning section within the maintenance department. This information is sent daily to all PGP technical personnel, including line managers, supervisors, and system engineers. This is where and how the researcher obtained the data. The below process demonstrates how the manipulated data was extracted from CMMS (SAP). Data capturers in the planning section are responsible for capturing all CMMS information about maintenance activities.

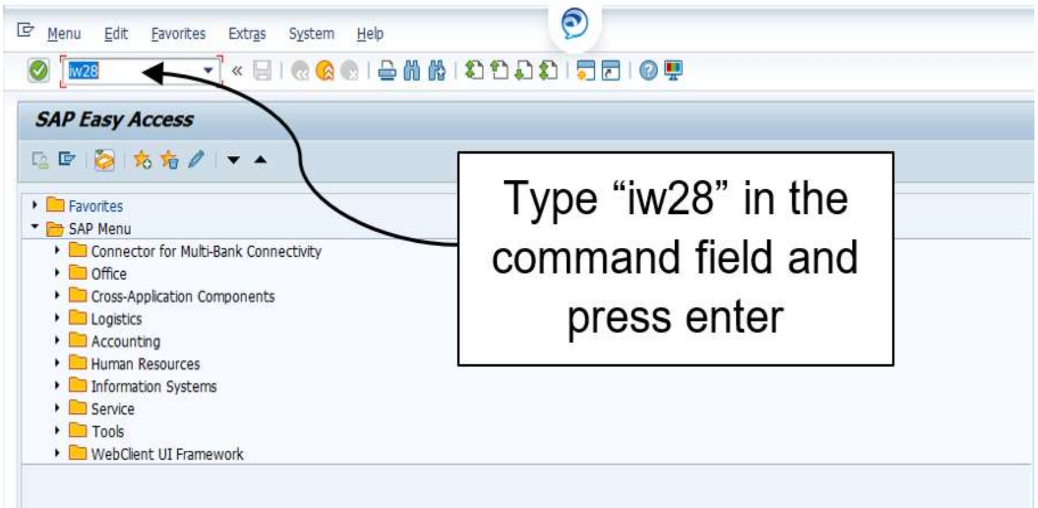


Figure 3.5: Step one of data extraction from CMMS (SAP system)

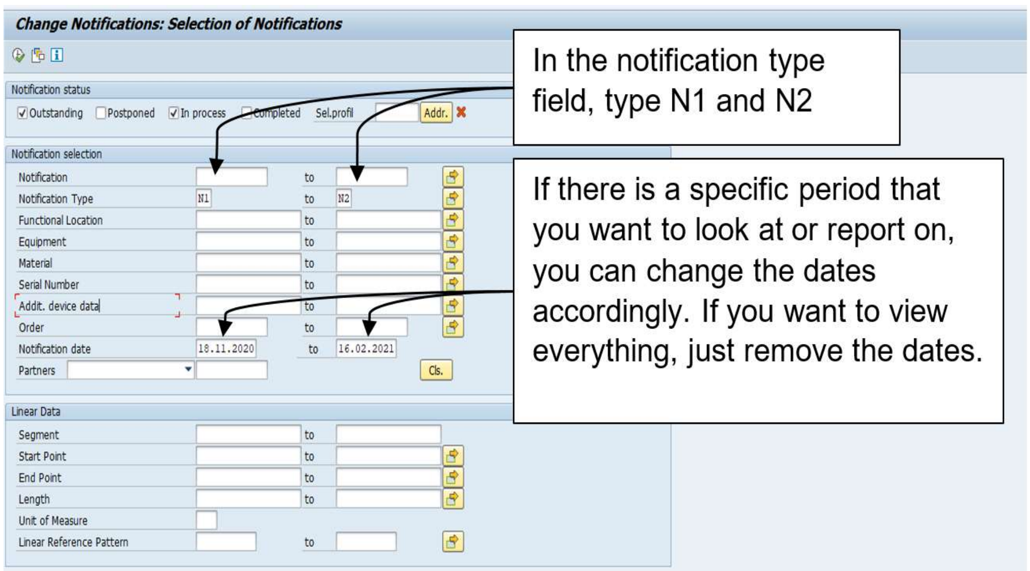


Figure 3.6: Step two of data extraction from CMMS (SAP system)

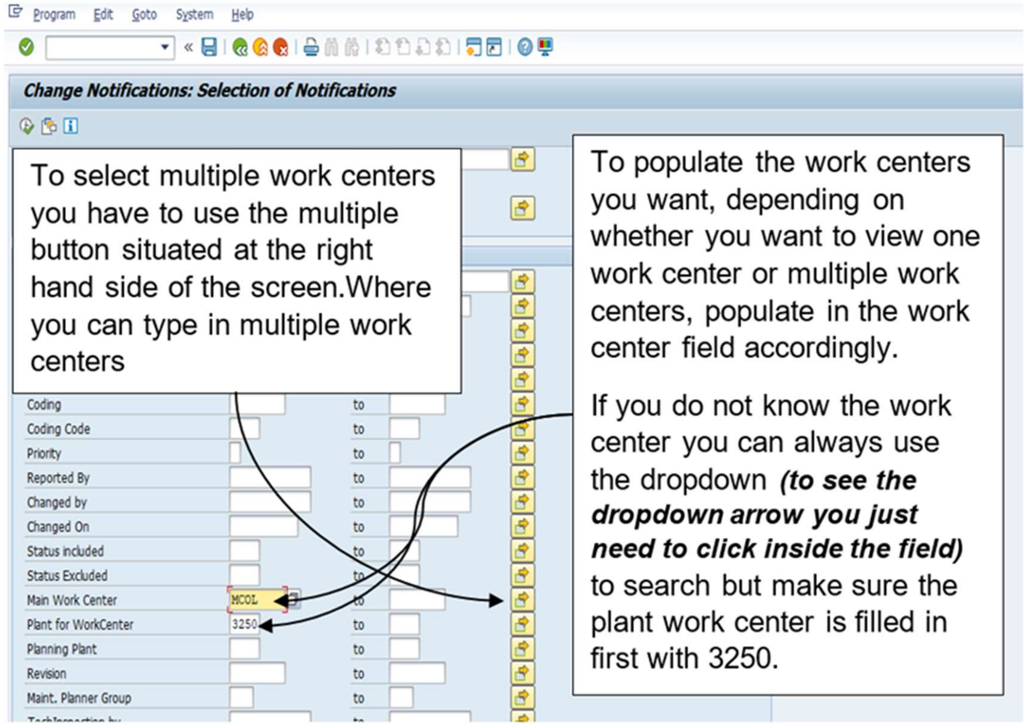


Figure 3.7: Step three of data extraction from CMMS (SAP system)

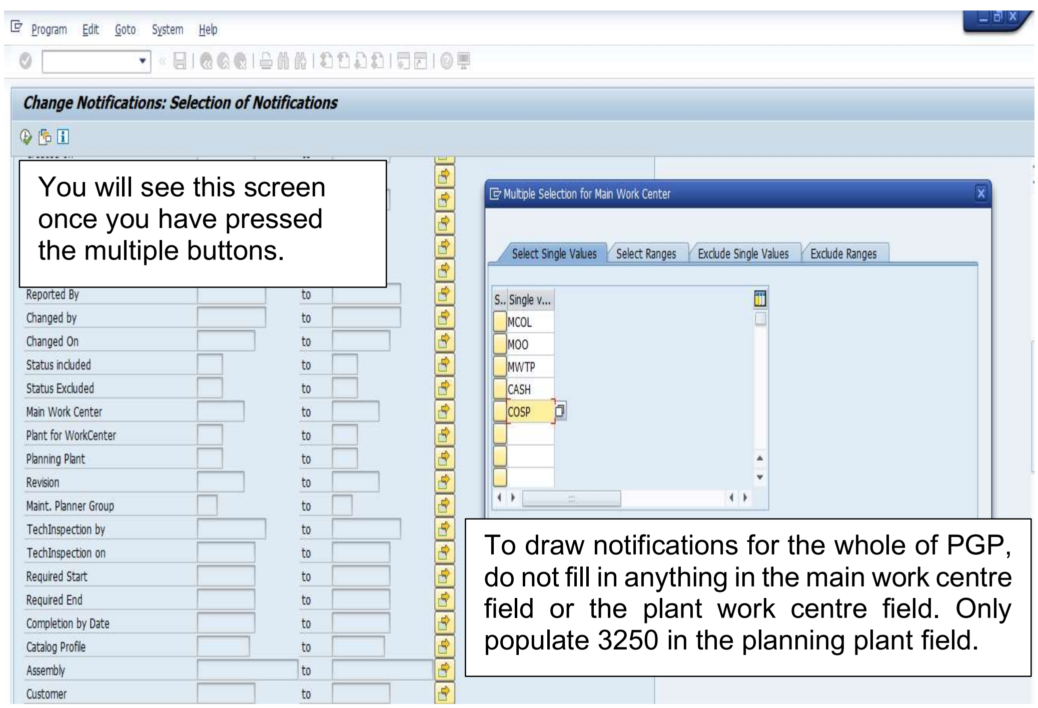


Figure 3.8: Step four of data extraction from CMMS (SAP system)

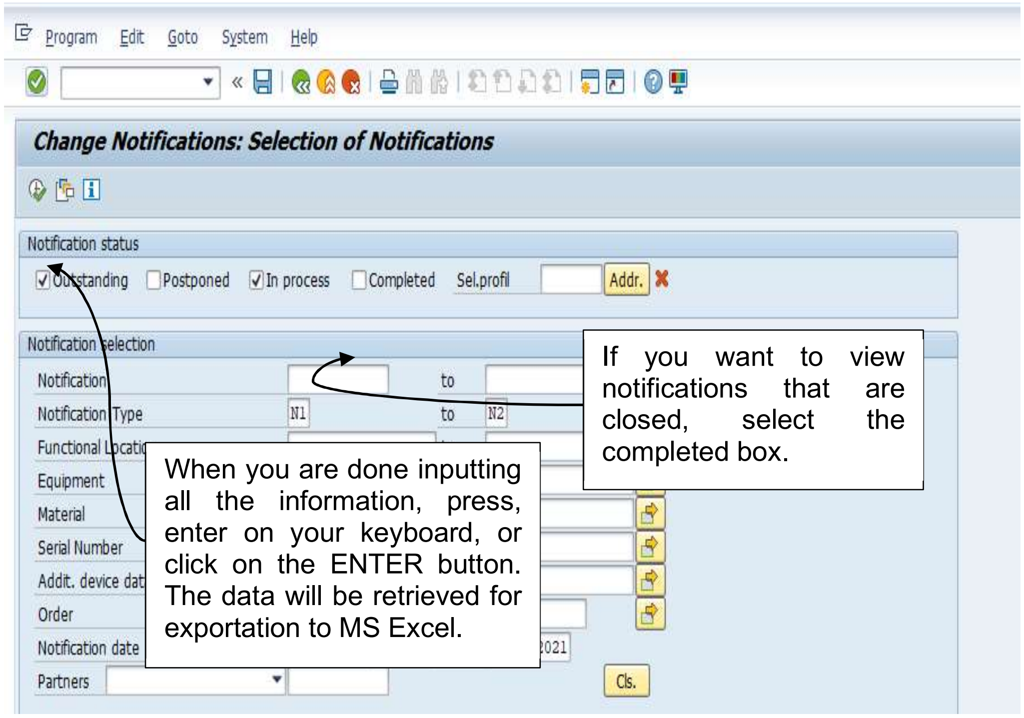


Figure 3.9: Step five of data extraction from CMMS (SAP system)

3.5.3.2 The process to manipulate secondary quantitative SAP data

A line graph indicating the defect backlog line, defects birth-rate line, awaiting plant/unit line and awaiting spares line is plotted against the period from Monday to Friday throughout the month. The second manipulation is to analyse further defect backlog, defects birth-rate, awaiting plant/unit and awaiting spares individually. The individual manipulation uses the Pareto principle in a spider web using a Microsoft Excel spreadsheet.

Data from the computerised maintenance management system (SAP System) was analysed using quality control tools, mainly the Pareto diagram, histogram, and scatter diagram. Maintenance data was extracted from the SAP system and exported into an Excel spreadsheet for manipulation, as indicated in Figure 3.9. The process flow chart demonstrated in Figure 3.10 reveals the researcher's path to analyse the secondary quantitative data. Defects from the SAP system are divided into four categories, and the appropriate quality tools employed to these defect categories to produce the required report as listed in Figure 3.10 below.

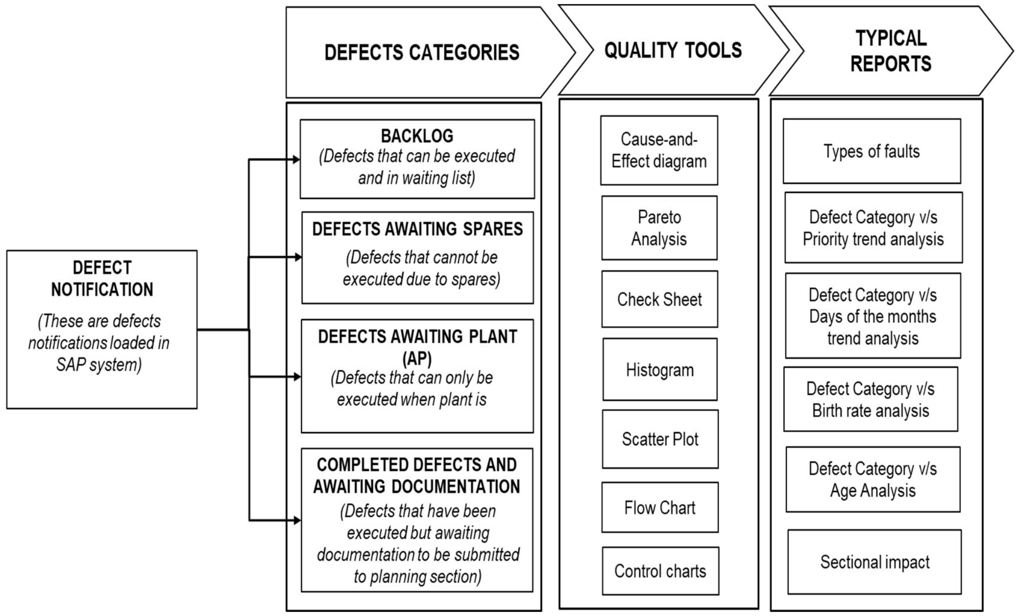


Figure 3.10: Secondary quantitative (SAP system) data analysis process flow
Source: Author's construction

3.5.4 Hyperwave secondary quantitative data

The secondary data was obtained from Hyperwave, the PGP electronic documentation system that manages all business documentation. This is the platform that provides all maintenance documentation related to the execution of work. The data extraction process is demonstrated from Figure 3.11 to Figure 3.20.

3.5.4.1 Maintenance document review

Data collection was done by evaluating maintenance documentation using ISO 9001: 2015 clause 7.5 requirements as the criteria. The three main areas of the requirements were:

i. Evaluating the existence of the necessary documented information within the maintenance
ii. Evaluating the creation and updating of maintenance recorded information
iii. Evaluating the control of maintenance written information

The graphical representation listed below provides a road map of how the data was extracted from the Hyperwave system, the official PGP document management repository.

