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AN INTEGRATED APPROACH TO REDUCE OPERATING COST FOR GOLD MINES.

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ABSTRACT

The mining of gold ore is a lucrative industry, but it is virtually difficult to regulate the fluctuations in currency and commodity prices caused by the world economy. However, miners have control over their operations by eliminating inefficiencies, reducing operating expenses, and boosting output. The difficulty most businesses confront is how to reduce their operating expenses, move away from impulsive cost cutting, and develop long-term initiatives for cost management. This study aims to analyze and provide an integrated method for gold mining operating cost optimization or reduction. It goes over how operational efficiency gaps can be found and closed using benchmarking and the implementation of Lean/Six Sigma approaches. We adopted a quantitative study, it utilized the analytical approach to provide guidelines and examples of where achievable and measurable reductions in operating costs and increased efficiencies are obtainable for mobile loading equipment, conveyor systems, transport equipment and infrastructure.

Keywords: Gold mining, Efficiency, Operating costs, Equipment utilization.

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1 INTRODUCTION

The gold mining industry is well-known for being highly profitable, but it is influenced by unpredictable changes in currency and commodity prices caused by the global economy. Miners cannot directly control these external factors, but they can make their operations more efficient by getting rid of waste, reducing expenses, and maximizing their output. However, mining businesses face a persistent challenge of finding long-term solutions for cost management instead of just making quick cuts. In order to succeed in this fast-paced industry, it is crucial for mining companies to reduce their operating expenses. This requires a comprehensive approach that goes beyond short-term fixes. By taking a strategic view, mining companies can identify and address inefficiencies and wasteful practices in all aspects of their operations, such as exploration, extraction, processing, and transportation. This way, they can find ways to optimize costs without compromising safety or quality.

Furthermore, it is important for mining companies to move away from reactive cost-cutting measures and focus on long-term strategies that prioritize efficiency, productivity, and innovation. This includes investing in advanced technologies and equipment, implementing strong maintenance and asset management systems, streamlining supply chain processes, and fostering a culture of continuous improvement. By integrating these initiatives into their operations, mining companies can achieve sustainable cost reductions while also improving their overall performance and resilience.

This study aims to investigate and propose integrated strategies to lower operating costs in gold mining operations while ensuring productivity and safety. By analysing various aspects of the mining process, including equipment utilization, energy consumption, labor management, and supply chain efficiency, the research seeks to identify areas for improvement and develop practical solutions. This integrated approach may involve leveraging advanced technologies, optimizing production processes, streamlining workflows, and implementing cost-effective maintenance strategies. Additionally, the research will examine resource utilization to minimize waste and reduce environmental impact. The goal is to provide gold mining companies with a comprehensive framework for reducing operating costs, enhancing production output, increasing profitability, improving sustainability, and strengthening their competitive position in the industry.

This paper is organized as follows: In Section 1 this study introduced the research topic and defined a problem statement, in section 2, we review relevant literature and describe the research methodology. In Section 3 we analyzed and discussed the finding, Section 4 outlines the guidelines for the proposed integrated approach and concludes the paper.

1.1 Problem statement

In gold mines, there are problems with the efficiency of equipment used for loading, transporting, and moving materials. This causes higher costs and a need for improvement. The inefficiencies are caused by outdated technology, not maintaining the equipment properly, inefficient workflows, not using resources effectively, and not providing proper training. To solve these problems, it is important to use newer technology, maintain the equipment well, improve coordination between different tasks, use resources efficiently, and train workers properly. By doing this, gold mining operations can become more efficient, save money, and be more successful.

1.2 Aim

The aim of this study is to investigate and propose an integrated approach to address efficiency gaps in mobile loading equipment, conveyor systems, and transport equipment within gold mines. The study aims to identify specific strategies and interventions that can optimize operations, reduce operating costs, and enhance overall cost-effectiveness in gold mining activities.

