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An Exploratory Mixed-Methods Study on Addressing Inefficiencies in Maintenance Operations: A Case Study from a South African Mine

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Abstract

This paper aims to investigate the causes and consequences of inefficient maintenance operations at XYZ mine and their impact on organizational performance. The study follows an exploratory sequential mixed methods design that begins with a qualitative observation followed by a quantitative analysis of historical maintenance data. The findings of the study revealed significant inefficiencies, including engine failure, worn-out ground engagement tools, poor equipment condition, and equipment accident damage as leading factors to frequent equipment breakdowns, heightened safety incidents, and maintenance costs. The study also highlights safety issues stemming from non-conformance with maintenance protocols and inadequate safety training. Recommendations include implementing risk assessments before the commencement of any operation, enhancing training programs, improving safety protocols, and considering investment in new equipment or comprehensive rebuilds. These measures aim to enhance equipment performance, lower maintenance costs, and increase safety, ultimately improving overall operational efficiency at the mine.

Keywords
Maintenance costs, Organizational performance, Maintenance safety, Operations efficiency, Equipment reliability

Introduction
The mining industry is very important for the economy as it supplies essential raw materials for many sectors, generates large income by exports, and creates employment. In South Africa, the mining industry is the cornerstone of its economy. In 2023 the Minerals Council of South Africa reported that the mining sector contributed approximately 8% to South Africa's GDP, translating to around R400 billion. From an employment standpoint, the industry significantly contributed to job development by generating over 450,000 direct jobs and many indirect occupations. The majority of the minerals are primarily intended for export markets. The overall value of exports in 2023 amounted to R883.5bn (equivalent to around US$54bn), representing a growth from R838.2bn in 2022. These figures highlight the critical role that mining plays in the economic landscape of South Africa, underpinning the importance of efficient and reliable mining operations (Minerals Council of South Africa 2023). The ultimate success of the mine is largely contingent upon the reliability and effectiveness of its heavy machinery. Mining companies encounter several obstacles in their continuous endeavors to minimize equipment downtime and sustain elevated production levels in the dynamic operational setting (Alta and Putri 2019).

A study by Chan (2021) highlighted that maintenance operations encounter several challenges that have a significant impact on organizational performance. Key among these challenges is rising costs associated with maintenance and repairs, a shrinking pool of skilled maintenance staff, and high equipment unavailability due to equipment failure. It is critical to acknowledge that each of these obstacles stems from maintenance operations that are not executed efficiently. Overall, this means that mining firms are under constant pressure to achieve operational efficiency with limited resources due to inefficient maintenance operations.

Inefficient maintenance operations lead to a wide range of operational issues and as a result, affect organizational performance from a financial and non-financial aspect. Chan (2021) argues that mining operations incur significant losses in productive capacity, ranging from 5% to 20%, because of equipment downtime caused by inefficient maintenance operations. A 2016 study by Fourie, titled "Improvement in the overall efficiency of Mining", the study concluded that enhancing maintenance efficiency may result in cost savings of 10-20% on labor, repair, and maintenance (R&M) expenses for components and tools. These expenses typically make up 15% of the overall expenditures for a normal mining firm. This meant that enhancing maintenance operations could lead to a decrease in conversion costs by 10-15%. Therefore, maintenance operations should be seen as a crucial operational activity inside an organization, as stated by Shao et al. (2022).

1.1 Problem Statement

The occurrence of equipment breakdowns in production mining, stemming from inefficient maintenance operations, is a notable concern (Fourie, 2018). According to Adams and Bansah (2019), it has been determined that these breakdowns are responsible for 15-28% of production delays within the sector. Mining companies face the risk of lagging behind in the competitive environment if they fail to anticipate and prevent equipment failures, as the availability of equipment is a crucial requirement on site (Humphreys 2019). At XYZ mine, the Executive Committee (EXCO) observed a troubling trend in equipment availability. From October 2022 to September 2023, there was a continuous decline in the availability of equipment, with no notable improvement detected, as shown in Figure 1 below.