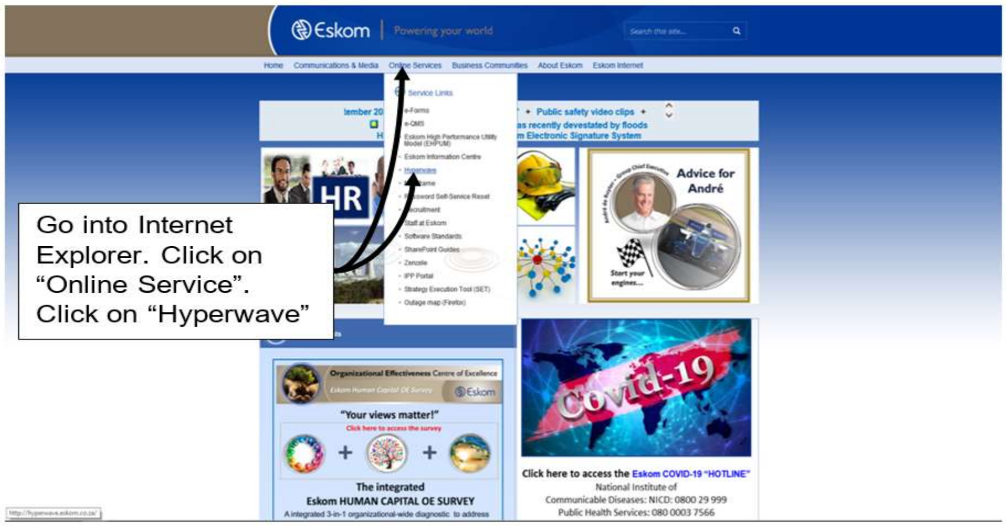


Figure 3.11: Step one of data extraction from Hyperwave

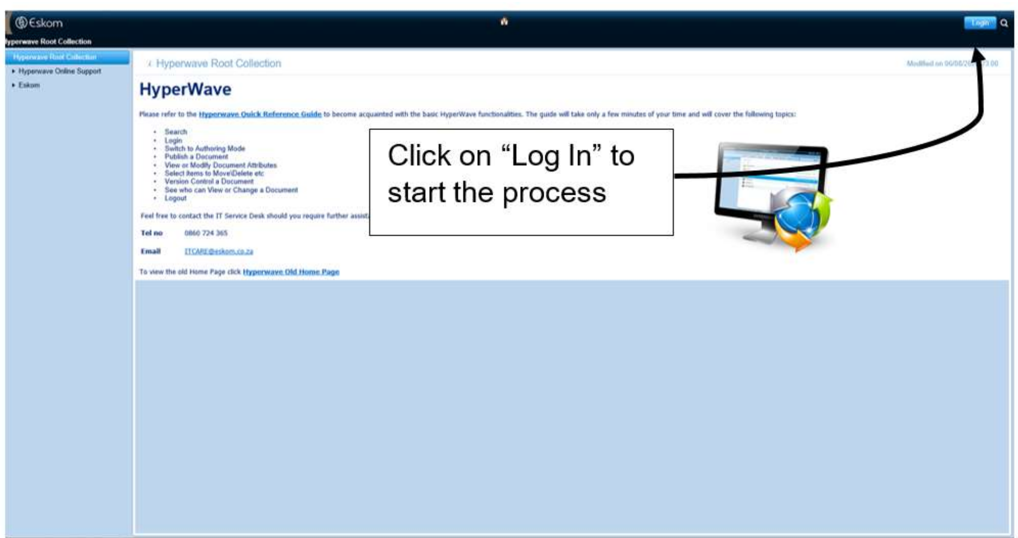


Figure 3.12: Step two of data extraction from Hyperwave

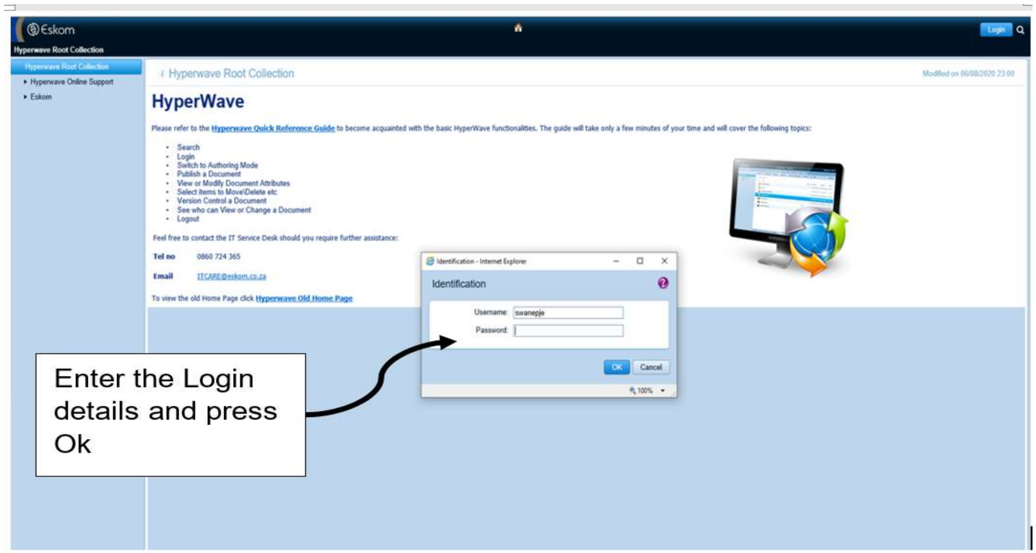


Figure 3.13: Step three of data extraction from Hyperwave

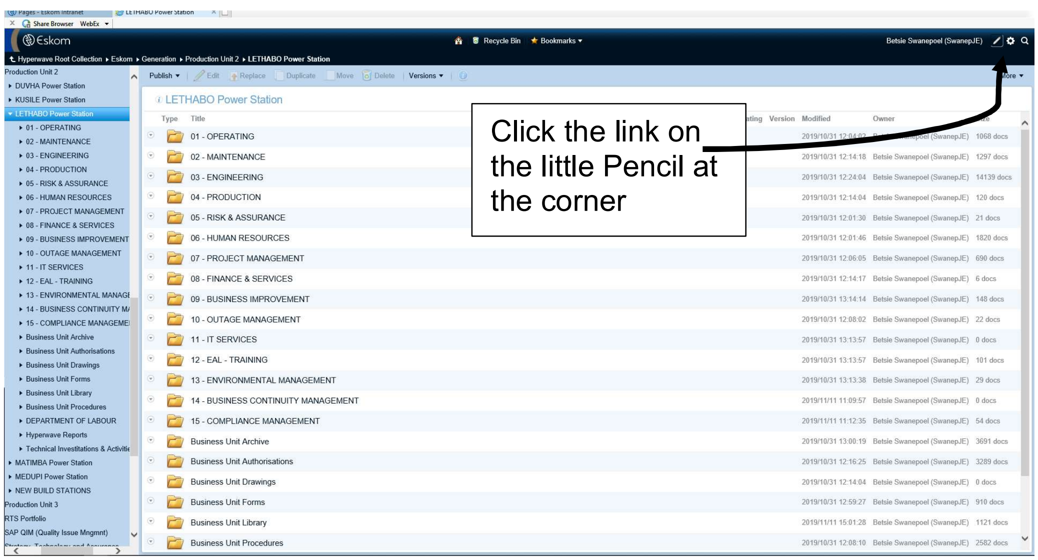


Figure 3.14: Step four of data extraction from Hyperwave

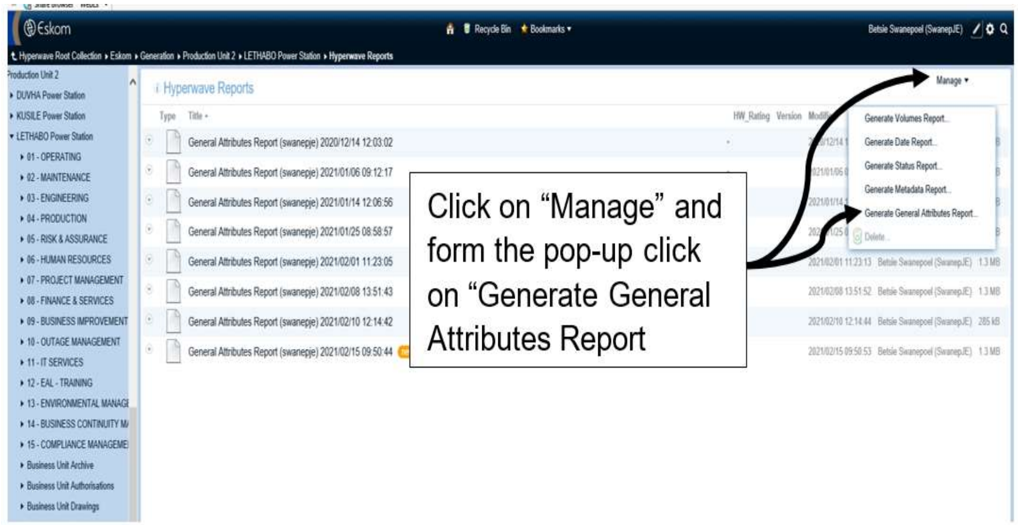


Figure 3.15: Step five of data extraction from Hyperwave

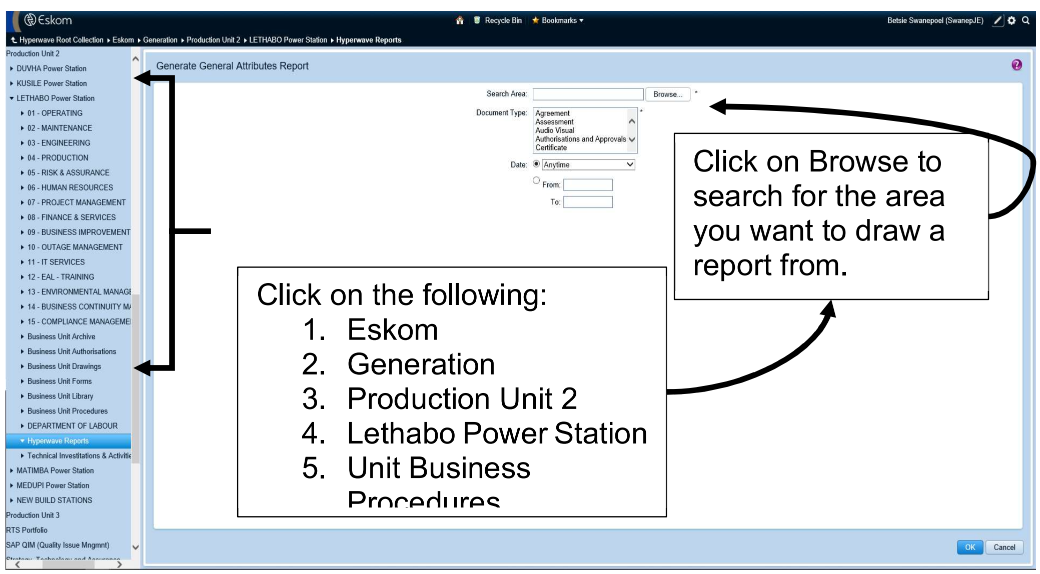


Figure 3.16: Step six of data extraction from Hyperwave

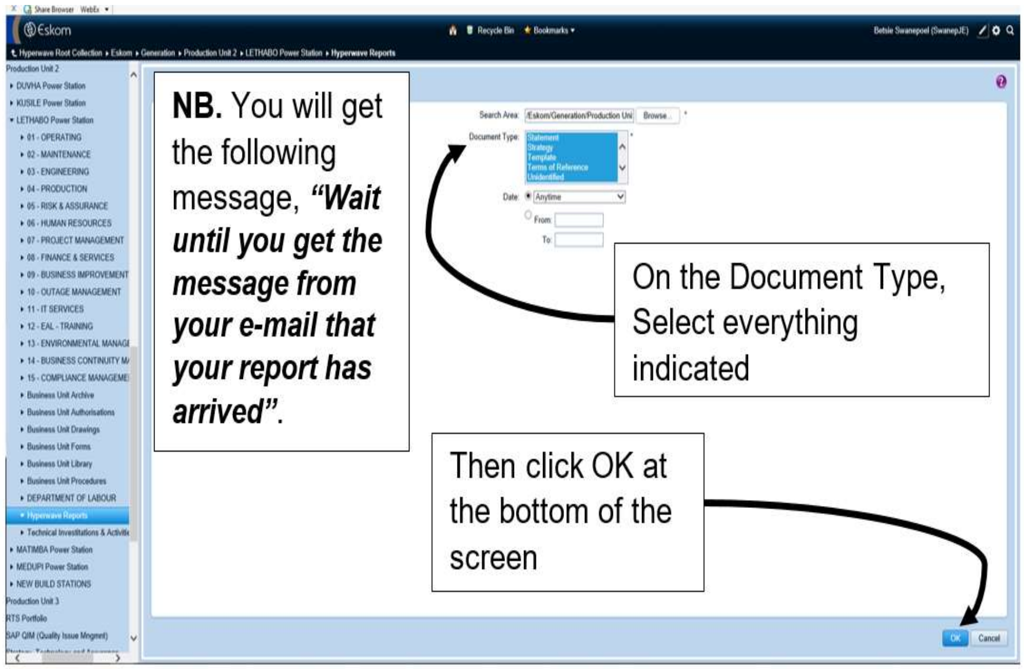


Figure 3.17: Step seven of data extraction from Hyperwave

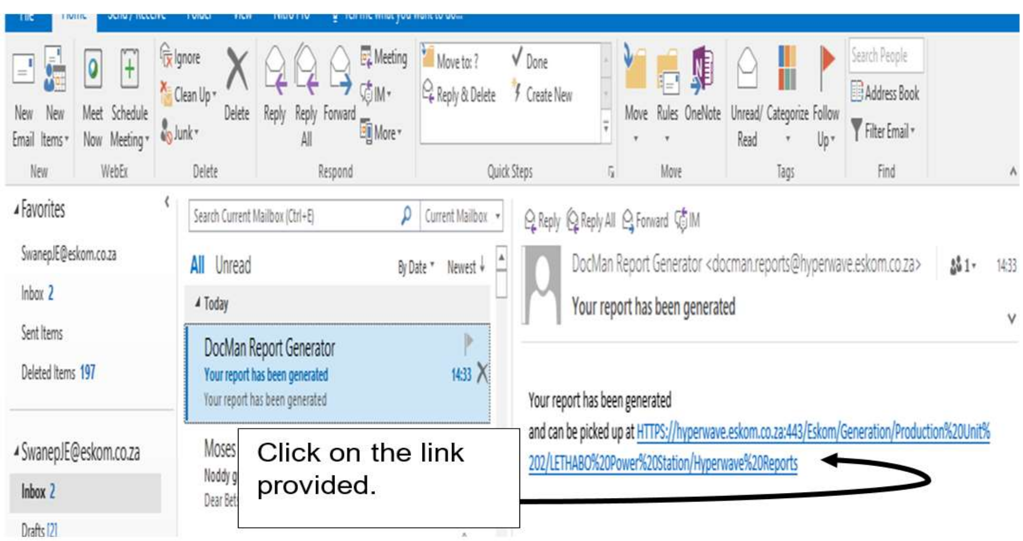


Figure 3.18: Step eight of data extraction from Hyperwave

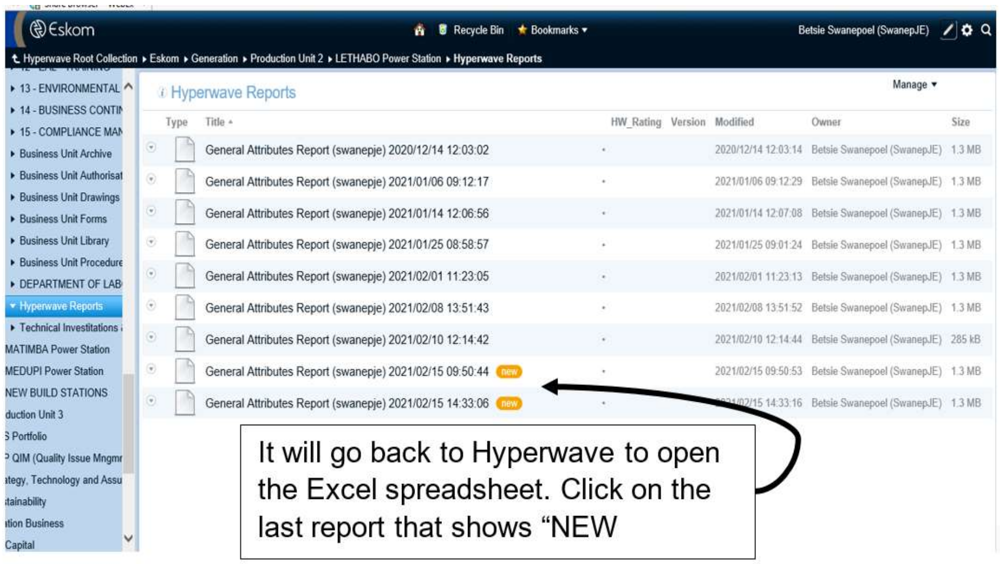


Figure 3.19: Step nine of data extraction from Hyperwave

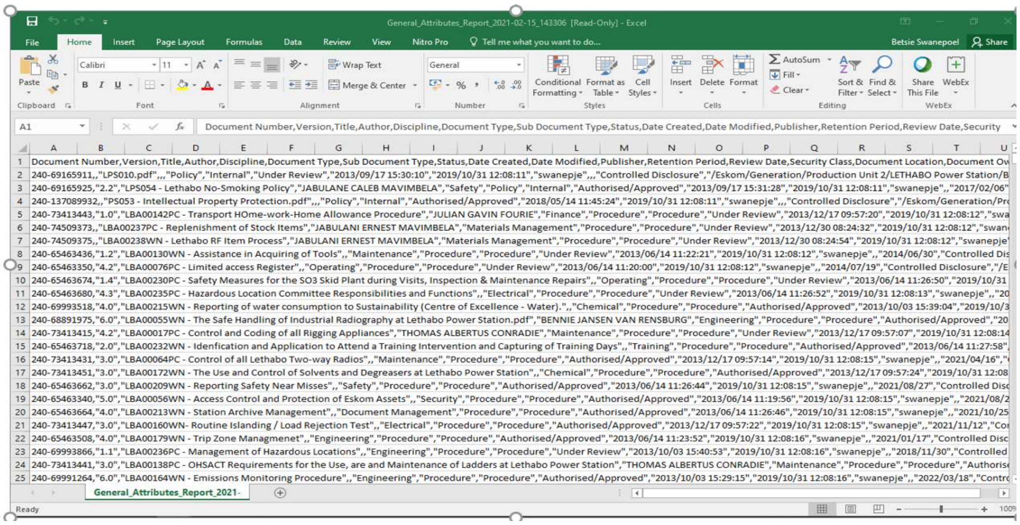


Figure 3.20: Step ten of data extraction from Hyperwave

3.6 Conclusion

An introduction to the chapter was given, which provided an overall picture of the chapter. After that, the research overview, research design and research methodology of the study were outlined. The population and sampling of the study were clearly outlined in which the approach followed was indicated. The data collection approach for primary and secondary qualitative data and primary and secondary quantitative data was demonstrated and explained in full.

CHAPTER 4: DATA PRESENTATION AND ANALYSIS

4.1 Introduction

The previous chapter explicated the research methodology for this study. This chapter focuses on re-stating the study objectives to present quantitative data and qualitative data analysis. It further unpacks sampling compliance, deliberates on the respondents' demographical profiles, and discusses the descriptive statistics of the collected and analysed data. The reliability of the constructs used in the data collection instruments is also outlined comprehensively before concluding the chapter.

4.2 Discussion of the research objectives

This study optimises corrective maintenance backlog using quality tools and principles at a selected PGP in South Africa. The study intended to optimise the CM/PM ratio, positively influencing the corrective maintenance backlog at the selected PGP. In support of the main objective mentioned above, the objectives of this study were set and are listed in section 1.3.3. The methodology followed to achieve these objectives is outlined in Figure 1.1.

4.3 Analysis of primary quantitative data

Data was exported from QuestionPro into Excel, and it was evaluated and cleaned to prepare the data for computing in SPSS software. Three returned surveys were discarded due to too much missing information. After that, the data was imported to SPSS software for computation.

This section presents and analyses the data obtained from the questionnaires. The questionnaire was the primary tool used to collect quantitative data and was distributed to the selected PGP employees. The data collected from the responses was analysed with SPSS version 27.0. The results present the descriptive statistics in graphs, cross-tabulations, and other Figures for the collected quantitative data. Inferential techniques include correlations and Chi-square test values, which are interpreted using the p-values. The traditional approach to reporting a result requires a statement of statistical significance; as a result, the p-value is generated from a test statistic. A significant result is indicated with "$p < 0.05$" (Napitupulu, Kadar and Jati 2017: 700).

4.3.1 Sampling compliance.

If possible, all units of a particular population under study would be included in the survey (Kaliyadan and Kulkarni 2019: 82). However, this is not practical in most situations, that is why a study looks at a subset of a population to reach conclusions, and this subset must be a representative sample with sufficient numbers to make meaningful and accurate conclusions, including minimisation of sampling error (Kaliyadan and Kulkarni 2019: 84). The population for this study was 320, all of the PGP's permanent employees, and the sample drawn from it was 221. Not comprising part of the population were contracted employees, students and utility workers. A total of 207 (93,67%) responses were received, with three incomplete surveys rejected, leaving 204 (92.31%) responses as valid. The descriptive statistics computed in SPSS version 27 was based on 92,31% of returned responses.

4.3.2 The research instrument

The research instrument consisted of forty-seven (47) items, with a level of measurement at a nominal and ordinal level. The questionnaire was divided into six questions which measured various themes as illustrated below:

1. Biographical data
2. The tools currently employed within the maintenance environment
3. The extent to which ISO 9000: 2015 Quality Management Principles are embedded in the maintenance practices
4. The factors that contribute to the corrective maintenance backlog
5. The gaps and limitations in the maintenance documentation
6. The extent to which external service providers contribute to the corrective maintenance backlog

4.3.3 Construct reliability analysis

The instrument's reliability was explained in section 3.5.1.3 in the previous chapter, which indicated that several items could measure one construct. Cronbach's α is the most frequently used test to determine the internal consistency of an instrument, with a number between 0 and 1 indicating the results. An acceptable reliability score is above 0.7 (Heale and Twycross 2015: 66-67).

In this study, Cronbach's alpha was used to analyse the internal consistency of the constructs. According to Lopes, Saraiva and Rodrigues (2018: 253), the following rules of thumb can be applied to interpret the values of Cronbach's alpha "α > 0.9 = Excellent, α > 0.8 = Good, α > 0.7 = Acceptable, α > 0.6 = Questionable, α > 0.5 = Poor, and α < 0.5 = Unacceptable". The internal consistency of the constructs for this study must have at least a minimum of α > 0.6 for them to be acceptable. Table 4.2 reflects the Cronbach's alpha score for all the items that constituted the questionnaire.

Table 4.1: Construct reliability Table

	Section	**Number of Items**	**Cronbach's Alpha**
RQ2	The tools currently employed within the maintenance environment	7	0.899
RQ3	The extent to which ISO9000:2015 Quality Management Principles are embedded in the maintenance practices	7	0.868
RQ4	The factors that contribute to the corrective maintenance backlog	7	0.771
RQ5	The gaps and limitations in the maintenance documentation	4	0.754
RQ6	The extent to which external service providers contribute to the corrective maintenance backlog	7	0.767
Overall:		**34**	**0.876**

The reliability scores for all sections exceed the recommended Cronbach's alpha value. This indicates a degree of acceptable, consistent scoring for these sections of the research.

4.3.4 Factor analysis

Factor analysis is a statistical technique whose primary goal is data reduction. A typical use of factor analysis is in survey research, where a researcher wishes to represent several questions with a small number of hypothetical factors (Samuels 2017: 1).

The matrix tables are preceded by a summarised table that reflects the results of KMO and Bartlett's Test. The KMO and Bartlett's Test in Table 4.2 shows two tests that indicate the suitability of data for structure detection. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy is a statistic that displays the proportion of variance in the variables that underlying factors might cause. High values (close to 1.0) generally indicate that factor analysis may be helpful with the data. If the value is less than 0.50, the results of the factor analysis probably will not be beneficial (Munir and Rahman 2016: 493)

Bartlett's test of sphericity tests the hypothesis that the correlation matrix is an identity matrix, which would indicate that the variables are unrelated and therefore unsuitable for structure detection. Small values (less than 0.05) of the significance level indicate that factor analysis may be helpful with the data (Napitupulu, Kadar and Jati 2017: 700).

Factor analysis is done only for the Likert scale items, whereas certain items are divided into more delicate components. This is presented in Appendix D in the rotated component matrix Table.

Table 4.2: KMO and Bartlett's Test

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.813
Bartlett's Test of Sphericity	Approx. Chi-square	2776.715
	df	496
	Sig.	0.000

For all conditions to be satisfied for factor analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy value should be greater than 0.500 and Bartlett's Test of Sphericity significant value should be less than 0.05 (Napitupulu, Kadar and Jati 2017: 700). Factor analysis for this data reveals that the Kaiser-Meyer-Olkin Measure of Sampling Adequacy value is 0.813, greater than 0.500 and Bartlett's Test of Sphericity significant value is 0.000 less than 0.05. Meaning all the conditions for factor analysis have been satisfied.

Concerning the table presented in Appendix E, the principal component analysis was used as the extraction method, and the rotation method applied was Varimax with Kaiser Normalisation. This is an orthogonal rotation method that minimises the number of variables with high loadings on each factor, simplifying the interpretation of the factors (Samuels 2017: 1). Factor analysis/loading show inter-correlations between variables. Items of questions that loaded similarly imply measurement along with a similar factor (Samuels 2017: 1). An examination of the content of items loading at or above 0.5 (and using the higher or highest loading in instances where items cross-loaded at more significant than this value) effectively measure along with the various components (Napitupulu, Kadar and Jati 2017: 703).

The statements that constituted questions 1, 2 and 3 loaded perfectly along with a single component. This implies that the reports that included these sections perfectly measured what they set out to measure. It is noted that the variables that constituted questions 4 and 5 loaded along with two components (sub-themes). This means that respondents identified different trends within the section. In question four, the item “The power generation plant documented information is necessary for effective management of corrective maintenance backlog” loaded differently from its other related items. Similarly, in question 5, the item “External service providers are often not provided with clear specifications of the required product and services, by the power generation plant” also; loaded differently from its related items.

4.3.5 Demographic profile of participants

This section summarises the biographical characteristics of the respondents. In this study, the demographic profile of interest was the departments and areas in which the participants work, the occupation and gender, and the job grade and years of experience. The demographic statistics in this section is presented through the Tables and graphs.

Suggestion: The structure of your analyses is critical to convey a clear understanding

4.3.5.1. Departments of respondents

Table 4.3: Departments of the respondents

	Frequency	Percentage
Maintenance	93	46.0
Engineering	52	25.7
Operations	28	13.9
Risk and Assurance	9	4.5
Outage	5	2.5
Environment	4	2.0
Production	3	1.5
Projects	3	1.5
Procurement	3	1.5
Finance	1	0.5
Human Resources	1	0.5
Total	202	100.0

Source: Output of SPSS version 27 software

More than 70% of the respondents were either in Maintenance or Engineering ($p < 0.001$). The statistical analysis indicates that maintenance appeared to have participated most in the survey due to the high number of staff in this department.

4.3.5.2. Gender of respondents

Figure 4.1 illustrates the gender frequency and its good percentage. The observation is that male participation was by far overwhelming, with a frequency of 140. The ratio of males to females is approximately 2:1 (69,7%/ 30,3%) ($p < 0.001$). This can be understandable due to the number of females in the PGP being far less than males. According to the PGP HR demographics report, the ratio of female: the male is 29%/71% respectively.

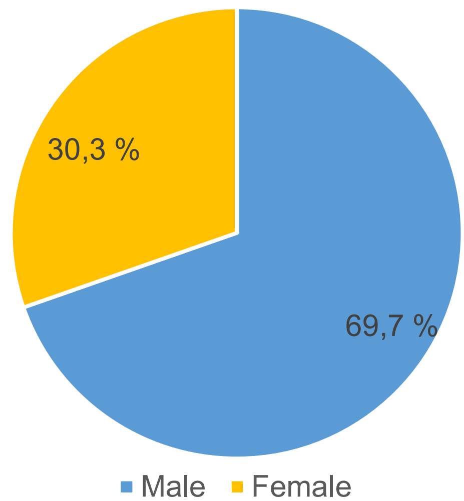
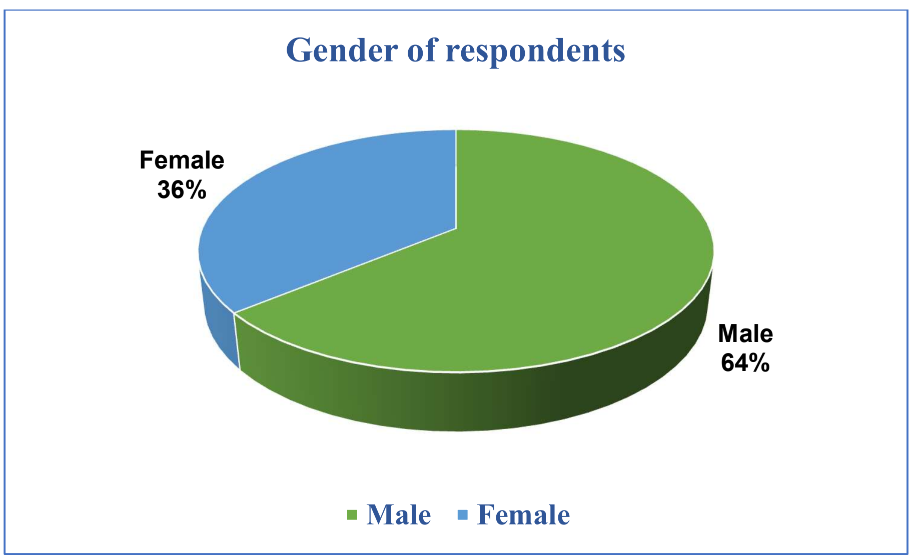


Figure 4.1: Gender frequency of respondents

Source: Output of SPSS version 27 software



4.3.5.3. The job grades of the respondents

Figure 4.2 indicates that T-Level (technical level) registered the highest frequency, making them the most participative group regarding job grades. Approximately two-thirds of the respondents (65,8%) were at T-Level ($p < 0.001$). The general observation in most organisations is that lower-level employees are more in numbers than the higher levels, which is the reason why the participation of technical employees is more.

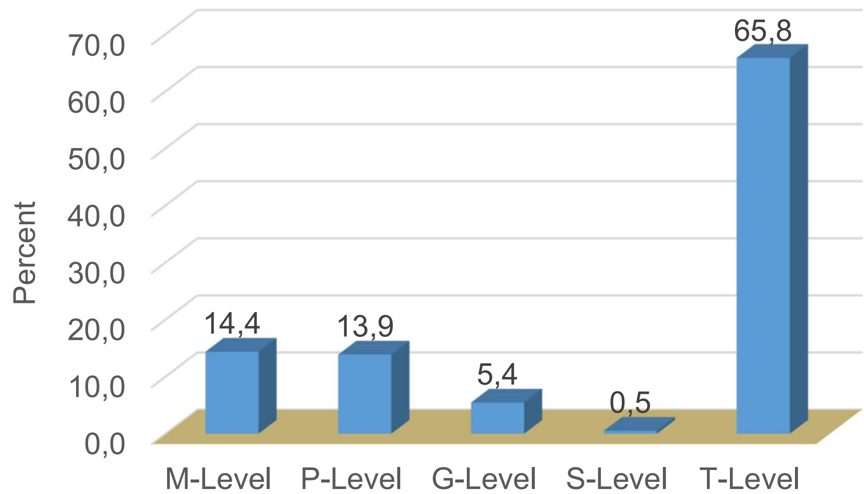


Figure 4.2: The job grades of the respondents

Source: Output of SPSS version 27 software

4.3.5.4. The occupations of the respondents

Figure 4.3 shows that most respondents were Technicians (36,9%), with average numbers of respondents between Supervisors, Managers and Engineers (average = 16,0%) ($p < 0.001$). Participation under this category can also be viewed according to job-grade reasoning of why the technician registered high participation.

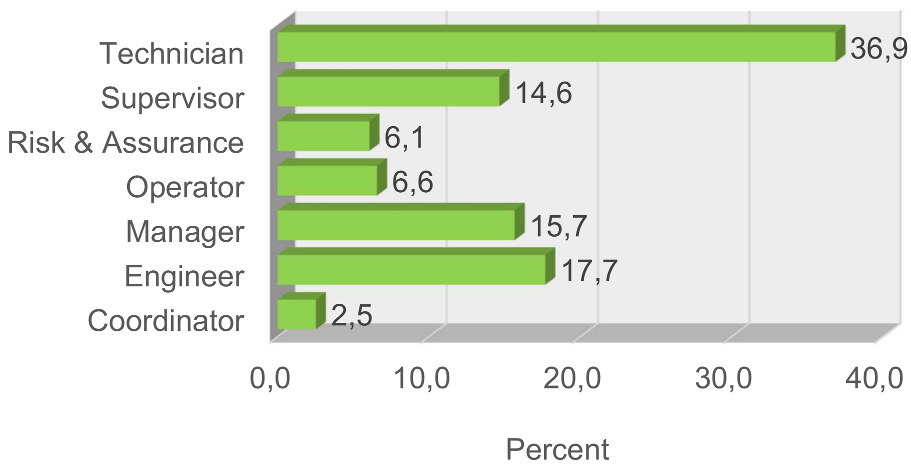


Figure 4.3: The occupations of the respondents

Source: Output of SPSS version 27 software

4.3.5.5. Length of service of the respondents

Figure 4.4 illustrates the length of service of the respondents, whereby the employees with work experience of 6-10 years registered the highest frequency, representing 24,9% of participation. With the experience of 6-10 years, the employees seem to be comfortable in their roles. Approximately 85% of the respondents had been employed for more than five years ($p = 0.003$). This implies that respondents had been in employment for a while, and this is a useful statistic as it indicates responses from experienced workers.

Figure 4.4: Length of service of respondents

Source: Output of SPSS version 27 software

4.3.6 Study research questions analysis

This section analyses the scoring patterns of the respondents per variable per question. The results are first presented using summarised percentages for the variables that constitute each question and then further analysed according to the importance of the statements.

4.3.6.1 Research Question 1

Participants were first asked if they were trained in the seven basic quality tools. This was to determine the extent to which quality tools are embedded in the maintenance practices, listed: Scatter plot, Cause-and-effect diagram, Flow chart Pareto diagram, Check sheet, Control chart and Histogram. Figure 4.5 provides a graphical presentation of the scoring, and Appendix F provides a summary of scoring patterns and the related p - values.

(a) Q1.1 I have been trained on how to apply each of the following tools:

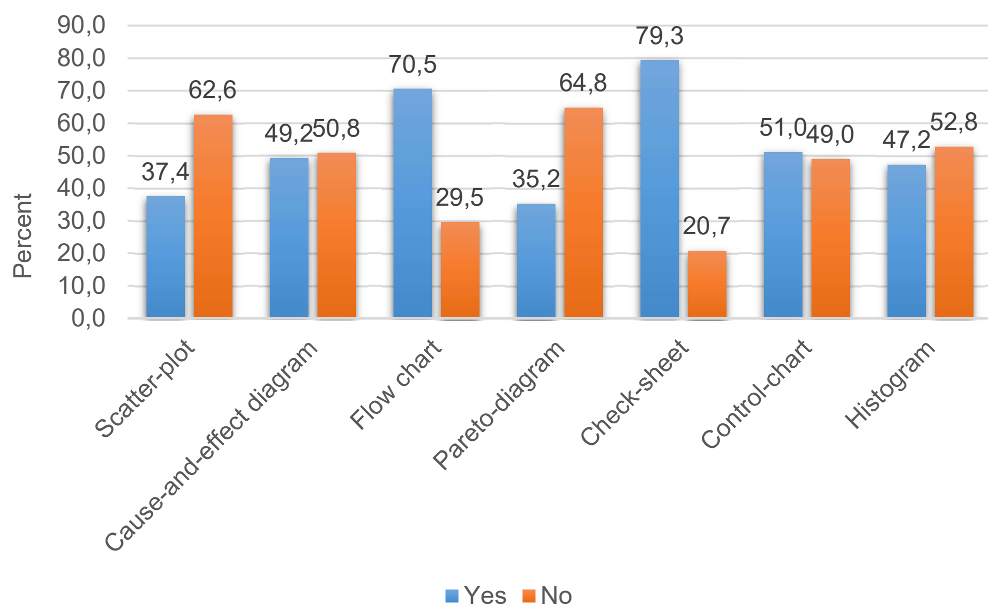


Figure 4.5: Q1.1 - I have been trained on how to apply each of the following tools

Source: Output of SPSS version 27 software

A Chi-square goodness-of-fit test was conducted to determine whether the scoring patterns per statement were significantly different per option. The null hypothesis claims that similar respondents scored across each option for each statement (one statement at a time). The alternate states that there is a significant difference between the levels of Yes and No, as indicated in Table 4.5. The highlighted important values (p-values) are less than 0.05 (the significance level), implying that the distributions were not similar. That is, the differences between the way respondents scored (Yes, No) were significant.

Regarding the scatter plot, 122 respondents, representing 62,6%, indicated that the PGP employees had not been trained on this quality tool. There is a marginal difference when looking at the statistical output on the cause-and-effect diagram. Responses received, representing 50,8% indicate that, they have not yet been trained on this quality tool.

Many respondents indicated that they had been trained on the flowchart. About 141 respondents making 70,5% specify that the PGP employee clearly understands this quality tool. The percentage further confirms a thorough implementation of the quality tool within the PGP. At 64,8% representing 125 respondents, the indication is that respondents have not been trained on the Pareto diagram. This percentage demonstrates that there is little evidence of this quality tool being implemented on the PGP. Almost 80% of the respondents say that they have been trained on the check sheet. This is a positive indication that this quality tool is fully implemented within the PGP.

The indication from the statistical output about the control chart shows that just over 50% of the PGP workforce with a frequency of 100 (51%) declared that they had been trained on this quality tool. The percentage suggests that there is still a large room for improvement. The results from the statistical output indicate that 52,8% declared they had not been trained on the histogram. This is an indication that the PGP must do more to ensure the quality tools are known, understood and used by the employees

(b) Q1.2 The analysis below rates the extent to which each quality tool is currently employed within the maintenance environment.

The second part of answering the first research question, “the extent to which quality tools are embedded in the maintenance practices,” a five-point Likert scale was used in the form of, 1 = very rarely, 2 = rarely, 3 = occasionally, 4 = often and 5 = very often. The question asked was, “for each of the following quality tools, rate the extent to which each tool is currently employed within the maintenance environment”. Here the objective was to see if the basic quality tools have been implemented within the PGP maintenance scope. The results thereof are presented in Figure 4.6 and Appendix G.

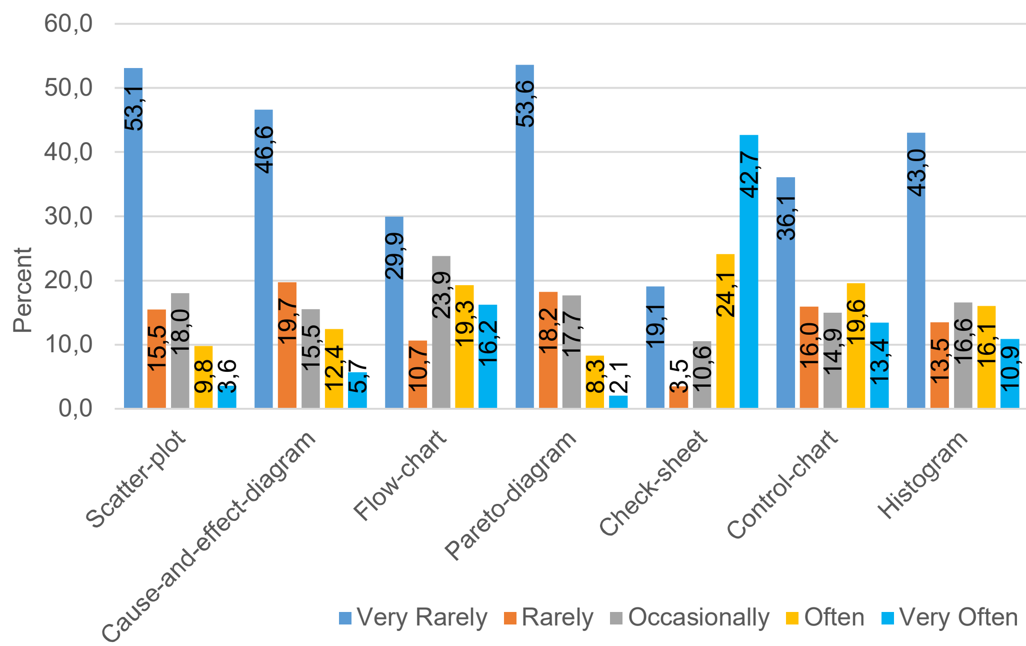


Figure 4.6: Q1.2 - The extent to which each tool is currently employed within the maintenance environment

Source: Output of SPSS version 27 software

The observation from the pattern is that six statements show (significantly) higher levels of low frequency (rarely) use. The check sheet indicates a higher frequency of use, but there is a huge gap in the usage of other tools. The Pareto diagram had the lowest frequency of use (53,6% very rarely + 18,2% rarely = 71,9%). A further indication of low-frequency application is seen on the Scatter-plot and Cause-and-effect bars. The significance of the differences is tested in a summary Table shown in Appendix G.

