Maintenance planning and asset optimisation processes in relation to production performance in South African mining operations

ADMIRE MHONDIWA

Student No. - 300029

300029@students.wits.ac.za

Supervisor – Prof. Logan Rangasamy

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DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted for the degree of Master of Business Administration to the Wits Business School, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

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Abstract

In the dynamic realm of South African mining, this report delves into the intricate interplay between maintenance planning, asset optimisation, and production performance. Drawing upon insights from industry professionals, the study identifies key themes that shape maintenance management dynamics within this context. The integration of sophisticated systems such as SAP and JD Edwards emerged as a crucial theme, highlighting the importance of leveraging advanced technology to streamline maintenance operations and enhance communication across various departments. Additionally, the significance of data-driven decision-making is underscored, emphasising the use of analytics tools and performance metrics to inform maintenance strategies and optimise resource allocation. Human factors, including personnel skills and organisational culture, are also recognised as pivotal in driving operational efficiency, emphasizing the importance of investing in employee training, and fostering a positive work environment.

Through meticulous interview transcripts analysis, the report proposes methodologies aimed at enhancing maintenance practices and optimising production performance. These methodologies encompass the identification of best practices gleaned from industry experience, as well as the formulation of actionable recommendations tailored to the specific challenges faced by mining companies in South Africa. By providing a comprehensive understanding of maintenance management dynamics and offering practical strategies for improvement, this study equips mining companies with the knowledge and tools needed to navigate the complexities of the South African mining industry. Ultimately, the report serves as a roadmap for achieving operational excellence amidst the challenges of the mining sector, enabling industry stakeholders to thrive in a competitive and ever-evolving environment.

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Abbreviations

KPI – Key Performance Indicators

MTBF – Mean time between failures

MTTR – Mean time to repair.

OEE – Overall equipment effectiveness

SAP – Systems Applications and Products in data processing

RCM – Reliability-Centered Maintenance

IoT – Internet of Things

RO – Research objective

Operational Definitions

***Maintenance* -** the process of preserving a condition of a machine or equipment to maximise service life or production.

***Maintenance planning* -** is a process of determining which assets or facilities need to be maintained, when they need to be maintained, at what intervals, by whom and the identification of the resources required for the maintenance.

***Asset* -** anything that has current or future economic value to a business and examples include patents, machinery, and investments.

***Asset optimisation strategy* –** is the process of finding the best use of assets for a company, by finding the balance between efficiency and reliability.

***Production performance* -** is the process of combining various inputs, both material and immaterial to create output and the output is measured against a set target.

***Metrics* –** a system or standard of measurement of performance and/or effectiveness

***Benchmarking* –** is a process of evaluating something against a known standard or a company that is considered to be the best in an industry.

***Key Performance Indicator (KPI)* –** this is a quantifiable measure that is used to evaluate the performance of a process, organisation among others, in meeting objectives for performance.

Total quality management (TQM) - is a management framework based on the belief that an organisation can build long-term success by having all its members, from low-level workers to its highest-ranking executives, focus on improving quality thus delivering customer satisfaction.

CHAPTER 1 – INTRODUCTION

1. Background

The South African mining sector is being characterised by large and well-established mining operations. The mining sector is becoming an important source of economic growth and development in the country. As such, mining operations are employing effective maintenance planning and asset optimisation processes to ensure that output is being efficiently produced. Most of these operations are employing sophisticated and expensive maintenance planning and asset optimisation processes.

Mining is requiring a huge amount of capital, which is being compounded with the harsh working conditions, leading to maintenance being one of the main contributors to total operational costs. To optimise profits, maintenance is needing to be done more efficiently and effectively. Innovation and technological advancement are having a positive impact on production performance within the South African mining industry. As the industry is expanding, it is important that both maintenance planning and asset optimisation are being explored to maximise production performance.

Maintenance planning, in relation to mining complexes, is requiring that all equipment is being maintained and functioning at optimal levels. To ensure proper maintenance planning, South African mines are considering the physical condition of all pieces of machinery, downtime, cost, and potential risks (Chinomona *et al.*, 2018). To achieve this, mining companies are employing maintenance techniques which are involving preventive, corrective, and predictive maintenance activities (Hussain and Sego, 2013).

An optimised maintenance plan is using an appropriate mix of all forms of maintenance, allowing for the best possible return on invested time and resources (Chinomona *et al.*, 2018). Maintenance planning and scheduling are adding value to businesses by efficiently utilising physical assets like plants, equipment, machinery, and infrastructure for product delivery. Enhanced planning is reducing time and resource wastage in asset maintenance, optimising production output (Bin95, 2003).

Simply put, maintenance planning is being the process of determining when and where maintenance activities are being performed on equipment, and what materials and spares are required to do so. It is involving the scheduling of routine preventive maintenance and other corrective maintenance activities as required to keep equipment functioning at peak levels, as well as deciding which spares to keep in inventory and deciding when to order replacement parts. The goal of maintenance planning is to be reducing the amount of downtime associated with machine breakdowns to maximise machine uptime and boost productivity.

In the real world, companies are needing to make profits for them to be viable. This is meaning taking on the risk of plant stoppages for maintaining the assets. Asset optimisation is seeking to minimise downtime while maximising profits by accurately modelling and projecting asset use, thus optimising the use of the asset. Asset optimisation is the process of finding the best use of assets for a company. Asset optimisation is seeking to find the balance between efficiency and reliability (Aspentech, 2023). Asset optimisation plans are needing to consider how individual, and all assets are best being managed for maximum efficiency, safety, and value throughout their service life.

To ensure successful asset optimisation, South African mining operations are implementing Total Quality Management (TQM) approaches in their systems (Kurniawan, 2019). TQM is helping to determine the costs, processes, and outputs of assets (Kurniawan, 2019). It is also necessary to be evaluating and reevaluating the effectiveness of the TQM and deciding how best to improve and optimise the maintenance of assets. Risk analysis and benchmarking are being important components in the asset optimisation process, assisting in identifying weaknesses and evaluating the effectiveness of current processes (Kurniawan, 2019).

1.1 Context of the study

This study is examining how maintenance planning and asset optimisation processes in South African mining operations are improving production performance. The study is considering how periodic maintenance activities, proper asset selection and management, as well as spare part availability, are improving production results. The research is focusing on how the maintenance planning and asset optimisation processes are being interconnected, to determine how each is directly affecting production performance. Furthermore, the study is investigating the challenges faced by South African mining operations in optimising their assets, and the possible strategies to improve performance in terms of maintenance and asset management in relation to production.

1.2 Problem Statement

The biggest challenge facing mining companies is how to create sustainable profits while working in a dynamic market environment to stay ahead of the competitors. The main objectives of this study are identifying how key maintenance planning and asset optimisation processes are influencing production performance in South African mining operations and determining how these processes can be improved to maximise production performance. Furthermore, this study is assessing the effectiveness of initiatives such as maintenance outsourcing and predictive analysis in improving production performance and developing new methodologies.

1.3 Objective of the study

This study is analysing the association between maintenance planning, asset optimisation, and production performance in South African mining operations. It is assessing the benefits and detriments of utilising asset optimisation processes to inform and improve mining production performance. The objectives of this study are to assess the impact of maintenance planning and asset optimisation processes on production performance in South African mining operations and to identify and develop methodologies/ways for improving operational efficiency.

The research is critically examining the current propositions in the field of maintenance planning and asset optimisation in relation to production performance. There is a need to gain a deeper understanding of the topic, identify areas for further exploration, and provide practical recommendations for organisations to enhance their maintenance planning and asset optimisation strategies, ultimately leading to improved production performance.

1.4 Justification/Rationale of the Study

Through this research, a better understanding is being gained of how maintenance planning and asset optimisation processes are affecting production performance in the South African mining industry. The research is important and valuable for several reasons. It is providing mining practitioners with valuable knowledge and understanding of the impact of maintenance planning and asset optimisation on production performance. This is helping them identify areas for improvement, optimise their maintenance strategies, and make informed decisions to maximise the utilisation of mining assets, thereby improving their operational efficiency, reducing downtime, and increasing productivity. Additionally, the mining industry is a significant contributor to the South African economy. By investigating the relationship between maintenance planning, asset optimisation, and production performance, the research is contributing to the development of strategies and practices that can boost the productivity and competitiveness of mining operations. This is leading to increased economic growth, job creation, and sustainable development within the mining sector. Moreover, the research is advancing scholarly knowledge by contributing to the existing body of scholarship in the field of maintenance planning, asset optimisation, and production performance in the context of South African mining operations. The study is enhancing our understanding of the complex dynamics and interplay between maintenance processes, asset optimisation strategies, and production performance outcomes.

1.5 Delimitations of the Study

The study is confined to how maintenance planning and asset optimisation are affecting or is linked to production performance, with no other parameters being investigated. The study is also only focusing on a few major mining companies.

1.6 Structure of the Dissertation

The dissertation will be comprised of five chapters, references, and appendices. The contents of the chapters are as follows:

Chapter 1 - Introduction

This chapter discusses the challenges that are faced by mining production operations in South Africa with respect to maintenance planning and asset optimisation are discussed. The chapter also includes the background of the topic, context of the study, problem statement, study objectives, justification of the study, delimitations of the study, and operational definitions.

Chapter 2 - Literature review

This chapter details the various strategies and processes associated with maintenance planning and asset optimisation in the South African mining industry. The existing studies on the management of asset optimisation with respect to production performance are analysed, taking into consideration the overall maintenance planning structure as well as innovations that have been developed to make the process more efficient and effective. The literature review explores the factors that influence the maintenance planning and the asset optimisation process such as technological advancements, changing regulations and public opinion.

Chapter 3 - Research Methodology

This chapter provides an outline of the methods used to gather relevant data and information. Qualitative methods are used to allow for the exploration of multiple perspectives on the study objectives and includes interviews with participants. The research is benchmarked against similar studies from related industries.

Chapter 4 – Analysis of results

In this chapter, the results of the study are presented and analysed.

Chapter 5 – Discussion of results, Conclusions and Recommendations:

This chapter discusses the results and provides some recommendations and conclusions drawn from the findings of the study.

CHAPTER 2 – LITERATURE REVIEW

2. Introduction

The literature review is focusing on the importance of maintenance planning and asset optimisation, and their impact on production performance. The South African mining industry is currently facing many challenges, including environmental and climate change pressures, trade wars and geopolitics, changing and uncertain demand, as well as technology changes, and a global maintenance skills shortage (Borley, 2022). Maintenance is one of the driving forces behind production, ensuring the sustainability of the business. Maintenance is being adequately planned and executed so that the assets are always ready and available when required for use as they are directly linked to production. All the assets are needing to be optimised so that production targets are being met.

2.1 Review of empirical literature

2.1.1 Maintenance Planning and its importance

Every organisation is having sound asset management strategies to be successful. The main reason for any business to be having interest in their asset management is as depicted below:

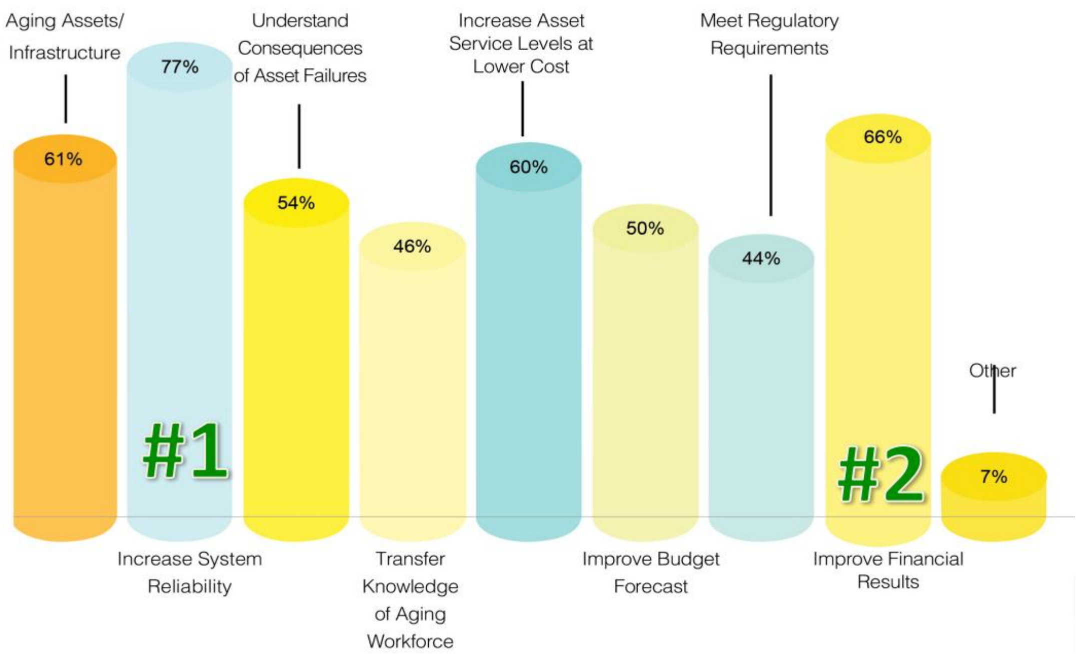

Fig 1: *Why an organisation should have an interest in their Asset Management (Abad, 2015)*

In maintenance planning and scheduling, the value of planning and scheduling contribution is in reducing the time wasted and minimising resources used in looking after the physical assets of an operation and resulting in maximum production. Maintenance is being seen as a subset of asset management, which is the management of physical assets over the whole life cycle to optimise operating profit (Abad, 2015).