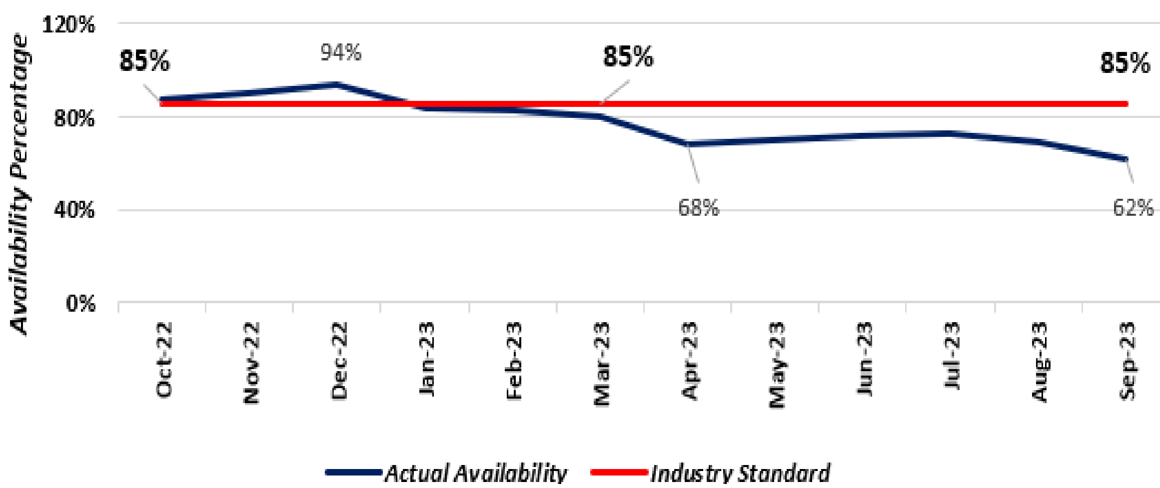

Figure 1. Equipment Availability Trend (Source: Author 2023)

The Committee raised concerns that the decrease in equipment availability was hindering the mine's capacity to meet its contractual commitments to its client and therefore affecting the mine's organizational performance. This downward trend was believed to stem from the inefficient maintenance operations that were carried out at the mine. This gap highlighted the need to scrutinize the mine's maintenance operations to validate the executive committee's statement. Therefore, this study was conducted to assess the inefficient maintenance operations at XYZ Mine to offer recommendations aimed at optimizing the mines' maintenance procedures.

1.2 Research Aim, Objectives, and Question

This study aims to identify the causes and consequences of inefficient maintenance operations at XYZ Mine, as well as to understand their impact on organizational performance and develop corrective measures to enhance equipment performance, reduce costs, and improve safety

To achieve the above main research objective, the following specific research objectives (SRO) have been established:

SRO1. To establish the factors contributing to inefficient maintenance operations on organizational performance at XYZ mine
SRO2. To examine the impact of inefficient maintenance operations on organizational performance at XYZ mine, particularly in terms of equipment performance, maintenance costs, and safety

Based on the above main objective, the study sought to address the following main research question: What are the causes and consequences of inefficient maintenance operations at XYZ mine, and how do these inefficiencies impact organizational performance in terms of maintenance costs, equipment performance, and safety?

To answer the above main research question, the following specific research questions (SRQs) have been developed:
SRQ1. What are the factors contributing to inefficient maintenance operations on organizational performance at XYZ mine?
SRQ2. What is the impact of inefficient maintenance operations on organizational performance at XYZ mine, particularly in terms of equipment performance, maintenance costs, and safety?

1.3 Scope, Limitations, and Significance of the Study

The study focuses on assessing the inefficient maintenance operations carried out at XYZ mine, with the intention to provide recommendations that will optimize the mines' maintenance operations. The study will analyze and interpret primary and secondary data to answer the research questions of the study. The study is limited to XYZ mine an open-cast mine situated in the Northwest of South Africa. A key player in the Northwest, the mine specializes in extracting copper and sinter. The study had several limitations that could impact the broader applicability of its findings. Firstly, as a case study, the findings of the study are specific to XYZ mine and cannot be generalized to other mining operations without further research. Each mine has unique operational contexts, maintenance practices, and environmental conditions that may influence the effectiveness of the proposed solutions. Even though the concepts employed are ideal for a variety of maintenance departments, the study's recommendations do not apply to other maintenance divisions without further work to complement that organization's maintenance philosophy. In addition, the study relied on historical data, which may not capture variables influencing equipment performance such as recent changes in operational practices. Lastly, the study focused exclusively on Front End Loaders (FELs) at XYZ mine. While this equipment is critical to the mine's operations, the findings and recommendations are limited to this specific category of equipment.

Inefficient maintenance operations are a significant challenge in the mining industry, affecting both small and large enterprises, including state-owned enterprises like Eskom. The consequences of delayed maintenance have led to reliability issues, load shedding, and decreased performance. The findings of this study will contribute to the existing body of knowledge in the South African mining sector and aid XYZ Mine in identifying factors contributing to inefficient maintenance operations, enabling corrective measures to improve performance. The research will have significant advantages in the Maintenance, Repair, and Operations (MRO) profession, particularly in production mining. The study's findings are expected to aid industry experts, particularly in the field of maintenance, with a practical process for identifying inefficiencies in their operations and implementing the necessary corrective measures.