A Chi-square goodness-of-fit test was done to determine whether the scoring patterns per statement were significantly different per option. The null hypothesis claims that similar respondents scored across each option for each statement (one statement at a time). The alternate states that there is a significant difference between the levels of agreement and disagreement. The results are shown in Appendix 1, where significant values (p-values) are less than 0.05 (the significance level), implying that the distributions were not similar. The differences between the way respondents scored (low frequency, occasionally, high frequency) were significant.

(c) Q1.3 and Q1.4

The third part of answering research Question 1, "the extent to which quality tools are embedded in the maintenance practices," is also based on a five-point Likert scale. In this case the scale is based on; 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree. In this case, the respondents were asked to indicate how they agree or disagree with the two statements below.

1. Continual improvement within the maintenance environment can be better achieved by applying quality tools at the power generation plant (Q1.3)
2. When applied within the power generation plant, the quality tools and techniques can enhance people's performance ability (Q1.4).

A graphical presentation of the results can be seen in Figure 4.7, and the summary result table is presented in Appendix H.

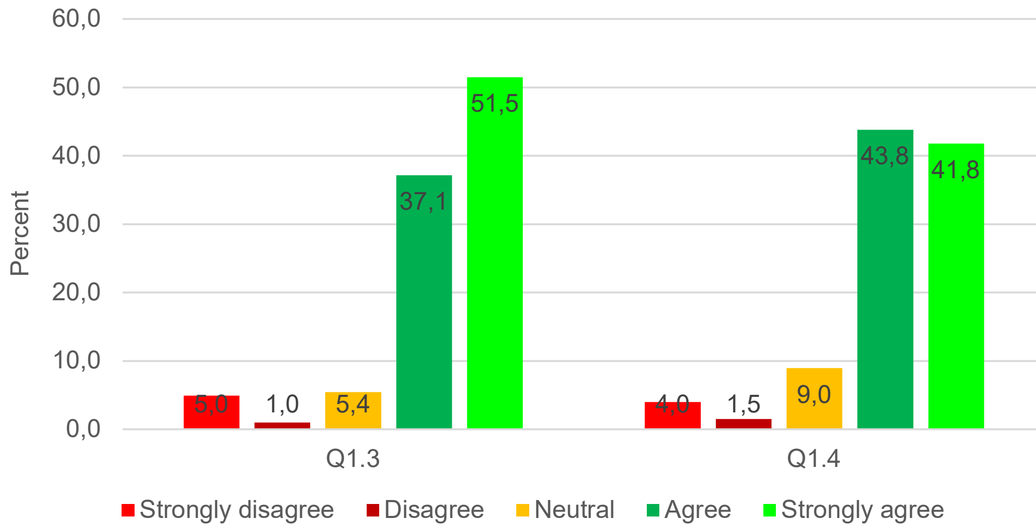


Figure 4.7: Summary of scoring patterns for Q1.3 and Q1.4

Source: Output of SPSS version 27 software

Both statements indicate significantly higher levels of agreement ($p < 0.001$). Figure 4.7 above demonstrates that respondents agree with the two statements. About 88,6% of the respondents believe that continual improvement within the maintenance environment can be better achieved by applying quality tools at the power generation plant. Additionally, 85,6% of the respondents believe the quality tools and techniques used within the power generation plant can enhance people's ability to perform. This is demonstrated by combining the scoring of agree and strongly agree presented in Figure 4.7.

4.3.6.2 Research Question 2

This research question seeks to determine the extent to which ISO 9000: 2015 Quality Management Principles are embedded in maintenance practices. The construct follows the five-point Likert scale and is measured by seven statements as indicated in Appendix I summary Table. The summary of the scoring pattern with its corresponding p values is demonstrated in Appendix I.

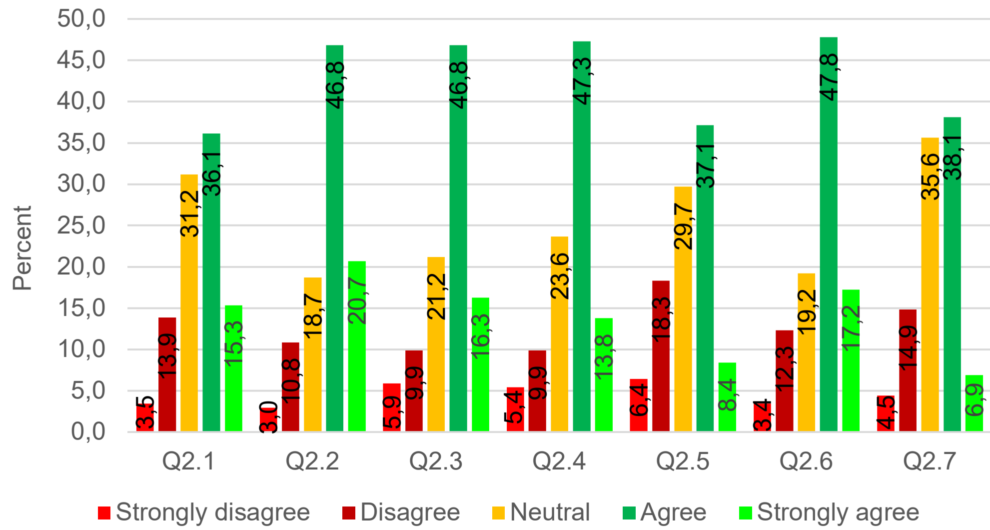


Figure 4.8: Summary of scoring patterns for Q2.1 to Q2.7

Source: Output of SPSS version 27 software

It is observed in Figure 4.8 that all of the statements show significantly higher levels of agreement, indicating that the respondents agree that ISO 9000: 2015 Quality Management Principles are embedded in the maintenance practices. There are no statements with higher levels of disagreement; however, significant respondents also scored neutral in some reports. Four statements had a level of agreement of 67%, and three had a level of agreement of 51%, where the total of agreement is equal to agree plus strongly agree.

A Chi-square goodness-of-fit test was done to determine whether the scoring patterns per statement were significantly different per option. The null hypothesis claims that similar numbers of respondents scored across each option for each statement (one statement at a time) (Barcelo 2018: 1 and Rana and Singhal 2015: 70). The alternate states that there is a significant difference between the levels of agreement and disagreement. The highlighted significant values (p-values) are less than 0.05 (the level of significance), implying that the distributions were not similar (Barcelo 2018: 3, Rana and Singhal 2015: 71 and Anezakis et al. 2018: 290003-3). The differences between the way respondents scored (agree, neutral, disagree) were significant. Overall question 2 feedback score registered a 17,4% total disagreement (which is an average of strongly disagree + disagree), an average of 25,6% neutral and 57% total agreement (which is an average of agree + strongly agree).

4.3.6.3 Research Question 3

This section deals with research Question no.3, whereby the respondents were asked about the factors that contribute to the corrective maintenance backlog. The construct consists of seven statements based on a five-point Likert scale. These statements indicated factors that are contributing to the maintenance backlog. To answer this question, the respondents were requested to indicate their agreement or disagreement with the indicated statements shown in the summary Table of Appendix J.

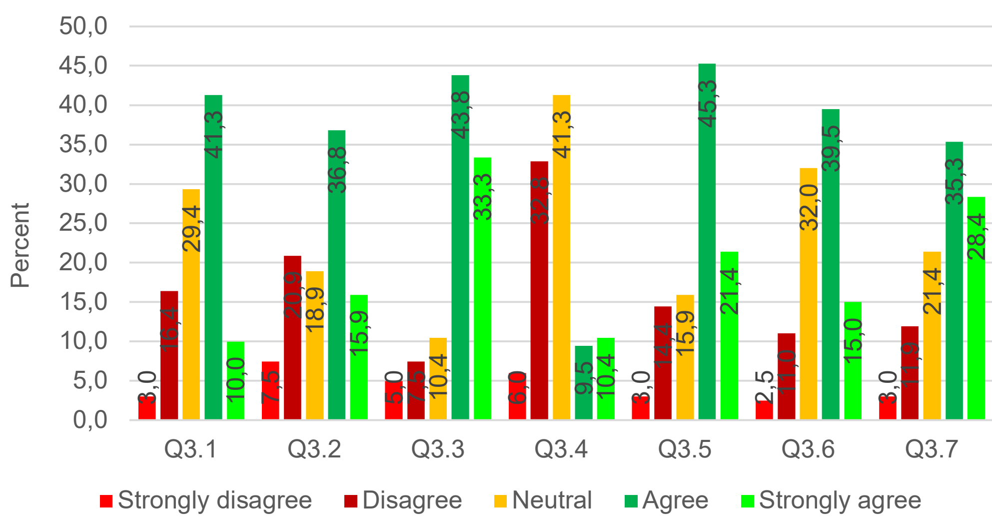


Figure 4.9: Summary of scoring patterns for Q3.1 to Q3.7

Source: Output of SPSS version 27 software

Figure 4.9 indicates that all statements specify significant high levels of the agreement except for the statement in Q3.4, where it registered only 19,9% of the agreement. Information in Q3.3 reported the most agreement (77,1%), followed by a statement in Q3.5 with an agreement of 66,7%. It can be further observed that three statements registered a high level of neutral feedback, with the statement in Q3.4 registered the most neutral outcome at 41,3%. Overall, Question 3 feedback score registered a 20,7% total disagreement (which is an average of strongly disagree + disagree), 24,2% neutral and 55% entire agreement (which is an average of agree + strongly agree).

4.3.6.4 Research Question 4

This segment deals with research question no.4, which unearth the gaps and limitations in the maintenance documentation. In this case, only four statements based on a five-point Likert scale issued highlighted positive factors favouring improving corrective maintenance backlog. The feedback from the respondents indicating the scoring of mentioned statements is summarised in the Table presented in Appendix K, and Figure 4.10 provides graphical patterns of the scoring.

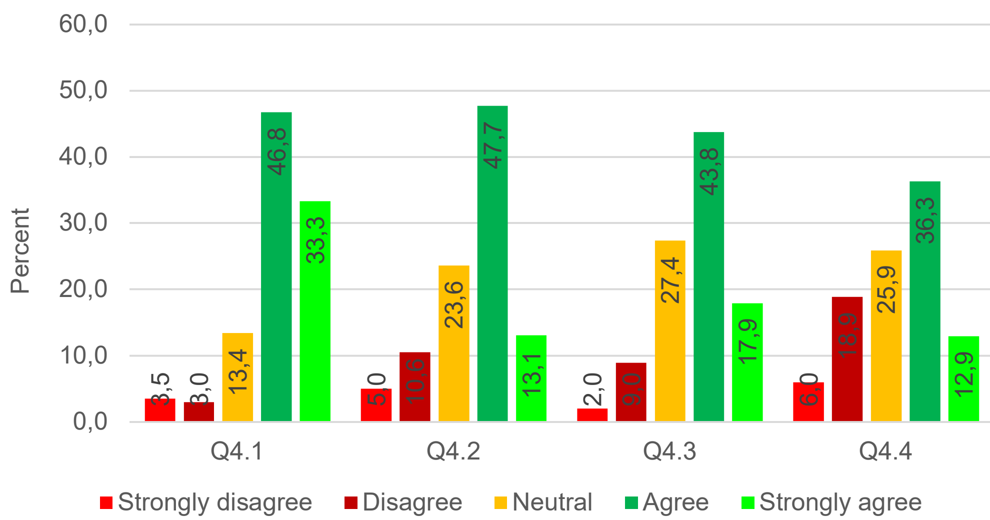


Figure 4.10: Summary of scoring patterns for Q4.1 to Q4.4

Source: Output of SPSS version 27 software

Observations from Figure 4.10 indicate an overall total agreement of 63%, in which statement Q4.1 contributed 80,1%, followed by statement Q4.3 at 61,7%. The statement that shows the lowest level of total agreement is Q4.4 with 49,3%. Three statements show a significant level of neutral feedback from the respondents. The final picture of Question 4 rating from the respondents is that there is a 14,5% of total disagreement (which is an average of strongly disagree + disagree), an average of 22,6% neutral and 63% of total agreement (which is an average of agree + strongly agree).

4.3.6.5 Research Question 5

This part provides feedback on Question no.5, in which the respondents were asked about the extent to which external service providers contribute to the corrective maintenance backlog. This construct was measured by seven statements based on the Likert scale. The overall results indicating all the statements are presented in Appendix L with an additional graphical demonstration in Figure 4.11.

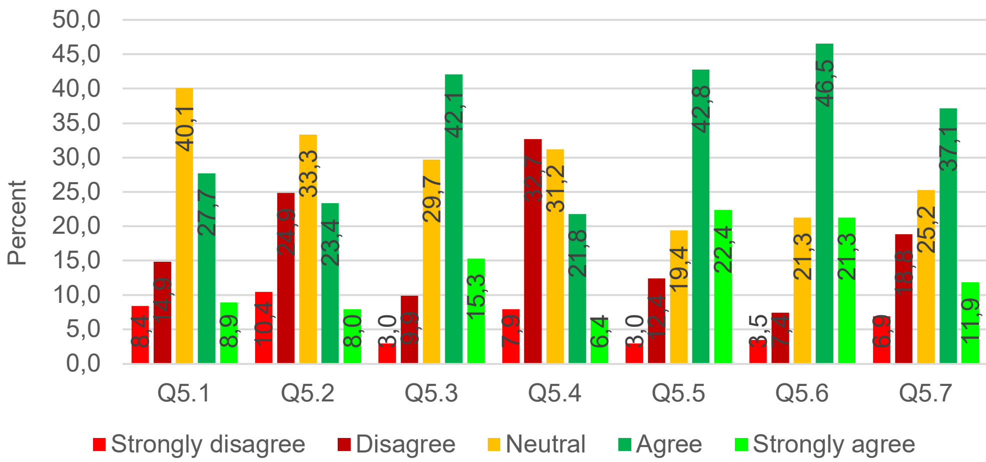


Figure 4.11: Summary of scoring patterns for Q5.1 to Q5.7

Source: Output of SPSS version 27 software

Scores of three statements show a very high total agreement, where the highest score being 67,8% (Q5.6) followed by 65,2% (Q5.5) and the third one at 57,4% (Q5.3). On the contrary, two statements (Q5.2 and Q5.4) show a significant total disagreement with the score 40.6% (Q5.4) and 35.3% (Q5.2). The final picture of Question 5 rating from the feedback is that there is a 23,4% of total disagreement (which is an average of strongly disagree + disagree), an average of 28,6% neutral and 47,9% of total agreement (which is an average of agree + strongly agree).

4.3.7 Crosstabulations

A Chi-square test of independence was performed to determine a statistically significant relationship between the variables (rows vs columns). The null hypothesis states that there is no association between the two, and the alternate hypothesis indicates an association (Rana and Singhal 2015: 69, and Anezakis et al. 2018: 290003-1). The table in Appendix L summarises the results of the Chi-square tests performed in this study.

For instance: The p-value between “Job Grade” and “I have been trained on how to apply scatter-plot” is 0.028. This means that there is a significant relationship between the variables highlighted in yellow in Appendix M. The job grade of the respondent did play a significant role in terms of how respondents viewed their training on using scatter plots. All the values in Appendix M with an * are significant.

4.3.8 Correlations

Bivariate correlation was also performed on the (ordinal) data, and the results are presented in Appendix N. Correlation is a measure of a monotonic association between two variables in which when a value of one variable increases, so is the value of the other variable, alternatively if a value of one variable increases, the value of the other variable decreases (Schober, Boer and Schwarte 2018: 1763). The results indicate the following patterns; positive values indicate a directly proportional relationship between the variables, and negative values indicate an inverse relationship (Schober, Boer and Schwarte (2018: 1764). A * or ** indicates all significant relationships on the table presented in Appendix M.

For example, the correlation value between “Maintenance activities at the power generation plant meet customer needs” and “Maintenance personnel are engaged in achieving the plant’s maintenance objectives” is 0.686. This is a directly related proportionality. Respondents indicate that the greater the maintenance levels, the more significant customer needs are met, and vice versa. Negative values imply an inverse relationship where the variables have an opposite effect on each other. That is, as one increases, the other decreases. For instance, the correlation value between “Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance” and “The under-utilisation of the workforce increases corrective maintenance backlog at the Power Generation Plant” is -0.151. That is, the more relationships are maintained with external providers, the less the backlog would be.

4.3.9 Structural equation model

The path diagram for the modified SEM shown in Figure 4.12 is the multivariate statistical result obtained using structural relationships applying a combination of factor analysis and multiple regression analysis techniques. It is used to analyse the structural relationship between measured variables and latent constructs.

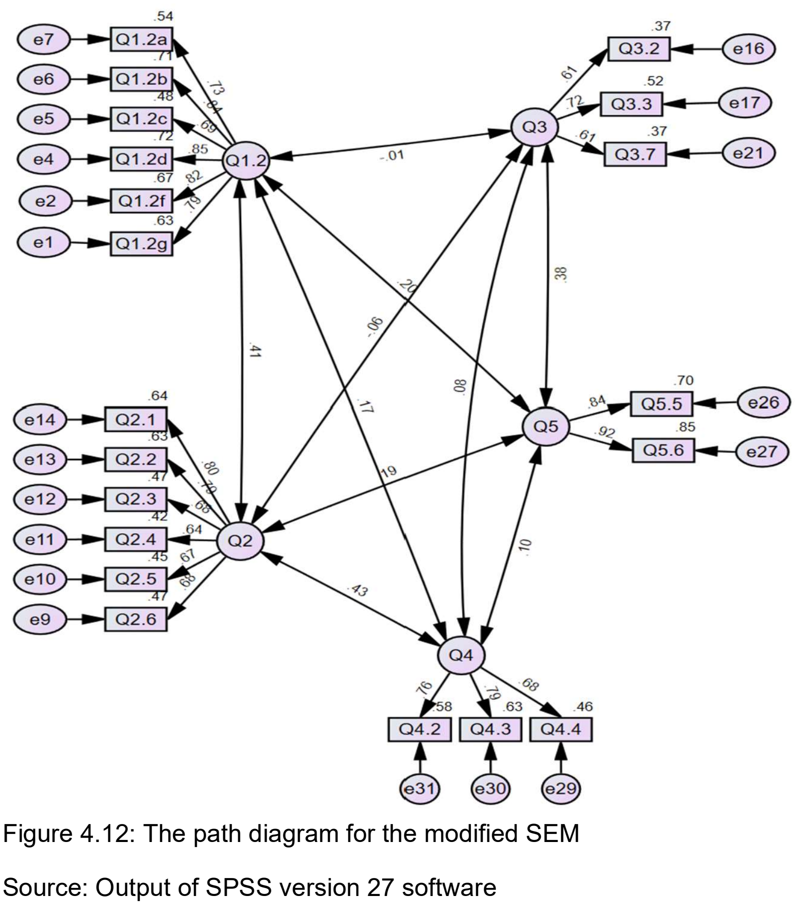


Figure 4.12: The path diagram for the modified SEM

Source: Output of SPSS version 27 software

Figure 4.12 provides a visual feature of causal effects on each question or construct with the measured statements or indicators. The arrows represent the regression/directional path of the causal effect with corresponding correlation values between the measured latent variable and observed variable. Each indicator is subjected to some degree of error, which is demonstrated in Figure 4.12.

4.3.9.1 Result (default model)

Chi-square	= 242.753
Degrees of freedom	= 160
Probability level	= .000

This Chi-square tests the null hypothesis that the overidentified (reduced) model fits the data as well as does a just-identified (full, saturated) model. In a just-identified model, there is a direct path (not through an intervening variable) from each variable to each other variable (Barcelo 2018: 1 and Anezakis et al. 2018: 290003-4). In such a model, the Chi-square will always have a zero value since the fit will always be perfect, and the probability should not be significant (Barcelo 2018: 1, Anezakis et al. 2018: 290003-4). In this model, the Chi-square p-value < 0.001 is obtained.

However, it is worth noting that even though, technically, the Chi-Square should be non-significant in model testing, this is very hard to achieve due to the usually large sample required for it (Barcelo 2018: 4). Hence, if it is significant, that is not a problem so long as the other fit indicators are good.

4.3.9.2 Maximum likelihood estimates

Table 4.4: Regression Weights: (Group number 1 - Default model)

Questions			Estimate	S.E.	C.R.	P	Label
Q1.2g	<---	Q1.2	1.000				
Q1.2f	<---	Q1.2	1.054	.084	12.508	***	par_1
Q1.2d	<---	Q1.2	.825	.063	13.099	***	par_2
Q1.2c	<---	Q1.2	.886	.087	10.195	***	par_3
Q1.2b	<---	Q1.2	.943	.073	12.955	***	par_4
Q1.2a	<---	Q1.2	.769	.071	10.873	***	par_5
Q2.6	<---	Q2	1.000				
Q2.5	<---	Q2	1.012	.119	8.490	***	par_6
Q2.4	<---	Q2	.950	.116	8.197	***	par_7
Q2.3	<---	Q2	1.043	.121	8.648	***	par_8
Q2.2	<---	Q2	1.147	.117	9.795	***	par_9
Q2.1	<---	Q2	1.182	.120	9.885	***	par_10
Q3.2	<---	Q3	1.000				
Q3.3	<---	Q3	1.088	.188	5.791	***	par_11
Q3.7	<---	Q3	.918	.160	5.738	***	par_12
Q5.5	<---	Q5	1.000				
Q5.6	<---	Q5	1.041	.145	7.183	***	par_13
Q4.4	<---	Q4	1.000				
Q4.3	<---	Q4	1.001	.121	8.291	***	par_14
Q4.2	<---	Q4	1.032	.125	8.237	***	par_15

Source: Output of SPSS version 27 software

In Table 4.4, the variables loaded strongly along with their various factors (significant p-values indicated by *** $p < 0.001$). These verify the EFA obtained under factor analysis.

Table 4.5 Standardised Regression Weights: (Group number 1 - Default model)

Questions			Estimate
Q1.2g	<---	Q1.2	.794
Q1.2f	<---	Q1.2	.819
Q1.2d	<---	Q1.2	.850
Q1.2c	<---	Q1.2	.694
Q1.2b	<---	Q1.2	.842
Q1.2a	<---	Q1.2	.733
Q2.6	<---	Q2	.684
Q2.5	<---	Q2	.671
Q2.4	<---	Q2	.644

Questions			Estimate
Q2.3	<---	Q2	.684
Q2.2	<---	Q2	.791
Q2.1	<---	Q2	.801
Q3.2	<---	Q3	.608
Q3.3	<---	Q3	.722
Q3.7	<---	Q3	.610
Q5.5	<---	Q5	.838
Q5.6	<---	Q5	.923
Q4.4	<---	Q4	.676
Q4.3	<---	Q4	.793
Q4.2	<---	Q4	.758

Source: Output of SPSS version 27 software

The parameters are estimated by maximum likelihood (ML) methods, an iterative procedure that attempts to maximise the likelihood that obtained values of the criterion variable will be correctly predicted. As indicated in Table 4.5, all the coefficients were above the suggested value of 0.600. Redundant variables were thus omitted.

4.3.9.3 Model fit summary

The suggested acceptable value for relative chi-square, CMIN/DF, should not be greater than 5, which is used to reduce sample size dependency. However, the cut-off points for TLI, CFI, NFI and IFI is between zero to one; a good model is indicated by an RMSEA value of less than or equal to 0.05 (Orçan 2018: 417).

Table 4.6 CMIN summary results

Model	**NPAR**	**CMIN**	**DF**	**P**	**CMIN/DF**
Default model	70	242.753	160	.000	1.517
Saturated model	230	.000	0		
Independence model	20	1939.356	210	.000	9.235

Source: Output of SPSS version 27 software

Model	**NPAR**	**CMIN**	**DF**	**P**	**CMIN/DF**
Default model	70	242.753	160	.000	1.517
Saturated model	230	.000	0		
Independence model	20	1939.356	210	.000	9.235

Table 4.6 CMIN is a Chi-square statistic comparing the tested and the independence models to the saturated model. The ratio, CMIN/DF, the relative Chi-square, is an index of how much the fit of data to model has been reduced by dropping one or more paths. The CMIN/DF is less than the acceptable value of 5 (1.517). This meets the CMIN condition.

Table 4.7: Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.875	.836	.953	.937	.952
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

Source: Output of SPSS version 27 software

This goodness of fit indices presented in Table 4.7 compares the model to the independence model rather than the saturated model. The Normed Fit Index (NFI) is the difference between the two models' chi-squares divided by the chi-square for the independence model. For this data, the NFI is 0.875, which is only slightly lower than the recommended value of 0.9 for a good fit. The Comparative Fit Index (CFI) uses a similar approach (with a noncentral chi-square) and is a good index for use even with small samples. It ranges from 0 to 1, like the NFI, and 0.90 indicates a good fit. The CFI value (0.952) exceeds the recommended value.

Table 4.8: Parsimony-Adjusted Measures table

Model	PRATIO	PNFI	PCFI
Default model	.762	.667	.725
Saturated model	.000	.000	.000
Independence model	1.000	.000	.000

Source: Output of SPSS version 27 software

PRATIO is the ratio of how many paths are dropped to how many could have been dropped (all of them). The Parsimony Normed Fit Index (PNFI) is the product of NFI and PRATIO, and PCFI is the product of the CFI and PRATIO. The PNFI and PCFI are intended to reward those whose models are parsimonious (contain few paths). A value greater than 0.900 is considered acceptable. As Table 4.8 shows, the model has a lower value than the recommended value (.762).

Table 4.9: RMSEA table

Model	**RMSEA**	**LO 90**	**HI 90**	**PCLOSE**
Default model	.050	.037	.063	.463
Independence model	.201	.193	.210	.000

Source: Output of SPSS version 27 software

The Root Mean Square Error of Approximation (RMSEA) estimates lack of fit compared to the saturated model. RMSEA of 0.05 or less indicates a good fit, and between 0.05 and 0.08 is adequate. On this estimate, LO 90 and HI 90 are the lower and upper ends of a 90% confidence interval. Table 4.9 show that this model has a good fit (RMSEA = 0.050). The PCLOSE p-value that tests the null that RMSEA is no greater than .05 is NOT significant (p = 0.463). This also satisfies the criteria for a good fit, as indicated from the regression outputs of the SEM.

Table 4.10: Covariances: (Group number 1 - Default model)

Questions			**Estimate**	**S.E.**	**C.R.**	**P**	**Label**
Q1.2	<-->	Q3	-.012	.074	-.160	.873	par_16
Q1.2	<-->	Q2	.327	.074	4.428	***	par_17
Q1.2	<-->	Q5	.199	.083	2.390	.017	par_18
Q4	<-->	Q1.2	.147	.073	2.007	.045	par_19
Q2	<-->	Q3	-.029	.046	-.626	.531	par_20
Q4	<-->	Q2	.222	.053	4.197	***	par_21
Q2	<-->	Q5	.118	.051	2.291	.022	par_22
Q4	<-->	Q3	.045	.052	.877	.381	par_23
Q3	<-->	Q5	.240	.069	3.460	***	par_24
Q4	<-->	Q5	.066	.055	1.194	.232	par_25

Source: Output of SPSS version 27 software

Table 4.11: Correlations: (Group number 1 - Default model)

Questions			**Estimate**
Q1.2	<-->	Q3	-.014
Q1.2	<-->	Q2	**.414**
Q1.2	<-->	Q5	**.200**
Q4	<-->	Q1.2	**.174**
Q2	<-->	Q3	-.057

Questions			Estimate
Q4	<-->	Q2	**.430**
Q2	<-->	Q5	**.194**
Q4	<-->	Q3	.084
Q3	<-->	Q5	**.381**
Q4	<-->	Q5	.102

Source: Output of SPSS version 27 software

The level of significance presented in table 4.11 relates to the strength of the relationships where correlations are tested. **Null hypothesis:** There is no correlation between Q1.2, Q2, Q3, Q4 and Q5. **Alternate hypothesis:** There is a significant correlation.