For maintenance to improve the operating performance of equipment, six key factors are being required: reducing the risk when operating, reducing plant failures, providing reliability of the equipment, achieving the least operating costs, eliminating defects in the operating plant, and maximising production. To achieve these factors, all the involved people are needing to work together i.e., operations, maintenance, and engineering personnel. They are all needing to have great discipline, cooperation, and integration within the systems (Palmer, 2018).

Maintenance planning is a process that involves the development of a comprehensive plan for the maintenance of equipment, machinery, and facilities. It is a critical aspect of any organisation that relies on equipment and machinery to carry out its operations. The primary objective of maintenance planning is to ensure that equipment and machinery are being maintained and are in good working condition to minimise downtime, reduce repair costs, and therefore extend the lifespan of the equipment. This section is discussing the benefits of implementing a maintenance planning program, which includes, among others, reducing downtime, reducing repair costs, extending equipment lifespan, and improving safety (Bin95, 2003).

2.1.2 Asset Management and Optimisation

Asset management and optimisation are the processes of managing, maintaining, and improving physical and digital assets to achieve optimal performance. Asset management is often correlated with production performance because of the importance of assets in the production process. The goal of asset management is to reduce risk, improve efficiency, and ultimately optimise investment.

Asset management is examining how assets such as tools, machines, and products are being used in the production process and how their performance can be improved to ensure that productions are maintaining efficient operations. By monitoring production performance, unnecessary costs are being avoided, and asset strategies are being updated to drive optimised returns from the assets involved. A thorough understanding of the functions and specifications of each of the assets is helping to determine the best way for them to be used and managed. Additionally, understanding the environment in which the assets are being used and operated, such as the climate and geography, is ensuring that the assets are being maintained and operated correctly.

Once the assets and their usage are understood, a set of maintenance processes is being established to ensure that they are being maintained correctly. This includes ensuring regular cleaning and lubrication, checking of parts and components, as well as monitoring of wear and tear. Establishing maintenance processes is allowing for early identification of issues that could later result in costly repairs and reduced efficiency. Asset optimisation, on the other hand, is ensuring that an organisation's assets are operating at their maximum potential, reducing maintenance costs, and increasing the lifespan of the asset. By optimising assets, organisations are reducing the risk of equipment failure, improving safety, and in the end, increasing profitability of the business.

Tam and John (2007) are asserting that maintenance optimisation is presenting a multifaceted challenge for asset managers. Recently, research emphasis has been pivoting toward asset management, recognising maintenance as pivotal within physical asset management. This perspective is drawing from Tsang et al.'s (2000) proposal of three concurrent decision dimensions output, risk, and resource essential for integrated maintenance optimisation. The company is defining the resources applicable to a system, serving as control variables in the process. Outputs are results related to production and are usually being set as targets by the company. However, it is a partially controlled variable as it cannot be guaranteed. This is the dependent variable that is depending on the two other dimensions. For example, fewer resources and higher performance goals are tending to have a greater risk aspect.

2.1.2.1 Strategies for Achieving Optimal Asset Management and Optimisation

To achieve optimal asset management and optimisation, organisations are implementing a range of strategies. These strategies involve tracking and monitoring assets to ensure efficient utilisation, using predictive maintenance to employ data analytics and machine learning to predict when an asset is likely to fail, and utilising asset performance management to monitor the performance of assets and identify areas for improvement. Additionally, asset lifecycle management is essential, which involves managing an asset from acquisition to retirement, including maintenance, repairs, and upgrades to ensure the asset operates at its maximum potential throughout its lifecycle. Furthermore, risk management is playing a critical role by identifying and mitigating risks associated with asset management and optimisation, which includes identifying potential failure points, developing contingency plans, and implementing risk mitigation strategies. Industries that are heavy on assets are always under a lot of pressure from tight operational or capital budgets, as plant leaders are always striving to improve on safety and production while making sure their teams are well trained to do the jobs. The onset of the COVID-19 pandemic is exacerbating the challenges being faced by plant managers and necessitating the need to optimise the maintenance and allocation of assets to maximise productivity and returns.

Asset Performance Management has different levels of maturity, and they range in technological sophistication. Depicted below are the levels and mature APM programmes can utilise all the levels.

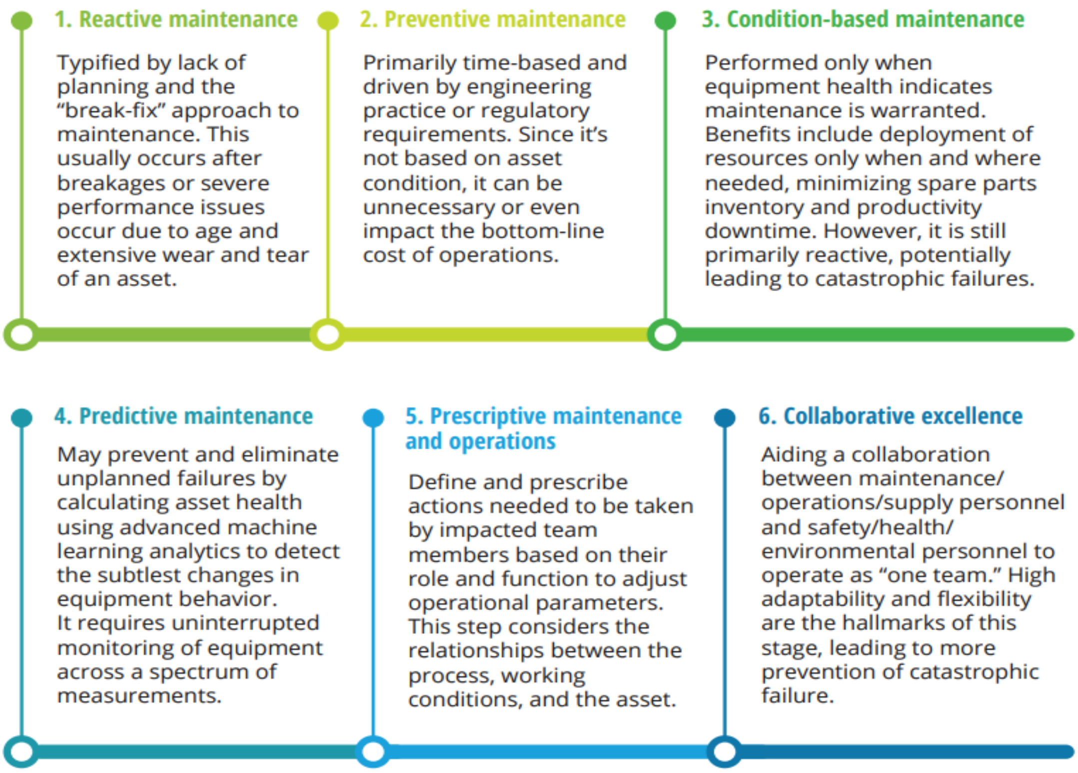

Fig. 2: *Different levels of APM approaches (Daecher, et al, 2019)*

To drive the APM, there are three pillars of Asset Management, namely:

People – these are the solution champions and managers. Responsible for creating and sharing their APM knowledge within the plant and across the industry to make informed and timely decisions that ultimately impact risk, cost, and performance.

Processes - that reflects and influences best practices and regulations and ensures that the correct direction, escalation procedures and discussions are in place for safe and efficient work.

Technology - that provide additional intelligence to increase efficiency by ensuring connectivity and understanding, especially in areas that are difficult to access or difficult to understand.

According to Filmer (2009), the mining and metals industry is improving its business operations by adopting a comprehensive approach that encompasses people, processes, and technology. He suggests that this approach is helping the industry achieve better performance, efficiency, and profitability. Filmer (2009) argues that the key to success in this industry is focusing on continuous improvement and investing in research and development. He emphasises the importance of using modern technologies such as automation, data analytics, and artificial intelligence to optimise operations and reduce costs. He also stresses the need for mining and metals companies to engage with stakeholders and implement sustainable practices to build trust and maintain a social license to operate.

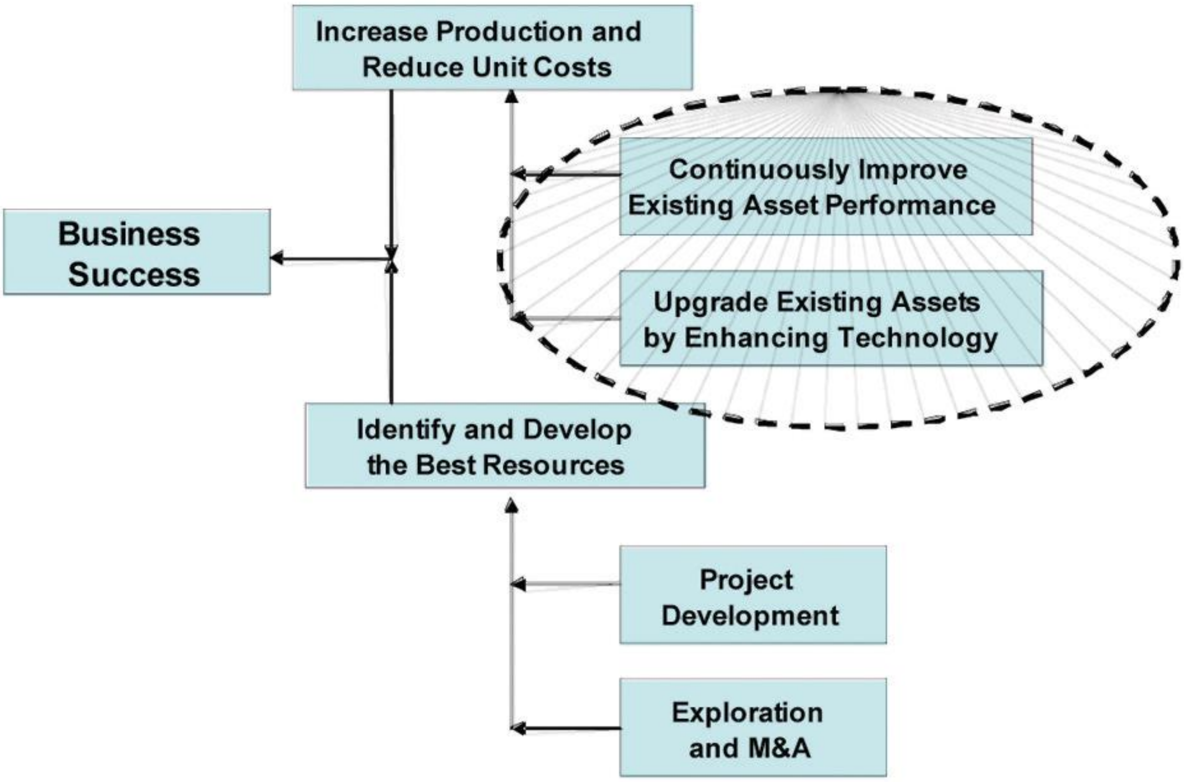

Fig. 3: *Asset effectiveness improvement though enhanced technology and/or continuous improvement (Filmer, 2009).*

2.1.3 Challenges (and gaps) being faced in maintenance planning and Asset optimisation processes.

Maintenance planning and asset optimisation are crucial for ensuring optimal production performance. Despite their significance, several challenges are being addressed to enhance their effectiveness. One major challenge in maintenance planning involves establishing robust systems and processes, necessitating careful coordination and management to maximise efficiency. Regular updates are essential, but determining the timing and content of these updates can lead to delays. The complexity of modern production systems poses another challenge, requiring organisations to invest in advanced analytics tools to identify patterns and trends in asset performance.

Balancing maintenance activities with production demands is a critical issue, as disruptions to tight production schedules must be minimised. Organisations must develop maintenance plans that align with production schedules and prioritise activities based on their impact. Managing costs is also a concern, requiring organisations to strike a balance between the expenses of maintenance activities and the benefits they yield. To address this, cost-effective maintenance plans that prioritise critical assets and emphasise preventive maintenance activities are crucial.

Through literature review certain themes can be drawn in with respect to maintenance planning and asset optimisation in relation to production performance. A table synthesising the findings based on the data from the literature review is also provided below.