1.3 Major Objectives

- Identify the specific inefficiency gaps in mobile loading equipment, conveyor systems, and transport equipment within gold mines.
- Propose an integrated approach that addresses the identified inefficiencies and aims to optimize operations, reduce operating costs, and enhance cost-effectiveness in gold mining activities.

1.4 Minor Objectives

- Analyze the impact of inefficiency gaps on operating costs in gold mines.
- Evaluate existing practices and technologies used in mobile loading equipment, conveyor systems, and transport equipment within gold mines.
- Propose specific interventions and strategies to improve efficiency and reduce operating costs in the identified areas.

1.5 Significance of the study

This study is important because it can help gold mining companies become more efficient and reduce their operating costs. By finding ways to improve mobile loading equipment, conveyor systems, and transport equipment, the study aims to make mining operations better and save money. This research can also promote sustainability by reducing waste and using resources more wisely. The findings can benefit mining companies, industry professionals, policymakers, and local communities. Mining companies can save money and grow, policymakers can make better rules, and local communities can have more jobs and a cleaner environment. Overall, this study is significant because it can bring positive changes to the gold mining industry by making it more efficient, saving money, and being better for the environment.

1.6 Scope

The study will investigate the problems related to inefficiency in mobile loading equipment, conveyor systems, and transport equipment within gold mines. It will focus on understanding the causes of these inefficiencies and how they affect operating costs. The study will analyze the current practices, technologies, and processes used for these equipment systems. It will also explore different ways to improve efficiency and reduce operating costs. The study will select specific journals, research papers and websites to examine, and it will mainly look at the operational aspects of gold mining operations and their costs. The goal is to find solutions that can improve productivity, safety, and environmental sustainability in a straightforward manner.

2 LITERATURE REVIEW

2.1 Introduction

The literature review is an essential component of the study as it provides valuable insights and knowledge related to improving operating costs in gold mines. By reviewing existing research, studies, and publications, the researchers can gain a comprehensive understanding of the current state of knowledge and identify the most effective strategies and approaches used in similar contexts. This review will establish a theoretical foundation by examining relevant theories and models, helping guide the research methodology. Additionally, it will identify best practices and successful case studies in the mining industry that have reduced operating costs while maintaining productivity and safety standards. The literature review will also highlight research gaps, enabling the study to contribute new knowledge and insights to the field. By building on existing knowledge, the study can validate previous findings, extend theories, and propose innovative approaches. Overall, the literature review will ensure the study is grounded in existing scholarship, inform the research design, and contribute to the advancement of knowledge in gold mining cost optimization.

2.2 Cost optimization strategies in the mining industry

The mining industry is facing increasing pressure to reduce operating costs and enhance cost-effectiveness, particularly in the context of gold mining operations [16]. As a result, there is a significant amount of literature available on cost optimization strategies in this industry. One key approach that has been widely studied is the use of advanced technologies and automation to reduce labor costs and improve operational efficiency. For example, research has shown that the use of autonomous mining equipment can lead to significant cost savings, as well as improved safety and productivity. In addition, the use of real-time data analytics and predictive maintenance can help to identify potential equipment failures before they occur, reducing downtime and maintenance costs [3].

Another important strategy is the optimization of supply chain management, including the use of advanced analytics and modelling techniques to streamline procurement, transportation, and inventory management. This can help to reduce waste and minimize costs associated with delays and disruptions in the supply chain [18]. In addition, many mining companies have focused on improving energy efficiency and reducing energy costs through the use of renewable energy sources, such as solar and wind power [4].

Several studies have also highlighted the importance of effective cost management and budgeting practices, including the use of activity-based costing and other cost allocation techniques [19]. By accurately tracking and allocating costs, mining companies can identify areas where costs can be reduced and make informed decisions about resource allocation.