- Q1.2 The tools currently employed within the maintenance environment
- Q2 The extent to which ISO9000:2015 Quality Management Principles are embedded in the maintenance practices
- Q3 The factors that contribute to the corrective maintenance backlog
- Q4 The gaps and limitations in the maintenance documentation
- Q5 The extent to which external service providers contribute to the corrective maintenance backlog

Table 4.11 the significant correlations, and the analysis of the results indicates a strong, directly proportional relationship between the latent variables. (Values that are not highlighted / bold) are not significant.

4.4 Analysis of secondary quantitative data

The results of both the SAP system, a computerised maintenance management system (CMMS) and Hyperwave system, are presented as the official documentation repository.

4.4.1 SAP system (CMMS) data analysis results

SAP-system is a maintenance management system used to manage and administer all maintenance activities executed in the PGP. This is the responsibility of the planning section, which is part of the maintenance department. The planning section exports data from the SAP system to an excel spreadsheet daily and sends it to all technical personnel. This is the data of interest that the researcher targeted to analyse.

4.4.1.1 Analysis of computerised maintenance management system (SAP system) data

Graphical representation of data is based on the Pareto principle and is displayed as a spiderweb. In this case, the zero in the spider web is right in the middle, and as the number increases, the position moves more outwards. This outward movement exposes the sections that possess many defects, and in this case, the expectation is that management intervention should be triggered. Sections that have the lowest number of defects, close to zero, will be in the middle of the spider web, indicating that the performance is good and there is no need for management intervention. In this way, only a few sections (20%) with high numbers will be exposed outward, and most sections (80%) with fewer defect numbers will be concentrated in the centre point.

4.4.1.2 PGP overall defect notifications analysis

Statistical analysis allows us to observe the behaviour of data, and this behaviour tells what is happening within the processes. Discussions have been triggered by graphical presentation leading to questions being asked due to the picture provided by statistical analysis. That is why statistical analysis is conducted to make the problem more interesting to be resolved.

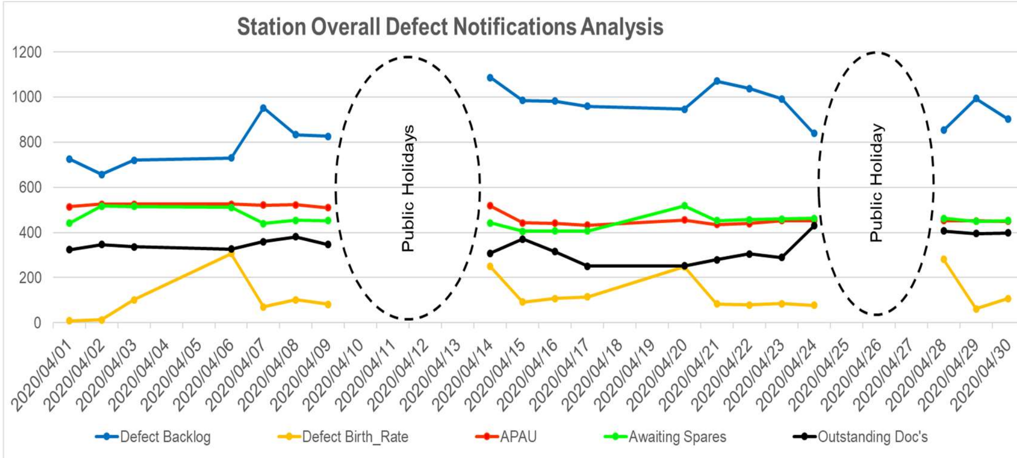


Figure 4.13: PGP overall defects notification analysis

Author's construction

The statistics displayed on the graphical representation of Figure 4.13 indicate the reflection of Figure 3.10, which display the categories of defects. These categories are now graphically presented in a line graph to show the trend throughout the month. A point on the line graph shows the value of defects on the day. It can be noticed that the defect backlog line is the highest for the month analysed. Following AP/AU and awaiting spares lines, below them is the line for outstanding documentation and defects birth rate.

4.4.1.3 PGP defect backlog analysis

Defect backlog is the defects that the maintenance section can execute without having any spares or waiting for the plant to be available. This means that the situation is under the full control of the line manager or maintenance supervisor, whereby they need to develop a proper plan to address the backlog. The objective is to reduce the defect notifications (Corrective Maintenance) so that the resources can be focused on the execution of PM's (Preventative Maintenance). Data was analysed using Microsoft excel and is presented in a graphical format in Figure 4.14.

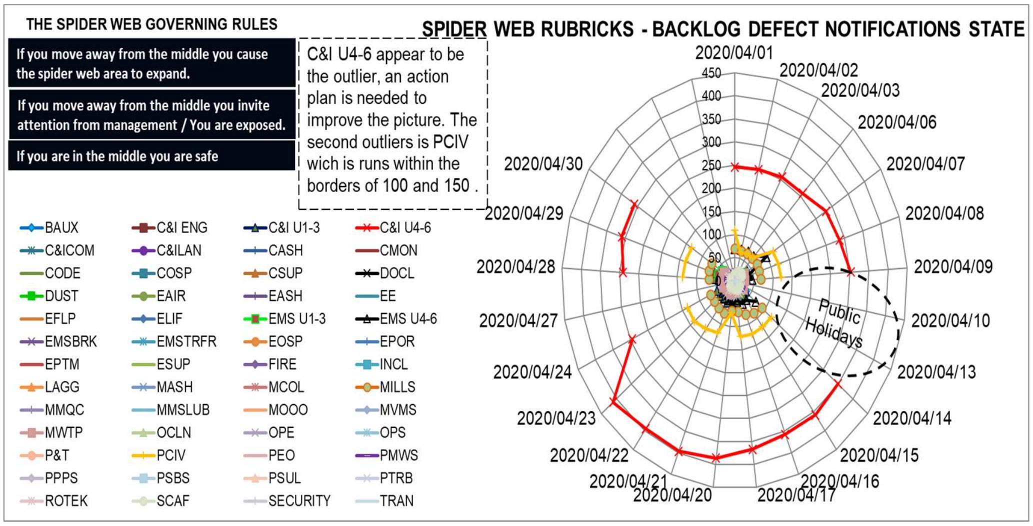


Figure 4.14: PGP defects backlog spider web graph

Author’s construction

The spider web (Figure 4.14) in this category shows or expose the sections that are not performing; sections whose lines are on the outer area of the spider web are the ones with more defects. The sections that seem to be further from the middle are the ones that need management intervention. The sections that are right in the middle are said to be performing well by having fewer defects and should escape management involvement.

4.4.1.4 PGP outstanding documentation submission analysis

Outstanding documentation refers to the record generated after the work is completed and has not yet been submitted to the planning section to be captured in the SAP system. The outstanding documentation/records seem to be stuck somewhere along the way before being reflected in the SAP system as completed. The route of the documentation or record is indicated in Figure 4.15. As stipulated in Figure 4.15, the process flow demonstrates that the issue can be stuck either in the execution section or in the planning section. In most cases, when the SAP system shows outstanding documentation, it is automatically presumed that the execution section is the guilty party. However, if the process is followed closely, it can be established where the process is stuck. The importance of documentation in a business is that it provides evidence that what was planned has been executed. It can also provide a basis for auditing to assure that work has been executed according to the plan.

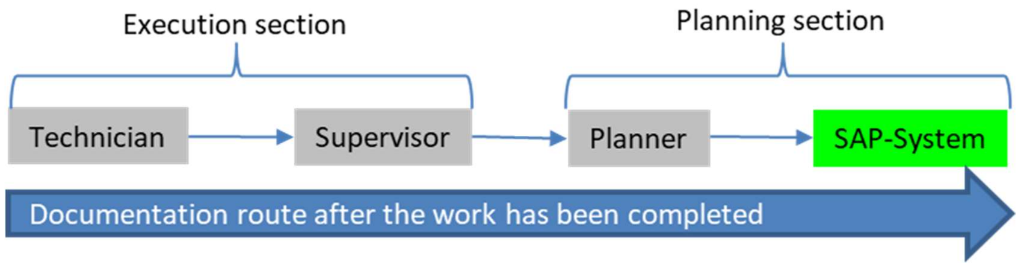


Figure 4.15: Maintenance documentation route

Source: Author's construction

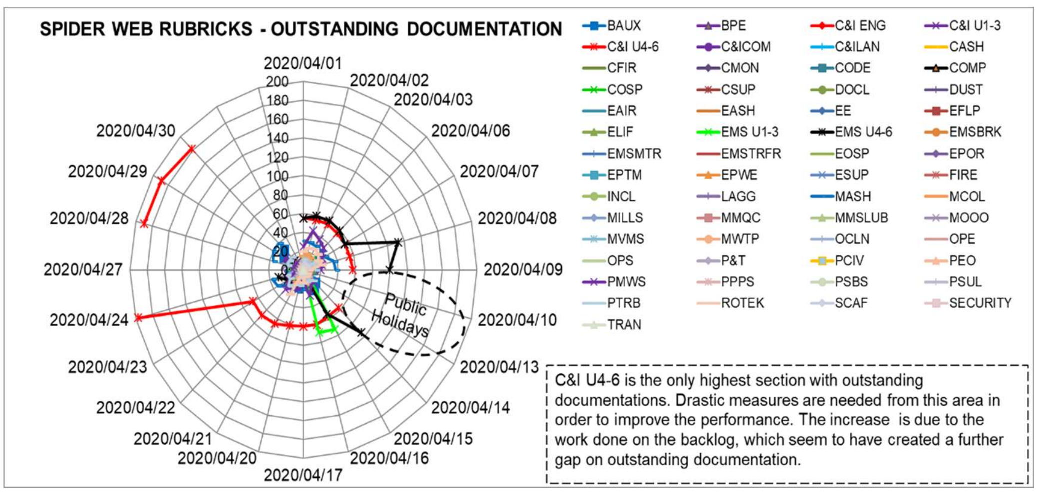


Figure 4.16: Outstanding documentation graph

Author’s construction

Graphical representation in Figure 4.16 shows that the spider web can be expanded by the section that is not performing or far from zero mark (the centre of the spider web). On the contrary, if all sections maintain good performance (the lowest number of defects), the spider web diameter will remain small. In the case of Figure 4.16 above, it can be seen that on the 24th, C&I U4-6 expanded the spider web by the number of outstanding documentation on that day, and it remained that way till the end of the month. This typical situation should trigger management intervention.

4.4.1.5 PGP awaiting plant defects analysis

Awaiting plant defects are those defects that can only be executed when the plant is made available for maintenance personnel. Some of the factors that come into consideration are production, the safety of personnel, and the plant's safety.

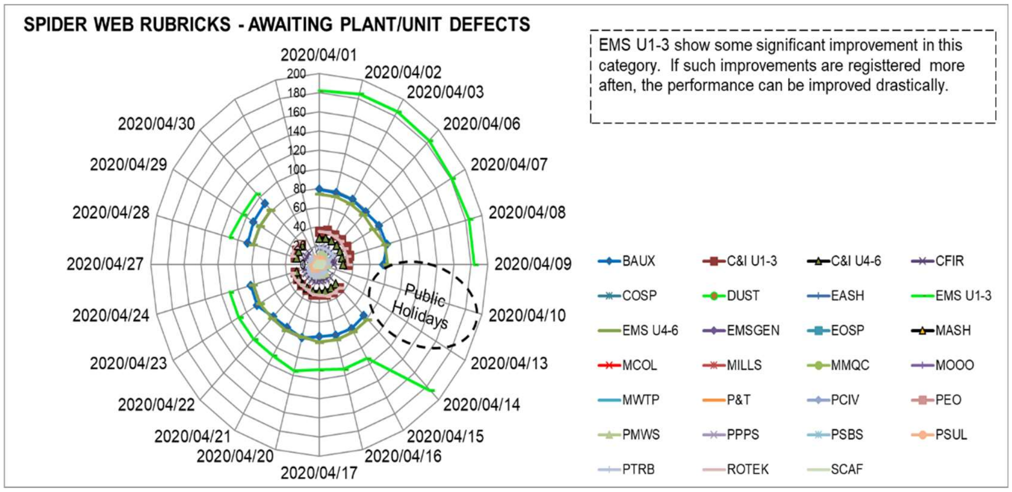


Figure 4.17: Awaiting plant/Unit defects graph

Author's construction

The graphical representation in Figure 4.17 indicates the status of defects in the awaiting plant and/or unit category. Same as explained in the previous graphical pictures, the sections with the highest defects in this category are exposed to the spider web outside. Maintenance can only be done when the plant is made available, meaning this work needs careful planning as it will interrupt production. The sections exposed outward within the spider web are most affected by awaiting plant conditions to execute their defect backlog.

4.4.1.6 PGP awaiting spares defect analysis

Awaiting plant defects are those defects that can only be executed when the spare is available for a particular plant equipment. Even though the PGP has a storage area where many spares are drawn, challenges still exist with spares availability. Due to ageing plants, many spares are not readily available in the market.

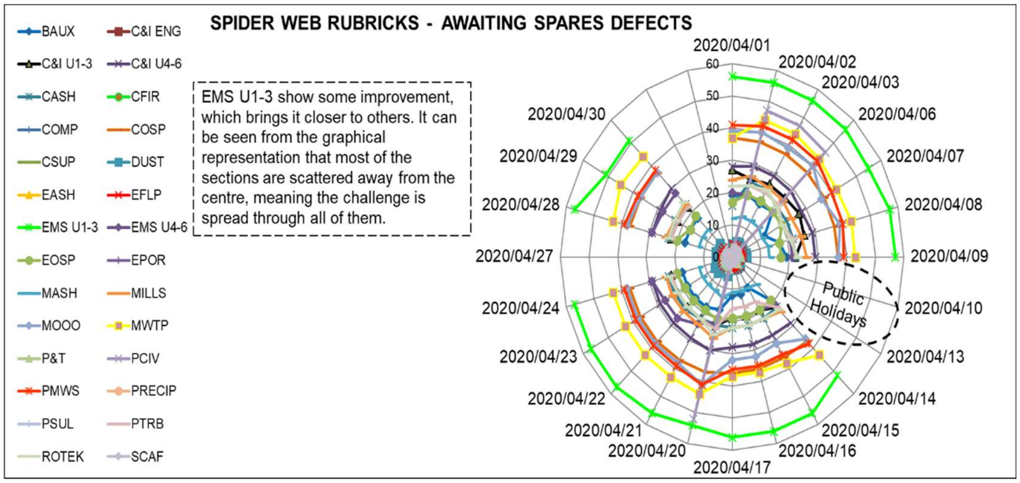


Figure 4.18: Awaiting spares defects graph

Author's construction

The picture (Figure 4.18) depicted in this category shows the sections affected by the non-availability of spares. In this case, most sections have moved away from the safe zone (the middle of the spider web). The graphical representation displayed in Figure 4.18 reveals that almost all the sections within the PGP are affected by the non-availability of spares

4.4.1.7 PGP defects birth rate analysis

The PGP has a notification process that is used when registering a defect to be addressed by maintenance. The planning section administers all defects registered on the PGP using a computerised management system. Analysis of defects birth rate is aimed to highlight where are more defects emerging. A Microsoft Excel spreadsheet is used to analyse data provided by the planning section to paint the picture.

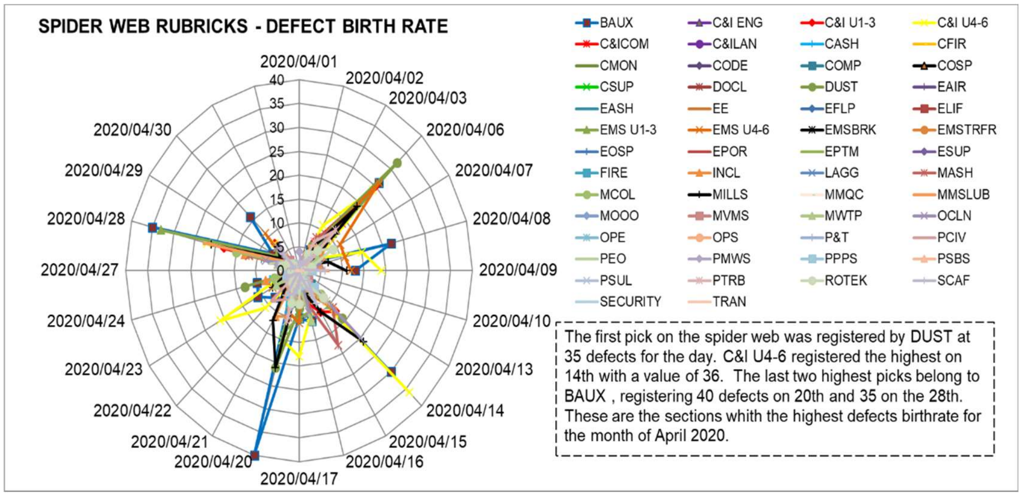


Figure 4.19: Defects birth rate graph

Author's construction

The information displayed in this graphical picture (Figure 4.19) shows the rate at which defects emerges daily from each section. The pick on the day shows the section that registered the highest defects. At the same time, the sections with the lowest number of defects are found around the zero areas. The section with the regular picks is the one that should be a concern to management, and an investigation should be initiated.

4.4.1.8 PGP defects age analysis

Under each category of defects, there were defects notifications with high age numbers. This presented an opportunity for the supervisor to investigate or even the line manager to ask questions. The defects age analysis aims to provide a clear picture of what needs to be addressed first or prioritise the areas that can be addressed first. It pinpoints the improvement areas for the PGP to focus on. It provides a structured way of addressing improvement by eliminating the oldest defect and find out why it has not been resolved yet. If we find out the issues that have delayed the execution of these defects, corrective action can be implemented. It is believed that managing age analysis and keeping the age of defects to the lowest could improve the performance of the PGP when reducing the backlog of the maintenance defects. The age analysis graph indicates where the old defects lie.

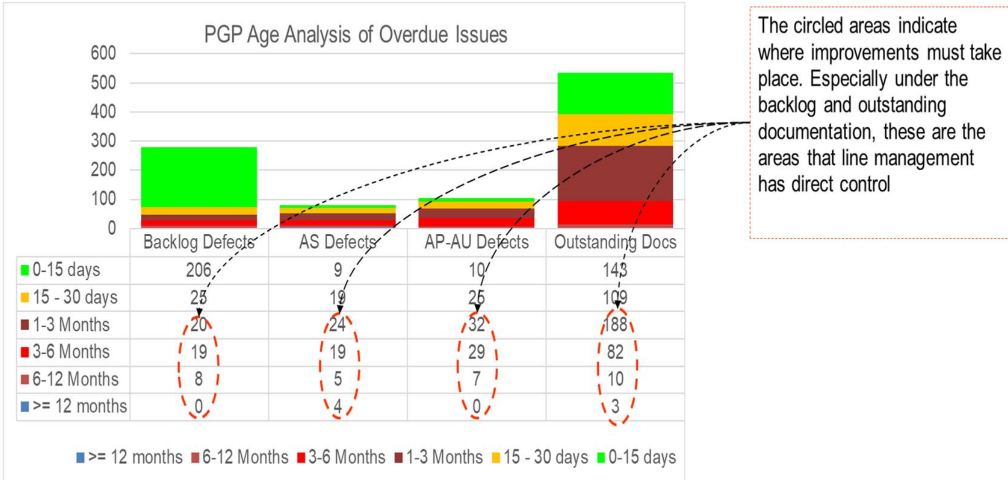


Figure 4.20: PGP defects age analysis graph

Source: Author's construction

The graphical picture in Figure 4.20 indicates the defects that have aged in the system. The aged defects are categorised according to their oldness, which allows prioritisation to take place. The oldest ones will be investigated first until the newest defects are left when investigating the defects in this category. This will allow the PGP to operate with the newest number of defects and eventually reduce the backlog.

4.4.1.9 PGP PM/CM ratio

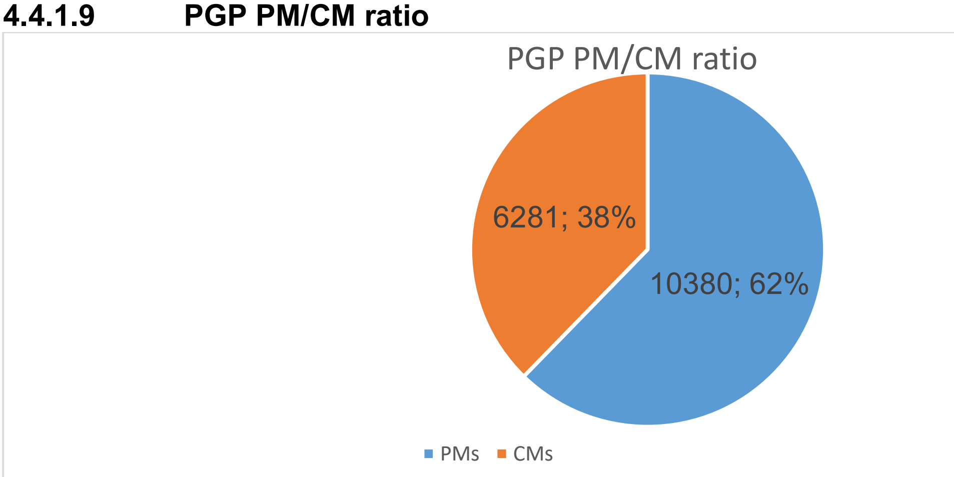


Figure 4.21: PGP CM/PM ratio pie chart

Source: Author's construction

Sections 4.4.1.1 to 4.4.1.8 above provided the details of PGP CM's and not the PM, as this study's objective is to optimise corrective maintenance (CM) backlog. Even though the performance measure includes preventive maintenance (PM), this was not the focus. The assumption is that when the CM is in control or low, the focus will then be on the PM. The outcome of data collected and analysed shows that the PGP CM/PM ratio stands at 38%/62%, respectively. While this is much better than the 34%/57% (Mashosho, 2019: 19), it still falls short of the targeted 20%/80% mentioned in the engineering maintenance standard by Runeyi and Sardini (2015: 3)

Table 4.12 Sections' CM/PM ratio

SECTIONS	PMs	CMs	% PM	% CM	Grand Total
COSP	2575	432	**86%**	**14%**	3007
C&I U4-6	1202	585	67%	33%	1787
C&I U1-3	1150	517	69%	31%	1667
OCLN	1013	435	70%	30%	1448
MMSDUST	996	760	57%	43%	1756
BAUX	900	916	50%	50%	1816
MWTP	826	561	60%	40%	1387
EMS U1-3	821	476	63%	37%	1297
MMSLUB	363	599	38%	62%	962
EOSP	290	429	40%	60%	719
MILLS	244	571	**30%**	**70%**	815
PGP	**10380**	**6281**	**62%**	**38%**	**16661**

Source: Author's construction

Table 4.12 above provide details of maintenance sections that are involved in the execution of maintenance activities. Each section performance is outlined in terms of the number of PM's and CM's and percentage values of PM's and CM's. Furthermore, the table shows the total of PM's and CM's for each section to date.

4.4.2 Hyperwave system data analysis results

The secondary quantitative data extraction method was explained in section 3.5.4 in the preceding chapter, where it details the criteria used and provides the data source. In this section, the analysis of this data is provided using a related graphical representation.

The line manager must ensure that documents owned by the function or section area are reviewed on time (Ndlela 2020: 23). This is to ensure that the necessary processes are subjected to continuous improvement. The PGP controlled documents are reviewed at least every 3 years unless the document compiler and responsible functional person obtain permission to set a more extended period. (Ndlela 2020: 23). This is to make sure that the information's content remains relevant to current PGP processes, technology, and legal requirements.

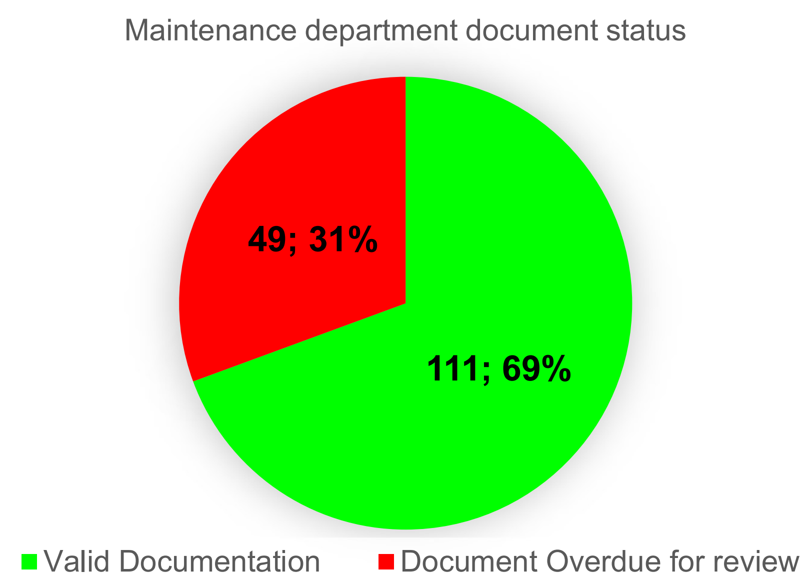


Figure 4.22: Maintenance documentation pie chart

Source: Author’s construction

The evaluation of maintenance documentation in Figure 4.22 revealed that 31% of the existing documentation are overdue for review. The assessment outcome indicates that 31% of the documented information still has to be reviewed for adequacy.

The maintenance department consists of nine sections, and the documentation status is depicted in Figure 4.23. Out of the 31% of overdue documents for review, a high number (29) of them have not been allocated to the correct section. The evaluation of documented information also reveals that the documents under **"?"** are uncontrolled documents which amount to 59% (see Figure 4.24) of all overdue documented information and are still in the old template, which invalidate their use. Overdue documented information amounts to 13% of the boiler plant section, followed by materials management with 12% and then support section with 10%.

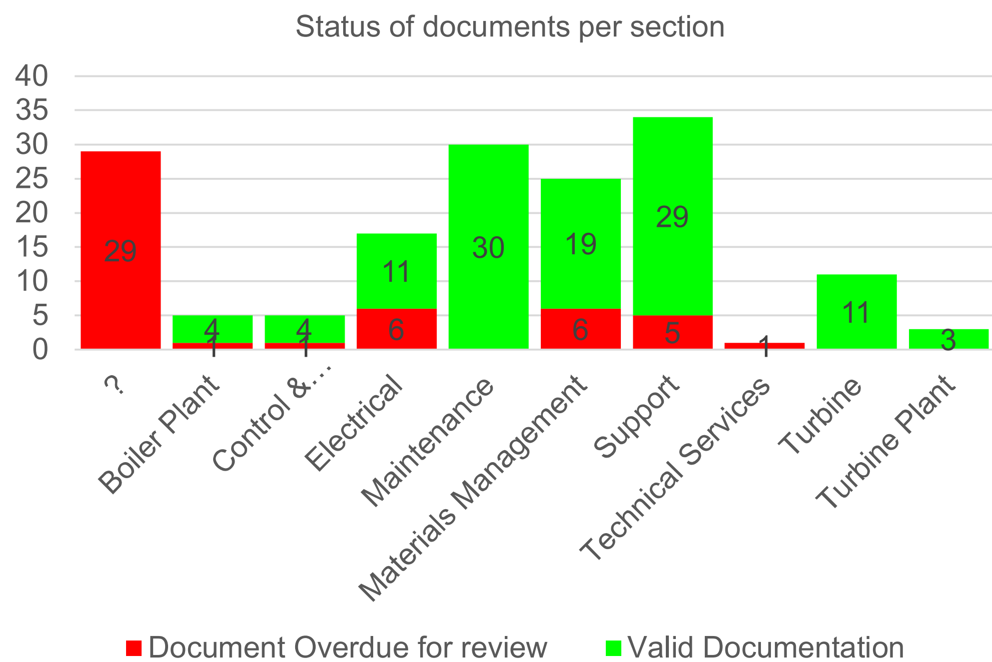


Figure 4.23: Maintenance sectional documentation graph

Source: Author's construction

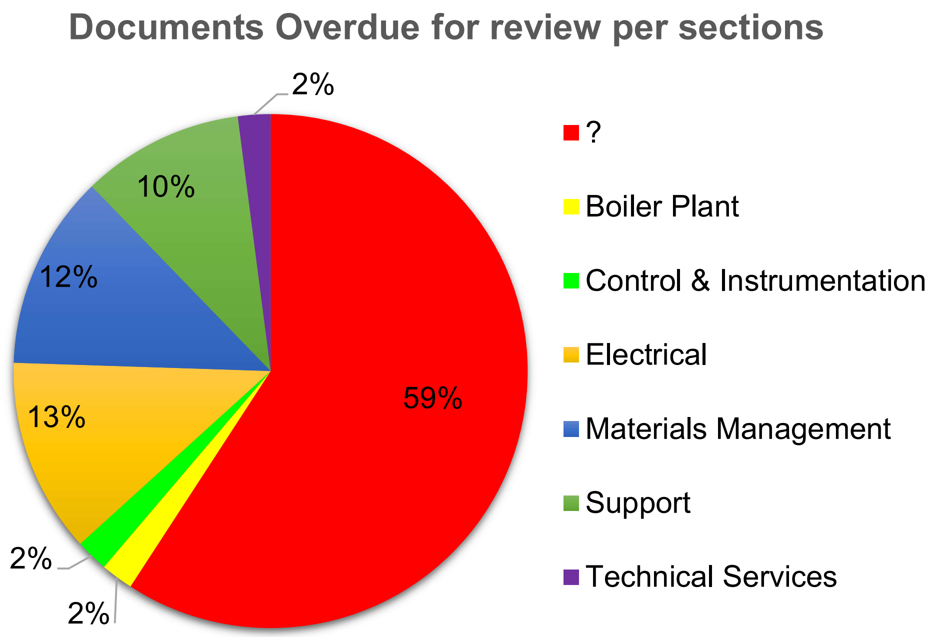


Figure 4.24: Maintenance documentation percentage graph

Source: Author's construction

4.5 Analysis of primary qualitative data

Primary qualitative data was collected by conducting semi-structured interviews, which were recorded on the MS Team platform. The recorded interviews were transcribed using the automatic transcription assistant to Microsoft Teams software available on the link https://otter.ai. After that, the data was cleaned by listening to the recordings and correcting content, spelling and grammar before it was analysed on Nvivo version 12 software. The data was analysed and is presented in section 4.5.2 to section 4.5.5.