2. Literature Review

2.1 Introduction to Maintenance Operations in the Mining Industry

According to Papic and Kovacevic (2016), maintenance operations encompass a broader range of tasks and obligations beyond simply repairing or maintaining equipment. Maintenance operations encompass a range of activities that involve strategic, administrative, and organizational functions. These operations are characterized by careful and detailed planning and implementation of strategies with the purpose of setting clear maintenance objectives, creating maintenance policies, using resources efficiently, and ensuring that maintenance activities are in line with the organization's overall goals. In addition, maintenance operations include selecting and applying the most fitting maintenance strategies—whether preventive, predictive, or corrective—along with the careful scheduling of maintenance tasks to enhance the performance and reliability of assets, as further detailed by Adebayo et al. (2021).

Swink et al. (2020) underscore the significance of cross-functional collaboration in effectively managing the various resources required for maintenance operations, such as personnel, spare parts, tools, and equipment to enhance the efficiency of maintenance activities. Lapesa (2022) emphasizes that such collaboration is critical for achieving successful outcomes in equipment repair operations. Maintenance operations, as a cross-functional activity, bring together specialists from various fields, including engineering, procurement, and production. This collaboration enables a synchronized approach to maintenance, guaranteeing that maintenance activities are not only carried out efficiently but also in complete accordance with the overarching objectives of the organization. Through these collaborative endeavors, maintenance operations go beyond traditional maintenance by cultivating a collaborative spirit within an organization.

2.2 The Role of Maintenance Operations in Organizational Performance

Organizations that optimize their maintenance operations see a rise in product quality and equipment reliability, which raises revenue, increases staff satisfaction, and raises overall productivity. Although maintenance operations traditionally entail equipment repairs, it has a bigger role in an organization. Maintenance operations impact production, safety, finance, and maintenance due to their cross-functionality (Adebayo et al. 2021). Efficient maintenance operations are key for a mine to achieve its production targets, reduce downtime, cut expenses, and maintain safety regulations. In fact, maintenance operations are the backbone of every efficient and successful mining business, and they are essential to its long-term viability (Cha et al. 2017)

According to Fasuludeen et al. (2022), the growing significance of maintenance operations highlights the key role it plays in an organization and its significant impact across various organizational sectors. The Maintenance, Repair, and Operations (MRO) study shows that the MRO industry grew steadily in 2022. The industry was projected to be valued at $411 billion in 2022 and rise to $472 billion by 2028. From 2023 to 2028 this would result in a compound annual growth rate of 2.28%. Adoption of Fourth Industrial Revolution (4IR) technologies and outsourcing plans to improve operational performance and save costs drives development mostly.

Smart factories and predictive maintenance using sensors, and the Internet of Things are expected to boost the Maintenance, Repair, and Operations market. Western Australian miners increased productivity by 20% by using autonomous technology in maintenance, demonstrating the power of automation in mining. A metal mine used Industrial Internet of Things (IIoT) sensors and machine learning to boost chemical recovery by 10-15%. The cases illustrate the way in which the incorporation of technology into maintenance operations has enhanced the efficiency of organizations, highlighting the crucial role that maintenance operations play in promoting ongoing improvement in organizational performance (McKinsey 2018).

2.3 Challenges in Maintenance Operations

Maintenance operations in various industries encounter numerous issues, ranging from new technology adoption to organizational reluctance to change. Below are some insights into these challenges and practical applications obtained from case studies across different sectors.

2.3.1 Technology Adoption in Maintenance Operations

The adoption of technology into maintenance operations signifies a substantial shift towards increased efficacy, economy, and flexibility in the dynamic field of maintenance, repair, and operations (MRO). Emerging technologies, including AI-driven analytics, IoT devices, and predictive maintenance, are revolutionizing the mining industry (Klishin et al. 2020). These technologies enable firms to automate repetitive tasks and predict potential problems. According to Ivanov and Shishkin (2017), firms encounter several problems when integrating technology into their maintenance operations. For instance, a notable case occurred in a manufacturing plant specializing in producing automobile components. When it switched to predictive maintenance from a traditional calendar-based maintenance strategy (Alexopoulos et al. 2021). The aim was to maximize the equipment's efficiency while reducing downtime and maintenance costs. To accomplish this, the firm invested in sensors and advanced analytics tools for real-time equipment monitoring and failure prediction.

The first challenge was the cost of buying sensors, analytics tools, and data storage, as well as the expenses related to integrating the new technology with the plant's pre-existing manufacturing execution system (MES) (Alexopoulos et al. 2021). Additionally, implementing predictive maintenance required a transformation in organizational culture. The adoption of new technology was met with resistance from employees, particularly those who had years of experience in traditional maintenance methods. Moreover, the maintenance personnel's lack of knowledge in data analysis and machine learning posed a significant challenge in terms of training. This case exemplifies the many challenges organizations face when adopting technology into their maintenance operations, such as resistance to change, the need for extensive training, and the complexities of integrating new technologies with outdated systems (Mahapatra and Shenoy 2021).