Finally, it is important to note that effective cost optimization strategies require a culture of continuous improvement and innovation. This involves engaging employees at all levels of the organization, promoting a mindset of cost consciousness, and encouraging the development of new ideas and approaches to cost optimization [16]. Overall, the literature suggests that a combination of these and other strategies, tailored to the specific needs and challenges of each mining operation, can lead to significant cost savings and improved cost-effectiveness. However, successful implementation requires careful planning and management, as well as a commitment to ongoing improvement and innovation.

2.3 *Lean Six Sigma in mining*

The use of Lean and Six Sigma methodologies in the mining industry has become increasingly popular in recent years as companies seek to improve efficiency, reduce costs, and increase profitability. A literature review on this topic provides insights into the various approaches, methodologies, and best practices used to implement Lean and Six Sigma in mining operations. Lean methodology is focused on eliminating waste and increasing efficiency in processes. In the mining industry, this can involve reducing the time and resources required for drilling, blasting, and transportation of ore. Several studies have highlighted the benefits of applying Lean principles to mining operations, including improved productivity, reduced costs, and increased safety [17][13].

The Six Sigma methodology, on the other hand, is focused on reducing defects and improving quality in processes. In the mining industry, this can involve improving the accuracy and precision of drilling and blasting operations, as well as reducing variability in ore grades. Several studies have demonstrated the benefits of applying Six Sigma principles to mining operations, including improved product quality, reduced rework, and increased profitability [17][2]. The integration of Lean and Six Sigma methodologies, known as Lean Six Sigma, has also been applied in the mining industry with promising results. This approach combines the waste elimination and efficiency improvement of Lean with the defect reduction and quality improvement of Six Sigma. Several studies have demonstrated the benefits of applying Lean Six Sigma principles to mining operations, including improved productivity, reduced costs, and increased safety [17][2]. However, implementing Lean and Six Sigma methodologies in the mining industry can be challenging due to the unique characteristics of mining operations, such as the complex geology, variability in ore grades, and harsh working

conditions. Successful implementation requires a tailored approach that takes into account these challenges, as well as a commitment to continuous improvement and a culture of data-driven decision making [13][2].

Overall, the literature suggests that the application of Lean and Six Sigma methodologies, either individually or in combination, can lead to significant improvements in efficiency, quality, and profitability in mining operations. However, successful implementation requires careful planning, management, and a commitment to ongoing improvement and innovation.

2.4 Supply chain management in supply chain

The mining industry has various stages like exploration, production, and transportation, requiring effective supply chain management. Studies show that advanced analytics and modelling techniques can optimize procurement, transportation, and inventory management, reducing waste and improving efficiency. Building strong relationships with suppliers and stakeholders helps build trust and collaboration. Risk management is important to identify and mitigate potential risks, while sustainability practices focus on renewable energy and responsible sourcing. Continuous improvement and innovation are necessary through employee engagement and a mindset of optimization. Regarding mining equipment, studies emphasize the importance of utilization, maintenance, and scheduling for productivity. Effective strategies in these areas can improve profitability, and advanced technologies aid in optimizing equipment usage. Efficient scheduling, supported by communication and collaboration, is crucial for productivity.

2.5 Equipment utilization and optimization

In one of the studies, they looked at measuring the performance of mining equipment, specifically focusing on utilization and availability. They found that how much equipment is used to be an important factor in determining how well mining operations perform. By improving utilization, they discovered that productivity and profitability can significantly increase. The study also emphasized the importance of effective maintenance and repair strategies to optimize equipment utilization [15].

In another study, they explored how equipment utilization and maintenance impact the productivity of gold mines. They found that both utilization and maintenance play critical roles in determining the productivity of gold mines [5]. Effective maintenance strategies were found to improve equipment availability and utilization, resulting in notable enhancements. The study also highlighted the value of advanced technologies like predictive maintenance and real-time monitoring in optimizing equipment utilization and maintenance. A third study [6] focused on optimizing equipment scheduling in underground gold mines. They found that effective scheduling strategies are crucial for maximizing equipment utilization and productivity. The study revealed that incorporating advanced scheduling tools and techniques can lead to significant improvements in scheduling efficiency. Effective communication and collaboration between different departments and stakeholders were also identified as vital for successful equipment scheduling.