4.5.1 Sample compliance

The initial sample for qualitative data was targeted at eight PGP top management participants. The researcher was able to conduct seven interviews, which is 87,5% sample compliance. Section 3.4 of this report provide more information on the research population and sampling.√

4.5.2 Demographic profile of participants

Table 4.27 shows that the sample comprised mostly males and in terms of field of work. It can be seen that non-technical participants prevailed. On the work experience, the participants with the least experienced fall under 11-15 years and the ones with the most experienced fall under 30^+ years. It indicated that the participants held high positions within the PGP and had vast experience in the business environment.

Table 4.13: Demographic profile of interviewees

	Count of Gender
Female	2
Male	**5**
Grand Total	7

	Count of Field of work
Non-technical	**4**
Technical	3
Grand Total	7

	Count of Work experience
11-15 yrs	1
16-20yrs	1
21-30 yrs	3
30^+ yrs	2
Grand Total	7

Source: Author's construction

4.5.3 Qualitative factors evaluated

The factors of interest evaluated from the interviews are indicated in Figures 4.25 and 4.26. There were two main themes identified, which were; "practices of quality tools (QT) within the PGP in maintenance environment" (Figure 4.25) and the second one being "practices of Quality Management Principles (QMP's) within the PGP in the maintenance environment" (Figure 4.26). The supporting sub-themes under these two main themes are; Adequate application, Adequate knowledge, Adequate management support, Lack of application, Lack of knowledge, Lack of management support, Impact of QMP/QT and Major barriers.

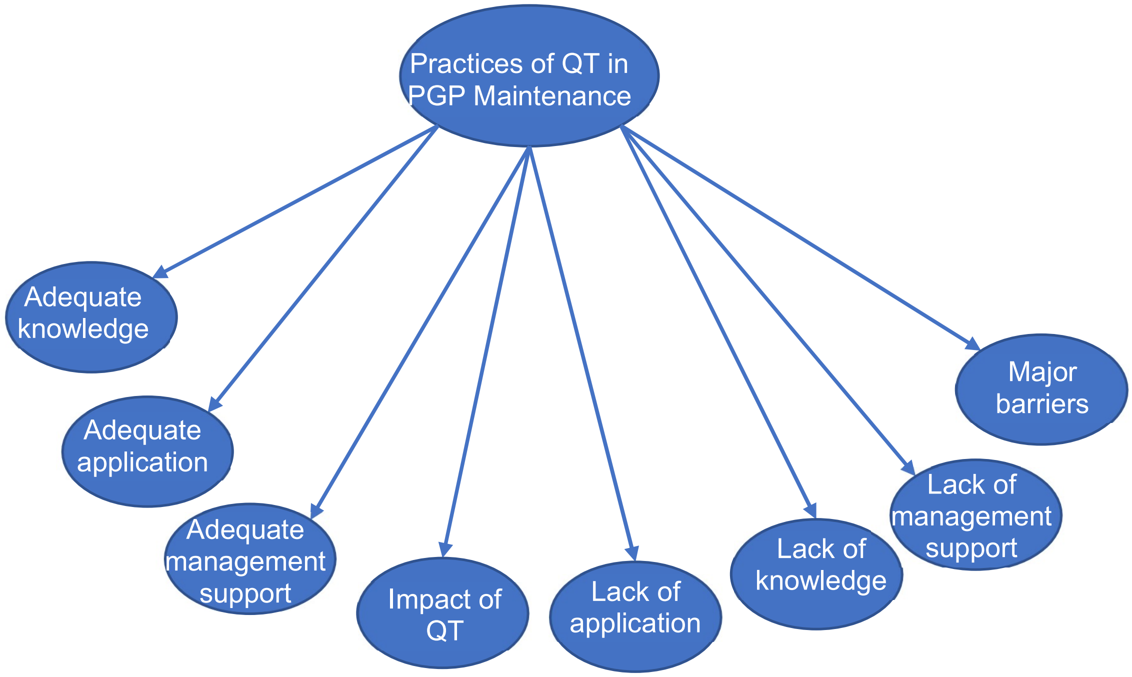


Figure 4.25: Practices of QT influencing factors

Source: Output of Nvivo version 12 software

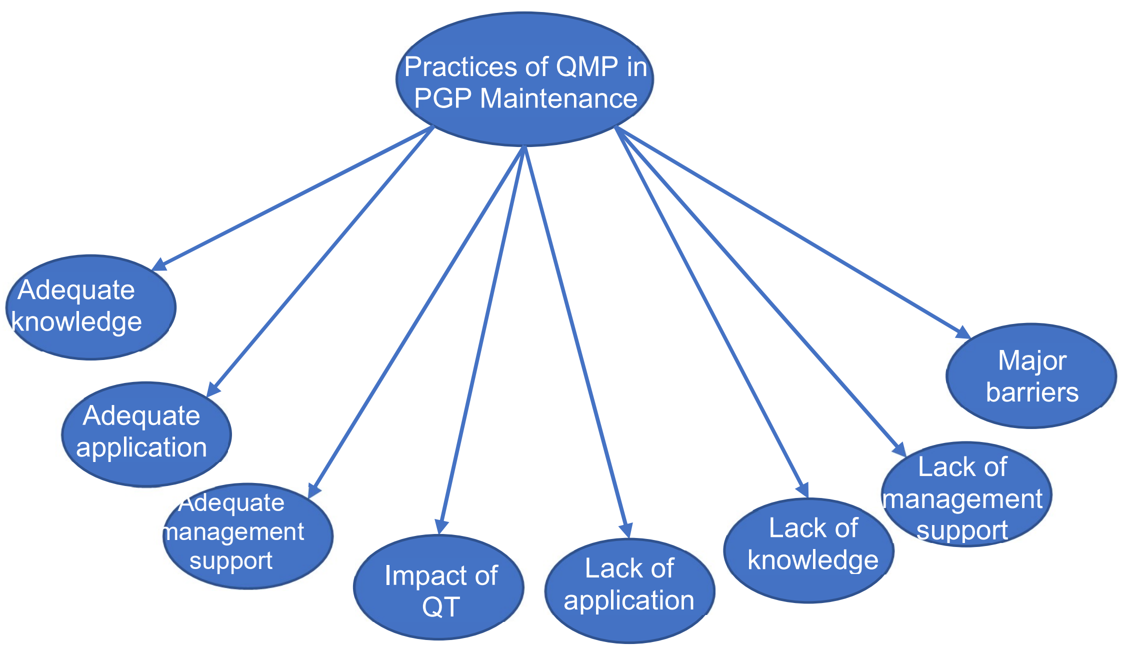


Figure 4.26: Practices of QMP's influencing factors

Source: Output of Nvivo version 12 software

Table 4.14 and Table 4.15 provide a comprehensive view of the evaluated themes for QT and QMP's practices in the PGP maintenance environment and lead to a conclusion of the presented data. Here, the themes with a negative statement are allocated a negative sign, and themes with a positive statement are allocated a positive sign as indicated in the column for "Sum of". This interpretation is adopted from the System Usability Scale (SUS), a tool used to assess the usability of a product. They use five positive and five negative statements to measure personal views (Bangor, Kortum and Miller 2009: 115). Furthermore, in their study, Adams-Bass, Stevenson and Kotzin (2014: 374) labelled image messages as positive and/or negative. They asked the participants to indicate how much they agreed with the positive or negative statements of the message. Huang and Li (2021:1) used Natural Language Processing (NLP) to translate negative sentiment to positive sentiment with resembling semantics to create negative-positive sentimental statement datasets.

Themes that have a negative statement and have been allocated a negative sign are lack of management support, lack of application, lack of knowledge and significant barriers. On the contrary, the themes that have a positive implication and are given a positive sign are adequate management support, adequate application, adequate knowledge and impact of QT.QMP's. When the negative and the positive themes are compared, the difference is noted and tabulated in a column marked "difference".

The values displayed in the "difference" column can be either positive or negative, denoting that if positive, the indication is that there is a strong appraisal for the practices of QT and QMP in the PGP maintenance environment. Whereas if the values are negative, the indication is that there is a weak appraisal for the practices of QT and QMP in the PGP maintenance environment. The third criterion is that, should the values be zero, the indication is that there is a neutral atmosphere for that theme in the practices of QT and QMP in the PGP maintenance environment. The further the value is from either side of zero, the stronger is the appraisal.

4.5.4 Practices of QMP in PGP maintenance environment statistical analysis

The graphical representation in Figure 4.27 provides a comparison between a technical view and a non-technical view, as indicated in the demographic table 4.13 above. Looking at the evaluated themes from the interviews conducted and presented in Figure 4.27, the non-technical view on "adequate knowledge" is higher than the technical one. Lack of knowledge according to non-technical view is higher as opposed to technical view. On "adequate application" of QMP's in the PGP maintenance environment was viewed equally by both technical and non-technical views. However, a non-technical view had an overwhelming view regarding the "lack of application" of QMP's in the PGP maintenance environment. The non-technical view believes that there is more "adequate management support" in QMP's practices than the technical view. Overall, the non-technical view was more prevalent than the technical view.

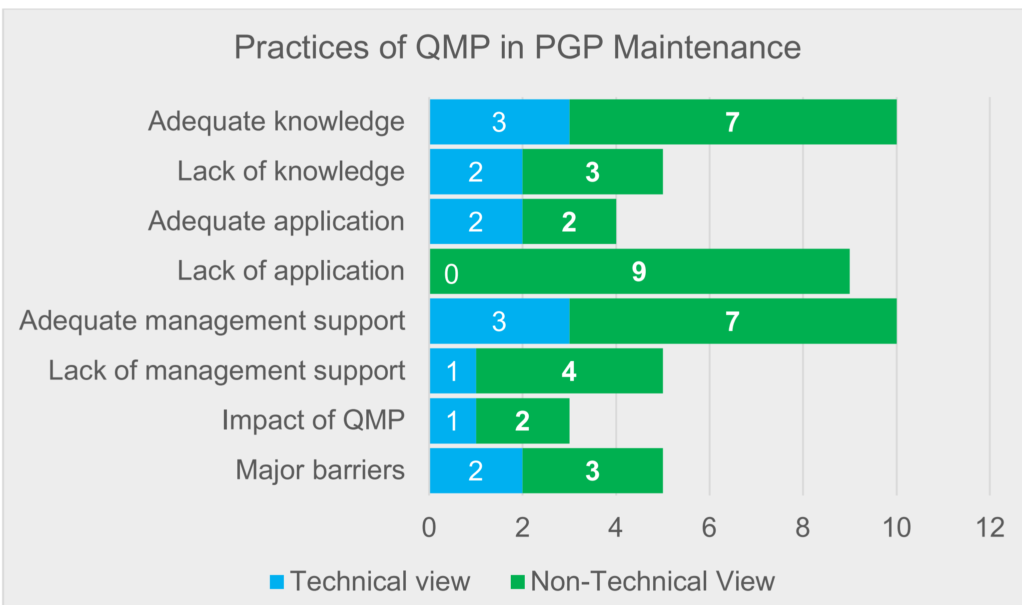


Figure 4.27: Practices of QMP's in the maintenance environment

Source: Author's construction

Based on table 4.14, when comparing major barriers and the impact of QMP, the observed result is **-2** indicating weak domination of major barriers. A comparison between adequate management support and lack of management support provides an outcome of **5,** denoting strong management support in the practices of Quality Management Principles in the PGP maintenance environment. When comparing adequate and lack of application, the outcome is **-5,** denoting strong domination of "lack of application". When comparing adequate knowledge and lack thereof, the outcome is **5**, providing strong domination of "adequate knowledge".

Table 4.14: Practices of QMP's assessment

Practices of QMP in PGP Maintenance	Technical view	Non-Technical View	Sum of	Difference
Major barriers	-2	-3	- 5	**-2**
Impact of QMP	+1	+2	+ 3	
Lack of management support	-1	-4	- 5	**5**
Adequate management support	+3	+7	+ 10	
Lack of application	0	-9	- 9	**-5**
Adequate application	+2	+2	+ 4	
Lack of knowledge	-2	-3	- 5	**5**
Adequate knowledge	+3	+7	+ 10	

Source: Author's construction

4.5.5 Practices of QT in PGP maintenance environment statistical analysis

The view around the practices of QT in the PGP maintenance environment has been evaluated in Figure 4.28. In addition, in this case, both technical and non-technical views are compared. It is further observed that the overall dominant view in this regard falls under non-technical, based on graphical representation in Figure 4.28. The non-technical view believes there are more barriers to practicing quality tools in the PGP maintenance environment. They also believe that there is adequate knowledge even though there is a lack of application.

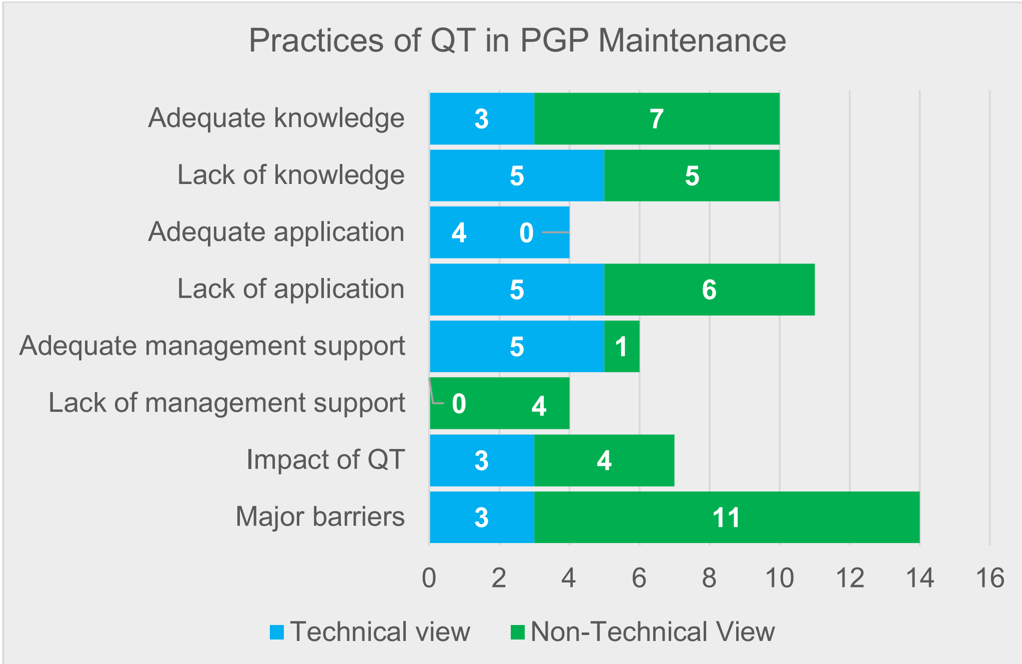


Figure 4.28: Practices of QT in the maintenance environment

Source: Author's construction

In table 4.15, the outcome of comparing the "impact of QT" and "major barriers" gives a difference of **-7,** which is strong domination of major barriers when practising quality tools. The strong domination is due to **-7** being further away from zero. When comparing adequate management support and lack of management support, the outcome value is 2, signifying domination of adequate management support, even though the domination is not that strong due to **2** is far from zero. When compared together, adequate application and lack of application give an outcome of **-7,** demonstrating intense domination of "lack of application". Comparing "adequate knowledge and "lack of knowledge" results in zero, providing a neutral situation.

Table 4.15: Practices of QT assessment

Practices of QT in PGP Maintenance	Technical view	Non-Technical View	Sum of	Difference
Major barriers	-3	-11	- 14	**-7**
Impact of QT	+3	+4	+ 7	
Lack of management support	0	-4	- 4	**2**
Adequate management support	+5	+1	+ 6	
Lack of application	-5	-6	- 11	**-7**
Adequate application	+4	+0	+ 4	
Lack of knowledge	-5	-5	- 10	**0**
Adequate knowledge	+3	+7	+ 10	

Source: Author's construction

4.5.6 Comparison between practices of QMP and QT in PGP maintenance

The comparison of the two main themes, "Practices of QMP in PGP maintenance and "Practices" of QT in PGP maintenance", is displayed in Figure 4.29. The graphical representation shows adequate knowledge of QMP's than that of quality tools. This view is further cemented by the large number presented under "lack of knowledge" when practising quality tools. However, the barriers identified when practicing quality tools are most interesting, which indicates that the PGP experience more resistance when practising quality tools.

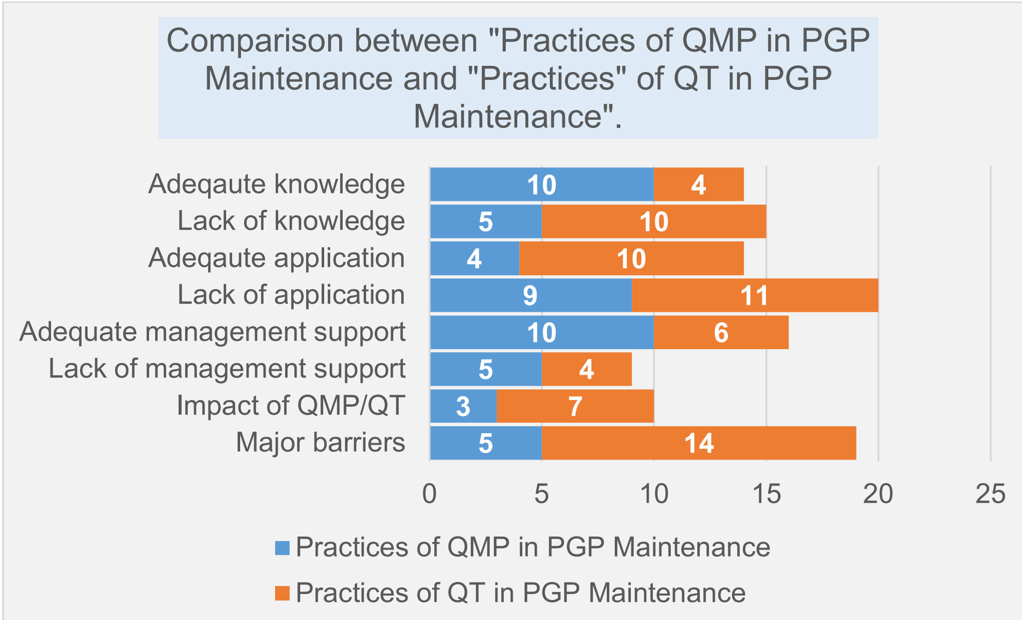


Figure 4.29: Comparison of QMP practices and QT practices

Source: Author's construction

4.6 Chapter conclusion

This chapter comprised data presentation and analysis. It also dealt with how the sampling requirements were addressed, how the participation in this study supported the process and how the detailed research results were outlined and deliberated. Graphs and Figures were used to explain the results further to ensure understanding of research outcomes.

CHAPTER 5: FINDINGS AND DISCUSSION

5.1 Introduction

This chapter focuses on matching the eight research questions identified in this study to the results elaborated in chapter 4. An in-depth discussion around primary and secondary quantitative output and primary qualitative data output is provided. The research findings are further aligned with previous studies.

5.2 Primary quantitative data analysis results discussion

Section 3.5 provided detailed information on how data was collected to answer research questions; RQ1 – RQ5. This section provides an overview of the data analysis outcome for each research question as documented from section 5.2.1 to section 5.2.5.

5.2.1 What is the extent to which quality tools are embedded in the maintenance practices - (RQ1)?

The data collection instrument was divided into three parts to answer this research question, as indicated in section 4.3.6.1. The outcome of the first part summarised in Figure 4.5 indicates that participants confirm being trained on the flow charts, check sheets, and control charts. The respondents confirmed not being trained on the cause-and-effect diagram, Pareto diagram and Histogram.

The outcome of the second part is displayed in Figure 4.6, highlighting that, out of all the seven essential quality tools, the check sheet is most often used, followed by the flow-chart and control chart. Whereas Pareto-diagram, scatter-plot and cause-and-effect diagram was the least used within the PGP maintenance environment. The study of Fotopoulos and Psomas (2008:570) also evidenced a similar pattern, wherein it was found out that at least two-thirds of the companies extensively used tools such as check sheet, flow chart and histogram, but fewer companies seem to use tools such as cause-and-effect diagram, Pareto diagram, scatter diagram and control charts. In this study, one would expect histogram to be one of the most used tools as indicated by Fotopoulos and Psomas (2008:573). However, surprisingly this study shows that histogram (26,9%) is rarely used among the quality tools at the PGP. Even the study of Fonseca, Lima and Silva (2015: 611) and Ismyrlis (2017: 684) found that histogram is amongst the most frequently used tools.

On the third outcome, with a total agreement of 88,6%, the respondent's feel that continual improvement within the maintenance environment can be better achieved by applying quality tools at the power generation plant. This is in line with Singh et al. (2012: 858), who states that the use of quality tools and techniques is a vital component of any successful improvement process, and this is supported by Sokovic et al. (2009: 3), who alluded that continuous improvement as one of the quality principles could not be realised without the quality tools. With a further 85,6%, the participants agree that the quality tools and techniques applied within the power generation plant can enhance people's ability to perform. This is in line with Magar and Shinde (2014: 364), who specifies that continuous use of quality tools upgrades the characteristics of individuals involved, enriches the ability to think, advances the generation of ideas and improves problem-solving.

5.2.2 What is the extent to which ISO 9000: 2015 Quality Management Principles are embedded in the maintenance practices - (RQ2)?

This research question is answered by a construct measured by seven statements as explicated in section 4.3.6.2. The outcome of data collected and analysed reveal that only 57,0% of participants agree that ISO 9000: 2015 Quality Management Principles are applied in the maintenance practices. This confirms the findings of Luburić (2015: 119) that applying quality principles leads to the more effective and efficient accomplishment of objectives.

5.2.3 What are the factors that contribute to the corrective maintenance backlog - (RQ3)?

As demonstrated in section 4.3.6.3, this research question is answered by a construct measured by seven statements, which highlight factors that contribute to the corrective maintenance backlog within the PGP. The outcome of data collected and analysed found that 55,0% of participants agreed with the statements or indicators listed in question 3 that contribute to CM backlog. This is in line with the view of Jasiulewicz-Kaczmarek (2014: 4472), Erkoyuncu (2017: 56) and Chen et al. (2017: 495), who listed similar statements/indicators that contribute to corrective maintenance. Mostafa, Dumrak and Soltan (2015: 440) also support this finding where they have identified fundamental types of waste found in the maintenance process, which are; unproductive maintenance or rework, waiting for maintenance resources, poor inventory management, unnecessary motion, under-utilisation of resources and ineffective data management, which are the exact dimensions that made up this research question.

5.2.4 What are the gaps and limitations in the maintenance documentation - (RQ4)?

The output of this research question is fully described in section 4.3.6.4, which ascertained whether the PGP documented information is necessary, is available at point of use, is suitable and is adequate for effective management of corrective maintenance backlog. The data collected and analysed outcome found that 63,0% of the participants agreed with the statements confirming that the PGP does not have major issues or gaps in this area. This finding contradicts what Koornneef, Verhagen and Curran (2017: 161) who found that gaps in maintenance documentation affect maintenance technicians' performance. They further found that failure to comply with maintenance documentation was the main reason for major malfunctions within 90 days of a heavy maintenance check in which 36% of the violations were associated with not using technical documentation. Feedback of 63,0% from the respondents indicates that the PGP performance is acceptable with some improvement opportunities to pursue.

5.2.5 To what extent are the external service providers contribute to the corrective maintenance backlog - (RQ5?)

This research question in which the outcome of data analysis is presented in Section 4.3.6.5 seeks to determine whether ISO 9001 certified service providers add better value than non-ISO 9001 certified service providers and whether internal service providers have a better impact than external service providers? The outcome of data collected and analysed reveals that 47,9% of participants agreed that external service providers contribute to the corrective maintenance backlog to some extent. The percentage of agreement is less than 50%, indicating that more than half of the participants are unsure if external service providers contribute to the corrective maintenance backlog or not or are even aware that external service providers contribute to the PGP performance. Although Al-Abdallah, Abdallah and Hamdan (2014:199) revealed that the client company improve its competitive performance by managing relationships with its suppliers, who play a fundamental role in improving competitive performance through technical specification, quality, cost, and flexibility.

5.3 Primary qualitative data analysis output

This section seeks to answer two research questions, which are; what are management's perception of the practices of quality tools (QT) in maintenance - (RQ6) and what is management's perception of the practices of ISO 9000: 2015 Quality Management Principles (QMP's) in maintenance - (RQ7)?

5.3.1 What is management's perception of quality tools (QT) practices in maintenance (RQ6)?

Figure 5.1 displays graphically the information provided in Table 4.15 to indicate the main theme, sub-themes and the outcome of the compared sub-themes. In this picture, the main theme is the "practices of QT in PGP maintenance environment".

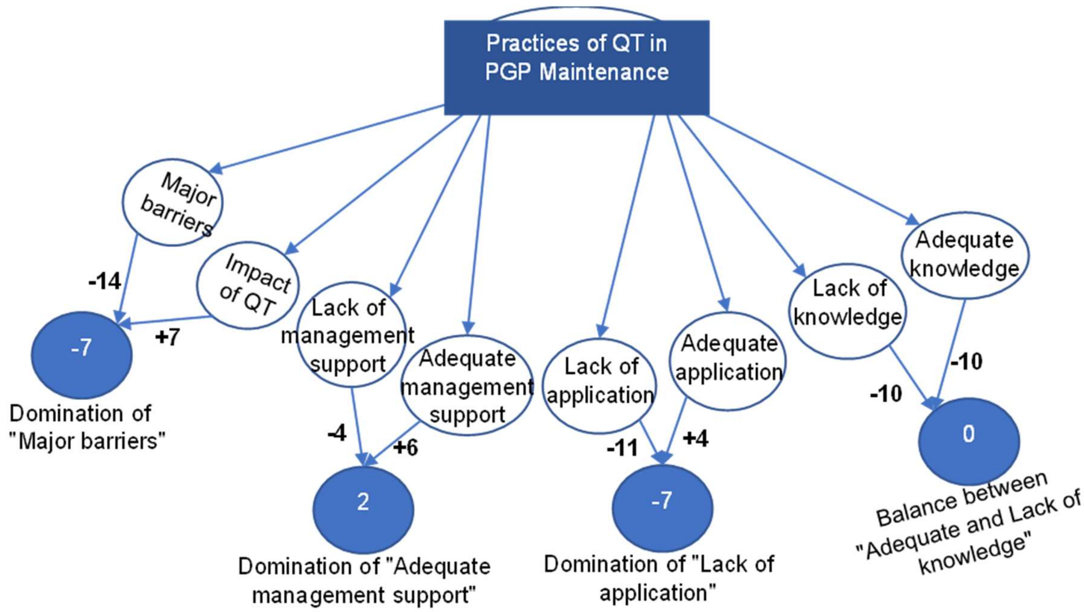


Figure 4.30: Practices of QT assessment demonstration

Source: Output of Nvivo version 12 software

The overall management perception presented by collected and analysed data suggests that there are many barriers observed when practising the quality tools in the PGP maintenance environment. There is a lack of application, and there is no sign of the required knowledge, even though there is some management support. This can align with Fotopoulos and Psomas (2008: 566)'s findings that quality tools and techniques require attention in several critical success factors, such as management support and commitment. In their work, sing et al. (2012: 858) added that management's quality tools can encourage a high number of employees to use them. Soković et al. s. (2009: 09) Their findings highlight the importance of turning the passive status of quality tools, techniques, and related methods into the proactive status to uphold continuous improvement further. The findings of Silombela, Mutingi and Chakraborty (2017: 18) stress that the effectiveness of quality tools should cover applications such as problem identification, data analysis, process analysis, decision making, planning, quality control and statistical process control.