2.3.2 Disappearing Talent from The Maintenance Industry

Jao Mateus Domingos, in his 2018 study titled "The socioeconomic impact of South Africa's brain drain" defines the term "brain drain" as the movement of qualified people from one company, sector or nation to another in search of better pay or more favourable possibilities, so resulting in the loss of highly skilled and talented individuals from industries and businesses. Staff attrition is a problem in the Maintenance Repair and Operations industry, as it is generally higher than in other industries, depending on the job type, industry, and geography.

According to the Association for Maintenance Excellence (2018), the typical mining operation experiences a 37% absenteeism and staff turnover rate. A separate investigation conducted by the Canadian Mining Network (2023) revealed that the mean rate of attrition for maintenance professionals and machine operators in Canada was at 22%. According to the 2023 data from the Bureau of Labor Statistics, the rate of involuntary turnover, which encompasses layoffs and dismissals, among maintenance professionals in the United States was 4% higher than the worldwide average. This further supports the notion that a high turnover rate in the maintenance field is clearly a phenomenon.

The logic for this phenomenon is that inefficient maintenance operations increase the burden on staff, resulting in a fast-paced operational environment that is prone to equipment failure. When maintenance operations do not operate smoothly or efficiently, various negative effects might occur, discouraging competent maintenance experts and leading to their departure. A concern is that employees are expected to work longer hours to compensate for downtime or cover for absent colleagues. Such cases have the potential to cause burnout and raise the possibility of individuals seeking different employment opportunities with less demanding working circumstances (Fessehaie and Rustomjee 2018). Because of the inherent nature of maintenance, unexpected equipment failure may force personnel to work outside of their usual working hours compounded by a lack of balance between work and home life leads to discontent and higher turnover.

2.3.3 Out-of-control maintenance and repair costs

"Out-of-control maintenance and repair costs" is the state in which equipment maintenance and repair expenses have escalated to unsustainable levels. In this regard, "out-of-control" implies that these expenses may be seriously impacting the financial stability and operations of an organization as they have grown beyond the planned or expected level (McClean and Smith 2021). Out-of-control maintenance costs are caused by inefficient maintenance operations as these operations can lead to unreliable equipment, long periods of unplanned equipment downtime, and the adoption of costly repair methods. As such this leads to a wide range of issues that drive up costs and adversely impact the financial performance of an organization.

According to Lemes and Hvam (2019), it has been estimated that maintenance expenses contribute 15% - 40% of the overall production costs. Unplanned downtime because of inefficient maintenance operations, costs three to nine times more than planned maintenance. This is because in situations requiring emergency repairs, it may be required to accelerate the procurement of replacement parts, hire the services of specialized technicians, or extend working hours to immediately resolve the breakdowns. The combination of all these additional expenses places a burden on the financial resources of an organization and has an impact on the overall profitability of the production process (Frank, 2019).

Many researchers and practitioners have emphasized the financial losses caused by inefficient maintenance operations (Andre 2021; Abouel-Seoud 2016; McKinsey and Company 2017; Stenström et al. 2015; Stern 2020). Another challenge is that maintenance is not given the attention that it deserves and is viewed as a cost center rather than a value-adding activity. This viewpoint was underscored by a survey conducted on 118 Swedish manufacturing companies, 70 percent of the respondents considered maintenance as a cost centre rather than a value-adding function (Alsyouf 2009). As such, there is a lack of attention from middle and senior-level management toward recognizing the impact of maintenance operations on many aspects of product quality, production costs, and most significantly, bottom-line profit. The prevailing notion implies that maintenance is an unavoidable burden or that there exist no other viable options to mitigate maintenance costs efficiently. Nevertheless, it is crucial to alter this perspective for organizations to seek progressive solutions that efficiently decrease maintenance costs.

3. Methods

The study used an exploratory sequential mixed methods design that was based on a case study. This is a two-phase mixed-methods design, the first step in an exploratory sequential design is to collect and analyze qualitative data. The next step is to collect and analyze quantitative data, which leads to interpretation. In this approach, the qualitative results are used to support and elaborate on the quantitative data (Creswell et al. 2006).

An exploratory sequential mixed-method study approach has various advantages. It enables researchers to investigate a problem from several angles, integrating qualitative and quantitative approaches. Using a sequential approach, researchers may establish links between variables qualitatively before deepening their understanding quantitatively. The mixture of approaches improves the validity and dependability of the study findings. Furthermore, mixed method designs enable triangulation, in which several approaches are employed to cross-validate findings, hence reinforcing study outputs (Creswell et al. 2006).

3.1 Research Design

The study employed an exploratory sequential mixed methods approach. The research design consisted of two phases:

1. Qualitative Phase: This phase involved in-depth observations to gain first-hand insights into the everyday operations and obstacles encountered at the mine.
2. Quantitative Phase: This phase involved analyzing historical maintenance records to assess and quantify the impact of maintenance inefficiencies on organizational performance in terms of maintenance costs, equipment performance, and safety.