Theme(s)	Organisational Problem	Research Problem	Conceptual Frame Used	Population & Sample	Research Gap
Maintenance strategies and their impact on operational performance	The need for effective maintenance strategies to improve operational performance in manufacturing organisations	To identify the impact of different maintenance strategies on operational performance and to determine the most effective maintenance strategy for manufacturing operations	It's based on Total Productive Maintenance (TPM) model	Manufacturing organisations in the US. The sample consists of 150 organisations selected based on their size, location, and industry.	Lack of empirical research on the effectiveness of different maintenance strategies in improving operational performance in manufacturing organisations.
Optimisation of maintenance planning and scheduling for improved Production Performance	Suboptimal maintenance planning and scheduling practices in manufacturing plants, leading to decreased production performance and increased maintenance costs	Optimise maintenance planning and scheduling practices in manufacturing plants to improve production performance and reduce maintenance costs	Mathematical optimisation model to integrate maintenance planning and scheduling with production planning	Case study of a specific manufacturing plant	Lack of integration between maintenance planning and scheduling and production planning leading to suboptimal maintenance practices.

Asset Optimisation and Production performance: The impact of maintenance planning policies	Suboptimal maintenance planning policies in manufacturing plants	Investigating the impact of maintenance planning policies on asset optimisation and production performance	Based on a simulation model on the integration of maintenance planning policies with asset optimisation and production performance	Case study of a manufacturing plant	Lack of understanding of the impact of maintenance planning policies on asset optimisation and production performance
Asset optimisation: Overview and Future Directions	The need for effective asset optimisation in industries to ensure reliability, availability and performance of assets while minimizing downtime and costs	Identify the key challenges and opportunities in asset optimisation and to develop a framework that can help organisations to optimise their asset management strategies	Based on the Asset Management Maturity Model (AMMM), which provides a structured approach to assets an organisation's asset management practices. The role of data analytics, machine leaning and AI on asset optimisation is also discussed	Case studies and various examples from industries such as transportation, manufacturing, and energy	The need for a more integrated and holistic approach to asset optimisation considering the entire asset lifecycle from design and construction to operation and maintenance. Need for a cross-functional approach that involves all stakeholders.

Table 1: *Research problems summary and conceptual frames used (Jardine, A (2016); Kim & Sing (2005);Costa & Franklin (2013) and Ghobakhloo et al, (2017)).*

2.2 Theoretical Review of Literature

2.2.1 Linking Maintenance Planning, Asset Optimisation and Production Performance

The link between maintenance planning and asset optimisation is directly related to production performance because assets are critical to production processes. Effective maintenance planning and asset optimisation can lead to improved asset performance, which in turn can improve production performance (Smith, 2020).

Maintenance planning is impacting production performance in several ways. For example, if maintenance is not planned effectively, it can lead to unplanned downtime and production delays (Jones, 2018). On the other hand, effective maintenance planning ensures that maintenance is conducted at appropriate times, minimising downtime. Furthermore, maintenance planning can also impact production performance by reducing the risk of equipment failure, which can lead to production delays, quality issues, and increased costs (Brown, 2019).

Asset optimisation is also closely linked to production performance. Effective asset optimisation can lead to improved asset availability, reliability, and performance, directly impacting production performance (Johnson & Smith, 2017). For example, by optimising maintenance activities, organisations can reduce downtime and improve asset availability. Similarly, by implementing condition monitoring techniques, organisations can identify and address potential issues before they impact production performance. In addition, asset optimisation can also impact production performance by reducing maintenance costs and improving equipment performance, leading to increased production efficiency and overall performance (Lee & Chen, 2016).

Overall, effective maintenance planning and asset optimisation are essential for improving production performance. By optimising maintenance activities and improving asset performance, organisations can reduce downtime, minimise equipment failure, and improve production efficiency. Furthermore, by linking maintenance planning, asset optimisation, and production performance, organisations can develop a holistic approach to maintenance and asset management that improves overall performance and reduces costs.

2.2.2 Theories in Maintenance Planning and Asset Optimisation

The following are key theories in maintenance planning and asset optimisation in relation to production planning:

1. Reliability centered maintenance (RCM): This approach enables the optimisation of maintenance to reduce the probability of failure of an asset and improve long-term performance without increasing costs (Berger *et al*. 2012). It also involves analysing the functions and failure modes of equipment to determine the most effective maintenance strategy (Moubray & Maintenance, 1997).

2. Total productive maintenance (TPM): This is an approach to maintenance with the goal of achieving the highest level of productivity and reliability. It involves maintaining and improving the performance of equipment through preventive and corrective maintenance, as well as proactive maintenance (Goyal, 2019).

3. Just-In-Time (JIT) Maintenance System: This system focuses on developing a maintenance plan based on specific short-term objectives, such as minimising costs and maximizing efficiency of the production line (Nakajima, 1988).

4. Life cycle asset management (LCAM): This approach focuses on the planning, managing, and optimising of lifecycle costs of assets. It involves determining the optimal timing of maintenance actions by considering the operational performance of the asset and the business/financial objectives of the organisation (Andersen and Krstev, 2014).

5. Predictive maintenance (PdM): Predictive maintenance systems use data related to the asset's condition to anticipate future failures and enable appropriate scheduling of maintenance activities. This approach helps reduce the time and cost of maintenance (Wang, Ma, Zhang, Gao, & Wu, 2018).

6. Condition based maintenance (CBM): is a maintenance strategy that uses real-time data to monitor the condition of equipment and predict when maintenance is required (Duffuaa, 2003). It involves using sensors and other monitoring devices to collect data on equipment performance, which is then analysed to identify potential problems before they occur.

In summary, these theories provide a framework for developing effective maintenance planning and asset optimisation strategies that can help organisations improve production planning and achieve their production goals, but they have their own shortcomings and weaknesses.

2.2.3 Maintenance theories and their shortcomings/weaknesses

Maintenance theory	Shortcomings/Weaknesses
Reliability Centered Maintenance (RCM)	1. Over-reliance on equipment failure history: Reliability Centered Maintenance (RCM) relies heavily on failure histories, which can be unreliable and can be difficult to obtain. This may lead to faulty decisions, causing added costs and maintenance delays. 2. Expense: RCM can be expensive to implement, as it requires skilled personnel and advanced technology to analyse and accurately assess equipment condition. 3. Time Required: RCM requires a great deal of time to analyse the system and its components, calculate risk and define a strategy for maintenance. In some cases, it may be more cost effective to conduct a different form of system analysis. 4. Risk Evaluation: Risk evaluation is largely subjective and may lead to wide variations in the approaches taken by different people. It also raises questions about the validity of the analysis, as well as whether the proposed maintenance plan is the most effective.
Total Productive Maintenance (TPM)	1. High initial investment: Implementing TPM requires a significant investment in training, equipment, and software. This can be a challenge for small and medium-sized businesses that may not have the resources to invest in TPM. 2. Resistance to change: TPM requires a cultural shift in the organization, which can be difficult to achieve. Employees may resist the changes required to implement TPM, which can lead to a lack of buy-in and poor results. 3. Time-consuming: TPM requires a significant amount of time and effort to implement and maintain. This can be a challenge for organizations that are already stretched thin and may not have the resources to devote to TPM. 4. Lack of standardization: TPM relies on standardization to be effective. However, if there is a lack of standardization in the organization, TPM may not be as effective as it could be. 5. Limited applicability: TPM is most effective in manufacturing environments where equipment is critical to production. It may not be as effective in other industries or environments where equipment is not as critical.
Just-In-Time (JIT) maintenance system	1. Increased risk of equipment failure: JIT maintenance relies on the assumption that equipment will not fail unexpectedly. However, if a failure does occur, it can be costly and disruptive to operations. 2. Lack of preventive maintenance: JIT maintenance focuses on fixing problems as they occur, rather than preventing them from happening in the first place. This can lead to a higher frequency of breakdowns and repairs. 3. Increased downtime: Since JIT maintenance only occurs when a problem arises, equipment may be out of service for longer periods of time, leading to increased downtime and lost productivity. 4. Increased costs: While JIT maintenance can reduce maintenance costs in the short term, it can lead to higher costs in the long term if equipment

	failures occur more frequently or if repairs become more complex and costly. 5. Lack of flexibility: JIT maintenance requires a high level of coordination and planning to ensure that maintenance activities are performed at the right time. This can limit the flexibility of maintenance schedules and make it difficult to respond to unexpected events or changes in production schedules.
Life Cycle Asset Management (LCAM)	1. High initial investment: Implementing LCAM requires a significant investment in equipment, software, and training. This can be a challenge for small and medium-sized businesses that may not have the resources to invest in LCAM. 2. Complexity: LCAM can be complex, requiring specialized equipment and software to manage assets throughout their life cycle. This can be a challenge for organizations that do not have the expertise to implement and maintain LCAM. 3. Limited applicability: LCAM is most effective in industries where assets have a long-life cycle, such as manufacturing or transportation. It may not be as effective in other industries where assets have a shorter life cycle. 4. Data overload: LCAM generates large amount of data which can be overwhelming for organizations that do not have the resources to analyse and act on the data. This can lead to missed opportunities for maintenance or unnecessary maintenance. 5. Resistance to change: LCAM requires a cultural shift in the organization, which can be difficult to achieve. Employees may resist the changes required to implement LCAM, which can lead to a lack of buy-in and poor results.
Predictive Maintenance (PdM)	1. High initial investment: Implementing PdM requires a significant investment in equipment, software, and training. This can be a challenge for small and medium-sized businesses that may not have the resources to invest in PdM. 2. Complexity: PdM can be complex, requiring specialized equipment and software to collect and analyse data. This can be a challenge for organizations that do not have the expertise to implement and maintain PdM. 3. False positives: PdM can generate false positives, indicating that maintenance is required when it is not. This can lead to unnecessary maintenance, which can be costly and time-consuming. 4. Limited applicability: PdM is most effective in industries where equipment failure can have serious consequences, such as aviation or nuclear power plants. It may not be as effective in other industries where equipment failure is less critical. **5.** Data overload: PdM generates large amount of data which can be overwhelming for organizations that do not have the resources to analyse and act on the data. This can lead to missed opportunities for maintenance or unnecessary maintenance.

Condition Based Maintenance (CBM)	1. High initial investment: Implementing CBM requires a significant investment in equipment, software, and training. This can be a challenge for small and medium-sized businesses that may not have the resources to invest in CBM. 2. Complexity: CBM can be complex, requiring specialized equipment and software to monitor equipment condition. This can be a challenge for organizations that do not have the expertise to implement and maintain CBM. 3. False positives: CBM can generate false positives, indicating that maintenance is required when it is not. This can lead to unnecessary maintenance, which can be costly and time-consuming. 4. Limited applicability: CBM is most effective in industries where equipment failure can have serious consequences. It may not be as effective in other industries where equipment failure is less critical. **5.** Data overload: CBM generates large amount of data which can be overwhelming for organizations that do not have the resources to analyse and act on the data. This can lead to missed opportunities for maintenance or unnecessary maintenance.

Table 2: *Summary of maintenance theories and their shortcomings/weaknesses (Berger et al., (2012); Goyal (2019); Koh et al., (2017); Husain & Sego (2018) and Khan M.A (2018))*

2.3 Conceptual framework for maintenance planning, asset optimisation, and production performance.

Maintenance planning is a critical component of asset management that has a significant impact on production performance. In recent years, several researchers have proposed different conceptual frameworks for maintenance planning and production performance. This section is discussing some of the conceptual frameworks proposed in the literature.

Khan (2018) is proposing a conceptual framework for preventive maintenance in a power plant context. The framework consists of five main stages: planning, scheduling, execution, monitoring, and feedback. The planning stage involves developing a preventive maintenance plan based on the equipment condition and criticality. The scheduling stage involves creating a maintenance schedule that optimises the use of resources while minimising downtime. The execution stage involves carrying out the maintenance activities according to the schedule. The monitoring stage involves tracking equipment condition and performance to identify potential problems before they occur. Finally, the feedback stage involves using the data collected during the monitoring stage to improve the maintenance plan and schedule.

Ahmed et al. (2016) are proposing a framework for the effect of Total Productive Maintenance (TPM) practices on manufacturing performance. The framework consists of three main components: TPM practices, manufacturing performance, and the mediating role of organisational culture. TPM practices include autonomous maintenance, planned maintenance, quality maintenance, and safety maintenance. Manufacturing performance includes quality, cost, delivery, and safety. The organisational culture mediates the relationship between TPM practices and manufacturing performance. The framework suggests that TPM practices positively influence manufacturing performance, and the relationship is mediated by organisational culture.