5.3.2 What is management's perception of the practices of iso 9000: 2015 Quality Management Principles (QMP's) in maintenance - (RQ7)?

Figure 5.2 displays graphically the information provided in Table 4.14 to indicate the main theme, sub-themes and the outcome of the compared sub-themes. In this picture, the main theme presented is the "practices of QMP's in PGP maintenance environment".

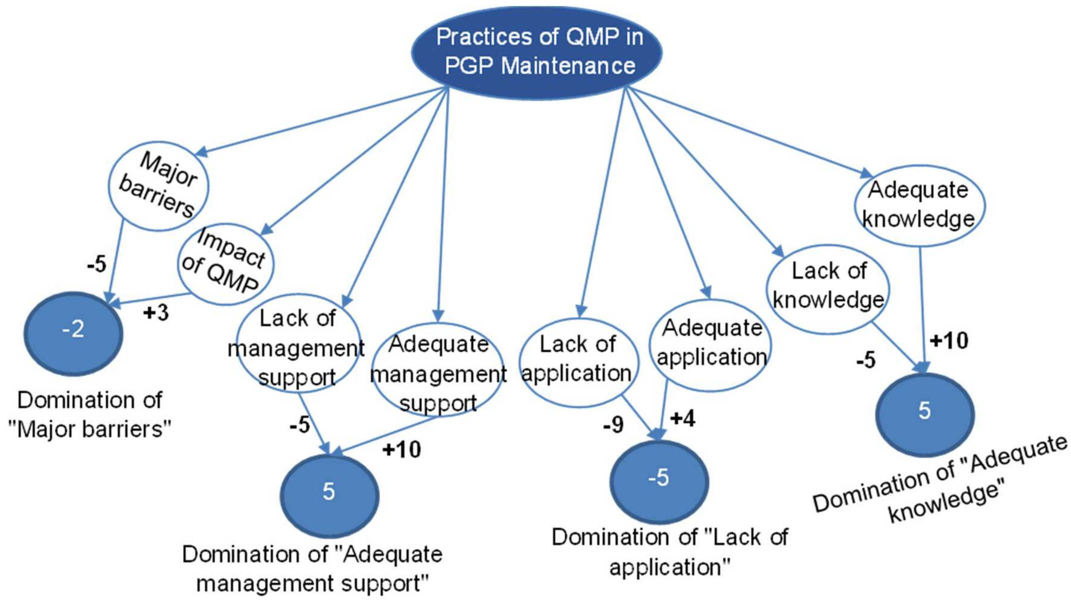


Figure 4.31: Practices of QMP's assessment demonstration

Source: Output of Nvivo version 12 software

In this case, the overall management perception presented by collected and analysed data informs that there are but a few barriers observed when practising the Quality Management Principles in the PGP maintenance environment. There is a lack of application; however, there is adequate knowledge strong management support. This link to Luburić (2015: 119), who support the approaches and synergistic activation of the Quality Management Principles to create one new, clear, an applicable and sustained paradigm of successful management. In which intangible leadership factors such as people management are crucial for organisational improvement Tenji and Foley

(2018: 401) with top management leadership expected to act as a driver for effective quality management implementation (Elshaer and Augustyn 2014: 1288). Furthermore, to provide a commitment to ensure the employees are stimulated to improve process performance by providing the necessary support (Malitic et al. 2014: 1750).

5.4 Secondary quantitative data analysis results discussion

Sections 5.3.3 and 5.3.4 look at data collected from the SAP system and the evaluation of the maintenance documentation management system.

5.4.1 SAP system data analysis results discussion

In the PGP, the recorded defects in the SAP system are categorised as backlog defects, awaiting spares defects, defects awaiting plant and completed defects but awaiting the submission of documents. Each maintenance section is expected to execute every defect under the four categories mentioned above. A high or low number of defects is a reflection of each maintenance section performance. The idea is to execute defects so that the number of defects/CM's stays as low as possible in support of Runeyi and Sardini (2015: 3) to achieve 20% of the corrective maintenance and 80% of preventive maintenance in terms of engineering maintenance standard ratio. Therefore, in the spider web graphical presentation, the lowest number of defects brings the section position close to zero or right in the middle of the graph refer to as a safe zone.

The sections in the middle of the spider web are deemed safe, meaning their performance does not need any attention from management. On the other hand, the sections indicated are far from the middle/centre to attract management intervention. This spider web graph is based on the Pareto principle to identify a few (20%) that cause the maximum (80%) influence within the process (Magar and Shinde 2014: 368; Gadre et al. 2015: 60 and Fonseca et al. 2015: 608). This is to highlight the areas that require assistance and support from management to improve their performance. Additionally, to find out what are the challenges faced by these highlighted sections.

Figure 4.21 indicates that PGP corrective maintenance (CM) and preventive maintenance (PM) ratio is CM/PM = 38%/62%, which is far from the expected CM/PM = 20%/80%, stipulated in the engineering maintenance standard by Runeyi and Sardini (2015: 3). It can be observed from Table 4.12 that only one section (COSP) is meeting the requirements with a performance of CM/PM = 14%/80%. The worst performing section is MILLS, with a performance of CM/PM = 70%/30%. Table 4.12 further clarifies the problem faced by the PGP by indicating that none of the sections meets the requirements stated in the engineering maintenance standard. It further indicates sections that need to improve to meet the stated engineering maintenance ratio of CM/PM = 20%/80%.

5.4.2 Maintenance documentation review results discussion

The criteria used to evaluate maintenance documentation is outlined in section 3.5.3.4 of this report. The outcome of maintenance document evaluation is based on clause 7.5 of ISO 9001: 2015 version. Under the criteria:

i. Evaluating the existence of the necessary documented information within maintenance, the maintenance department does have procedures in place, as demonstrated in table 4.11, which indicates the number of procedures per section. This is in line with the requirements of ISO 9001: 2015 clause 7.5.1(a) and (b).
ii. While evaluating the creation and updating of maintenance documented information, it was established that documents had been created, but 49.31% of these documents were found not to have been updated. This finding violates ISO 9001: 2015 clause 7.5.2 (b) and (c).
iii. While evaluating the control of maintenance documented information, the outcome is that 59% of maintenance documentation were found to be in an old template signifying that, these documents are not controlled

adequately. This finding is also in violation of ISO 9001: 2015 clause 7.5.2 (b) and (c) and clause 7.5.3.2 (c).

5.5 Structural equation modelling

The structural equation modelling in this study validates the measurement model to assess the relationship between latent constructs and clusters of observed variables underlying each construct. It further measures the relationship between latent constructs (de Carvalho and Chima 2014: 7 and Henseler 2017: 179).

It is not easy to gain a good sense of fit solely from the chi-square value due to its sensitivity to sample size; as a result, other indexes of model fit have been considered in this study (de Carvalho and Chima 2014: 10). Table 5.1 provide a summary of indexes considered for model fit in this research.

Table 4.16: Summary of model indexes

Index	**Recommended value**	**Actual value**	**Conclusion**
CMIN/DF	≤ 5	1.517	Meets the condition
Norm Fit Index (NFI)	≥ 0.9	0.875	Slightly lower than the recommended value
Comperative Fit Index (CFI)	≥ 0.9	0.952	Acceptable fit
PRATIO Index	≥ 0.9	0.762	Lower than the recommended value
RMSEA Index	≥ 0.05	0.05	Indicate good fit

Source: Author’s construction

Two of the indices did not meet the required cut-off value. The indices do indicate that the model is a good fit. Some of the low loading factors (statements) were omitted from the model. An inspection of the coefficients for each latent variable indicated high factor loadings. In addition, the path coefficients are reflected in Figure 4.12. All the coefficients are high, indicating strong positive correlations between the latent variables.

As this was a newly developed construct, it is also expected that the structural relationships may not have fitted accurately. However, specific indices are met, and it is recommended that the model be revised in terms of the measured variables constituting the latent variables to improve factor loadings.

The SEM has confirmed the relationship between the constructs of this study. It further confirms the quality of the measurement of the construct chosen. It can be concluded that the SEM supports that the model is a good fit.

5.6 Chapter conclusion

In this chapter, the eight research requisitions and related objectives were aligned to the research results delineated in chapter 4. The research outcomes were clearly stated and linked to other studies to check for similarities, variances, or even linkages to the known facts.

CHAPTER 6: RESEARCH CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter aims to provide a brief overview of the study and further present observations, conclusions, and recommendations. The study limitations and the practical and implementable framework established from this study are introduced. Lastly, the inputs for future work are presented.

6.2 Overview of the study

This study sought to optimise corrective maintenance backlog using quality tools and principles at a selected power generation plant in South Africa. The strategy employed was to develop a framework to optimise the CM/PM ratio towards CM of 20% and PM of 80% with the empirical aim of reducing corrective maintenance backlog at a selected PGP. This empirical aim was supported by eight objectives that formed the basis for research questions answered in this study. Chapters 1 provided an introduction to the study. Chapter 2 highlighted the in-depth literature review conducted, and Chapter 3 provided a detailed research method followed. Chapters 4 and 5 provided more information on the collected and analysed data, in which the eight research questions were answered with constructs bearing reliability of more than 0.7 Cronbach alpha.

6.3 Reflection of study objectives

A summary and conclusion on each research objective are highlighted from Sections 6.3.1 to 6.3.8.

6.3.1 Conclusion and recommendation on Objective No.1

- To ascertain the extent to which quality tools are embedded in the maintenance practices.

After assessing the use of quality tools at the PGP, there is evidence of a lack of application of these tools. The most intriguing aspect was observing the lack of histogram application, which did not even reach 30% of usage. Even previous studies of Fotopoulos and Psomas (2008:570), Fonseca, Lima and Silva (2015: 611) and Ismyrlis (2017: 684) registered histogram as one of the highest applied quality tools. This research presents a worrying factor for the PGP if the most used quality tool demonstrated by other studies is indicated as not widely used. A need to improve on the use of basic quality tools is highlighted in this study. This is demonstrated by the extent to which quality tools are embedded in the maintenance practices. The respondents who do not use the quality tools feel that continuous improvement can be achieved when applying the basic quality tools. They further feel that people's abilities can also be enhanced by using these quality tools. It is therefore recommended that the PGP management encourage the use of quality tools. This can be achieved by providing training on the basic quality tools to ensure that they have practical knowledge. The use of a standardised template for each quality tool will further enhance the practical use within the PGP.

6.3.2 Conclusion and recommendation on Objective No.2

- To ascertain the extent to which ISO 9000: 2015 Quality Management Principles are embedded in maintenance practices of the PGP.

The conclusion on this objective is based on the total agreement value of 57% on ISO 9000: 2015 Quality Management Principles being embedded in maintenance practices of the PGP. Therefore, the extent to which ISO 9000: 2015 Quality Management Principles are embedded in maintenance practices of the PGP can be confirmed. However, the issues stated in Section 6.3.7 can be considered to improve this objective for further. Nevertheless, the researcher also notes the 25,6% (neutral feedback) of respondents who presented no knowledge of whether ISO 9001 Quality Management Principles are being used in the PGP maintenance environment or not. This indicates that the PGP needs to heighten the application of ISO 9001 Quality

Management Principles. It is recommended that Line Managers and supervisors discuss the Quality Management Principles in their team briefing to enhance the understanding and practical alignment during the execution of activities.

6.3.3 Conclusion and recommendation on Objective No.3

- To ascertain the factors that are contributing to the corrective maintenance backlog.

The respondents affirmed the statements or factors that were listed and highlighted the issues contributing to the corrective maintenance backlog. It can be concluded that unproductive maintenance or rework, waiting for maintenance resources, poor inventory management, unnecessary motion, under-utilization of resources and ineffective data management contribute to corrective maintenance. The two most contributing factors to corrective maintenance backlog are poor management of the inventory of spares/parts and too much unnecessary motion/movement of maintenance personnel within the power generation plant. It is recommended that the PGP management looks into these two factors towards corrective maintenance backlog improvement.

The secondary data analysis provides a detailed picture of the CM/PM ratio when measuring maintenance performance. The PGP maintenance department is struggling to meet the CM/PM ratio of 20%/80%, respectively. However, the statistical analysis provides an approach that can assist the PGP in improving its corrective maintenance backlog. The spider web graphs give a clear picture of the sections that contribute to the corrective maintenance backlog, and these are the sections that management must pay attention to. Recommended action to improve the areas that have shown poor performance is to implement the “Hit Squad” approach. This means that management should move the workforce around to assist the sections that are battling with their corrective maintenance backlog. In this way, the backlog can be tackled to restore normality. It is recommended that line managers address the issues with the most-aged defects in the list first. If the top 10 oldest defects are addressed first, that will create a new top 10 oldest defects. Until the lowest age is reached, in this way the improvement will be systematic and can reduce the PGP corrective maintenance backlog.

6.3.4 Conclusion and recommendation on Objective No.4

- To evaluate the extent to which the maintenance documentation aligns to ISO 9001: 2015 requirements.

The statements used to address this objective were written in positive content, whereby a disagreement on the Likert scale indicated gaps and limitations in the maintenance documentation. They agreed that on Likert scale indicated no gaps and limitations in the maintenance documentation. It can be concluded that there are no gaps and limitations in the maintenance documentation, meaning the PGP documented information is necessary, is available at point of use, is suitable and is adequate for effective management of corrective maintenance backlog. The observation from the primary collected and analysed data indicate that the PGP is doing well, and it is recommended that the current practices of the PGP be enhanced to gain further performance improvement.

Whereas according to the secondary collected and analysed data, the maintenance department does have procedures in place. However, it was established that even though documents have been created, some gaps can be addressed in cases where documents were found not to have been updated. A further finding is that some maintenance documentation was in the old template, which violates the PGP quality management system. It is recommended that documents be updated on the latest approved PGP template to ensure conformance to the PGP quality management system. √

6.3.5 Conclusion and recommendation on Objective No.5

- To determine the extent to which external service providers contribute to corrective maintenance backlog.

The finding on this objective is that external service providers contribute to the corrective maintenance backlog. On the neutral level, it concerns if PGP employees are not sure if external service providers contribute to the corrective maintenance backlog or not. This means they have no clear indication of what value do service providers bring to the PGP performance. This can be seen by PGP management as an area of improvement to educate the employees about the value that service providers bring to the organisation. Secondly, to ensure that the PGP relationship with the service providers is sound and transparent, each employee can attest to it.

6.3.6 Conclusion and recommendation on Objective No.6

- To ascertain management's perception of the practices of quality tools in the maintenance

The observation from primary qualitative collected and analysed data reveals that management's perception of the issue of practicing quality tools (QT) in the maintenance environment is that there are barriers that need to be addressed. Above that, they confirm there is no established application of the quality tools due to a lack of knowledge on these tools, even though they indicate that management support is given. The question brought forward from the researcher is how can there be management support if there are confirmed barriers and there is no application of quality tools and related knowledge available to employees? The reflection around this issue concludes that quality tools are not practiced within the PGP due to a lack of management support. This can be an improvement area that the PGP management can explore. √

6.3.7 Conclusion and recommendation on Objective No.7

- To capture management's perceptions on how much ISO 9000: 2015 Quality Management Principles are practised in the maintenance department.

The reflection from primary qualitative collected and analysed data reveals that management's perception of the practices of ISO 9000: 2015 Quality Management Principles (QMP's) in maintenance is that some barriers prevent the practices of ISO 9000: 2015 Quality Management Principles (QMP's) in maintenance environment. In the case of Quality Management Principles practices, it is revealed that there is strong management support and strong knowledge on the Quality Management Principle. However, contrary to that, there is a lack of application. In conclusion, management support is confirmed by adequate knowledge of quality principles, meaning there has been some training provided in this regard. However, due to some barriers and lack of application, it indicates that management still must put more effort into ensuring that the practices of ISO 9000: 2015 Quality Management Principles (QMP's) do exist in a maintenance environment. These issues are highlighted as a point of departure for continuous improvement. √

6.3.8 Conclusion and recommendation on Objective No.8

- To develop a practical and implementable framework to be adopted to optimise corrective maintenance backlog.

Conclusions and recommendations of the first seven objectives mentioned above form a basis for conclusions and recommendations of objective eight. After considering the findings for the first seven objectives, it was possible to construct a practical and implementable framework that can be adopted to reduce corrective maintenance backlog in the PGP. This framework is presented in figure 6.1 under section 6.4.2 where it is elaborated in detail.

6.4 Recommendations

Recommendations have already been outlined under each objective's conclusion in Sections 6.3.1 to 6.3.8. The primary recommendation is outlined under Section 6.4.2.

6.4.1 Practical and implementable framework

This study's practical and implementable framework has considered all the data collected and analysed from the questionnaire, interviews, document reviews, and SAP system. The last research question considers the findings of all other research questions to build an implementable model.

6.4.2 What type of practical and implementable framework can be adopted to reduce corrective maintenance backlog? (RQ8)

The conceptual framework presented in Figure 1.2 forms the backbone of the perceived practical and implementable framework. The process flow indicated on the framework (ISO 9001: 2015: Viii) demonstrate how a reduced corrective maintenance backlog can positively improve production. Figure 6.1 provides a suggested framework to be implemented when optimising corrective maintenance backlog within a power generation plant in South Africa.

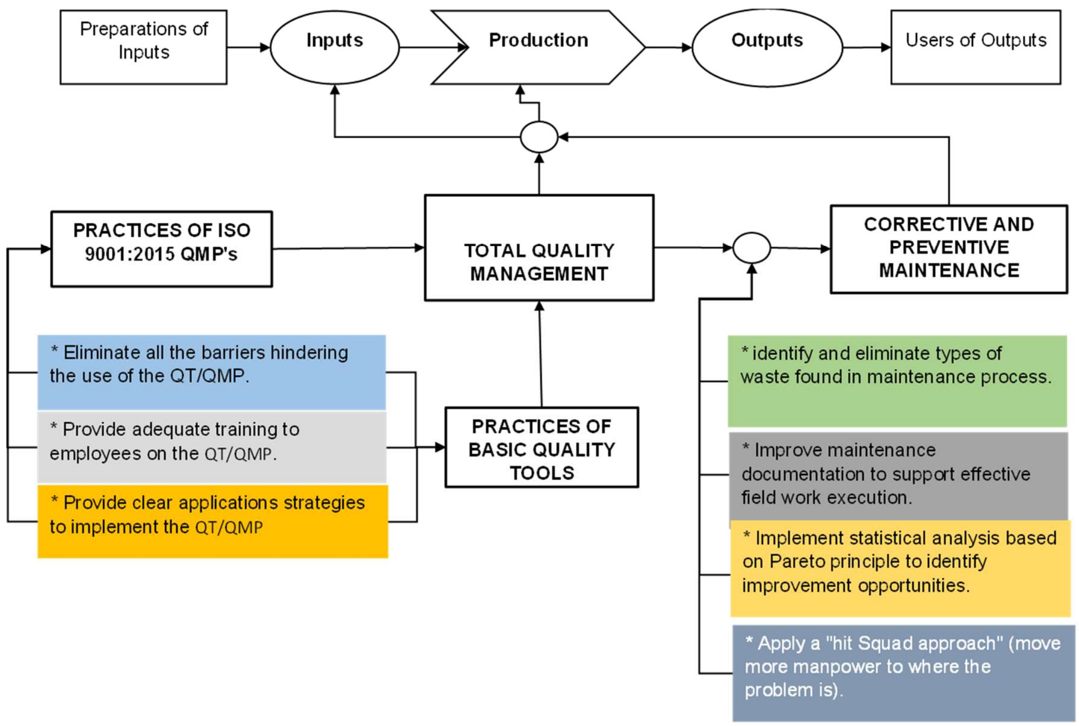


Figure 6.132: Practical and implementable framework

Source: Author's construction

Preparation or sources of inputs is a starting point where the process inputs are created. These inputs are transformed in the production stage into outputs that are handed to the users of the outputs (ISO 9001: 2015: viii). The users of the outputs are both the internal and external customers, including other relevant interested parties (ISO 9001: 2015: viii).

The recommendations from Figure 6.1 is that, to practice the ISO 9001: 2015 QMP's and the essential quality tools, it is imperative to create a conducive atmosphere. To create this perceived atmosphere, the following strategies must be implemented:

- Eliminate all the barriers hindering the use of the QMP's and the quality tools.
- Provide the necessary and/or adequate training to employees on the QMP's and essential quality tools.

- Provide clear application strategies to implement the QMP's and quality tools, such as developing standardised templates.

It is suggested that if the quality tools and quality principles are practiced effectively, Quality Management System will be established and will impact positively corrective and preventive maintenance processes. In addition to that, some maintenance strategies must be employed to influence corrective and preventive maintenance processes such as:

- Identify and eliminate different types of wastes found in maintenance processes.
- Improve maintenance documentation to support effective fieldwork execution.
- Implement statistical analysis based on the Pareto principle to identify improvement opportunities.
- Apply a “Hit squad approach”, which means moving resources where the issues are and normalising the situation.

Overall, once the corrective and preventive maintenance activities are deemed adequate, the expectation is that production performance will improve. Ultimately, the outputs of the PGP will meet the users' requirements. An essential aspect of maintenance interventions is that it requires integration and interfaces with other internal and external systems, which will result in cooperation between maintenance and its stakeholders (Jasiulewicz-Kaczmarek 2014: 4474). The undertaken is that effective corrective and preventive maintenance processes will positively contribute to the power generation plant performance.

6.5 Study limitations

The study was conducted on one out of fifteen power generation plants within the organisation. It is perceived that a more conclusive outcome could be attained if all were included. Only the power generation plant's top management was interviewed, leaving out Line managers who could have added a more precise picture on the researched topic.

6.6 Input for future studies

What could be of interest is unpacking the barriers that hinder the application of essential quality tools and Quality Management Principles in the PGP environment. It could further be interesting to find out how the ‘Hit squad” approach can be unfolded to prove a positive impact on the performance of the PGP.

6.7 Chapter conclusions

In this chapter, objective conclusions were outlined with the recommendations provided. A suggested framework established by this study was presented, and study limitations and suggestions for future studies were indicated.

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APPENDICES

Appendix A: Data gathering research survey questionnaire

BIOGRAPHICAL INFORMATION								
Department		Job grade			Years of Experience			
Section		M-Level		G/S - Level	0-5 yrs.		16-20yrs	
Sex	Occupation				6-10 yrs.		21-30 yrs.	
M / F		P-Level		T- Level	11-15 yrs.		30+ yrs.	

#	Optimising corrective maintenance backlog using quality tools and quality principles at a selected power generation plant in South Africa				
1	**The extent to which quality tools are embedded in the maintenance practices (RQ1)? Please rate the below statements based on the adjacent scale by placing an "x" in the appropriate column.**				
1.1	I have been trained on how to apply each of the following tools:				
• Scatter plot		Yes		No	
• Cause-and-effect diagram		Yes		No	
• Flow chart		Yes		No	
• Pareto diagram		Yes		No	
• Check sheet		Yes		No	
• Control chart		Yes		No	
• Histogram		Yes		No	

1.2	For each of the following tools, rate the extent to which each tool is currently employed within the maintenance environment.	1 Very Rarely	2 Rarely	3 Occasionally	4 Often	5 Very Often
• Scatter plot						
• Cause-and-effect diagram						
• Flow chart						
• Pareto diagram						
• Check sheet						
• Control chart						
• Histogram						
		1 ☹	2	3 😐	4	5 ☺

For each of the following statements, indicate the extent to which you agree or disagree by placing an **"x"** in the appropriate column.		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1.3	Within the maintenance environment, continuous improvement can be better achieved by applying quality tools at the power generation plant.					
1.4	When applied within the power generation plant, the quality tools and techniques can enhance people's ability to perform.					
2	**The extent to which ISO9000:2015 Quality Management Principles are embedded in the maintenance practices (RQ2)?**	**1** ☹	**2**	**3** 😐	**4**	**5** ☺
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
2.1	Maintenance activities at the power generation plant meet customer needs.					
2.2	Maintenance personnel are engaged in achieving the power generation plant's maintenance objectives.					
2.3	Sharing of knowledge and experience is encouraged among maintenance personnel.					
2.4	Maintenance management ensures that work instructions are available before executing maintenance activities.					
2.5	Improvement is recognised and acknowledged within the maintenance environment.					
2.6	Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience.					
2.7	Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance.					
3	**The factors that contribute to the corrective maintenance backlog (RQ3)?**	**1** ☹	**2**	**3** 😐	**4**	**5** ☺
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
3.1	There is little focus on trying to ascertain the extent to which unproductive maintenance contributes to the corrective maintenance backlog					
3.2	Corrective maintenance backlog is increased by the under-utilisation of the workforce at the Power Generation Plant.					
3.3	Corrective maintenance backlog is negatively influenced by poor management of the inventory of spares/parts at the power generation plant					
3.4	There is too much unnecessary motion/movement of maintenance personnel within the plant					
3.5	Waiting for the production plant to carry out maintenance activities leads to a corrective maintenance backlog.					
3.6	The lack of an effective maintenance data management system impedes the optimising of the maintenance backlog.					
3.7	The level of rework due to poor maintenance workmanship is at such a level that it significantly impacts the corrective maintenance backlog.					
4	**The gaps and limitations in the maintenance documentation (RQ4)?**	**1** ☹	**2**	**3** 😐	**4**	**5** ☺

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
4.1	The power generation plant documented information is necessary for effective management of corrective maintenance backlog.					
4.2	Documented information is available for use where and when is it is needed to perform corrective maintenance.					
4.3	Documented information is suitable for the execution of corrective maintenance activities.					
4.4	Documented information related to corrective maintenance is adequately retained as evidence of conformity.					
5	**The extent to which external service providers contribute to the corrective maintenance backlog (RQ5)?**	**1** ☹	**2**	**3** 😐	**4**	**5** ☺
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
5.1	The power generation plant's external non-certified service providers have a lower value-adding impact on maintenance activities outputs than the plant's external ISO 9001 certified service providers					
5.2	Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality					
5.3	There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close					
5.4	Compared to the internal service providers, the external service providers do not meet the power generations plant quality standards better					
5.5	Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant					
5.6	Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant					
5.7	External service providers are often not provided with clear specifications of the required product and services by the power generation plant					

Appendix B: Description ID for all Items

ID	Description of an item/dimension for a related construct
Item 1.1a	1.1a I have been trained on how to apply scatter-plot.
Item 1.1b	1.1b I have been trained on how to apply a cause-and-effect diagram.
Item 1.1c	1.1c I have been trained on how to apply a Flow chart.
Item 1.1d	1.1d I have been trained on how to apply Pareto-diagram.
Item 1.1e	1.1e I have been trained on how to apply Check-sheet.
Item 1.1f	1.1f I have been trained on how to apply Control-chart.
Item 1.1g	1.1g I have been trained on how to apply Histogram.
Item 1.2a	1.2 a The extent to which Scatter-plot is currently employed within the maintenance environment.
Item1.2b	1.2 b The extent to which a cause-and-effect diagram is currently employed within the maintenance environment.
Item 1.2c	1.2 c The extent to which a Flow chart is currently employed within the maintenance environment.
Item 1.2d	1.2 d The extent to which Pareto-diagram is currently employed within the maintenance environment.
Item 1.2e	1.2 e The extent to which Check-sheet is currently employed within the maintenance environment.
Item 1.2f	1.2 f The extent to which Control-chart is currently employed within the maintenance environment.
Item 1.2g	1.2 g The extent to which Histogram is currently employed within the maintenance environment.
Item 1.3	1.3 Continual improvement within the maintenance environment can be better achieved by applying quality tools at the power generation plant.
Item 1.4.	1.4 The quality tools and techniques applied within the power generation plant can enhance people's ability to perform.
Item 2.1	2.1 Maintenance activities at the power generation plant meet customer needs.
Item 2.2	2.2 Maintenance personnel are engaged in achieving the power generation plant’s maintenance objectives.
Item 2.3	2.3 Sharing of knowledge and experience is encouraged among maintenance personnel.
Item 2.4	2.4 Maintenance management ensure that work instructions are available before executing maintenance activities.
Item 2.5	2.5 Improvement is recognised and acknowledged within the maintenance environment.
Item 2.6	2.6 Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience.
Item 2.7	2.7 Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance.
Item 3.1	3.1 There is little focus on ascertaining the extent to which unproductive maintenance contributes to the corrective maintenance backlog.
Item 3.2	3.2 Corrective maintenance backlog is increased by the under-utilisation of the workforce at the Power Generation Plant.