This approach allowed for a comprehensive understanding of the factors contributing to inefficient maintenance operations and their impact on organizational performance at XYZ mine, with the case study adding specificity and practical relevance, making the findings directly applicable to the mine.

3.2 Research Design

3.2.1 Qualitative Phase

The study commenced with the collection of qualitative data. The data was collected through direct observations of the daily maintenance operations at the mine. Notes were taken to document observed practices and any apparent inefficiencies. The site visit took place between the period of 01 October 2022 and 30 September 2023.

3.2.2 Quantitative Phase

Secondary data was obtained from the mine's maintenance database. The extracted data comprised of repair frequencies, operational uptime, maintenance costs, and other relevant metrics such as safety records. The historical data spanned over a period of 12 months, from the 1st of October 2022 to the 30th of September 2023 ensuring a comprehensive dataset for analysis. It is crucial to emphasize that the study exclusively used existing historical maintenance records for quantitative analysis. There was no collection of new quantitative data, thereby eliminating the need for surveys or questionnaires.

3.2.3 Data Collection Process

Data from the site visit and historical maintenance records were gathered to establish and gain a clear foundational understanding of the maintenance operations at XYZ Mining company. Once the data had been obtained, the maintenance operations were examined using problem-solving methods, namely a Pareto Analysis, to identify the main factors responsible for the inefficient maintenance operations at the mine. Equipment reliability indicators were employed to evaluate the impact of the inefficiencies on organizational performance

The data collection process involved the following steps:

1. Preparation: Prior to conducting the site visit to the mine, a detailed plan was developed outlining the observation protocols. Authorizations were obtained from XYZ Mine's management.
2. Site Visit: The researcher conducted the observations, documenting the findings.
3. Data Retrieval: Historical maintenance records were extracted from the mines database
4. Data Cleaning: The collected data was cleaned to address inconsistencies such as missing values, duplicates, and discrepancies ensuring reliable analysis

3.2.4 Data Analysis

The historical maintenance data was analyzed using Microsoft Excel. Descriptive statistics and data visualization were employed to identify trends and patterns from the maintenance data. Key performance indicators (KPIs) such as equipment availability, maintenance costs and safety incidents were calculated. The analysis aimed to quantify the impact of the identified inefficiencies on organizational performance. The study was reliable in as far as if the same method was used across a different mine, it would reveal consistent data as well. Triangulation enhanced the validity and reliability of the findings as the study cross-verified data from multiple sources. This was achieved by using qualitative data to corroborate the quantitative findings.

"Operational Availability = Run Time / Planned Production Time"
"Run Time = Planned Production Time – Downtime"

3.3. Population and Sample Size

The population targeted for this study included the entire fleet of FEL's (Front-end loaders) at the Northwest mine, which comprised of 12 Caterpillar loaders and 6 Komatsu loaders. The study did not use sampling methods and hence examined the entire fleet of the mine, resulting in a study population of 18 loaders. The loaders were selected as the target population because of their critical role in the day-to-day mining operations at the mine. The loaders were important subjects for studying and played a key role in evaluating the mine's maintenance operations. In any mining operation, equipment performance is a direct reflection of the effectiveness and efficiency of the maintenance operations of a mine (Ribeiro et al. 2019). The study assessed the loaders' performance by examining important metrics such as equipment availability, downtime, maintenance costs and safety. This evaluation aimed to identify the factors contributing to inefficient maintenance operations and their impact on organizational performance.

4. Results and Discussion

4.1Findings from the site visit to XYZ mine

The site visit observations revealed several critical issues affecting maintenance efficiency at the mine:

Poor equipment condition

The observations revealed that FEL SE1, E6, F11 and F12 were in poor condition, showing visible signs of wear, corrosion, and oil leaks. This deterioration made the equipment prone to failures, leading to frequent breakdowns that halted production and disrupted overall mining operations. Furthermore, these constant failures had an impact on both staff morale and productivity, as workers faced the challenges of unpredictable equipment performance, resulting in decreased job satisfaction and inefficiency.

Ageing equipment

The observations revealed the prevalence of ageing mining equipment. Notably, FEL F11 and F12 had been out of operation for weeks. These two pieces of equipment were among the oldest equipment in the fleet, with approximately 35,248 and 41,235 machine hours, respectively. The equipment was frequently not operational due to breakdowns, rendering it unreliable and costly to maintain. The ongoing requirement for urgent repairs was depleting the mine's financial resources that could otherwise be used to upgrade the equipment or improve other aspects of operations.

Ineffective critical spares and inventory management

An issue of significant concern was the ineffective spares and inventory management system in place at the mine. Challenges included inadequate stock levels, disorganized storage areas, and a lack of critical spares, which led to extended equipment downtime and increased costs. The inefficiency forced maintenance staff to improvise or postpone important repairs, which resulted in less-than-ideal repair solutions and additional equipment degradation.