2.6 Maintenance strategies for mining equipment

In one study, they looked at using predictive maintenance for mining equipment. They found that predictive maintenance can be helpful in improving equipment availability and reducing maintenance costs by identifying potential equipment failures before they happen [7]. The study emphasized the importance of collecting and analyzing data to develop effective predictive maintenance strategies. In another study [21], they developed a model for making maintenance decisions about mining equipment. The model combines different maintenance strategies like corrective, preventive, and predictive maintenance. It uses a fuzzy analytic hierarchy process (FAHP) to prioritize maintenance activities based on their importance and urgency. The study

showed that the model can optimize maintenance activities, reduce downtime, and improve equipment reliability and availability. In a third [10], they focused on using big data analytics to optimize maintenance in mining equipment. The study found that big data analytics can help identify equipment failures and predict maintenance needs. This leads to better equipment availability and more efficient maintenance. The study also highlighted the importance of integrating different types of data, such as sensor data, maintenance records, and operational data, to develop effective maintenance strategies. Energy cost optimal operation of belt conveyors using model predictive control methodology.

Research suggests that there are four levels at which the energy efficiency of belt conveyors can be improved: performance, operation, equipment, and technology (POET). Existing literature primarily focuses on the equipment and operational levels. At the equipment level, efforts are made to make idlers, belts, and drive systems more efficient. The operational level aims to improve energy efficiency by adjusting belt speed, feed rate, operating status, and time in a coordinated manner. These adjustments are usually formulated as optimization problems. Developing an energy model is an important aspect of optimizing energy for belt conveyors. While research proposed a model for energy auditing, it is not suitable for operational optimization. On the other hand, it proposed an analytical energy model based on the ISO 5048 standard, which is more suitable for optimization calculations.

Optimal control is widely used for energy optimization. It has been used to save energy in pneumatic actuator systems and reduce costs in belt conveyor systems by considering time-of-use (TOU) tariffs and coordinating belt status and time for optimization. These approaches have shown significant energy cost reduction. However, the methods proposed by studies are open-loop control methods and have limitations in dealing with practical issues like disturbances and forecast inaccuracies. Therefore, closed-loop control approaches, such as model predictive control (MPC), are preferred as they can handle uncertainties and disturbances better. Another study used MPC to design closed-loop controllers that incorporate near-optimal switching schemes and binary integer programming (BIP) methods to reduce TOU and electricity costs based on maximum demand. One study investigated the application of MPC with linear programming-based optimizers for energy management in production environments. Similarly, another proposed an MPC approach for closed-loop feedback control to improve the operational efficiency of individual belt conveyors. These optimal scheduling problems typically involve implementing optimal solutions periodically over a time horizon, which some classify as a special class of optimal dynamic resource allocation problems.

2.7 Methodology

The study collects information about inefficiencies in gold mines using existing data and literature. The researcher collects data from research papers, reports, and case studies. The study uses statistical analysis to identify patterns and relationships in the data. The findings are presented clearly, and recommendations are made based on the research. However, the study has limitations as it relies on existing data.

2.7.1 Limitations

- The study relies on existing data, which may have limitations.
- Primary data collection and field observations are not included, limiting the depth of analysis.
- The findings and recommendations may not apply to all gold mines.

Despite these limitations, the study can provide valuable insights for future research and practical implementation of cost reduction strategies in gold mining operation.