Item 3.3	3.3 Corrective maintenance backlog is negatively influenced by poor management of the inventory of spares/parts at the power generation plant.
Item 3.4	3.4 There is too much unnecessary motion/movement of maintenance personnel within the plant.
Item 3.5	3.5 Waiting for the production plant to carry out maintenance activities leads to a corrective maintenance backlog.
Item 3.6	3.6 The lack of an effective maintenance data management system impedes the optimising of the maintenance backlog.
Item 3.7	3.7 The level of rework due to poor maintenance workmanship is at such a level that it has a significant impact on the corrective maintenance backlog.
Item 4.1	4.1 The power generation plant documented information is necessary for effective management of corrective maintenance backlog.
Item 4.2	4.2 Documented information is available for use where and when is it is needed to perform corrective maintenance.
Item 4.3	4.3 Documented information is suitable for the execution of corrective maintenance activities.
Item 4.4	4.4 Documented information related to corrective maintenance is adequately retained as evidence of conformity.
Item 5.1	5.1 The power generation plant's external non-certified service providers have a lower value-adding impact on maintenance activities outputs than the plant's external ISO 9001 certified service providers.
Item 5.2	5.2 Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality.
Item 5.3	5.3 There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close.
Item 5.4	5.4 Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality.
Item 5.5	5.5 Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant.
Item 5.6	5.6 Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant.
Item 5.7	5.7 External service providers are often not provided with clear specifications of the required product and services by the power generation plant.

Appendix C: Approval of research proposal letter

DUT DURBAN UNIVERSITY OF TECHNOLOGY

FACULTY OF MANAGEMENT SCIENCES

8 November 2019

Reference: Proposal Approval: Mr M Maseola

Student number: 2156763

Dear Mr M Maseola

MASTER OF PHILOSOPHY: QUALITY

This serves to confirm the approval of your research proposal by the Faculty Research Committee, at its meeting on 30 **October 2019**, as follows:

1. Research proposal and provisional dissertation title:

   OPTIMISING CORRECTIVE MAINTENANCE BACKLOG USING QUALITY TOOLS AND PRINCIPLES AT A POWER GENERATION PLANT IN SOUTH AFRICA

   Supervisor: **Dr M Ramchander**

   Co-supervisor: n/a

   Please note that any proposed changes in the thesis/dissertation title require the approval of your supervisor/s, the Faculty Research Committee, as well as ratification thereof by the Higher Degrees Committee.

2. Research budget to the amount of **R10 000.00**

   Please note that this funding is not a scholarship or bursary and is therefore not paid directly to you, but is controlled by the Faculty. Any proposed changes to the use of this funding allocation requires the approval of your supervisor and the Dean. Please note that funding will be reimbursed to you after the provision of receipts.

The Institutional Research Committee has stipulated that:

(a) This University retains the ownership of any Intellectual Property (patent, design, etc.) registered in respect of the results of your Masters/Doctors Degree in Technology studies as a result of the award and the provisions of the above Act;

(b) Should you find any of the terms above not acceptable then you are given the option to decline the Research budget award to your project in writing.

PROPOSAL APPROVAL_OCT 2019_4 1

Graduation requirements:

1. Ensure that you submit a completed signed PG10 form
2. one hard bound dissertation/thesis with a pdf version on CD
3. response to post graduate examination form
4. completion of study form (IREC form)

Should you experience any problems relating to your research, your supervisor must be informed of the matter as soon as possible. If the difficulties persist, you should then approach your Head of Department and thereafter the Faculty Research Coordinator.

Please refer to the 2017 General Rule Book and the Postgraduate Students' Guide 2017 concerning the rules relating to postgraduate studies, which include *inter alia* acceptable minimum and maximum timeframes, submission of thesis/dissertations, etc. Please do not hesitate to contact this office for any assistance. We wish you success in your studies.

Kind regards,

Prof JP Govender

Obo FRC Chairperson: Professor VP Rawjee

Faculty of Management Sciences

Cc Supervisor: **Dr M Ramchander**

Appendix C: Ethics related training certificates

TRREE

Clinical Trials Centre
The University of Hong Kong

Zertifikat
Certificado
Certificat
Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Moses Maseola

a complété avec succès - has successfully completed

Introduction to Research Ethics

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2020/08/29
CID : ovxgL4tbHj

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

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TRREE

Clinical Trials Centre
The University of Hong Kong

Zertifikat
Certificado
Certificat
Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Moses Maseola

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Informed Consent

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2020/08/30
CID : x6TGIEaqhZ

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

FMH Continuing Education Program (5 Credits)
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[REV : 20170310]


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Research Ethics Evaluation

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2020/08/30
CID : wnsitWif3s

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[REV : 20170310]

Appendix D: Rotated component matrix table

ITEMS		Component				
		1	2	3	4	5
The extent to which Scatter-plot is currently employed within the maintenance environment	Q1.2a	0.788	0.111	-0.013	0.003	0.034
The extent to which cause-and-effect-diagram is currently employed within the maintenance environment	Q1.2b	0.834	0.176	0.022	0.008	-0.033
The extent to which Flow-chart is currently employed within the maintenance environment	Q1.2c	0.729	0.237	0.089	0.111	0.014
The extent to which Pareto-diagram is currently employed within the maintenance environment	Q1.2d	0.846	0.131	-0.018	0.029	0.028
The extent to which Check-sheet is currently employed within the maintenance environment	Q1.2e	0.606	0.121	0.154	0.144	-0.047
The extent to which Control-chart is currently employed within the maintenance environment	Q1.2f	0.841	0.129	-0.019	0.089	0.121
The extent to which Histogram is currently employed within the maintenance environment	Q1.2g	0.830	0.079	0.037	-0.006	0.131
Maintenance activities at the power generation plant meets customer needs	Q2.1	0.241	0.786	-0.037	0.012	-0.011
Maintenance personnel are engaged in achieving the power generation plant’s maintenance objectives	Q2.2	0.147	0.820	0.051	0.103	0.024

Sharing of knowledge and experience is encouraged among maintenance personnel	Q2.3	0.009	0.743	-0.037	0.029	0.147
Maintenance management ensure that work instructions are available before executing maintenance activities	Q2.4	0.173	0.652	-0.021	0.025	0.093
Improvement is recognised and acknowledged within the maintenance environment	Q2.5	0.256	0.647	-0.012	-0.117	0.218
Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience	Q2.6	0.113	0.772	-0.016	0.024	0.113
Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance	Q2.7	0.134	0.608	-0.076	-0.066	0.347
There is little focus on trying to ascertain the extent to which unproductive maintenance contributes to the corrective maintenance backlog	Q3.1	0.110	-0.176	0.596	0.083	-0.085
Corrective maintenance backlog is increased by the under-utilisation of the workforce at the Power Generation Plant	Q3.2	-0.064	-0.035	0.666	0.088	-0.041
Corrective maintenance backlog is negatively influenced by poor management of the inventory of spares/parts at the power generation plant	Q3.3	-0.016	0.063	0.782	0.103	-0.103
There is too much unnecessary motion/movement of maintenance personnel within the plant	Q3.4	-0.016	-0.019	0.669	0.074	-0.016
Waiting for the production plant to be available to carry out maintenance activities lead to the corrective maintenance backlog	Q3.5	0.023	0.255	0.462	0.410	-0.018
The lack of an effective maintenance data management system impedes the optimising of the maintenance backlog	Q3.6	0.164	0.020	0.485	0.092	0.270
The level of rework due to poor maintenance workmanship is at such a level that it has a significant impact on a corrective maintenance backlog	Q3.7	0.045	-0.095	0.679	-0.019	0.152
The power generation plant documented information is necessary for effective management of corrective maintenance backlog	Q4.1	0.034	0.089	0.585	0.094	0.439
Documented information is available for use where and when is it is needed to perform corrective maintenance	Q4.2	0.020	0.236	-0.009	0.241	0.750
Documented information is suitable for the execution of corrective maintenance activities	Q4.3	0.032	0.144	0.151	0.033	0.816
Documented information related to corrective maintenance is adequately retained as evidence of conformity	Q4.4	0.087	0.285	-0.029	-0.054	0.698
The power generation plant's external non-certified service providers have a lower value-adding impact on maintenance activities outputs than the plant's external ISO 9001 certified service providers	Q5.1	0.006	0.037	0.233	0.491	0.273
Compared to the internal service providers, the external service providers do not	Q5.2	-0.010	-0.239	-0.045	0.757	0.088

provide the power generation plant with a higher level of service quality						
There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close	Q5.3	0.199	0.036	0.324	0.523	0.131
Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Q5.4	0.060	-0.157	-0.081	0.788	0.118
Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant	Q5.5	0.052	0.205	0.250	0.701	-0.120
Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant	Q5.6	0.120	0.175	0.243	0.714	-0.149
External service providers are often not provided with clear specifications of the required product and services by the power generation plant	Q5.7	0.033	-0.001	0.399	0.298	0.040

- Extraction Method: Principal Component Analysis.
- Rotation Method: Varimax with Kaiser Normalization.
- Rotation converged in 5 iterations.

Appendix E: Graphical analysis for Q1.1 (I have been trained to apply each of the following tools).

Items		Very Rarely		Rarely		Occasionally		Often		Very Often		Chi Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
Scatter-plot	Q1.2a	103	53.1%	30	15.5%	35	18.0%	19	9.8%	7	3.6%	< 0.001
Cause-and-effect-diagram	Q1.2b	90	46.6%	38	19.7%	30	15.5%	24	12.4%	11	5.7%	< 0.001
Flow-chart	Q1.2c	59	29.9%	21	10.7%	47	23.9%	38	19.3%	32	16.2%	< 0.001
Pareto-diagram	Q1.2d	103	53.6%	35	18.2%	34	17.7%	16	8.3%	4	2.1%	< 0.001
Check-sheet	Q1.2e	38	19.1%	7	3.5%	21	10.6%	48	24.1%	85	42.7%	< 0.001
Control-chart	Q1.2f	70	36.1%	31	16.0%	29	14.9%	38	19.6%	26	13.4%	< 0.001
Histogram	Q1.2g	83	43.0%	26	13.5%	32	16.6%	31	16.1%	21	10.9%	< 0.001

Appendix F: Summary statistics for Q1.2 (The extent to which each tool is currently employed within the maintenance environment).

Statements		Very Rarely		Rarely		Occasionally		Often		Very Often		Chi-Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
The extent to which Scatter-plot is currently employed within the maintenance environment	Q1.2a	103	53,1%	30	15,5%	35	18,0%	19	9,8%	7	3,6%	< 0.001
The extent to which cause-and-effect-diagram is currently employed within the maintenance environment	Q1.2b	90	46,6%	38	19,7%	30	15,5%	24	12,4%	11	5,7%	< 0.001
The extent to which Flow-chart is currently employed within the maintenance environment	Q1.2c	59	29,9%	21	10,7%	47	23,9%	38	19,3%	32	16,2%	< 0.001
The extent to which Pareto-diagram is currently employed within the maintenance environment	Q1.2d	103	53,6%	35	18,2%	34	17,7%	16	8,3%	4	2,1%	< 0.001
The extent to which Check-sheet is currently employed within the maintenance environment	Q1.2e	38	19,1%	7	3,5%	21	10,6%	48	24,1%	85	42,7%	< 0.001
The extent to which Control-chart is currently employed within the maintenance environment	Q1.2f	70	36,1%	31	16,0%	29	14,9%	38	19,6%	26	13,4%	< 0.001
The extent to which Histogram is currently employed within the maintenance environment	Q1.2g	83	43,0%	26	13,5%	32	16,6%	31	16,1%	21	10,9%	< 0.001

Appendix G: Summary statistics for Q1.3 and Q1.4

Statements		Strongly disagree		Disagree		Neutral		Agree		Strongly agree		Chi-Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
Continual improvement, within the maintenance environment, can be better achieved by applying quality tools at the power generation plant	Q1.3	10	5,0%	2	1,0%	11	5,4%	75	37,1%	104	51,5%	< 0.001
The quality tools and techniques when applied within the power generation plant can enhance people's ability to perform	Q1.4	8	4,0%	3	1,5%	18	9,0%	88	43,8%	84	41,8%	< 0.001

Appendix H: Summary statistics for Q2 (The extent to which ISO9000:2015 Quality Management Principles are embedded in the maintenance practices (RQ2))

Statements		Strongly disagree		Disagree		Neutral		Agree		Strongly agree		Chi-Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
Maintenance activities at the power generation plant meets customer needs	Q2.1	7	3,5%	28	13,9%	63	31,2%	73	36,1%	31	15,3%	< 0.001
Maintenance personnel are engaged in achieving the power generation plant's maintenance objectives	Q2.2	6	3,0%	22	10,8%	38	18,7%	95	46,8%	42	20,7%	< 0.001
Sharing of knowledge and experience is encouraged among maintenance personnel	Q2.3	12	5,9%	20	9,9%	43	21,2%	95	46,8%	33	16,3%	< 0.001
Maintenance management ensure that work instructions are available before executing maintenance activities	Q2.4	11	5,4%	20	9,9%	48	23,6%	96	47,3%	28	13,8%	< 0.001
Improvement is recognised and acknowledged within the maintenance environment	Q2.5	13	6,4%	37	18,3%	60	29,7%	75	37,1%	17	8,4%	< 0.001
Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience	Q2.6	7	3,4%	25	12,3%	39	19,2%	97	47,8%	35	17,2%	< 0.001
Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance	Q2.7	9	4,5%	30	14,9%	72	35,6%	77	38,1%	14	6,9%	< 0.001

Appendix I: Summary statistics for Q3 (The factors that contribute to the corrective maintenance backlog. (RQ3))

Statements		Strongly disagree		Disagree		Neutral		Agree		Strongly agree		Chi-Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
There is little focus on trying to ascertain the extent to which unproductive maintenance contributes to corrective maintenance backlog	Q3.1	6	3,0%	33	16,4%	59	29,4%	83	41,3%	20	10,0%	< 0.001
Corrective maintenance backlog is increased by the under-utilisation of the workforce at the Power Generation Plant	Q3.2	15	7,5%	42	20,9%	38	18,9%	74	36,8%	32	15,9%	< 0.001
Corrective maintenance backlog is negatively influenced by poor management of inventory of spares/parts at the power generation plant	Q3.3	10	5,0%	15	7,5%	21	10,4%	88	43,8%	67	33,3%	< 0.001
There is too much unnecessary motion/movement of maintenance personnel within the plant	Q3.4	12	6,0%	66	32,8%	83	41,3%	19	9,5%	21	10,4%	< 0.001
Waiting for the production plant to be available to carry out maintenance activities lead to corrective maintenance backlog	Q3.5	6	3,0%	29	14,4%	32	15,9%	91	45,3%	43	21,4%	< 0.001
The lack of an effective maintenance data management system impedes the optimising of maintenance backlog	Q3.6	5	2,5%	22	11,0%	64	32,0%	79	39,5%	30	15,0%	< 0.001
The level of rework due to poor maintenance workmanship is at such a level that it has a significant impact on corrective maintenance backlog	Q3.7	6	3,0%	24	11,9%	43	21,4%	71	35,3%	57	28,4%	< 0.001

Appendix J: Summary statistics for Q4 (The gaps and limitations in the maintenance documentation (RQ4))

Statements		Strongly disagree		Disagree		Neutral		Agree		Strongly agree		Chi-Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
The power generation plant documented information is necessary for effective management of corrective maintenance backlog	Q4.1	7	3,5%	6	3,0%	27	13,4%	94	46,8%	67	33,3%	< 0.001
Documented information is available for use where and when is it is needed to perform corrective maintenance	Q4.2	10	5,0%	21	10,6%	47	23,6%	95	47,7%	26	13,1%	< 0.001
Documented information is suitable for the execution of corrective maintenance activities	Q4.3	4	2,0%	18	9,0%	55	27,4%	88	43,8%	36	17,9%	< 0.001
Documented information related to corrective maintenance is adequately retained as evidence of conformity	Q4.4	12	6,0%	38	18,9%	52	25,9%	73	36,3%	26	12,9%	< 0.001

Appendix K: Summary statistics for Q5 (The extent to which external service providers contribute to the corrective maintenance backlog (RQ5)?

Statements		Strongly disagree		Disagree		Neutral		Agree		Strongly agree		Chi-Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
The power generation plant's external non-certified service providers have a lower value adding impact on maintenance activities outputs than the plant's external ISO 9001 certified service providers	Q5.1	17	8,4%	30	14,9%	81	40,1%	56	27,7%	18	8,9%	< 0.001
Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Q5.2	21	10,4%	50	24,9%	67	33,3%	47	23,4%	16	8,0%	< 0.001
There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close	Q5.3	6	3,0%	20	9,9%	60	29,7%	85	42,1%	31	15,3%	< 0.001
Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Q5.4	16	7,9%	66	32,7%	63	31,2%	44	21,8%	13	6,4%	< 0.001
Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant	Q5.5	6	3,0%	25	12,4%	39	19,4%	86	42,8%	45	22,4%	< 0.001
Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant	Q5.6	7	3,5%	15	7,4%	43	21,3%	94	46,5%	43	21,3%	< 0.001
External service providers are often not provided with clear specifications of the required product and services, by the power generation plant	Q5.7	14	6,9%	38	18,8%	51	25,2%	75	37,1%	24	11,9%	< 0.001

Appendix L: Pearson Chi-Square Tests

Pearson Chi-Square Tests							
		Department	Section	Gender	Job Grade	Occupation	Work experience (years)
I have been trained on how to apply scatter-plot	Chi-square	11,626	37,728	0,102	10,834	9,229	8,312
	df	10	28	1	4	6	5
	Sig.	0,311	0,104	0,749	.028*	0,161	0,140
I have been trained on how to apply cause-and-effect diagram	Chi-square	12,681	43,254	0,375	9,555	15,267	9,703
	df	10	28	1	4	6	5
	Sig.	0,242	.033*	0,540	.049*	.018*	0,084
I have been trained on how to apply Flow chart	Chi-square	11,622	44,978	0,404	11,899	19,039	10,060
	df	10	28	1	4	6	5
	Sig.	0,311	.022*	0,525	.018*	.004*	0,074
I have been trained on how to apply Pareto-diagram	Chi-square	18,196	43,929	0,010	23,986	21,228	2,067
	df	10	28	1	4	6	5
	Sig.	0,052	.028*	0,921	.000*	.002*	0,840
I have been trained on how to apply Check-sheet	Chi-square	36,678	62,648	0,723	14,605	22,113	14,150
	df	10	28	1	4	6	5
	Sig.	.000*	.000*	0,395	.006*	.001*	.015*
I have been trained on how to apply Control-chart	Chi-square	14,560	52,747	0,317	4,221	4,422	3,969
	df	10	28	1	4	6	5
	Sig.	0,149	.003*	0,573	0,377	0,620	0,554
I have been trained on how to apply Histogram	Chi-square	21,399	41,159	0,003	11,874	20,516	10,385
	df	10	28	1	4	6	5

	Sig.	.018*	0,052	0,959	.018*	.002*	0,065
The extent to which Scatter-plot is currently employed within the maintenance environment	Chi-square	50,588	162,994	3,439	20,313	26,915	22,211
	df	40	112	4	16	24	20
	Sig.	0,122	.001*	0,487	0,206	0,308	0,329
The extent to which cause-and-effect-diagram is currently employed within the maintenance environment	Chi-square	54,296	179,684	1,083	22,557	38,047	27,998
	df	40	112	4	16	24	20
	Sig.	0,065	.000*	0,897	0,126	.034*	0,109
The extent to which Flow-chart is currently employed within the maintenance environment	Chi-square	71,241	162,440	1,237	22,780	48,369	19,630
	df	40	112	4	16	24	20
	Sig.	.002*	.001*	0,872	0,12	.002*	0,481
The extent to which Pareto-diagram is currently employed within the maintenance environment	Chi-square	45,245	134,209	0,957	18,960	35,791	28,017
	df	40	112	4	16	24	20
	Sig.	0,262	0,075	0,916	0,271	0,057	0,109
The extent to which Check-sheet is currently employed within the maintenance environment	Chi-square	57,223	149,512	2,405	29,005	42,573	19,580
	df	40	112	4	16	24	20
	Sig.	.038*	.010*	0,662	.024*	.011*	0,484
The extent to which Control-chart is currently employed within the maintenance environment	Chi-square	53,449	177,329	4,656	32,275	44,325	28,823
	df	40	112	4	16	24	20
	Sig.	0,076	.000*	0,324	.009*	.007*	0,091
The extent to which Histogram is currently employed within the maintenance environment	Chi-square	63,497	155,839	7,079	32,880	52,049	35,877
	df	40	112	4	16	24	20
	Sig.	.010*	.004*	0,132	.008*	.001*	.016*
Continual improvement, within the maintenance environment, can be better achieved by applying quality tools at the power generation plant	Chi-square	37,462	102,218	4,258	9,378	27,164	21,957
	df	40	112	4	16	24	20
	Sig.	0,585	0,735	0,372	0,897	0,297	0,343
	Chi-square	51,267	117,398	2,977	17,789	29,492	24,714

The quality tools and techniques, when applied within the power generation plant, can enhance people's ability to perform	df	40	112	4	16	24	20
	Sig.	0,109	0,345	0,562	0,336	0,202	0,213
Maintenance activities at the power generation plant meets customer needs	Chi-square	48,011	131,213	2,846	17,427	48,702	21,965
	df	40	112	4	16	24	20
	Sig.	0,18	0,104	0,584	0,359	.002*	0,342
Maintenance personnel are engaged in achieving the power generation plant's maintenance objectives	Chi-square	47,621	118,553	5,322	18,215	40,401	12,415
	df	40	112	4	16	24	20
	Sig.	0,19	0,318	0,256	0,311	.019*	0,901
Sharing of knowledge and experience is encouraged among maintenance personnel	Chi-square	76,384	159,042	4,044	52,266	52,967	13,705
	df	40	112	4	16	24	20
	Sig.	.000*	.002*	0,400	.000*	.001*	0,845
Maintenance management ensure that work instructions are available before executing maintenance activities	Chi-square	40,593	117,189	6,709	9,453	31,747	6,598
	df	40	112	4	16	24	20
	Sig.	0,444	0,35	0,152	0,894	0,133	0,998
Improvement is recognised and acknowledged within the maintenance environment	Chi-square	53,705	138,426	1,550	25,347	41,028	24,092
	df	40	112	4	16	24	20
	Sig.	0,072	.046*	0,818	0,064	.017*	0,238
Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience	Chi-square	29,739	97,195	6,535	12,765	18,726	10,020
	df	40	112	4	16	24	20
	Sig.	0,882	0,839	0,163	0,69	0,766	0,968
Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance	Chi-square	60,050	136,658	3,059	11,834	32,462	16,874
	df	40	112	4	16	24	20
	Sig.	.022*	0,057	0,548	0,755	0,116	0,661
	Chi-square	43,269	118,019	0,355	13,683	31,479	27,938

There is little focus on trying to ascertain the extent to which unproductive maintenance contributes to the corrective maintenance backlog	df	40	112	4	16	24	20
	Sig.	0,334	0,33	0,986	0,622	0,14	0,111
Corrective maintenance backlog is increased by the under-utilisation of the workforce at the Power Generation Plant	Chi-square	53,929	149,684	4,255	15,812	38,566	21,896
	df	40	112	4	16	24	20
	Sig.	0,07	.010*	0,373	0,466	.030*	0,346
Corrective maintenance backlog is negatively influenced by poor management of the inventory of spares/parts at the power generation plant	Chi-square	29,024	124,843	0,945	15,005	29,324	11,576
	df	40	112	4	16	24	20
	Sig.	0,901	0,192	0,918	0,524	0,208	0,93
There is too much unnecessary motion/movement of maintenance personnel within the plant	Chi-square	45,536	148,526	2,228	18,152	62,687	31,834
	df	40	112	4	16	24	20
	Sig.	0,253	.012*	0,694	0,315	.000*	.045*
Waiting for the production plant to be available to carry out maintenance activities lead to the corrective maintenance backlog	Chi-square	42,187	130,810	5,337	37,513	33,787	17,583
	df	40	112	4	16	24	20
	Sig.	0,377	0,108	0,254	.002*	0,089	0,615
The lack of an effective maintenance data management system impedes the optimising of the maintenance backlog	Chi-square	61,579	110,097	5,369	19,121	32,338	27,807
	df	40	112	4	16	24	20
	Sig.	.016*	0,533	0,252	0,262	0,119	0,114
The level of rework due to poor maintenance workmanship is at such a level that it has a significant impact on a corrective maintenance backlog	Chi-square	33,748	125,792	1,882	13,367	32,426	12,848
	df	40	112	4	16	24	20
	Sig.	0,747	0,176	0,757	0,646	0,117	0,884
	Chi-square	45,508	147,436	0,588	11,944	22,463	16,953

The power generation plant documented information is necessary for effective management of corrective maintenance backlog	df	40	112	4	16	24	20
	Sig.	0,254	.014*	0,964	0,748	0,552	0,656
Documented information is available for use where and when is it is needed to perform corrective maintenance	Chi-square	61,148	124,395	16,465	22,368	48,385	28,478
	df	40	112	4	16	24	20
	Sig.	.017*	0,199	.002*	0,132	.002*	0,099
Documented information is suitable for the execution of corrective maintenance activities	Chi-square	50,029	93,621	6,683	9,011	42,903	20,703
	df	40	112	4	16	24	20
	Sig.	0,133	0,896	0,154	0,913	.010*	0,415
Documented information related to corrective maintenance is adequately retained as evidence of conformity	Chi-square	47,311	116,218	1,082	26,910	45,297	22,293
	df	40	112	4	16	24	20
	Sig.	0,199	0,373	0,897	.042*	.005*	0,325
The power generation plant's external non-certified service providers have a lower value-adding impact on maintenance activities outputs than the plant's external ISO 9001 certified service providers	Chi-square	79,688	164,242	0,761	19,357	58,579	17,733
	df	40	112	4	16	24	20
	Sig.	.000*	.001*	0,944	0,251	.000*	0,605
Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Chi-square	56,614	143,315	4,257	23,291	43,572	21,893
	df	40	112	4	16	24	20
	Sig.	.043*	.025*	0,372	0,106	.009*	0,346
There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close	Chi-square	78,168	133,624	7,873	16,307	46,140	31,232
	df	40	112	4	16	24	20
	Sig.	.000*	0,08	0,096	0,432	.004*	0,052

Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Chi-square	57,972	154,742	6,690	19,189	42,533	24,831
	df	40	112	4	16	24	20
	Sig.	.033*	.005*	0,153	0,259	.011*	0,208
Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant	Chi-square	57,480	146,537	6,779	13,384	50,255	14,345
	df	40	112	4	16	24	20
	Sig.	.036*	.016*	0,148	0,645	.001*	0,813
Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant	Chi-square	52,151	150,225	5,034	15,537	41,734	22,575
	df	40	112	4	16	24	20
	Sig.	0,094	.009*	0,284	0,486	.014*	0,31
External service providers are often not provided with clear specifications of the required product and services by the power generation plant	Chi-square	52,427	135,644	4,177	19,247	21,546	28,959
	df	40	112	4	16	24	20
	Sig.	0,09	0,064	0,383	0,256	0,606	0,089

