School of Mining Engineering

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

# ASSESSMENT AND IMPROVEMENT OF TOPSOIL AND SUBSOIL LOADING AND HAULING OPERATION AT MANUNGU COLLIERY

Andrew Denhere

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2025

## DECLARATION

I have familiarised myself with the University of the Witwatersrand Student Academic Misconduct Policy (SAMP). I hereby declare that the work I am submitting for assessment is my original work. I affirm that I have not plagiarised, misrepresented, or colluded with any other person or source. I have properly acknowledged, cited, and referenced all the sources that I have used in my work. I also declare that where I have used artificial intelligence (AI) tools it has only been as a means of guidance. The ideas and arguments presented in my work are my original thoughts and interpretations. I acknowledge that any academic misconduct, such as plagiarism or collusion, will result in serious consequences. According to the SAMP, these consequences may include a reduced grade, a fail mark, or disciplinary action. The Faculty of Engineering and the University of the Witwatersrand have my consent to investigate any potential academic misconduct in my work. This investigation may include the use of similarity and AI detection software to check the originality of my work. I undertake to abide by the decision of any such investigation. `

Andrew Denhere                9 July 2025

Signature of Candidate                Date

*“Continuous improvement is better than delayed perfection*

Mark Twain

# ABSTRACT

This study investigated optimising the stripping load, and haul operation at Manungu Colliery to boost productivity amid declining global coal demand and the operation’s production shortfalls. As coal prices continue to drop due to the shift toward greener energy sources, improving operational performance has become critical to maintaining profitability. The study involved a baseline assessment to evaluate key performance indicators (KPIs), including time utilisation, hauling conditions, loading efficiency, and cycle times. Interventions aimed at improving these KPIs were then implemented during an intervention study. A mixed-methods approach combined quantitative data from production reports, survey records, time studies, and shift logs with qualitative insights from observations and interviews with the operation’s personnel.

Results from the time studies, document reviews, and observations were analysed to identify feasible interventions for increasing production while maintaining or reducing input levels. The implementation of targeted operational adjustments led to measurable improvements. In May 2024, production increased by 27% compared to March, with a 32% cycle time reduction due to improved haul routes and flatter ramps, while diesel efficiency improved by 12%. By November 2024, the year-to-date production had a positive variance of 9%, compared to a 27% negative variance in the 2023 financial year, highlighting the effectiveness of the implemented strategies.

The findings indicate that continuous operational improvements boost efficiency. Challenges like adverse weather conditions and limited direct supervision persisted. Recommendations include integrating advanced technologies, expanding the scope to include a cost-benefit analysis of the improvement efforts, conducting prolonged studies, and focusing on environmental impacts. The study provides a framework for enhancing

productivity through data-driven strategies and operational best practices in open-pit mining operations.

## ACKNOWLEDGMENTS

I extend all the glory to Almighty God for granting me the wisdom and strength to complete this research. I also wish to express my heartfelt gratitude to the following individuals for their invaluable contributions:

- Professor Isadore Matunhire (Honorary Adjunct Professor, School of Mining Engineering, University of the Witwatersrand) for his invaluable insights, academic guidance, constructive feedback, and meticulous review of the draft reports.
- Mr. Humphrey Mokwena (General Manager, Manungu Colliery) for granting me access to the mine's operations and data, which were instrumental in compiling this report.
- My wife Fortune and my family for their unwavering love, support, and encouragement during challenging times and for their patience and understanding as this research demanded much of my time away from them.

While the permission to utilise certain materials within this research report is sincerely appreciated, the views expressed herein are solely those of the author. They may not necessarily reflect the policies of Manungu Colliery. Despite the invaluable contributions of the individuals, any remaining errors, omissions, or ambiguities in this research report are entirely my own responsibility.

## TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

# LIST OF EQUATIONS

# LIST OF ABBREVIATIONS AND SYMBOLS

| Abbreviation | Description |
|---|---|
| ADTs | Articulated Dump Trucks |
| AI | Artificial Intelligence |
| ANOVA | Analysis of Variance |
| BCM | Bank Cubic Meters |
| BFF | Bucket Fill Factor |
| CBA | Cost-Benefit Analysis |
| DOH | Direct Operating Hours |
| E-bcm | Excavated Bank Cubic Meters |
| FMS | Fleet Management System |
| GPS | Global Positioning System |
| GR | Gradient Ratio |
| IPCC | In-Pit Crushing and Conveying |
| KPIs | Key Performance Indicators |
| Km/h | Kilometres Per Hour |
| NPV | Net Present Value |
| RR | Rolling Resistance |
| ROI | Return on Investment |
| SOPs | Standard Operating Procedures |
| Ton | Tonnes |
| TR | Total Resistance |
| TSLHS | Topsoil and Subsoil Load and Haul Stripping |