Zhang et al. (2016) are proposing a conceptual framework for the influence of preventive maintenance on production performance. The framework consists of four main components: preventive maintenance, production performance, system reliability, and maintenance cost. Preventive maintenance is the maintenance activities that aim to prevent equipment failure. Production performance includes equipment availability, production rate, and quality. System reliability is the probability of the system operating without failure. Maintenance cost includes both the direct and indirect costs of maintenance activities. The framework suggests that preventive maintenance positively influences production performance by increasing system reliability and reducing maintenance costs.

Banadaki and Shokouhi (2017) are proposing a conceptual framework for the impact of TPM practices on manufacturing performance. The framework consists of four main components: TPM practices, manufacturing performance, organisational learning, and competitive advantage. TPM practices include autonomous maintenance, planned maintenance, quality maintenance, and safety maintenance. Manufacturing performance includes quality, cost, delivery, and safety. Organisational learning is the process of acquiring and applying knowledge to improve performance. Competitive advantage is the ability to outperform competitors by delivering superior value to customers. The framework suggests that TPM practices positively influence manufacturing performance, and the relationship is mediated by organisational learning and competitive advantage.

Another framework proposed by Sharif and Kumar (2018) is the Asset Performance Management (APM) framework. The framework consists of six main components: asset strategy, asset condition assessment, asset maintenance management, asset performance management, asset life cycle management, and continuous improvement. The asset strategy involves developing a comprehensive plan for managing assets that aligns with the organisation's overall strategy. The asset condition assessment involves using various techniques to assess asset condition, including non-destructive testing and visual inspection. The asset maintenance management involves planning and scheduling maintenance activities to minimise downtime and optimise asset performance. The asset performance management involves monitoring asset performance and identifying potential problems before they occur. The asset life cycle management involves managing assets throughout their life cycle, from acquisition to disposal. Finally, the continuous improvement involves using data collected during the asset performance management stage to continuously improve asset performance and optimise production performance.

For this study, the main conceptual framework being used is from Zhang et al. (2016). Their framework, which examines the impact of preventive maintenance on production performance, includes four main components: preventive maintenance, production performance, system reliability, and maintenance cost. Preventive maintenance involves activities designed to prevent equipment failure, while production performance encompasses equipment availability, production rate, and quality. System reliability is defined as the likelihood of the system operating without failure, and maintenance cost includes both direct and indirect costs associated with maintenance activities. Zhang et al.'s framework indicates that preventive maintenance positively affects production performance by improving system reliability and reducing maintenance costs. This makes it an appropriate model for this study to monitor and analyse the effectiveness and efficiency of maintenance planning and asset optimisation strategies.

Figure 4 is a framework to monitor and analyse the effectiveness and efficiency of the production process, as well as the performance of operations before and after implementing asset optimisation strategies and practices. It outlines the business process relationships between senior management, line-of-business/business unit management, internal customers, and other personnel. This integrated, systemic approach is implemented to evaluate production and maintenance performance pre- and post-asset optimisation.

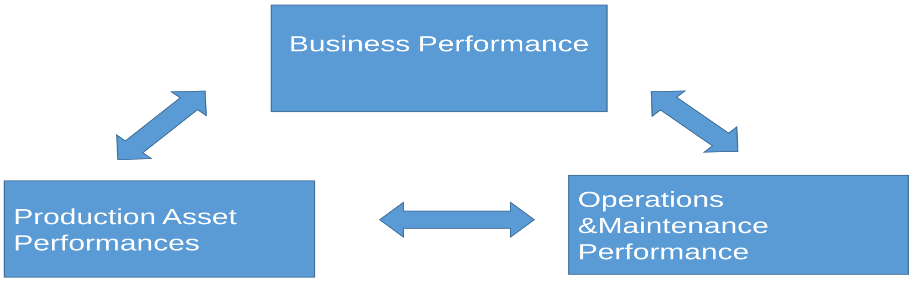

Fig 4: *Productivity improvement framework.*

2.4 Technological advancements and industry 4.0 in mining maintenance

The mining industry is undergoing a transformative shift by embracing advanced technologies as part of the broader Industry 4.0 framework. This paradigm shift involves the convergence of digital technologies, automation, and data analytics to enhance operational efficiency and decision-making processes. One of the focal points of research within this context is the integration of advanced technologies, including sensors, the Internet of Things (IoT), and data analytics, with a specific emphasis on revolutionising maintenance practices.

2.4.1 Sensors in mining maintenance

Sensors are playing a pivotal role in monitoring the health and performance of mining equipment. These devices are being deployed to collect real-time data on various operational parameters such as temperature, vibration, and wear. The data generated by sensors is offering continuous insights into the condition of critical machinery, enabling the timely identification of potential issues. For example, accelerometer sensors are being used to measure vibrations in mining equipment. Abnormal patterns in these vibrations can indicate potential faults or impending failures, allowing for proactive maintenance interventions.

2.4.2 Internet of things (IoT) applications

The Internet of Things (IoT) is facilitating the seamless connectivity of devices and systems within the mining environment. Through IoT applications, mining equipment is becoming part of an interconnected network, enabling real-time communication. This connectivity is enhancing the ability to monitor equipment health, share data, and respond promptly to maintenance needs. For instance, IoT-enabled devices on haul trucks are communicating information about their location, fuel consumption, and operational status, contributing to more informed decision-making in maintenance planning.

2.4.3 Data Analytics for predictive maintenance

The abundance of data generated by sensors and IoT devices is being leveraged through data analytics techniques. Predictive maintenance models are analysing historical and real-time data to forecast equipment failures, enabling proactive maintenance measures. Machine learning algorithms, for example, are analysing patterns in equipment performance data to predict when components are likely to fail, optimising maintenance schedules.

2.4.4 Condition-based monitoring

Condition-based monitoring is involving continuous assessment of equipment condition through real-time data analysis. This approach is shifting maintenance practices from routine schedules to a dynamic, condition-dependent model, reducing unnecessary downtime. Remote monitoring systems, supported by advanced technologies, are allowing maintenance teams to remotely assess the condition of equipment and plan interventions accordingly.

2.4.5 Asset health management systems

Integrated asset health management systems are consolidating data from various sources, including sensors and maintenance records. These systems are applying analytics to provide a comprehensive overview of asset health, guiding maintenance strategies, and contributing to overall reliability. These systems are facilitating a holistic approach to maintenance, considering the health of the entire asset and optimising maintenance practices accordingly.

As Industry 4.0 continues to evolve, the mining sector is standing to benefit significantly from the ongoing integration of advanced technologies into maintenance practices, resulting in increased efficiency, reduced downtime, and improved decision-making processes.

2.5 Propositions in maintenance planning theories and asset optimisation

According to Saravi et al. (2018), effective maintenance planning and scheduling strategies are enhancing production performance. This means that well-executed maintenance planning, including preventive maintenance scheduling, task prioritisation, and resource allocation, are minimising disruptions, reducing downtime, and improving overall production performance. The use of condition monitoring, real-time data analytics, and predictive modeling are enabling proactive maintenance actions, reducing unplanned downtime, and enhancing equipment reliability and productivity (Zhang et al., 2019). Optimising maintenance intervals based on equipment condition, performance data, and reliability analysis is improving production performance by minimising unnecessary maintenance and maximising equipment uptime (Wang et al., 2017). Other propositions in this field are:

1. Integrating maintenance planning with enterprise asset management (EAM) systems or computerised maintenance management systems (CMMS) is enhancing coordination, streamlining data management, and supporting data-driven decision-making, leading to improved production performance (Abdul-Kadir et al., 2016).
2. Employee skills, training, collaboration, and the organisation’s attitude towards maintenance are playing a vital role in the effectiveness of maintenance planning and asset optimisation processes, thus impacting production performance (Abdul-Kadir et al., 2016).
3. Analysing the cost-effectiveness of maintenance strategies and optimising resource allocation based on criticality and performance metrics are leading to improved production performance while managing limited resources (Zhang et al., 2020).

These propositions are providing a general overview of common themes and findings in the field of maintenance planning and asset optimisation in relation to production performance. For this work, the main proposition is that effective maintenance planning and scheduling strategies, including preventive maintenance scheduling, task prioritisation, and resource allocation, are enhancing production performance by minimising disruptions, reducing downtime, and improving overall production efficiency. This is being supported by the integration of condition monitoring, real-time data analytics, and predictive modeling to enable proactive maintenance actions, reduce unplanned downtime, and enhance equipment reliability and productivity. Additionally, optimising maintenance intervals based on equipment condition, performance data, and reliability analysis is further contributing to improved production performance by minimising unnecessary maintenance and maximising equipment uptime.

2.6 Conclusion

Maintenance planning is a critical aspect of any organisation that is relying on equipment and machinery to carry out its operations. It is helping to ensure that equipment and machinery are maintained in good working condition, which is reducing downtime and repair costs. A well-planned maintenance program is also helping to extend the lifespan of equipment and machinery, resulting in significant cost savings for the organisation. By implementing a maintenance planning program, organisations are improving safety in the workplace, reducing downtime, and reducing repair costs.

Several conceptual frameworks are being proposed in the literature to explain the relationship between maintenance planning and production performance. The frameworks discussed in this section are highlighting the importance of preventive maintenance, TPM practices, system reliability, organisational culture, organisational learning, and lean construction. These frameworks are providing a useful guide for organisations to develop effective maintenance plans that are optimising production performance. The frameworks discussed in this section are highlighting the importance of asset strategy, asset management, asset monitoring, and asset optimisation. Also of importance are asset condition assessment, asset maintenance management, asset life cycle management, as well as continuous improvement. These frameworks are providing a useful guide for organisations to develop effective asset management plans that are optimising production performance.

The research is exploring the propositions that effective maintenance planning and scheduling strategies are enhancing production performance. The notion that predictive maintenance technologies are also improving production performance is being tested. Human factors and organisational culture influences on maintenance planning and asset optimisation outcomes are being investigated.

CHAPTER 3 – RESEARCH METHODOLOGY

3. Introduction

This chapter provides an outline detail of methods used to gather relevant data and information. Qualitative methods were used to allow for exploration of multiple perspectives on the study i.e., interviews with participants. The research was benchmarked against success or failure indicators from related industries. A description of sample size and sample instruments, research techniques and the validity and consistency thereof, is also included.

3.1 Research Approach

This research is employing qualitative data collection and analysis methods for investigating maintenance planning and asset optimisation. This approach is chosen for several reasons. Qualitative methods enable a thorough exploration of contextual factors influencing maintenance planning, such as organisational, cultural, and operational aspects, through interviews, observations, and document analysis. Since maintenance planning involves subjective experiences, qualitative methods like interviews help capture the perspectives, insights, and reasoning of individuals involved, such as maintenance managers and operators. Additionally, qualitative methods allow researchers to delve into the complexities of maintenance planning, addressing interdependent variables and trade-offs that may not be easily quantifiable, thereby aiding in understanding decision-making intricacies. This approach provides flexibility to explore emerging themes and adapt data collection methods based on initial findings, ensuring comprehensive coverage and a deeper understanding of the topic. Emphasising the importance of organisational and operational context, qualitative data collection helps contextualise findings, revealing how specific factors impact planning processes and outcomes, which informs actionable recommendations relevant to the organisational context. Lastly, qualitative research uncovers barriers and facilitators to effective maintenance planning, revealing challenges, constraints, and organisational dynamics, and this knowledge informs the development of strategies to overcome obstacles and leverage facilitators for improved outcomes.

3.2 Research Design

Research design is the blueprint or plan that outlines the methodology, data collection, analysis, and interpretation strategies for a research study (Creswell, 2014). It serves as the framework for the entire research process and determines how the study will be conducted, from the formulation of the research question to the dissemination of the results. Research design is a crucial aspect of any research study as it provides structure and direction for the research process, enabling researchers to achieve their objectives in a systematic and organised manner.

The overall research design for the research on maintenance planning and asset optimisation in relation to production performance, with a focus on South African mining operations, involved the use of interviews. Interviews were conducted with key personnel involved in maintenance planning, asset optimisation, and production management in South African mining operations. The interviews allowed for in-depth exploration of participants' experiences, opinions, and insights. Semi-structured interviews were used to gather qualitative data, enabling a more nuanced understanding of the processes and factors influencing production performance. The interviews were also audio-recorded and transcribed for analysis.

3.3 Research method and data collection methods

A research method refers to the approach or technique used to conduct a research study or investigation. It involves a systematic process of collecting and analysing data to answer a research question or test a hypothesis. For this research, data was collected through structured interviews.

3.3.1 Structured Interviews

Structured interviews are a research methodology used in academic research to gather standardised and comparable data from research participants. They are commonly used in quantitative research to collect data on attitudes, behaviours, and experiences of study participants among others. Structured interviews involve asking all participants the same set of pre-determined questions, in the same order, using standardized phrasing and response options. This approach allows researchers to collect data that is comparable across participants and over time thus reducing bias and increasing the reliability of the data collected.