Nonconformance in maintenance operations

The site visit revealed non-conformance issues within the maintenance and mining operations, such as deviations from standard maintenance procedures and poor compliance with safety protocols. The lack of regular toolbox talks raised concerns about safety awareness and compliance at the mine. In December, there was a rise in safety incidents, including workers showing up intoxicated and reported cases of near misses throughout the mine. These non-conformances led to increased maintenance costs and equipment downtime due to incident-related damage, straining the mine's resources and compromising the safety of the workers.

4.2 Assessing the factors contributing to inefficient maintenance at XYZ mine

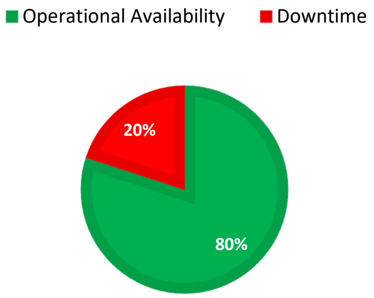

Figure 2. Overall Equipment Availability vs Downtime

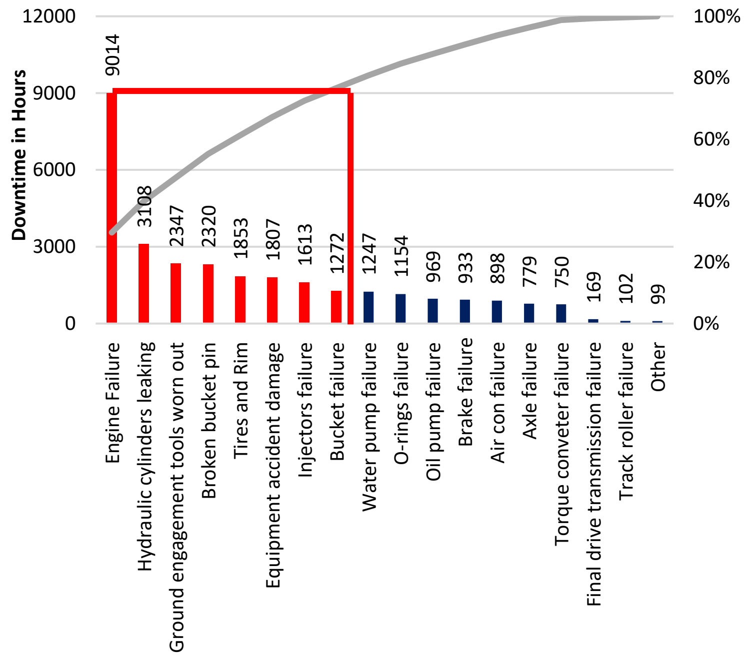

Figure 3. Pareto Analysis of Maintenance Issues

Prior to developing any recommendations, it was crucial to assess the performance of the overall fleet against the industry standard. To achieve this, the equipment availability metric was used, which serves as a critical indicator of the effectiveness of maintenance operations and the overall reliability of the equipment (Silva et al. 2016), figure 2 illustrates this key metric. Figure 2 depicts the overall equipment availability at the mine, showing that the mine maintained an operational availability rate of 80%, with 20% downtime. The mining industry's benchmark for equipment availability is cited at 85%, anything below indicates inefficiencies (Trout 2019). Figure 2 implies that over the 12-month period, the equipment was operational and readily accessible for 80% of the time. Compared to the industry standard of 85%, XYZ mines' operational availability of 80% indicates a shortfall. The lower availability rate, as depicted in Figure 2 in comparison to the industry standard, underscores the challenges the mine faces in keeping its equipment operational. These inefficiencies not only hinder the mine's ability to maintain productivity but also highlight the need for targeted improvements in maintenance operations to meet industry standards and enhance overall performance.

Figure 2 illustrated an overview of the mine's overall operational availability and made it evident that the mine's performance fell short of the industry standard. To further analyze the root causes of this underperformance, figure 3 presents the Pareto Chart of the factors responsible for the mine's poor performance. The chart revealed that engine failure, hydraulic cylinder leakage, worn ground engagement tools, broken bucket pins, tires and rim issues, accident-related equipment damage, injector failure, and bucket failure were the issues responsible for 80% of the maintenance inefficiencies at the mine. Addressing these key issues was essential for reducing downtime and, consequently, improving the overall maintenance operations at the mine.