3 FINDINGS AND DATA ANALYSIS

3.1 Introduction

Within this section, we delve into the comprehensive analysis and insightful discussion of the findings acquired from the collected data. Our primary objective is to identify significant patterns, emerging trends, and explore potential opportunities for cost reduction. To achieve this, the study employed appropriate analytical techniques and tools, enabling us to derive meaningful insights from the dataset. Our analysis entails a thorough comparison of various mining operations, the identification of shared cost drivers, and a critical assessment of the effectiveness of previous cost reduction initiatives. By delving into these aspects, we aim to provide valuable recommendations and strategies for optimizing operational efficiency and enhancing cost-effectiveness within the mining industry.

3.2 Evaluating rules of thumb using conveyor belt.

In a study that evaluated the conveyor haulage versus truck haulage, the focus was on the costs associated with conveyors and the commonly used guidelines in underground mining. The study aimed to demonstrate how Sherpa for Underground Mines, a software tool provided by Cost Mine, can enhance confidence in these guidelines. Sherpa's speed and engineering capabilities enable a more comprehensive assessment of De la Vergne's rules of thumb, which were chosen for analysis. Below are some of the key rules/assumptions that were examined in the study.

a) An underground mine is more economically served by a belt conveyor than railcars or trucks when the daily mine production exceeds 5,000 tons.
b) As a rule, a belt conveyor operation is more economical than truck haulage if the conveying distance exceeds 1 km (3,280 ft.).
c) The ton-mile cost of transport by belt conveyor may be as low as one-tenth the cost by haul truck.
d) The installed capital cost of a long belt conveyor system to be put underground is approximately equal to the cost of driving the heading in which it is to be placed.

In the study, different mining projects using cut and fill, sublevel long hole, and room and pillar stopping methods were simulated in Sherpa for Underground Mines. These simulations considered typical deposits and varying production rates. As per rule of thumb No. 1, conveying distances were set at 1 km. The analysis, depicted in Figure 1, supported de la Vergne's rule of thumb, which suggests that using a conveyor is economically favorable compared to rail or truck haulage when production rates exceed 5,000 t/d (tons per day). The results aligned with this rule, indicating that conveyor systems are advantageous at higher production rates. The analysis of sublevel long hole and room and pillar methods exhibited similar trends overall. However, in comparison to the cut and fill models in Sherpa, the cost variations above 5,000 t/d were more significant in the sublevel stopping analysis, while the room and pillar analysis showed narrower cost variations.

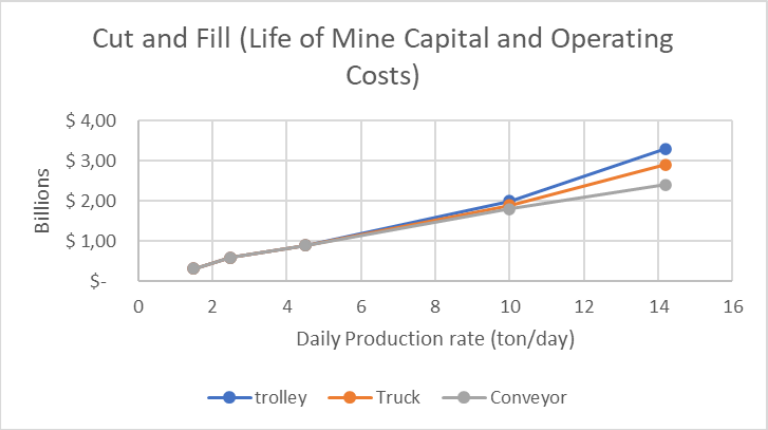

Figure 1: Cut and fill haul method, production rates and LOM costs.

The results show that haul length is a primary factor when comparing the costs of truck and conveyor transport. Production rates also have a significant impact, and above a certain production rate, it is more cost-effective to use a conveyor to transport ore over a specific haul distance. The study also points out the benefits of more detailed analysis, as the finite availability of machine sizes can affect cost per ton. The evaluation shows that conveyor transport costs are typically about 39% of those for truck transport, including the costs of diesel, electricity, maintenance, repair parts and labour, tires, lubricants, and operator for the truck. The results of the analysis indicate that while trucks offer high flexibility and lower upfront capital outlay, conveyor haulage offers a better measure of performance on all three metrics of measuring equipment performance, namely, utilized time, operating time, and valuable operating time. The conveyors achieved an average of 3,509 hours in valuable operating time compared to the average valuable operating time of 2,638 hours for the truck fleet.