# 1 INTRODUCTION

The world is increasingly going green and ditching the use of coal for alternative sources of energy, which are purported to be greener for the environment (Agnolucci et al.,2023; Barrera, 2023). As a result, the demand and price for coal globally have dropped, which has put much pressure on the feasibility and profitability of coal mining operations. To ensure the profitability of coal mines, it is essential to prioritise operational efficiency to counter shrinking profits by boosting productivity (Pasch & Uludag, 2018). This can be achieved by increasing output while using fewer resources. Open-pit coal mining operations typically have seven mining activities, namely: free diggable material load and haul, drilling, blasting, blasted material load and haul, fleet management, dumping, and processing (Minerals Council South Africa, 2023; Evans & Ramani, 2023). This study focused on the free-digable material load and haul operation, collectively known as the topsoil and subsoil load and haul stripping (TSLHS) operation. Manungu Colliery's TSLHS operation experienced low productivity with a 27 % negative variance to plan for the 2023 Financial Year (Manungu Colliery, 2023). Productivity is a measure of how efficiently inputs, such as labour, equipment, and capital, are used to produce outputs, evaluated as output per unit of input. In open-pit mining, productivity is commonly assessed through key indicators such as tonnes per hour, tonnes per litre of fuel, or the number of productive machine hours (Otto & Lindeque, 2021). The underperformance influenced performance of downstream activities, including blasting and mining of blasted material as well as coaling, ultimately disrupting the overall production schedule and operational efficiency. This study investigated and estimated the significant factors contributing to the low productivity of the TSLHS operation at Manungu Colliery.

Loading is when trucks are filled with material in preparation for the haulage process. Hauling is an operational activity that transports waste or coal from the loading area to the dumping area for waste and the processing plant for coal. Fleet management is associated with scheduling and monitoring trucks to improve hauling routes and ensure that trucks are loaded to capacity. Dumping is when a truck discharges its load at a dumping area or a coal processing plant. In the context of open-pit coal mining, loading and hauling operations are very important as they constitute a significant portion of the cost structure of open-pit coal mining operations. In this regard, the efficiency and effectiveness of loading and hauling operations are critical to the overall success of open-pit coal mining operations.

Open-pit loading and hauling has challenges, which include equipment selection, safety, environmental impact, road maintenance, productivity and efficiency of these operations (Owolabi, 2019; Otto & Lindeque, 2021) .Therefore, efficient loading and hauling operations are essential for more productive and cost-effective open-pit coal mining operations. As such, they require careful planning, coordination, modern technology and equipment to ensure that coal can be extracted and transported to its destination efficiently. This study investigated ways of improving the TSLHS operation at Manungu Colliery to reduce low productivity.

## 1.1 Research Background and Context

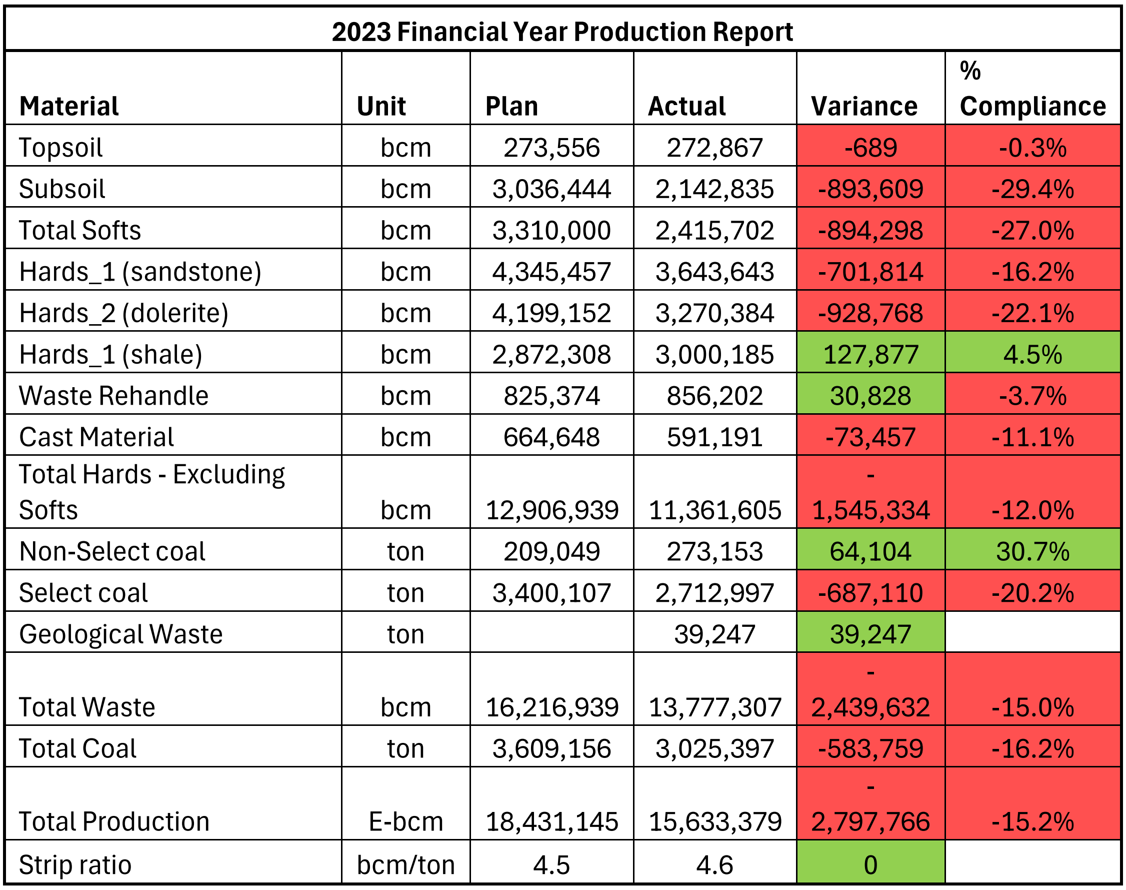
Manungu Colliery is operated by Mbuyelo Coal Group and is located 65km from Johannesburg in the coalfield of eMalahleni near Delmas in the Mpumalanga province. The mine has a coal resource base of over 130 million tonnes and employs the opencast mining method, using loading and hauling machinery to perform the mining activities (Manungu Colliery, 2023). The locality map of this operation is shown in Figure 1.1.