Appendix M: Correlation table

Correlations

			The extent to which Scatter-plot is currently employed within the maintenance environment	The extent to which cause-and-effect-diagram is currently employed within the maintenance environment	The extent to which Flow-chart is currently employed within the maintenance environment	The extent to which Pareto-diagram is currently employed within the maintenance environment	The extent to which Check-sheet is currently employed within the maintenance environment	The extent to which Control-chart is currently employed within the maintenance environment	The extent to which Histogram is currently employed within the maintenance environment	Continual improvement, within the maintenance environment, can be better achieved by applying quality tools at the power generation plant	The quality tools and techniques when applied within the power generation plant can enhance people's ability to perform	Maintenance activities at the power generation plant meets customer needs	Maintenance personnel are engaged in achieving the power generation plant's maintenance objectives	Sharing of knowledge and experience is encouraged among maintenance personnel	Maintenance management ensure that work instructions are available before executing maintenance activities	Improvement is recognised and acknowledged within the maintenance environment	Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience	Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance	There is little focus on trying to ascertain the extent to which unproductive maintenance contributes to corrective maintenance backlog	Corrective maintenance backlog is increased by the under-utilisation of the workforce at the Power Generation Plant	Corrective maintenance backlog is negatively influenced by poor management of inventory of spares/parts at the power generation plant	There is too much unnecessary motion/movement of maintenance personnel within the plant	Waiting for the production plant to be available to carry out maintenance activities lead to corrective maintenance backlog	The lack of an effective maintenance data management system impedes the optimising of maintenance backlog	The level of rework due to poor maintenance workmanship is at such a level that it has a significant impact on corrective maintenance backlog	The power generation plant documented information is necessary for effective management of corrective maintenance backlog	Documented information is available for use where and when is it is needed to perform corrective maintenance	Documented information is suitable for the execution of corrective maintenance activities	Documented information related to corrective maintenance is adequately retained as evidence of conformity	The power generation plant's external non-certified service providers have a lower value adding impact on maintenance activities outputs than the plant's external ISO 9001 certified service	Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close	Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant	Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant	External service providers are often not provided with clear specifications of the required product and services, by the power generation plant
Spearman's rho	The extent to which Scatter-plot is currently employed within the maintenance environment	Correlation Coefficient	1,000
		Sig. (2-tailed)	
		N	194
	The extent to which cause-and-effect-diagram is currently employed within the maintenance environment	Correlation Coefficient	.672**	1,000
		Sig. (2-tailed)	0,000	
		N	192	193
	The extent to which Flow-chart is currently employed within the maintenance environment	Correlation Coefficient	.520**	.563**	1,000
		Sig. (2-tailed)	0,000	0,000	
		N	193	192	197
	The extent to which Pareto-diagram is currently employed within the maintenance environment	Correlation Coefficient	.688**	.770**	.542**	1,000
		Sig. (2-tailed)	0,000	0,000	0,000	
		N	192	191	191	192
	The extent to which Check-sheet is currently employed within the maintenance environment	Correlation Coefficient	.232**	.333**	.544**	.315**	1,000
		Sig. (2-tailed)	0,001	0,000	0,000	0,000	
		N	192	192	195	191	199
	The extent to which Control-chart is currently employed within the maintenance environment	Correlation Coefficient	.586**	.673**	.628**	.706**	.514**	1,000
		Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,000	
		N	192	192	193	191	193	194
	The extent to which Histogram is currently employed within the maintenance environment	Correlation Coefficient	.580**	.701**	.568**	.724**	.425**	.707**	1,000
		Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,000	0,000	
		N	191	191	192	190	192	192	193
	Continual improvement, within the maintenance environment, can be better achieved by applying quality tools at the power generation plant	Correlation Coefficient	0,066	.196**	.143*	0,044	.292**	.197**	.159*	1,000
		Sig. (2-tailed)	0,361	0,006	0,045	0,542	0,000	0,006	0,027	
		N	194	193	197	192	199	194	193	202
	The quality tools and techniques when applied within the power generation plant can enhance people's ability to perform	Correlation Coefficient	0,069	0,142	0,137	0,117	.258**	.226**	.208**	.739**	1,000
		Sig. (2-tailed)	0,338	0,050	0,056	0,107	0,000	0,002	0,004	0,000	
		N	193	192	196	191	198	193	192	201	201
	Maintenance activities at the power generation plant meets customer needs	Correlation Coefficient	.261**	.326**	.271**	.341**	.265**	.335**	.259**	.178*	.193**	1,000
		Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,011	0,006	
		N	194	193	197	192	199	194	193	202	201	202
	Maintenance personnel are engaged in achieving the power generation plant's maintenance objectives	Correlation Coefficient	.202**	.301**	.278**	.262**	.215**	.271**	.189**	.231**	.256**	.686**	1,000
		Sig. (2-tailed)	0,005	0,000	0,000	0,000	0,002	0,000	0,009	0,001	0,000	0,000	
		N	194	193	197	192	199	194	193	202	201	202	203
	Sharing of knowledge and experience is encouraged among maintenance personnel	Correlation Coefficient	0,102	.142*	.191**	.146*	0,132	0,120	0,082	0,049	0,118	.503**	.555**	1,000
		Sig. (2-tailed)	0,158	0,048	0,007	0,044	0,063	0,095	0,257	0,489	0,095	0,000	0,000	
		N	194	193	197	192	199	194	193	202	201	202	203	203
	Maintenance management ensure that work instructions are available before executing maintenance activities	Correlation Coefficient	.200**	.201**	.256**	.193**	.158*	.279**	.231**	.143*	.225**	.449**	.466**	.476**	1,000
		Sig. (2-tailed)	0,005	0,005	0,000	0,007	0,026	0,000	0,001	0,043	0,001	0,000	0,000	0,000	
		N	194	193	197	192	199	194	193	202	201	202	203	203	203
	Improvement is recognised and acknowledged within the maintenance environment	Correlation Coefficient	.271**	.335**	.272**	.282**	.151*	.304**	.336**	.157*	.147*	.551**	.439**	.409**	.537**	1,000
		Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,034	0,000	0,000	0,026	0,038	0,000	0,000	0,000	0,000	
		N	193	192	196	191	198	193	192	201	200	201	202	202	202	202
	Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience	Correlation Coefficient	.192**	.188**	.270**	.214**	0,121	.220**	.151*	0,110	.176*	.489**	.513**	.459**	.528**	.459**	1,000
		Sig. (2-tailed)	0,007	0,009	0,000	0,003	0,089	0,002	0,037	0,118	0,012	0,000	0,000	0,000	0,000	0,000	
		N	194	193	197	192	199	194	193	202	201	202	203	203	203	202	203
	Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance	Correlation Coefficient	.181*	.221**	.176*	.229**	0,046	.175*	.168*	0,084	0,098	.358**	.435**	.452**	.360**	.469**	.536**	1,000
		Sig. (2-tailed)	0,012	0,002	0,014	0,001	0,519	0,015	0,020	0,236	0,168	0,000	0,000	0,000	0,000	0,000	0,000	
		N	193	192	196	191	198	193	192	201	200	201	202	202	202	201	202	202
	There is little focus on trying to ascertain the extent to which unproductive maintenance contributes to corrective maintenance backlog	Correlation Coefficient	0,085	0,055	0,034	0,086	0,041	0,034	0,106	0,092	0,094	-.171*	-0,120	-0,098	-0,107	-.173*	-.143*	-0,048	1,000
		Sig. (2-tailed)	0,239	0,452	0,637	0,238	0,565	0,638	0,142	0,196	0,186	0,015	0,090	0,167	0,130	0,014	0,042	0,498	
		N	192	191	195	190	197	192	192	200	199	200	201	201	201	200	201	200	201
	Corrective maintenance backlog is increased by the under-utilisation of the workforce at the Power Generation Plant	Correlation Coefficient	-0,036	0,012	-0,014	-0,067	-0,052	-0,041	0,006	.154*	.170*	-0,071	0,006	-0,087	0,013	-0,087	-0,058	-.151*	.308**	1,000
		Sig. (2-tailed)	0,618	0,865	0,845	0,355	0,468	0,575	0,932	0,029	0,016	0,319	0,936	0,220	0,850	0,219	0,414	0,033	0,000	
		N	192	191	195	190	197	192	192	200	199	200	201	201	201	200	201	200	201	201
	Corrective maintenance backlog is negatively influenced by poor management of inventory of spares/parts at the power generation plant	Correlation Coefficient	-0,003	-0,009	0,086	-0,016	.149*	-0,028	-0,022	.173*	0,124	-0,062	0,023	0,008	-0,022	-.156*	0,004	-0,097	.400**	.397**	1,000
		Sig. (2-tailed)	0,967	0,906	0,232	0,822	0,037	0,695	0,759	0,014	0,081	0,385	0,742	0,906	0,757	0,028	0,959	0,170	0,000	0,000	
		N	192	191	195	190	197	192	192	200	199	200	201	201	201	200	201	200	201	201	201
	There is too much unnecessary motion/movement of maintenance personnel within the plant	Correlation Coefficient	0,057	-0,037	-0,045	-0,049	0,032	-0,076	-0,087	0,135	.151*	-0,052	-0,013	-0,033	0,000	-0,023	-0,061	-.150*	.269**	.384**	.335**	1,000
		Sig. (2-tailed)	0,435	0,608	0,533	0,506	0,655	0,297	0,228	0,057	0,034	0,465	0,857	0,638	0,998	0,742	0,389	0,034	0,000	0,000	0,000	
		N	192	191	195	190	197	192	192	200	199	200	201	201	201	200	201	200	201	201	201	201
	Waiting for the production plant to be available to carry out maintenance activities lead to corrective maintenance backlog	Correlation Coefficient	0,099	0,031	.194**	0,068	0,105	0,038	0,085	.270**	.294**	0,084	.180*	.167*	.193**	0,107	0,093	0,082	.214**	.190**	.338**	.253**	1,000
		Sig. (2-tailed)	0,172	0,672	0,007	0,351	0,143	0,596	0,244	0,000	0,000	0,239	0,011	0,018	0,006	0,130	0,189	0,249	0,002	0,007	0,000	0,000	
		N	192	191	195	190	197	192	192	200	199	200	201	201	201	200	201	200	201	201	201	201	201
	The lack of an effective maintenance data management system impedes the optimising of maintenance backlog	Correlation Coefficient	0,137	.153*	0,059	0,073	0,105	0,124	.171*	.274**	.272**	-0,001	0,061	0,000	0,020	0,092	0,023	0,132	.308**	.239**	.317**	.152*	.238**	1,000
		Sig. (2-tailed)	0,058	0,035	0,417	0,320	0,144	0,088	0,018	0,000	0,000	0,988	0,393	0,995	0,783	0,194	0,751	0,064	0,000	0,001	0,000	0,032	0,001	
		N	191	190	194	189	196	191	191	199	198	199	200	200	200	199	200	199	200	200	200	200	200	200
	The level of rework due to poor maintenance workmanship is at such a level that it has a significant impact on corrective maintenance backlog	Correlation Coefficient	0,054	-0,026	0,047	0,023	0,116	0,020	0,006	.310**	.264**	-.161*	-0,097	-0,104	0,050	-0,028	-0,006	-0,050	.315**	.331**	.401**	.264**	.309**	.363**	1,000
		Sig. (2-tailed)	0,455	0,722	0,511	0,750	0,105	0,784	0,930	0,000	0,000	0,023	0,171	0,140	0,479	0,699	0,935	0,479	0,000	0,000	0,000	0,000	0,000	0,000	
		N	192	191	195	190	197	192	192	200	199	200	201	201	201	200	201	200	201	201	201	201	201	200	201
	The power generation plant documented information is necessary for effective management of corrective maintenance backlog	Correlation Coefficient	0,029	0,040	0,100	0,000	.150*	0,084	0,062	.363**	.221**	.146*	.167*	.158*	0,117	.148*	.147*	0,101	.185**	.177*	.365**	.304**	.349**	.281**	.342**	1,000
		Sig. (2-tailed)	0,693	0,586	0,166	1,000	0,036	0,249	0,392	0,000	0,002	0,039	0,018	0,025	0,098	0,036	0,038	0,155	0,009	0,012	0,000	0,000	0,000	0,000	0,000	
		N	192	191	195	190	197	192	191	200	199	200	201	201	201	200	201	200	200	200	200	200	200	199	200	201
	Documented information is available for use where and when it is needed to perform corrective maintenance	Correlation Coefficient	0,070	0,051	0,088	0,129	0,095	.189**	.156*	.194**	.156*	.248**	.226**	.338**	.327**	.238**	.265**	.326**	-0,021	0,023	-0,025	0,035	0,081	0,128	0,124	.269**	1,000
		Sig. (2-tailed)	0,337	0,485	0,224	0,077	0,188	0,009	0,032	0,006	0,029	0,000	0,001	0,000	0,000	0,001	0,000	0,000	0,767	0,744	0,722	0,625	0,259	0,073	0,081	0,000	
		N	190	189	193	188	195	190	189	198	197	198	199	199	199	198	199	198	198	198	198	198	198	197	198	199	199
	Documented information is suitable for the execution of corrective maintenance activities	Correlation Coefficient	0,076	0,051	0,114	0,113	0,007	0,140	.182*	.238**	.192**	.235**	.231**	.232**	.195**	.291**	.283**	.302**	-0,079	0,069	0,007	0,119	0,048	.151*	0,096	.415**	.625**	1,000
		Sig. (2-tailed)	0,293	0,486	0,114	0,122	0,927	0,053	0,012	0,001	0,007	0,001	0,001	0,001	0,006	0,000	0,000	0,000	0,265	0,333	0,919	0,092	0,503	0,033	0,177	0,000	0,000	
		N	192	191	195	190	197	192	191	200	199	200	201	201	201	200	201	200	200	200	200	200	200	199	200	201	199	201
	Documented information related to corrective maintenance is adequately retained as evidence of conformity	Correlation Coefficient	0,133	0,129	0,038	0,133	-0,058	.154*	0,128	0,105	0,107	.263**	.282**	.348**	.167*	.326**	.299**	.396**	-0,133	0,029	-0,127	-0,007	0,005	0,097	-0,012	.159*	.516**	.541**	1,000
		Sig. (2-tailed)	0,065	0,074	0,596	0,068	0,419	0,033	0,077	0,138	0,133	0,000	0,000	0,000	0,018	0,000	0,000	0,000	0,060	0,688	0,072	0,925	0,949	0,174	0,867	0,024	0,000	0,000	
		N	192	191	195	190	197	192	191	200	199	200	201	201	201	200	201	200	200	200	200	200	200	199	200	201	199	201	201
	The power generation plant's external non-certified service providers have a lower value adding impact on maintenance activities outputs than the plant's external	Correlation Coefficient	-0,032	-0,028	0,139	0,003	.168*	0,104	0,036	.147*	0,098	-0,022	0,023	0,055	.148*	0,047	0,036	-0,006	0,008	.167*	.167*	0,114	.243**	0,113	0,132	.210**	.240**	.163*	0,027	1,000
		Sig. (2-tailed)	0,656	0,700	0,052	0,966	0,018	0,152	0,623	0,037	0,168	0,759	0,741	0,440	0,036	0,507	0,609	0,937	0,915	0,018	0,018	0,107	0,001	0,111	0,063	0,003	0,001	0,020	0,707	
		N	193	192	196	191	198	193	192	201	200	201	202	202	202	201	202	201	200	200	200	200	200	199	200	201	199	201	201	202
	Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Correlation Coefficient	-0,039	-0,033	0,017	0,002	0,010	0,004	-0,047	-0,032	-0,061	-.194**	-0,039	-0,083	0,009	-.165*	-.171*	-0,117	0,087	0,116	0,048	0,023	.171*	0,070	0,007	-0,007	0,089	-0,067	-0,113	.334**	1,000
		Sig. (2-tailed)	0,593	0,645	0,808	0,980	0,887	0,957	0,517	0,658	0,389	0,006	0,584	0,239	0,897	0,020	0,015	0,098	0,223	0,103	0,497	0,752	0,016	0,324	0,924	0,926	0,212	0,343	0,112	0,000	
		N	193	192	196	191	198	193	192	200	199	200	201	201	201	200	201	200	199	199	199	199	199	198	199	200	198	200	200	201	201
	There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close	Correlation Coefficient	0,102	0,122	.223**	0,104	.296**	.224**	.142*	.353**	.327**	0,071	0,134	-0,016	0,056	0,001	0,078	-0,010	.178*	0,108	.265**	.195**	.374**	.241**	.187**	.372**	0,131	.178*	0,026	.328**	.195**	1,000
		Sig. (2-tailed)	0,156	0,092	0,002	0,154	0,000	0,002	0,049	0,000	0,000	0,314	0,058	0,825	0,432	0,986	0,272	0,887	0,012	0,129	0,000	0,006	0,000	0,001	0,008	0,000	0,065	0,012	0,719	0,000	0,005	
		N	193	192	196	191	198	193	192	201	200	201	202	202	202	201	202	201	200	200	200	200	200	199	200	201	199	201	201	202	201	202
	Compared to the internal service providers, the external service providers do not provide the power generation plant with a higher level of service quality	Correlation Coefficient	-0,008	0,074	-0,018	0,092	0,040	0,065	-0,001	0,038	0,007	-0,071	0,036	-0,025	-0,056	-0,106	-0,072	-0,080	0,103	0,054	0,005	0,059	.159*	0,065	0,009	-0,019	.167*	0,020	0,058	.195**	.669**	.263**	1,000
		Sig. (2-tailed)	0,912	0,308	0,806	0,207	0,575	0,373	0,993	0,591	0,925	0,315	0,612	0,725	0,427	0,134	0,307	0,261	0,146	0,447	0,942	0,404	0,025	0,361	0,900	0,787	0,019	0,775	0,413	0,005	0,000	0,000	
		N	193	192	196	191	198	193	192	201	200	201	202	202	202	201	202	201	200	200	200	200	200	199	200	201	199	201	201	202	201	202	202
	Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant	Correlation Coefficient	0,091	0,141	.165*	0,098	0,128	.168*	0,090	.281**	.254**	.158*	.260**	0,056	0,077	0,042	0,134	0,059	0,067	.211**	.230**	0,099	.312**	.156*	0,115	.140*	0,113	0,085	-0,017	.262**	.288**	.259**	.363**	1,000
		Sig. (2-tailed)	0,209	0,051	0,021	0,178	0,072	0,020	0,213	0,000	0,000	0,025	0,000	0,428	0,279	0,553	0,058	0,409	0,350	0,003	0,001	0,162	0,000	0,028	0,105	0,048	0,113	0,230	0,814	0,000	0,000	0,000	0,000	
		N	192	191	195	190	197	192	191	200	199	200	201	201	201	200	201	200	199	199	199	199	199	198	199	200	199	200	200	201	200	201	201	201
	Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant	Correlation Coefficient	0,139	.192**	.217**	.159*	.183*	.201**	0,069	.266**	.204**	0,119	.182**	0,037	0,088	-0,008	.172*	0,046	0,105	.174*	.277**	0,050	.335**	.158*	.166*	.146*	0,052	-0,003	-0,048	.226**	.251**	.344**	.332**	.735**	1,000
		Sig. (2-tailed)	0,054	0,008	0,002	0,028	0,010	0,005	0,341	0,000	0,004	0,093	0,009	0,599	0,212	0,906	0,015	0,520	0,138	0,014	0,000	0,483	0,000	0,025	0,019	0,039	0,466	0,970	0,502	0,001	0,000	0,000	0,000	0,000	
		N	193	192	196	191	198	193	192	201	200	201	202	202	202	201	202	201	200	200	200	200	200	199	200	201	199	201	201	202	201	202	202	201	202
	External service providers are often not provided with clear specifications of the required product and services, by the power generation plant	Correlation Coefficient	0,091	0,049	0,050	0,012	0,072	0,020	0,083	0,091	0,135	0,057	0,033	0,027	-0,023	-0,013	0,045	-0,013	.271**	.177*	.216**	.326**	.173*	0,129	0,134	.271**	0,061	.141*	-0,045	0,091	0,096	.179*	0,126	.221**	.188**	1,000
		Sig. (2-tailed)	0,208	0,500	0,487	0,867	0,314	0,779	0,251	0,201	0,057	0,425	0,642	0,704	0,749	0,849	0,524	0,856	0,000	0,012	0,002	0,000	0,014	0,069	0,059	0,000	0,391	0,046	0,529	0,197	0,175	0,011	0,075	0,002	0,007	
		N	193	192	196	191	198	193	192	201	200	201	202	202	202	201	202	201	200	200	200	200	200	199	200	201	199	201	201	202	201	202	202	201	202	202

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix O: Turnitin report

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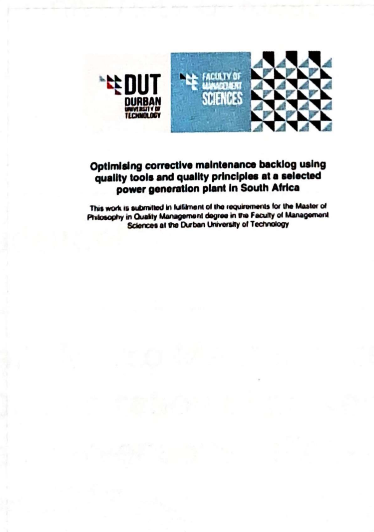

DUT DURBAN UNIVERSITY OF TECHNOLOGY

FACULTY OF MANAGEMENT SCIENCES

Optimising corrective maintenance backlog using quality tools and quality principles at a selected power generation plant in South Africa

This work is submitted in fulfilment of the requirements for the Master of Philosophy in Quality Management degree in the Faculty of Management Sciences at the Durban University of Technology

Optimising corrective maintenance backlog using quality tools and quality principles at a selected power generation plant in South Africa

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Appendix P: Gate keeper's approval

PG 2a

DUT DURBAN UNIVERSITY OF TECHNOLOGY

Faculty of Management Sciences

Department of Operations and Quality Management

Date: 01 July 2019

Dear Mr Thomas Conradie

A permission is requested to conduct a research at your business unit for a period of approximately 2 years and not exceeding 3 years. The research will commence from July 2019 and estimated end date of December 2020. The research will be under the auspices of Durban University of Technology and supervised by Dr Manduth Ramchander.

The research will focus on a power generation plant to explore the impact of quality management in support of maintenance strategies to obtained optimal performance. Purpose of the study is to explore quality strategies that can assist in reducing corrective maintenance backlog that affect plant health. This can be achieved through the application of quality tools and quality principles within a maintenance environment.

The maintenance standard is to execute 20% of corrective maintenance and 80% of the preventive maintenance. The current situation that this study aim to influence is standing 43% corrective maintenance and 57% preventive maintenance. Further objective of the research is to come up with a practical and implementable framework that can support maintenance strategies in order to improve business performance.

The study will use a combination of questionnaires, interviews and SAP system to collect the necessary data during the research period. No risk to people, animal and environment is anticipated throughout the study. The research is governed by Durban University of Technology's ethics policy and guidelines. Hence this research can be classified as ethically binding.

Contribution arising from the study will include the following; to provide the business unit with practical and implementable framework to reduce CM backlog towards 20% and automatically influence PM execution towards 80%. The research will also highlight some gaps during the period of investigation that the business unit can address and bring about improvement in those areas. Some learning will also be shared between the researcher and the people involved. The business unit can end up being the benchmark site within the division. Externally the study will contribute to the body of knowledge within the quality management fraternity.

Yours Sincerely,

E-mail: maseolmm@eskom.co.za; Cell: 082 908 8179; Work: (016) 457 5488
Student Contact Details

E-Mail: ManduthR@dut.ac.za; Cell: 0744004400; Work: (031) 373 5288
Supervisor / Promoter Contact Details

N/A
Co-Supervisor/Co-Promoter Contact Details

Approved:	✓	Not Approved:		Signature:		Date:	2019-07-03

Comments: ....

....

Moses Maseola – 21856763 24

Appendix Q: Ethics approval letter

MANAGEMENT SCIENCES: FACULTY RESEARCH ETHICS COMMITTEE (FREC)

14 February 2020

Student Name: **Mr M Maseola**

Student No: **21856763**

FREC REF: 64/19FREC

Dear **Mr M Maseola**

MASTER OF PHILOSOPHY IN QUALITY

TITLE: OPTIMISING CORRECTIVE MAINTENANCE BACKLOG USING QUALITY TOOLS AND PRINCIPLES AT A POWER GENERATION PLANT IN SOUTH AFRICA

Please be advised that the FREC Committee has reviewed your proposal and the following decision was made: **Approved – Ethics Level 2**

Date of FRC Approval: 30th October 2019

Approval has been granted for a period of two years from the above FRC date, after which you are required to apply for safety monitoring and annual recertification. Please use the form located at the Faculty. This form must be submitted to the FREC at least 3 months before the ethics approval for the study expires.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the FREC according to the FREC SOP's.
Please note that ANY amendments in the approved proposal require the approval of the FREC as outlined in the FREC SOP's.

Yours sincerely

____

Prof JP Govender

Chairperson: Faculty Research Ethics Committee

Appendix R: Research consent letter

PG 2a

DUT DURBAN UNIVERSITY OF TECHNOLOGY

INSTITUTIONAL RESEARCH ETHICS COMMITTEE

CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, **Moses Maseola** (name of researcher), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: 64/19FREC ,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

Full Name of Participant **Date** **Time** **Signature / Right Thumbprint**

I, **Moses Maseola** (name of researcher) herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Moses Maseola
Full Name of Researcher 2020/06/23 **Date** **Signature**

Full Name of Witness (If applicable) **Date** **Signature**

Full Name of Legal Guardian (If applicable) **Date** **Signature**

Appendix S: Research letter of information

PG 2a

DUT DURBAN UNIVERSITY OF TECHNOLOGY — INSTITUTIONAL RESEARCH ETHICS COMMITTEE

LETTER OF INFORMATION

Title of the Research Study:
Optimising corrective maintenance backlog using quality tools and quality principles at a selected power generation plant in South Africa
Principal Investigator/s/researcher:
Moses Maseola, Master of Philosophy in Quality Management
Co-Investigator/s/supervisor/s:
Dr Manduth Ramchander, PhD
Brief Introduction and Purpose of the Study:
The research will focus on a power generation plant to explore the effect of quality management in support of maintenance strategies to obtained optimal maintenance performance. Main drive of the study is to reduce corrective maintenance backlog that affect plant health (reliability & availability) through the use of statistical tools and quality principles at a power generation plant.

The study will use a combination of questionnaires, interviews and SAP system to collect the necessary data during the research period. No risk to people, animal and environment is anticipated throughout the study. The research is governed by Durban University of Technology's ethics policy and guidelines.

Contribution arising from the study will be to improve business unit performance by minimising execution of CM's towards 20% and maximising PM's execution towards 80%. The study will also donate to the body of knowledge within quality management fraternity.
Outline of the Procedures:
The affected employees will be requested to participate in answering the questionnaires and partake in the interviews. The study will take place at the business area and at the participant's convenience space and time. The names of participants will not be mentioned in the study, only data obtained from them will be used in the research. To fill-in the questionnaires will be 20 minutes at the most and the interview to be not more than 30 minutes. Only top management will be interviewed for the research.
Risks or Discomforts to the Participant:
No risk to people, animal and environment is anticipated throughout the study
Benefits: No direct benefits to the participants. The benefits to the researcher will be the qualification and publication of the article.
Reason/s why the Participant May Be Withdrawn from the Study: Participation will be on a voluntary base and no consequences to the participant should they wish to withdraw from participating in the research.
Remuneration: The participant will not receive any monetary or other types of remuneration when participating in the research.
Costs of the Study: The participant will not be expected to incur any costs towards the study.
Confidentiality: The study is governed by Durban University of Technology's ethics policy and guidelines. Names of the participants will remain anonymous throughout the study.
Research-related Injury: Injury during the research is highly unlikely to happen and no remuneration in that regard is expected.
Persons to Contact in the Event of Any Problems or Queries:
Please contact the researcher at (0829088179), my supervisor (Dr. Ramchander, senior lecturer at 0744004400) or the Institutional Research Ethics administrator on 031 373 2900. Complaints can be reported to the DVC: TIP, Prof F. Otieno on 031 373 2382 or dvctip@dut.ac.za.

Appendix T: Editor's report

Report by: Babalwa Nchekwube - Language Editor

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unique words

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Sentence Length

Measures average sentence length

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words per sentence