The steps involved in data collection through interviews include developing an interview protocol, where a list of open-ended questions is prepared to form the basis for a semi-structured interview guide. These questions are designed to elicit detailed and context-specific information relevant to the research objectives. Sampling will involve selecting a sample of participants based on the target population. During participant recruitment, the purpose of the study is explained to the participants, and informed consent is obtained, ensuring they understand their rights and the confidentiality of their responses. Data collection is conducted through an interview questionnaire, with participants encouraged to provide detailed responses and probing follow-up questions used to gain deeper insights. Finally, data analysis involves analysing the interview data using qualitative analysis techniques, such as thematic analysis, to derive patterns, themes, and insights from the interview responses.

3.4 Population and Sampling

Data was gathered from the mining industry in South Africa (a few mines), regardless of the size of the mine and its mining sector.

3.4.1 Population

The population for the research consisted of individuals or entities directly involved in or responsible for maintenance planning, asset optimisation, and production performance within the South Africa mining industry. The specific population for this study included Mining operation managers, Maintenance personnel, Production managers, Asset optimisation specialists and Maintenance planners.

3.4.2 Sample and Sampling method

The sample consisted of mining professionals. These included mining operation managers, maintenance engineers, production managers, and asset optimisation specialists. This sampling involved selecting participants based on accessibility and availability. The sample size was 18 participants. As mentioned by Braun and Clark (2016), for a Masters or Professional Doctorate project, the sample size range for interviews is 6 - 15. The objectives of the study were explained first to the participants, as well as giving assurance that their identities will remain anonymous. Only their roles in their various mining sectors will be used in the final presentation if such need arose.

3.5 Research Instrument

The research process used was structured interviews and the research instrument for this study was an interview guide. Interviews were used to gather qualitative data on the experiences and perspectives of mining operators, maintenance planners, engineers, and asset managers. Document analysis was then used to review and analyse the maintenance plans, asset management policies, and production performance reports of the mining operations.

3.6 Data analysis strategies and interpretation

Data analysis is a systematic process of interpreting data to derive meaningful insights, crucial in qualitative research where it entails identifying patterns, themes, and categories from collected questionnaire and interview data. Various methods, such as content analysis, thematic analysis, and grounded theory, are employed. Content analysis codes recurring words, thematic analysis categorizes patterns, and grounded theory develops a theory by analysing relationships and patterns.

Braun and Clarke (2006) highlight thematic analysis as a widely utilised method in qualitative data analysis. Its flexibility and systematic approach allow for stages like familiarisation with the data, generating initial codes, identifying themes, and refining them. The process culminates in a final analysis, demonstrating the method's adaptability and effectiveness in extracting insights from qualitative data. For this study, thematic analysis method of analysing qualitative data from interviews was used.

3.7 Possible limitations and challenges of the study

There were several possible limitations and challenges in conducting the study on maintenance planning and asset optimisation in relation to production performance. Some of these limitations and challenges included data availability and quality, technical complexity, cost, organisational culture, resistance to change, balancing competing priorities and interdisciplinary collaborations.

3.8 Quality Assurance

In this research, several aspects related to the quality and trustworthiness of the data were considered, including transferability, dependability, credibility, and confirmability.

3.8.1 Transferability

Transferability refers to the extent to which the findings of the study can be applied or generalised to other contexts or populations beyond the specific research setting. In the case of this study, the transferability of the data depended on factors such as the representativeness of the sample and the similarity of maintenance planning, asset optimisation, and production performance practices across different mining operations in South Africa.

3.8.2 Dependability

Dependability refers to the consistency and stability of the data and findings over time and across different researchers or research contexts. To establish dependability, it was ensured that data collection methods and procedures were well-documented and replicable. By maintaining transparent documentation and allowing for potential replication, other researchers will be able to verify and build upon the findings.

3.8.3 Credibility

Credibility refers to the believability and trustworthiness of the data and findings. In the context of this study, credibility was enhanced through transparent reporting. Triangulation of data sources (e.g., interviews, and reports from literature) strengthened credibility by providing multiple perspectives on the research topic.

3.8.4 Confirmability

Confirmability refers to the objectivity and neutrality of the data and findings, indicating that they are based on the participants' experiences and not influenced by the researchers' biases or preconceived notions. Maintaining an audit trail, documenting decisions from data collection to interpretation, bolsters confirmability, reinforcing the integrity and credibility of the research.

3.9 Ethical considerations

To guarantee ethical conduct in the research, the outlined essential principles and practices were adhered to in alignment with the anticipated ethical benchmarks.

1. Ethical approval from the institution’s ethics committee was sought before commencing the research.
2. Informed consent from all participants involved in the study was obtained, ensuring that they fully understood the purpose, procedures, potential risks, and benefits of their participation.
3. The privacy and confidentiality of participants was safeguarded by ensuring that personal information and responses are kept confidential and are not disclosed to unauthorised individuals.
4. Participation in the study was entirely voluntary.
5. The research was conducted with honesty, integrity, and transparency.
6. Inclusivity and diversity in participant selection was ensured, respecting the rights and perspectives of all individuals, and avoiding any form of discrimination or bias.
7. The research findings will be shared responsibly and appropriately.
8. Professional standards and codes of conduct relevant to this research field were adhered to.

CHAPTER 4 – ANALYSIS OF RESULTS

4. Introduction

This chapter focuses on the analysis of results on the assessment of the responses from the interviews. The study involved engaging with 18 participants from diverse mining entities in South Africa, representing a breadth of perspectives within the mining sector. The interviews lasted 20-35mins. The participants occupy various professional roles namely, maintenance planners, maintenance engineers, maintenance planning managers, engineering managers, production superintendents, and production managers. The mines under consideration produce distinct commodities, such as copper, diamond, platinum, and phosphate, reflecting the multifaceted nature of the mining industry.

With respect to professional backgrounds, the participants exhibited a spectrum of experience spanning from 7 to 31 years within the mining domain, contributing to a wealth of knowledge and insights. The diversity in roles and tenure added richness to the dataset, offering a nuanced understanding of maintenance practices in the industry.

The thematic analysis approach was employed to analyse the interview results. This rigorous technique involved the systematic coding and categorisation of the gathered data, allowing for the identification of recurring themes and patterns. Through this method, the analysis sought to unveil insights aligned with the overarching research objectives, '*to assess the impact of maintenance planning and asset optimisation processes on production performance in South African mining operations?*' and *'identify and develop methodologies/ways for improving operational efficiency?'*. This provided a structured and in-depth exploration of the participants' perspectives and experiences within the dynamic landscape of the mining sector.

4.1 Data analysis

From the analysis of the interview responses to the questions, several themes could be established. The initial phase focused on familiarising myself with the data, wherein I immersed myself in the responses thus identifying key concepts and generated preliminary codes. The interview transcripts were loaded into Microsoft Word 365, and later Microsoft Excel and NVivo 14. Thereafter the processes of coding, categorisation, and the development of overarching themes followed in Microsoft Excel and NVivo 14 (as a check). An inductive approach was used, thus implying that the data underwent coding or categorisation for analysis without conforming to a preset coding framework, ensuring the analysis was guided solely by the data gathered during the evaluation, devoid of any analytical preconceptions. Each theme is carefully described, supported by illustrative quotes or excerpts from the data to provide a vivid and contextual understanding.

4.1.1 Familiarisation with the data

To familiarise myself with the data, I had to read the interview transcripts and listen to the recordings several times. This helped to figure out the themes that might emerge through the data and helped to gain a holistic understanding of the content, identifying key concepts, ideas, and patterns. Significant points, recurring themes, and interesting patterns were then noted. While reviewing the transcripts, noteworthy information was highlighted, totalling 134 points of interest, which were then cross-referenced with the research objectives (see Table 3). The primary aim of this thorough data examination was to fully immerse in the dataset and gather initial points of interest, thereby providing comprehensive insights into the content's scope and depth.

Table 3: *Familiarisation of data – Points of interest linked to the research objectives.*

Research objectives	Codes	Initial points of interest
Impact of maintenance planning and asset optimisation on production performance	Prevalence of preventative, predictive, and reactive strategies	17
	Use of SAP, JD Edwards, and metrics like MTBF and OEE for a holistic view	14
	Challenges in resource constraints, cultural misalignment, and the role of KPI tracking	12
	Influence of skills, training, and organisational culture on maintenance outcomes	11

in South African mining operations	Benefits and challenges of predictive maintenance technologies	13
	Utilisation of RCM processes and tools like SAP for optimal resource allocation	9
Methodologies for improving operational efficiency	Emphasis on a balanced approach and investment in skilled personnel and technology	8
	The importance of clear objectives, robust plans, continuous improvement, and regular evaluations	9
	Focus on data-driven decision-making and the role of data analysis	6
	Integration of systems like SAP and JD Edwards for operational efficiency	14
	The significance of a holistic approach considering equipment life cycles and personnel skills	14
	The impact of human factors, including skills and organisational culture	7

4.1.2 Generating initial codes

In the process of thematic analysis, generating initial codes is a fundamental step that involves systematically labeling and categorising meaningful segments within the dataset. This section explores the initial coding phase, delving into the iterative process through which descriptive labels are assigned to data excerpts. By breaking down the text into manageable units, the groundwork is laid for identifying emerging patterns and themes, setting the stage for a meticulous understanding of the dataset and subsequent in-depth analysis. Insights into the initial coding process, as a crucial bridge towards uncovering the rich tapestry of themes inherent in qualitative data, are discussed in this sub-section. From the transcripts, relevant data extracts were identified that addressed the research objectives and phases (codes) that best represented the excerpts were then identified.

	5. In your experience, what are the main challenges and barriers faced by organizations in implementing effective maintenance planning and asset optimization strategies for production performance improvement?	
P1	Lack of understanding of the value of planning, not following compliance schedules.	
P3	No support from stakeholders, lack of knowledge of most equipment by their personnel (no training)	
P4	Lack of skills (due to inadequate training); limited funds for maintenance, unavailability of critical equipment	
P5	Equipment Operability. Time allocated to maintenance compromised effective maintenance. Competency of Employees that are Maintaining Equipment. Production targets also compromises effective maintenance. Poor planning for maintenance.	Lack of knowledge/skills
P12	Unrealistic production expectations, incompetent maintenance teams and leadership that does not understand the importance of maintenance.	
P15	Reluctance to stop the plant for maintenance when the plant is running well. Inaccurate analysis of breakdowns and equipment reliability.	
P16	The production operators not understanding how the equipment is maintained and how to quickly detect problems before failures occur.	
P17	Lack of skills, behaviour of the maintenance personnel and operational pressures to produce more. Low margins that affect the budgeting for maintenance.	
P18	Setting unrealistic production targets and unskilled maintenance personnel.	
P13	Pressure to achieve production thus deviating from planned maintenance schedule, lack of management of changes thereby strategies are not reviewed properly.	
P14	Effectively incorporating the necessary maintenance strategies, the execution thereof into the production plan. Allowing enough time to perform effective maintenance vs pushing for additional production or catching up on production losses. When maintenance events are planned, the challenge is to ensure that all maintenance tasks are performed effectively and timeously to a high standard.	Non-compliance to set plans
P2	Labour shortages, spares shortages, buying sub-standard spares.	Labour shortages
P8	Lack of Data and Data Quality on asset performance and maintenance history, limited labour and financial resources and misalignment of teams on production goals	
P6	No Capital plans to effect replacement strategies, unavailability of critical spares, prioritising production over maintenance, procurement challenges.	Lack of spares/funds
P7	Maintenance misalignment between operations and engineering, Resource coordination challenges	
P9	Not complying to maintenance plans i.e., not handing over equipment due to production pressure and 2) Delays in providing funds for major overhauls.	Lack of planning
P10	Lack of maintenance models to deal with work identification, planning and scheduling.	
P11	Compliance to set maintenance strategies, misalignment of strategies with certain equipment, misalignment of planners and maintainers.	

Fig 5: *Generating initial codes from data extracts in MS Excel*

Research objective	Code	Coded for
Impact of maintenance planning and asset optimisation on production performance in South African mining operations	Preventative, Predictive, Reliability-Centered maintenance (RCM).	Diverse maintenance strategies
	RCM, Critical Asset Lists, Business Interruption	Optimal maintenance intervals
	Equipment Availability, MTBF, OEE	Key Performance Indicators
	SAP, JD Edwards, Systems Integration	Integration of asset management Systems

Methodologies for improving operational efficiency	Lack of Understanding, Labour Shortages, Production Pressure	Challenges in implementation
	Continuous Evaluation, Equipment Reliability, Compliance	Methods of evaluating the effectiveness.
	Employee Skills, Training, Organisational Culture	Influence and impact of human factors
	Benefits, Drawbacks, Initial Capital outlay	Predictive maintenance Technologies
	Optimal Resource Allocation, Financial and Human Resources	Resourcing
	Invest in Technology, Clear Objectives, Risk Assessments	Investment

Table 4: *Data extracts and codes.*

Fig. 5 outlines the data coding process and steps in MS Excel. Codes and relevant extracts were exported from MS Word and MS Excel, then compiled into a table. This table aided in enhancing the comprehension of the data in the study.