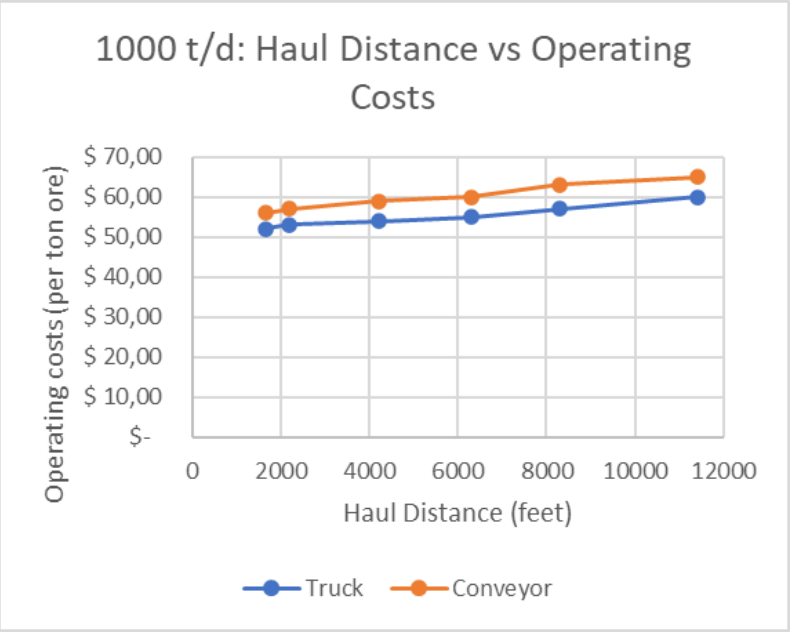

Figure 2: 1000 t/d Haul Distance vs Operating Costs

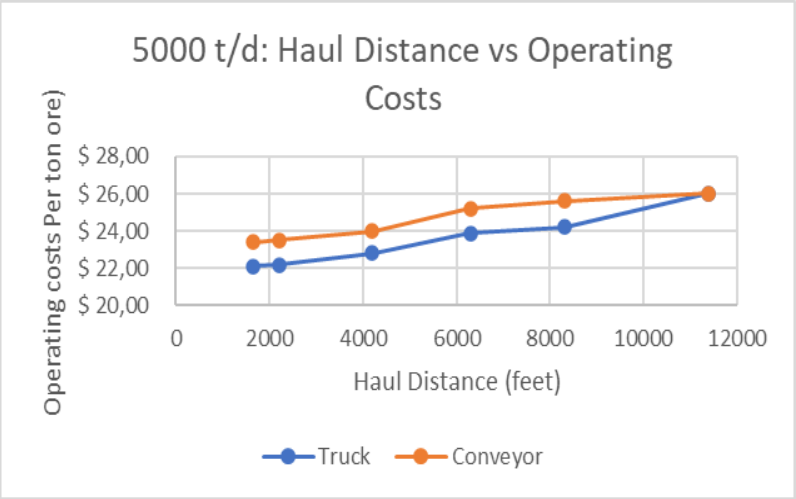

Figure 3: 5000 t/d Haul Distance vs Operating Costs

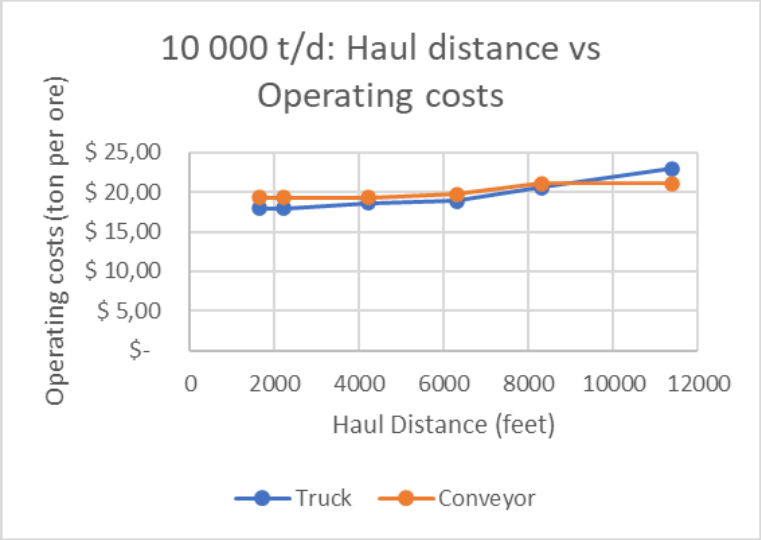

Figure 4: 10 000 t/d Haul Distance vs Operating Costs

3.3 Energy costs and conveying

Determining the lifespan of a motor used in conveyor systems can be challenging since there is no fixed definition for a "typical" motor lifespan. However, Leeson, a manufacturer of electric motors, has developed a rule of thumb for motor life expectancy based on horsepower. For example, a 5 hp motor generally has a life expectancy of approximately 17.1 years, while a 10 hp motor may last up to 19.4 years. This means that a conveyor system installed in 1999 could still be in operation today with its original equipment. Although the conveyor might be technically functional, it is likely to be less energy-efficient compared to newer systems. Therefore, upgrading to more efficient motors and equipment can not only improve energy efficiency but also extend the lifespan of the conveyor system.

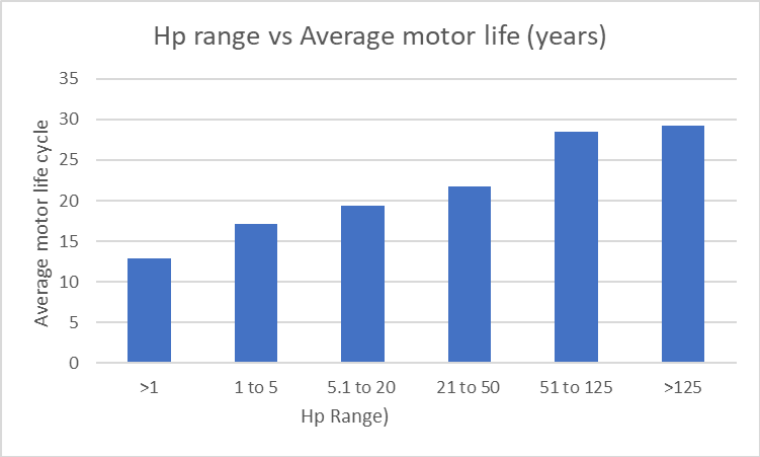

Figure 3: Hp range vs average motor life cycle

4 FRAMEWORK

Based on the findings from the literature review and data analysis, the following framework or set of guidelines can be developed to outline an integrated approach to reducing operating costs in gold mines:

4.1 Advanced Technologies and Automation:

- Implement autonomous mining equipment to reduce labor costs, improve operational efficiency, and enhance safety.
- Utilize real-time data analytics and predictive maintenance to identify potential equipment failures before they occur, reducing downtime and maintenance costs.

4.2 Supply Chain Optimization:

- Apply advanced analytics and modeling techniques to streamline procurement, transportation, and inventory management, reducing waste and minimizing costs.
- Develop strong relationships and partnerships with suppliers, distributors, and other stakeholders to improve communication and collaboration in the supply chain.
- Implement effective risk management strategies to identify and mitigate potential risks, such as natural disasters and supply chain disruptions.
- Incorporate sustainability practices, such as using renewable energy sources and responsible sourcing of raw materials, to meet social and environmental demands.