4.3 Assessing the impact of inefficient maintenance operations on organizational performance

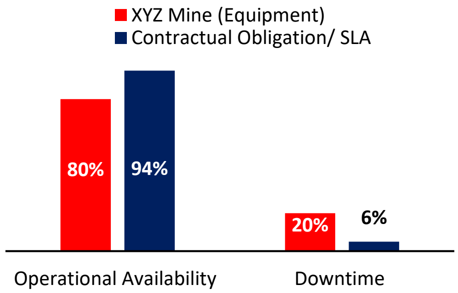

Figure 5. Equipment Availability vs Contractual Obligations

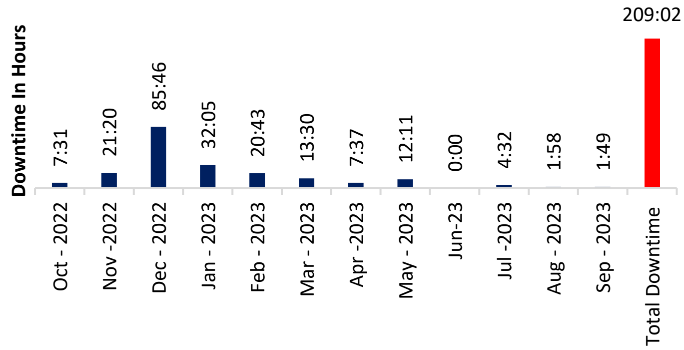

Figure 4. Downtime by Safety Related Incidents

A Service Level Agreement (SLA) is a legal agreement between an organization and its customers that defines the expected aspects of quality, availability and responsibilities (Swain and Garza, 2023). XYZ Mine pledged to maintain a maximum level of 94% operational availability for its stakeholders, acknowledging that a 100% operational availability was unrealistic due to the mine's severe operational circumstances. The agreement allowed for a maximum downtime of 6%, with penalties for non-compliance. Figure 4 illustrates the mine's performance against its service level agreement. The issues identified in the pareto analysis collectively played a significant role in reducing the operational availability of the mine. This resulted in operational availability standing at merely 80%. The mine's subpar operational availability rate of 80% corroborates with the inefficiencies observed during the site visit. The site visit revealed several key issues directly impacting equipment availability and reliability. These factors led to frequent breakdowns, extended downtime, and overall reduced equipment availability, aligning with the observed 80% availability rate, which clearly fell short of the SLA target of 94%. This considerable difference between the actual equipment availability and the SLA target demonstrates the mine's failure to meet its contractual obligations as a result of inefficient maintenance operations, ultimately impacting organizational performance and failing to achieve key KPIs.

Incorporating the aspect of safety into the maintenance discussion is crucial, as it extends the analysis beyond financial metrics to encompass the human element of maintenance operations. This critical perspective emphasizes the far-reaching effects maintenance operations have on overall organizational performance. Figure 5 illustrates the impact of safety related incidents on operational downtime. The graph illustrates that December stood out as the most affected month, during which the mine experienced an alarming total of 85 hours and 46 minutes of lost production time due to safety-related incidents. Following December, October recorded the next highest downtime with 32 hours and 5 minutes lost, and November saw a loss of 21 hours and 20 minutes. The bulk of the downtime came from these three months alone, which emphasizes the great necessity of better safety precautions. The high rate of incidents at the mine corroborates with the inefficiencies observed during the site visit. These inefficiencies resulted in a poor safety culture at the mine that put the mining operations at risk, resulting in a high rate of incidents. The mine experienced a total of 209 hours of downtime due to safety-related incidents throughout the year. This represents lost production time that could have been productively allocated to production and mining operations, further supporting the notion that these inefficiencies directly contributed to operational risks and incidents that impacted the mines overall organizational performance as illustrated by figure 5.

Assessing the mine's maintenance costs was crucial as it shed light on the financial implications of inefficient maintenance operations. Figure 6 illustrated an overall breakdown of the mine's yearly maintenance costs, categorized by the different maintenance strategies used by the mine. The annual maintenance expenses revealed that Reactive Maintenance accounted for the highest share of costs, totaling R5,507,394. This was followed by "Other" Maintenance cost at R2,759,813. The costs for Condition-Based Maintenance were relatively lower, at R1,412,684, and Preventive Maintenance incurred the smallest costs, amounting to R1,354,895.