4.1.3 Searching for themes

The process of searching for themes is a crucial step in thematic analysis, requiring a systematic and iterative approach. For starters, researchers should immerse themselves in the data through multiple readings to gain a comprehensive understanding of the content (Braun & Clarke, 2006). This allowed for familiarisation with the nuances and diversity of perspectives present in the dataset. The next step involved generating initial codes as illustrated in 4.1.2. This coding process is inductive thus allowing themes to emerge naturally from the data (Saldana, 2016). The codes acted as building blocks for identifying broader themes.

As coding progressed, there was continuous comparison, moving back and forth between the data and the emerging codes. Clusters of related codes began to form, suggesting potential themes within the dataset. The process involved a careful balance between staying close to the data and maintaining a broader perspective to capture the overall patterns (Braun & Clarke, 2006). It was essential to consider the context and connections between codes, aiming for themes that sum up multiple codes and convey a meaningful narrative. Throughout this process, maintaining reflexivity was also critical. As mentioned by Braun & Clarke, 2019, researchers should continuously question their interpretations, acknowledge potential biases, and remain open to unexpected themes that may challenge initial assumptions. The goal was to ensure that themes accurately represent the dataset and provide valuable insights into the research objectives.

All information was transferred into a Microsoft Excel spreadsheet, consolidating responses from all participants into a single column. Initially, a data review was conducted to remove duplicate entries resulting from similar participant responses. Subsequently, the data underwent analysis to categorise thematic areas. Each cell was examined and assigned to a thematic area and color-coded accordingly. This inductive approach yielded eleven thematic areas, presented as clusters in Table 5 and Table 6. In instances where points overlapped over two themes, the respective comment or worksheet cell was duplicated, each appropriately color-coded for comprehensive recording.

Using Microsoft Excel's sorting tool, the data was sorted based on the assigned cell colours, effectively organising it by thematic area. This sorting and collation procedure merged all essential points associated with each theme, thereby streamlining further analysis, all accomplished within a single worksheet of the Excel workbook.

At the outset, the data was replicated onto a secondary Excel worksheet, initiating a preliminary review aimed at merging or clustering similar points or comments to consolidate the data. Following this initial data consolidation phase for each thematic area, the data was moved to a fresh worksheet. Employing multiple worksheets facilitated the ability to revert to the original unconsolidated dataset if needed. Subsequently, within each worksheet, another data review was conducted to pinpoint sub-themes, connect relevant quotes to points, and further refine the information.

The same information was loaded in NVivo 14 and coded again. The codes generated through NVivo 14 were similar to the ones generated through MS Excel (Fig 6) for the two research objectives. The only difference was that there were more sub-themes in NVivo 14.

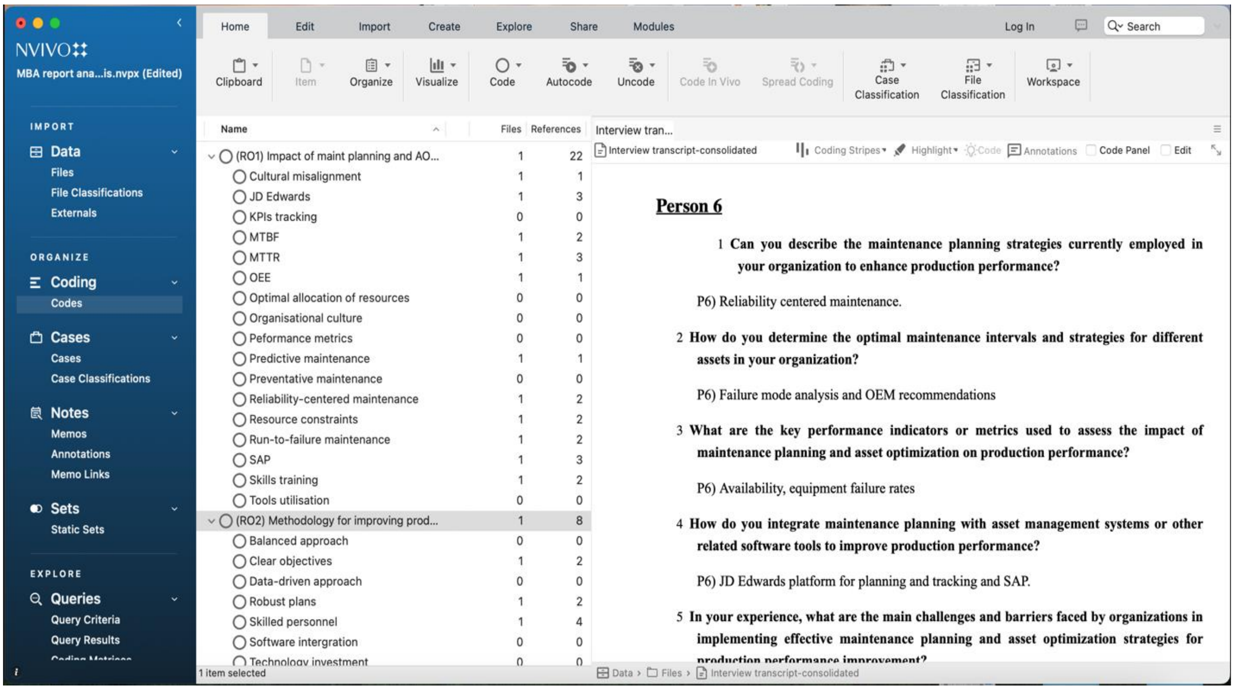

Fig 6: *Process of generating codes in NVivo 14.*

(RO1) Assess the impact of maintenance planning and asset optimisation processes on production performance in South African mining operations? Impact of maintenance planning and asset optimisation on production performance.

Table 5: *Grouping codes into clusters based on shared relationship for research objective 1.*

Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
• Preventative maintenance • Predictive maintenance • Reactive maintenance • Run-to-failure.	• SAP • JD Edwards • MTBF • MTTR • OEE	• Resource constraints • Cultural misalignment • Performance metrics, • KPI tracking	• Skills • Training • Organisational culture	• Optimal allocation of resources • Tools utilisation

(RO2) Identify and develop methodologies for improving operational efficiency? Methodologies/ways for improving operational efficiencies.

Table 6: *Grouping codes into clusters based on shared relationship for research objective 2.*

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
• Balanced approach • Theory vs. Practice • Skilled personnel • Technology investment	• Clear objectives • Robust plans • Continuous improvement • Regular evaluations	• Data-driven approach • Data analysis	• Software integration • Systems utilisation.	• Holistic approach • Technology and personnel	• Human skills • Organisational culture

4.1.4 Reviewing the themes

Reviewing themes is a critical phase in the thematic analysis process that necessitates a meticulous and iterative examination of identified patterns within qualitative data. This step was integral in ensuring the credibility, reliability, and richness of the analytical outcomes. The purpose of reviewing themes extended beyond a mere cursory examination; it involved a systematic and thoughtful evaluation to enhance the interpretive depth of the analysis.

One primary objective during theme review was to guarantee internal coherence within each identified theme. Coherence ensures that the thematic boundaries are clear, and the constituent elements align logically to represent a unified concept. A coherent theme enhances the analytical rigour by providing a distinct and unified narrative that resonated with the underlying meaning in the data. The thematic content was scrutinised to eliminate any ambiguity or inconsistencies thereby fostering a robust foundation for subsequent interpretations.

The relationship between themes and sub-themes formed another critical dimension of the review process. I explored how these elements interacted and contributed to the overarching narrative of the data. Sub-themes, representing more granular patterns within themes, added granularity to the analysis, offering depth and specificity. Assessing the interplay between themes and sub-themes allowed for a comprehensive exploration of the data, uncovering intricate connections and variations. Moreover, the review process was an opportunity to refine and fine-tune the interpretation of each theme. This iterative refinement process contributed to the development of a nuanced and contextually rich analysis that went beyond surface-level observations. This process elevates the analytical outcomes, providing a robust foundation for deriving meaningful insights and constructing a comprehensive narrative that aligns with the research objectives.

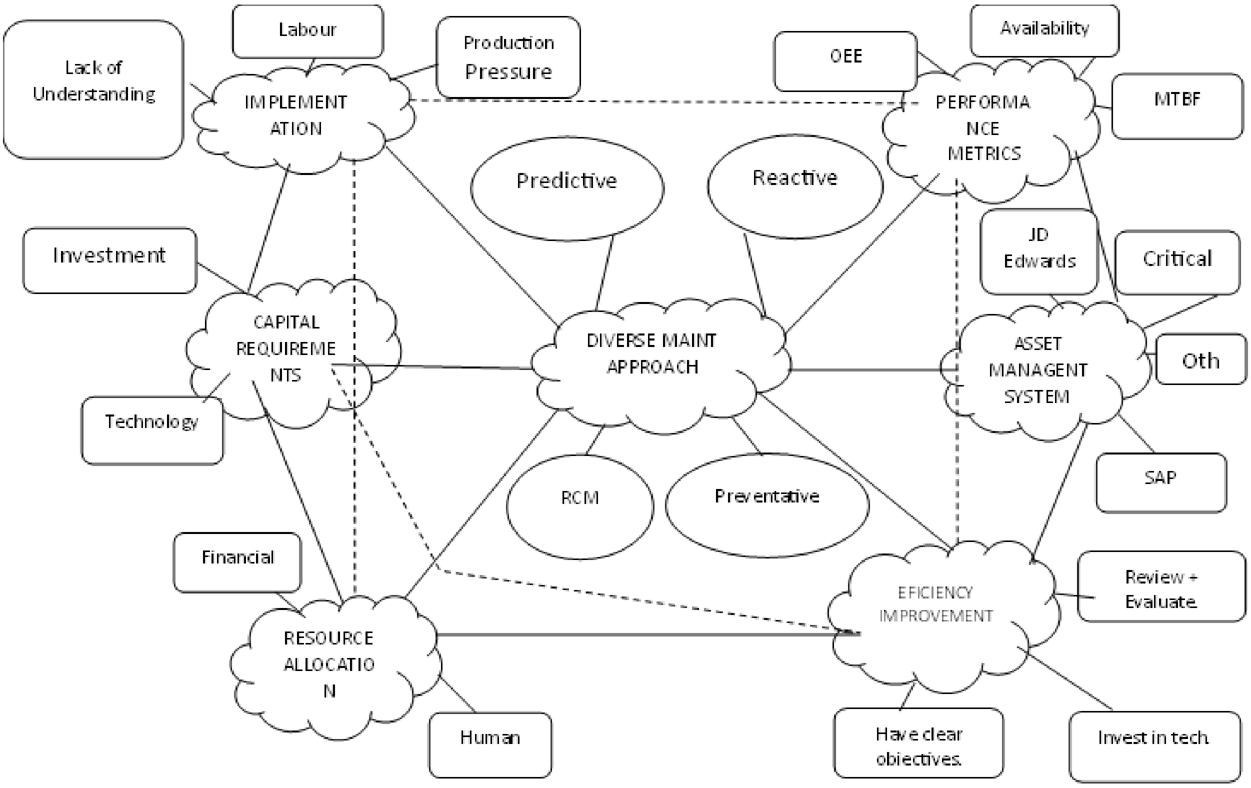

Fig 7: *Initial thematic map developed.*

4.1.5 Defining and naming the themes

Defining and naming themes is a pivotal step in thematic analysis, contributing significantly to the clarity, coherence, and communicative power of the research findings. This phase involved distilling the essence of identified patterns within the qualitative data and encapsulating them in clear, concise, and evocative terms. The process of defining and naming themes was instrumental in transforming this complex qualitative data into a structured and understandable narrative.

Clear definition of themes involved articulating the central concept or idea encapsulated by each identified pattern. It required me to succinctly describe the key elements, characteristics, and nuances that defined the theme. This clarity ensured that the thematic boundaries were well-delineated, providing a roadmap for subsequent analysis and interpretation. A well-defined theme served as a conceptual anchor, guiding the people through the intricacies embedded in the data.

The naming of themes was equally crucial, representing the bridge between the raw data and the overarching story that emerged from the analysis. Theme names were carefully crafted to reflect the essence of the content they encapsulated accurately. These names served as shorthand labels that conveyed the core message of the theme, allowing for efficient communication and comprehension. Reflecting the content ensured that the names resonated with the richness and depth of the qualitative data, enhancing the overall authenticity of the analysis.

Alignment between theme names and the data they represent was fundamental. The chosen names accurately captured the core idea without introducing bias or misrepresentation. Alignment ensured that the themes authentically mirror the lived experiences or perspectives embedded in the data, upholding the integrity of the qualitative inquiry.