4.3 Lean Six Sigma Methodologies:

- Apply Lean principles to eliminate waste and increase efficiency in mining processes, such as drilling, blasting, and transportation of ore.
- Implement Six Sigma methodologies to reduce defects, improve quality, and increase productivity in mining operations, including drilling accuracy and ore grade variability.
- Integrate Lean and Six Sigma methodologies (Lean Six Sigma) to optimize efficiency, quality, and profitability, considering the unique characteristics and challenges of mining operations.

4.4 Cost Management Practices:

- Utilize activity-based costing and other cost allocation techniques to accurately track and allocate costs, identifying areas for cost reduction and resource allocation optimization.

- Foster a culture of continuous improvement and innovation, engaging employees at all levels of the organization and promoting cost-consciousness.

4.5 Equipment Utilization and Optimization:

- Focus on improving equipment utilization through effective maintenance and repair strategies, as well as the use of advanced technologies like predictive maintenance and real-time monitoring.
- Optimize equipment scheduling through the use of advanced scheduling tools and techniques, considering effective communication and collaboration between different departments and stakeholders.

4.6 Maintenance Strategies:

- Implement predictive maintenance to optimize equipment availability and reduce maintenance costs by identifying potential equipment failures before they occur.
- Develop maintenance decision-making models using a prioritization approach, such as fuzzy analytic hierarchy process (FAHP), to optimize maintenance activities based on importance and urgency.
- Utilize big data analytics to identify equipment failures, predict maintenance needs, and improve equipment availability and maintenance efficiency.

4.7 Energy Efficiency:

- Consider upgrading to more energy-efficient motors and equipment in conveyor systems to improve energy efficiency and extend the lifespan of the system.
- Evaluate and optimize the energy costs associated with different modes of transportation, such as trucks and conveyors, considering factors like haul length and production rates.

These guidelines provide a comprehensive framework for reducing operating costs in gold mines, covering various aspects from technology adoption to supply chain management, lean six sigma methodologies, cost management practices, equipment utilization, maintenance strategies, and energy efficiency considerations. By implementing these strategies and approaches, mining companies can enhance their cost-effectiveness, sustainability, and overall profitability.

4.8 Conclusion and recommendations

The paper discusses the challenges faced by the gold mining industry in reducing operating costs and improving efficiency. It emphasizes the need for a comprehensive approach that goes beyond short-term fixes and proposes an integrated approach to address inefficiency gaps in mobile loading equipment, conveyor systems, and transport equipment within gold mines. The major objectives of the study include identifying specific inefficiencies, proposing strategies to optimize operations and reduce costs, and analyzing the impact of inefficiency gaps on operating costs.

The literature review highlights various cost optimization strategies in the mining industry, including the use of advanced technologies, automation, supply chain management, and Lean Six Sigma methodologies. It also emphasizes the importance of effective equipment utilization and maintenance, as well as equipment scheduling. The review identifies best practices, successful case studies, and the challenges associated with implementing these strategies in the mining industry.

The findings and data analysis section focuses on evaluating the effectiveness of rules of thumb in conveyor belt haulage and the impact of energy costs on conveying systems. The study utilizes Sherpa for Underground Mines software to assess the guidelines and demonstrates the economic advantages of using conveyor systems over truck haulage at higher production rates. It also

discusses motor life expectancy and provides insights into optimizing energy costs in conveying systems.

Based on the research findings, the study recommends implementing the proposed integrated approach to address inefficiencies in mobile loading equipment, conveyor systems, and transport equipment within gold mines. It suggests adopting advanced technologies, automation, and predictive maintenance for improved efficiency and cost reduction. The study also emphasizes the importance of effective supply chain management, equipment utilization, maintenance strategies, and equipment scheduling. Furthermore, it highlights the need for continuous improvement, innovation, and a data-driven decision-making culture in the mining industry.

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