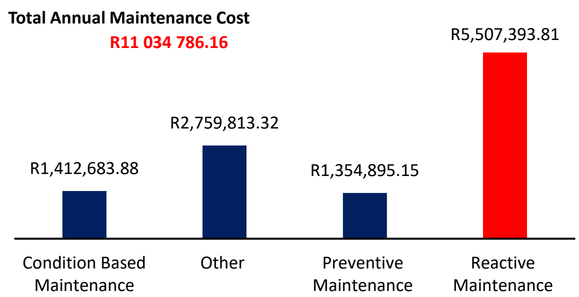

Figure 6. Annual Maintenance Costs by Strategy Breakdown by Strategy

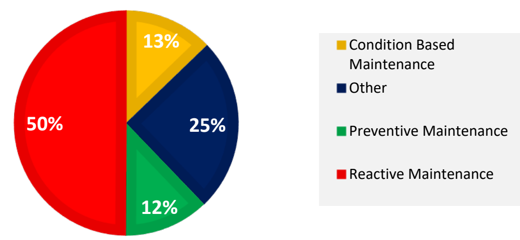

Figure 7. Annual Maintenance Costs by Strategy

In addition, Figure 7 illustrates the distribution of these costs. The graph illustrates that there was a significant reliance on reactive maintenance, which accounted for 50% of the annual maintenance costs, equivalent to half of the total maintenance expenditure. The reliance on reactive maintenance driven by frequent equipment failures and safety related incidents is a direct result of the inefficient maintenance operations identified during the site visit. Ultimately, the inefficient maintenance operations at the mine led to increased maintenance expenses, which substantially impacted the mine's financial performance, as demonstrated by the extensive dependency on an expensive reactive maintenance approach.

4.4 Proposed improvements

Based on the inefficient maintenance operations identified at the mine, this portion of the study proposed targeted solutions to address these inefficiencies. FEL F11 and F12 are the oldest equipment in the fleet as a result are prone to engine failure due to their advanced age, posing a significant risk to operational efficiency at the mine. The mine must conduct a cost-benefit analysis on either opting for a complete rebuild of FEL F11 and F12, which will require a special budget and planned downtime, versus investing in newer, more reliable equipment. Although rebuilding could be a less expensive temporary fix, this one does not deal with the underlying cause of reliability issues. Investing in new equipment may provide a more sustainable solution to improving operational efficiency and reducing long-term risks.

To address the constant hydraulic leaks, equipment bucket failures and broken bucket pins, the mine should implement regular operator refresher training focused on safe methods for optimal material handling, this should include correct lifting methods, in addition to that the mine must enhance supervision during operations to ensure safe loading procedures are being followed. These issues suggest that the equipment is being subjected to excessive loads, leading to their failure. To prevent tyre and rim damage, the mine should establish a mandatory risk assessment procedure before the commencement of any operation. This procedure will help in the identification of any protruding objects or potential threats that may put the operation at risk. To improve safety at the mine, it is imperative to conduct regular safety training sessions and toolbox talks, while rigorously enforcing strict adherence to safety protocols.

5. Conclusion

The study provided a comprehensive analysis of how inefficient maintenance operations impacted the various aspects of organizational performance at XYZ Mine, specifically focusing on equipment reliability, maintenance costs, and safety. The analysis revealed engine failure, hydraulic cylinder leakage, worn ground engagement tools, broken bucket pins, tires and rim issues, accident-related equipment damage, injector failure, and bucket failure as factors responsible for inefficiency at the mine. These inefficiencies resulted in constant equipment breakdowns and major disturbances to the daily mining operations, therefore reducing the operational availability of the mine to 80%, which is below the industry benchmark. As a result of this, the mine significantly relied on a reactive maintenance approach and experienced a high frequency of safety incidents due to non-compliance. These factors collectively had a detrimental impact on the overall organizational performance of the mine.

In addition, based on the performed results and analysis conducted it validates the claim by EXCO that the subpar equipment availability was indeed because of the inefficient maintenance operations carried out at the mine. If the mine adopts the suggested solutions, it may substantially improve its maintenance operations significantly. This would lead to more reliable equipment, less downtime, lower maintenance costs, higher safety, and improved overall organizational performance. The study did a good job of meeting its objectives by identifying the key factors responsible for the inefficient maintenance operations at the mine and examining their impact on organizational performance. The findings and recommendations provided a clear pathway for XYZ Mine to enhance its maintenance operations and overall organizational performance. Therefore, based on the findings and the solutions provided, the study accomplished its intended aim and objectives.

It is also worth noting that the implementation of these proactive strategies may encounter a variety of obstacles. First, there may be resistance from staff who are accustomed to the old ways of conducting tasks, which include a reactive attitude and disregard for safety regulations. Implementing the change would require a significant adjustment in both mindset and operational procedures. Moreover, the financial impact cannot be overlooked. For instance, the decision to invest in new equipment or rebuild is costly. Then there are the initial costs and resources required to invest in operator training programs. All these factors add up, potentially straining the mine's budget and disrupting existing workflows. Another factor that needs to be taken into account is ensuring consistent compliance with the new maintenance protocols, which may require continuous monitoring and management; this could prove to be difficult, taking into account the mine's demanding operational environment. Overcoming these challenges will be critical to successfully implementing proactive strategies therefore enhancing the mine's maintenance operations and improving overall efficiency.

Future studies should investigate the long-term effects of implementing the recommended improvements on organizational performance at XYZ mine and similar mining operations. Future studies could also look into conducting a comparative study between mines that rely on reactive maintenance versus those that have adopted proactive maintenance strategies, focusing on equipment performance, cost reduction and safety outcomes.

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