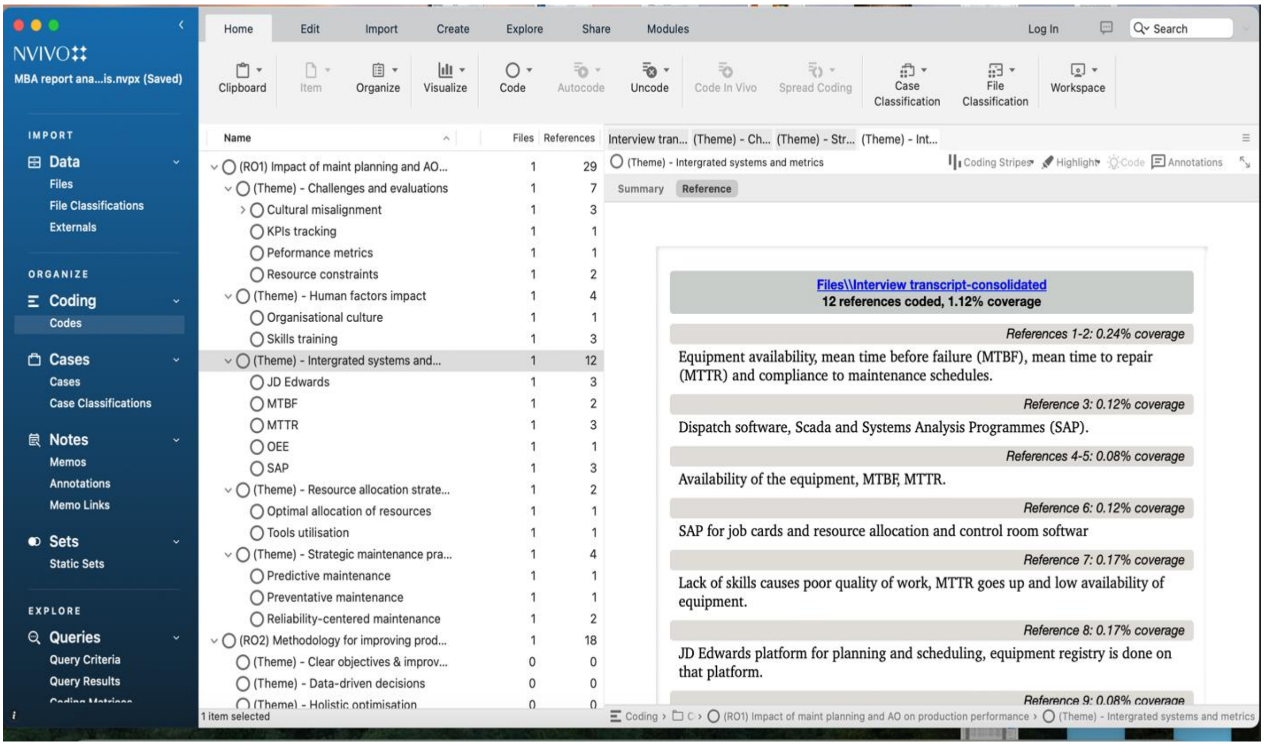

Fig 8: *Grouping similar codes to generate themes in NVivo 14.*

Table 7: *Labelling the clusters to form themes for research objective 1.*

Cluster 1 - *Strategic maintenance approaches*	**Cluster 2 - *Integrated systems and metrics***	**Cluster 3 - *Challenges and evaluation***	**Cluster 4 - *Human factors impact***	**Cluster 5 - *Resource allocation strategies***
• Preventative maintenance • Predictive maintenance • Reactive maintenance • Run-to-failure.	• SAP • JD Edwards • MTBF • MTTR • OEE	• Resource constraints • Cultural misalignment • Performance metrics, • KPI tracking	• Skills • Training • Organisational culture	• Optimal allocation of resources • Tools utilisation

Table 8: *Labelling the clusters to form themes for research objective 2.*

Cluster 1 - *Balanced approach and investment*	**Cluster 2 - *Clear objectives and improvement***	**Cluster 3 - *Data-driven decisions***	**Cluster 4 - *Systems integration for efficiency***	**Cluster 5 – *Holistic optimisation***	**Cluster 6 - *Human factors consideration***
• Balanced approach • Theory vs. Practice • Skilled personnel • Technology investment	• Clear objectives • Robust plans • Continuous improvement • Regular evaluations	• Data-driven approach • Data analysis	• Software integration • Systems utilisation.	• Holistic approach • Technology and personnel	• Human skills • Organisational culture

The two tables below represent a summary of the generated themes with the associated excerpts from the interview transcripts. The themes are classified according to the associated research objective in each table.

Theme	Codes	Excerpts from transcript
Strategic maintenance approaches	Preventative, Predictive, Reactive	Planned and predictive strategies, Condition-based and predictive maintenance, Online monitoring, and critical equipment focus
Integrated systems and metrics	SAP, JD Edwards, MTBF, MTTR, OEE	SAP and JD Edwards integration, Use of SAP for job cards and works orders, Monitoring OEE and performance metrics.
Challenges and evaluation	Resource constraints, Cultural misalignment, Performance metrics, KPI tracking	Labour and spares shortages, Misalignment between operations and engineering, KPI tracking for evaluation.
Human factors impact	Skills, Training, Organisational culture	Unskilled workforce and poor planning, Employee skills and training impact, Positive organisational culture.
Technology in maintenance	Predictive maintenance technologies, benefits, drawbacks	Benefits of predictive technologies, Initial investment and false alarms as drawbacks, Advantages and challenges of predictive maintenance.
Resource allocation strategies	Optimal allocation or resources, Tools Utilisation	Optimal allocation through RCM process, Use of SAP-based maintenance schedules, Efficient resource allocation.

(a)

Theme	Codes	Excerpts from transcript
Balanced approach and investment	Balanced Approach, Theory vs. Practice, Skilled Personnel, Technology Investment	Practical and proven approaches, Investment in human capital and technology, Skills, and technology investment
Clear objectives and improvement plans	Clear Objectives, Robust Plans, Continuous Improvement, Regular Evaluation	Developing clear objectives and robust plans, Continuous improvement, and regular evaluation
Data-driven decisions	Data-Driven Approach, Data Analysis	Data-driven decision-making
System integration for efficiency	Software Integration, Systems Utilised	SAP and JD Edwards integration, Use of systems for optimisation
Holistic optimisation	Holistic Approach, Technology and Personnel	Focusing on equipment life cycles and personnel skills, Holistic approach to maintenance
Human factors consideration	Human Skills, Organisational Culture	Importance of skilled employees, Organisational culture impact

(b)

Table 9: *The themes with associated excerpts from the interview transcripts.*

CHAPTER 5 – DISCUSSION OF RESULTS, RECOMMENDATIONS and CONCLUSION

5. Introduction

This chapter is focused on the discussion of results from the thematic analysis conducted. The section explains the meaning of the themes derived from the analysis and how the themes address the research objectives and provide a rich, nuanced understanding of the data. Recommendations are also discussed in detail.

5.1 Discussion of themes

In the realm of South African mining operations, the efficiency and performance of production processes are pivotal for sustained success. Maintenance planning and asset optimisation play crucial roles in achieving operational excellence. The research aimed at addressing the two research objectives namely, *'assess the impact of maintenance planning and asset optimisation processes on production performance?'* and *'identify and develop methodologies/ways for improving operational efficiencies?'*. The below themes were deduced from the interviews that related to the research objectives.

***Themes for research objective 1*:**

5.1.1 Strategic maintenance approaches

Maintenance strategies employed by companies significantly influence production performance. The transcript revealed a diversity of approaches are being employed by different mines in South Africa. The main strategies being employed varied from preventative, predictive, and reactive strategies. These strategies, when strategically employed, contribute to minimising downtime and enhancing equipment reliability.

Overall, the diverse array of maintenance approaches outlined in the transcript underscores the multifaceted nature of asset optimisation strategies within mining operations. By strategically deploying a combination of these maintenance techniques, organisations can enhance equipment reliability, minimise downtime, and ultimately optimise production performance in pursuit of operational excellence. If not strategically employed, production performance will be negatively affected.

5.1.2 Integrated systems and metrics

The seamless integration of sophisticated systems, exemplified by platforms like SAP and JD Edwards, represents a transformative leap in how mining operations monitor and manage equipment health and performance. Most participants highlighted the instrumental role played by these integrated systems in providing a comprehensive and real-time view of critical metrics, such as MTBF and OEE. By harnessing the capabilities of SAP and JD Edwards, mining companies can consolidate vast amounts of data from disparate sources into centralised repositories, enabling stakeholders to access timely and accurate information at their fingertips. This integration facilitates informed decision-making by offering a holistic perspective on equipment health, performance trends, and potential areas for improvement.

Moreover, the utilisation of key performance indicators (KPIs) like MTBF and OEE serves as a compass for evaluating equipment reliability and operational efficiency. MTBF provides insights into asset reliability and maintenance effectiveness. Meanwhile, OEE offers a comprehensive assessment of equipment utilisation, performance, and quality, highlighting opportunities for optimisation across the production process. The synergy between sophisticated systems and key metrics not only streamlines operational workflows but also empowers organisations to identify bottlenecks, implement targeted improvements, and optimise resource allocation. By leveraging real-time data and analytics, mining companies can proactively address maintenance needs, optimise equipment utilisation, and enhance overall operational performance.

Furthermore, the integration of systems like SAP, JD Edwards, and other advanced systems fosters a culture of continuous improvement by facilitating data-driven decision-making and fostering collaboration across departments. Through regular performance monitoring and analysis, organisations can identify emerging trends, benchmark performance against industry standards, and drive innovation to stay ahead in an increasingly competitive landscape. By leveraging these tools, organisations can gain deeper insights, make smarter decisions, and embark on a journey of sustained excellence in the dynamic world of mining.

5.1.3 Challenges faced and evaluation of matrices

Implementing maintenance strategies in mining operations is rife with challenges, as most participants revealed. These hurdles, spanning from limited resources, competing priorities to cultural disparities, highlight the complexity of achieving peak performance in the mining sector. Resource constraints, including tight budgets and workforce shortages, often impede the allocation of sufficient resources to maintenance tasks, as noted by some participants. Cultural misalignment further complicates matters, with resistance to change and entrenched practices hindering progress. Regular evaluation through performance metrics and KPI tracking emerges as vital for pinpointing improvement areas. By monitoring metrics such as equipment downtime and maintenance costs, organisations can identify inefficiencies and prioritise actions, as also stressed by the participants. Additionally, KPI tracking enables benchmarking against industry standards, fostering a culture of continual improvement, as outlined by some of the participants. Addressing these challenges and leveraging performance metrics can pave the way for sustained success in mining operations.

5.1.4 Human factors impact

The effectiveness of maintenance outcomes within mining operations is intricately tied to the skills, training, and organisational culture of the workforce, as highlighted by insights from participants. Skilled personnel equipped with the requisite knowledge and expertise play a pivotal role in executing maintenance tasks with precision and efficiency. Several of the participants underscored the importance of having personnel who possess specialised skills in equipment diagnostics and repair, as their proficiency directly influences the quality and timeliness of maintenance activities. Furthermore, ongoing training and professional development initiatives are essential for equipping the workforce with the latest tools, techniques, and best practices in maintenance management. The significance of continuous learning and upskilling programs in ensuring that personnel remain abreast of industry advancements and emerging technologies was emphasised. By investing in training programs, organisations can empower their workforce to adapt to evolving maintenance challenges and drive continuous improvement.

Moreover, the organisational culture plays a critical role in shaping maintenance outcomes. A positive and supportive culture fosters collaboration, innovation, and a shared commitment to excellence in maintenance planning and execution. The importance of cultivating a culture that values proactive maintenance practices, encourages knowledge sharing, and celebrates achievements in maintenance performance was also highlighted. Such a culture not only enhances employee engagement and morale but also reinforces the importance of maintenance in achieving organisational goals. By prioritising skills development, fostering a culture of continuous learning and improvement, and nurturing a positive organisational climate, mining companies can enhance maintenance outcomes and drive sustainable performance excellence.

5.1.5 Resource allocation strategies

Efficient allocation of resources is paramount for maximising productivity and minimising costs within mining operations. Processes such as Reliability Centered Maintenance (RCM) and tools like SAP-based Maintenance Scheduler, as underscored by the participants play a crucial role in achieving this goal. Reliability Centered Maintenance (RCM) stands out as a systematic approach to asset management that prioritises maintenance activities based on their criticality and impact on operational performance. By identifying the most critical components and focusing resources on proactive maintenance efforts, organisations can optimise the allocation of manpower and finances. Participants highlighted the efficacy of RCM in streamlining maintenance workflows and maximising equipment reliability, ultimately leading to enhanced operational efficiency and improved productivity.

Tools like SAP-based Maintenance Scheduler provide mining companies with the means to plan, schedule, and track maintenance activities in a centralised and efficient manner. By leveraging real-time data and analytics, organisations can allocate resources dynamically, ensuring that maintenance tasks are executed at the right time and with the right resources. Participants attested to the benefits of utilising such tools in optimising resource allocation and improving overall maintenance performance. Furthermore, the integration of these processes and tools enables organisations to adopt a proactive stance towards maintenance management, minimising downtime, reducing operational risks, and enhancing asset reliability. By aligning maintenance activities with strategic objectives and operational priorities, mining companies can achieve greater efficiency and competitiveness in the market. By embracing these methodologies and technologies, organisations can optimise manpower and financial resources, leading to improved productivity, reduced costs, and sustained performance growth.

***Themes for research objective 2*:**

5.1.6 Balanced approach and investment

Achieving operational excellence in mining operations requires a balanced approach that combines established practices with theoretical insights. Most participants emphasised the importance of striking this balance to drive efficiency and effectiveness. Investment in skilled personnel is paramount. By recruiting and retaining personnel with specialised knowledge and expertise, mining companies can ensure that maintenance activities are carried out with precision and effectiveness. Moreover, ongoing training and professional development initiatives, as advocated by some participants, are essential for equipping the workforce with the latest tools, techniques, and best practices in maintenance management.

In addition to investing in human capital, technology also plays a crucial role in driving efficiency within mining operations. The participants underscored the significance of leveraging technology to streamline processes, optimise resource allocation, and enhance decision-making. By embracing advancements in technology, such as predictive analytics, IoT sensors, and automation tools, mining companies can achieve greater operational agility, reliability, and cost-effectiveness. By investing in talent and embracing innovation, organisations can position themselves for sustained success in the dynamic mining industry.

5.1.7 Clear objectives and improvements

Clear objectives and robust plans form the cornerstone of successful maintenance planning, as emphasised by the participants. By establishing clear goals and laying out comprehensive strategies, mining operations can ensure alignment with organisational objectives and effectively allocate resources. Moreover, a commitment to continuous improvement, coupled with regular evaluations, fosters adaptability and optimisation. Participants underscored the importance of ongoing assessment to identify areas for enhancement and refine maintenance practices over time. This iterative approach enables mining companies to stay agile, responsive, and proactive in addressing evolving challenges and opportunities in the maintenance landscape.

5.1.8 Data-driven decisions

The emphasis on data-driven decision-making, exemplified by a data-driven approach and rigorous data analysis, underscores the pivotal role of leveraging data for informed choices, as indicated by most of the participants. By harnessing the power of data analytics, mining operations can gain valuable insights into performance trends, identify patterns, and uncover actionable intelligence. This enables stakeholders to make informed decisions based on empirical evidence, rather than relying solely on intuition or past experiences. Ultimately, the adoption of a data-driven approach empowers organisations to optimise processes, mitigate risks, and drive continuous improvement in pursuit of operational excellence.

5.1.9 System integration for efficiency

The integration of systems like SAP and JD Edwards is pivotal for achieving operational efficiency, as emphasised by some participants. These platforms streamline processes and enhance communication across various departments, enabling seamless coordination and collaboration. By centralising data and automating workflows, organisations can eliminate redundancies, minimise errors, and optimise resource allocation. The integration of such systems enables real-time access to critical information, empowering decision-makers to respond swiftly to changing conditions and make informed choices. In the end, this integration fosters a more agile, responsive, and interconnected operational environment, driving efficiency and performance improvement across the organisation.

5.1.10 Holistic optimisation

A holistic approach, encompassing considerations of equipment life cycles and personnel skills, is essential for overall optimisation, as noted by the participants. By considering the entire lifespan of equipment and the capabilities of the workforce, organisations can develop maintenance strategies that align closely with business goals and production requirements. This approach facilitates proactive maintenance planning, minimises downtime, and maximises equipment reliability. It fosters a strategic alignment between maintenance activities and broader organisational objectives, ensuring that resources are allocated effectively, and efforts are directed towards achieving sustainable operational excellence.

5.1.11 Human factors consideration

Acknowledging human factors, such as skills and organisational culture, is imperative for successful maintenance outcomes, as highlighted by most of the participants. Investing in employee skills through training and development initiatives ensures that personnel are equipped with the necessary competencies to perform maintenance tasks effectively. Furthermore, fostering a positive organisational culture promotes collaboration, innovation, and a shared commitment to excellence in maintenance practices. By prioritising these human-centric aspects, organisations can enhance employee engagement, morale, and performance, leading to improved maintenance outcomes and overall operational success.

5.2 Recommendations and future work

Based on the themes discussed regarding maintenance planning and asset optimisation processes in mining operations in South Africa, the following recommendations can be made:

1. **Invest in advanced maintenance systems:** Mining companies should invest in sophisticated maintenance management systems like SAP, JD Edwards and others to streamline processes, enhance communication, and gain real-time insights into equipment health and performance. This investment enables better decision-making and resource allocation.
2. **Prioritise data-driven decision-making:** Emphasis should be on the importance of data-driven decision-making by promoting the use of analytics tools and performance metrics like MTBF and OEE. Encourage personnel to rely on empirical evidence and data analysis for planning and executing maintenance activities effectively.
3. **Promote continuous improvement:** Foster a culture of continuous improvement by providing ongoing training and development opportunities for employees. Encourage learning and knowledge sharing to keep the workforce updated with the latest maintenance practices and technologies.
4. **Enhance organisational culture:** Cultivate a positive organisational culture that values proactive maintenance practices, collaboration, and innovation. Encourage open communication channels and reward initiatives that contribute to improving maintenance outcomes and operational efficiencies.

5. **Align maintenance strategies with business objectives:** Ensure that maintenance strategies are aligned with broader business objectives and production requirements. Develop clear objectives and plans that prioritise activities based on their impact on production performance and overall operational efficiency.
6. **Optimise resource allocation:** Continuously assess resource allocation practices to ensure optimal utilisation of manpower, finances, and technology. Implement methodologies like Reliability Centered Maintenance (RCM) to prioritise maintenance tasks and allocate resources efficiently.

Future work:

From the literature analysis, research gaps have been found and shortcomings in the current maintenance theories as depicted in the table below. The research gaps identified are listed and summarised as follows:

	Theme	**Identified research gap**
1	Application of advanced analytics techniques	The use of advanced analytics techniques, such as machine learning, data mining and predictive modelling, has the potential to improve maintenance planning and asset optimisation. However, there is a lack of research on how these techniques can be effectively applied to production planning and asset management.
2	Evaluation of the effectiveness of maintenance strategies	There are various maintenance strategies, including preventive maintenance, corrective maintenance, and predictive maintenance. However, there is a lack of research on the effectiveness of these strategies in the context of production planning and asset optimisation.
3	Optimisation of maintenance scheduling	Maintenance scheduling can have a significant impact on production planning and asset optimisation. Future research could focus on developing optimisation models and algorithms for maintenance scheduling to minimise downtime and maximise asset utilisation.
4	Integration of sustainability considerations	As companies are increasingly focusing on sustainability, there is a need to integrate sustainability considerations into maintenance planning and asset optimisation. Future research could focus on developing frameworks for integrating sustainability considerations into production planning and asset management.

Table 10: *Future work - Summary of themes and associated research gaps*

5.3 Conclusion

The exploration of themes related to maintenance planning and asset optimisation processes provides valuable insights into their impact on production performance and opportunities for improving operational efficiencies within mining operations. The integration of sophisticated systems, such as SAP and JD Edwards, coupled with the emphasis on data-driven decision-making, underscores the importance of leveraging technology and analytics to optimise maintenance planning and asset management. These tools facilitate streamlined processes, enhance communication, and provide valuable insights into equipment health and performance, thereby contributing to improved production performance.

Furthermore, the emphasis on developing clear objectives, investing in personnel skills, and fostering a positive organisational culture aligns with the goal of enhancing operational efficiencies. By prioritising continuous improvement, training, and collaboration, mining companies can enhance workforce capabilities, minimise downtime, and optimise resource allocation, ultimately driving operational excellence and achieving long-term success. The findings discussed in relation to maintenance planning and asset optimisation processes contribute to a deeper understanding of their impact on production performance and provide methodologies for improving operational efficiencies within mining operations. By embracing technology, data-driven decision-making, and human-centric approaches, organisations can unlock opportunities for enhancing productivity, reducing costs, and sustaining competitive advantage in the mining industry.

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APPENDICES

<u>Appendix 1</u>: The Interview Questions

1. Can you describe the maintenance planning strategies currently employed in your organisation to enhance production performance?
2. How do you determine the optimal maintenance intervals and strategies for different assets in your organisation?
3. What are the key performance indicators or metrics used to assess the impact of maintenance planning and asset optimisation on production performance?
4. How do you integrate maintenance planning with asset management systems or other related software tools to improve production performance?
5. In your experience, what are the main challenges and barriers faced by organisations in implementing effective maintenance planning and asset optimisation strategies for production performance improvement?
6. How do you evaluate the effectiveness of maintenance planning and asset optimisation in improving production performance in your organisation? Can you provide specific examples?
7. How do human factors, such as employee skills, training, and organisational culture, influence the outcomes of maintenance planning and asset optimisation on production performance?
8. What are your perceptions of the benefits and drawbacks of predictive maintenance technologies in improving production performance?
9. How do you allocate resources, both financial and human, to support maintenance planning and asset optimisation for production performance improvement?
10. Based on your experience and expertise, what are some practical recommendations or insights for organisations looking to enhance maintenance planning and asset optimisation for production performance improvement?

Appendix 2: Grouping and categorising codes to generate themes

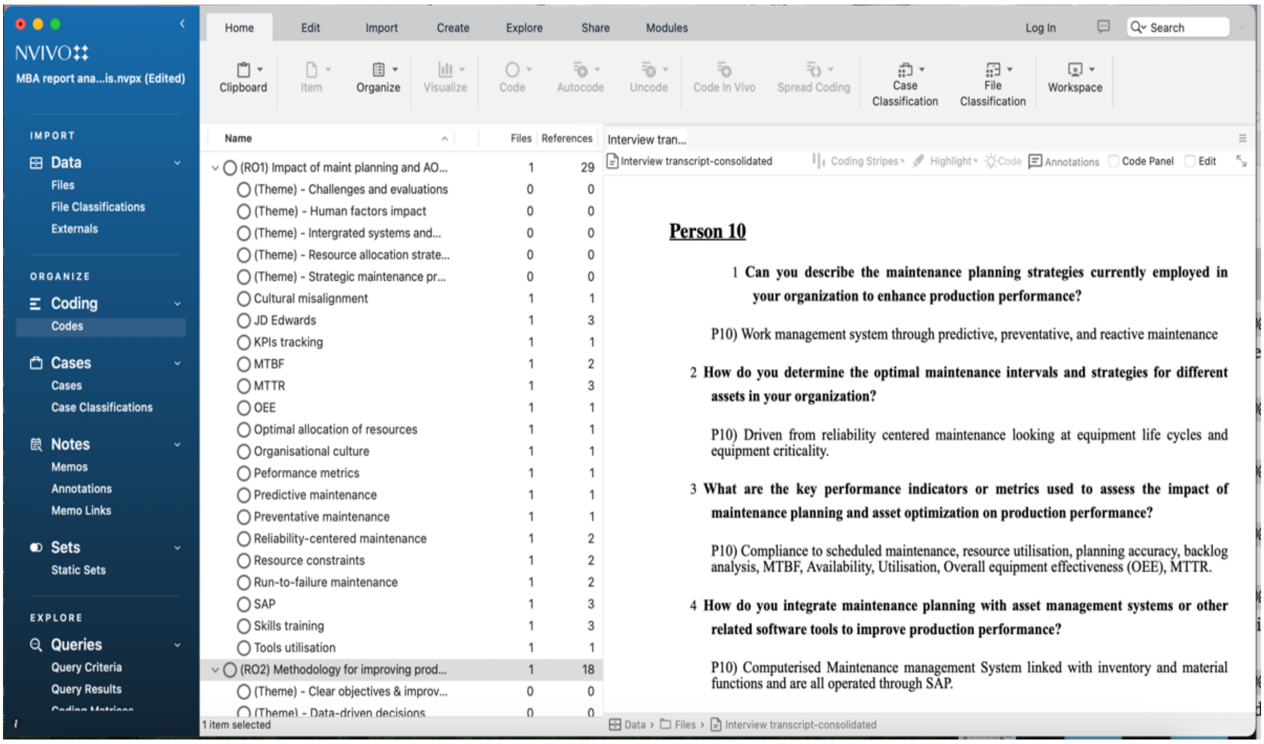

Fig 9: *Grouping and categorising codes to generate themes in NVivo 14.*