Figure 1.1: Locality map

Source: Adapted from (Google_Maps, 2024)

The first coal was produced from the colliery in 2015, a bituminous thermal grade supplied to Eskom through a coal supply agreement (Manungu Colliery, 2023). Manungu Colliery has an average monthly production of approximately 320,000 tonnes of coal and employs 1,200 workers, including contractors, across various departments. Manungu Colliery strives to enhance operational efficiency across all departments, thereby improving productivity and profitability (Manungu Colliery, 2023). However, the underperformance of the TSLHS operation had a ripple effect on downstream activities in 2023, disrupting blasting schedules, delaying the mining of blasted material, and negatively impacting coaling. One way was to improve the TSLHS operation to maximise productivity, reduce the operational cost burden, and maximise shareholder value. This study focused on the TSLHS operation to address the low productivity experienced during the 2023 financial year, as shown in Table 1.1.

Table 1-1 Manungu Colliery Production Report 2023 Financial Year



**2023 Financial Year Production Report**

| Material | Unit | Plan | Actual | Variance | % Compliance |
|---|---|---|---|---|---|
| Topsoil | bcm | 273,556 | 272,867 | -689 | -0.3% |
| Subsoil | bcm | 3,036,444 | 2,142,835 | -893,609 | -29.4% |
| Total Softs | bcm | 3,310,000 | 2,415,702 | -894,298 | -27.0% |
| Hards_1 (sandstone) | bcm | 4,345,457 | 3,643,643 | -701,814 | -16.2% |
| Hards_2 (dolerite) | bcm | 4,199,152 | 3,270,384 | -928,768 | -22.1% |
| Hards_1 (shale) | bcm | 2,872,308 | 3,000,185 | 127,877 | 4.5% |
| Waste Rehandle | bcm | 825,374 | 856,202 | 30,828 | -3.7% |
| Cast Material | bcm | 664,648 | 591,191 | -73,457 | -11.1% |
| Total Hards - Excluding Softs | bcm | 12,906,939 | 11,361,605 | -1,545,334 | -12.0% |
| Non-Select coal | ton | 209,049 | 273,153 | 64,104 | 30.7% |
| Select coal | ton | 3,400,107 | 2,712,997 | -687,110 | -20.2% |
| Geological Waste | ton |  | 39,247 | 39,247 |  |
| Total Waste | bcm | 16,216,939 | 13,777,307 | -2,439,632 | -15.0% |
| Total Coal | ton | 3,609,156 | 3,025,397 | -583,759 | -16.2% |
| Total Production | E-bcm | 18,431,145 | 15,633,379 | -2,797,766 | -15.2% |
| Strip ratio | bcm/ton | 4.5 | 4.6 | 0 |  |

Open pit mining operations typically include “drilling, blasting, loading, hauling, dumping, and general services” (Choi et al., 2009, p. 1541). Amongst these activities, loading and hauling accounts for 40 – 50% of the total open-pit mining costs (Akbari, et al., 2009) (Ercelebi & Bascetin, 2009). Therefore, Manungu Colliery must improve the stripping loading and hauling operation efficiency to maximise productivity within the current loading and hauling costs . Nehring et al. (2018) state that shovels and hauling trucks can be adapted to meet different operational conditions for varying tonnage requirements. In light of this, improving the efficiency of loading and hauling operations would require measures to reduce truck cycle times (Choi et al., 2009). To do so, mining engineering researchers have considered many theories, such as the queuing theory and computerised truck dispatching systems, to improve the scheduling and routing of hauling trucks. For instance, the queuing theory can be utilised to improve randomly increasing demands in shovel-truck haulage systems (Trivedi et al., 1999). In addition, it is simpler and faster to implement than computerised simulation techniques (Elijah et al., 2021). While queuing theory provides a straightforward and quick way to model and analyse truck dispatch systems, it may not capture the full complexity and variability of real-world operations. It offers valuable insights into average performance metrics but lacks the dynamic adaptability of computerised systems. On the other hand, computerised truck dispatch systems excel in handling real-time data and optimising operations on the fly. They offer higher efficiency, reduced wait times, and better resource utilisation, especially in environments with high variability and complexity. However, they require a more significant investment in infrastructure and technology (Aksoy & Yalcin, 2000).

According to Elijah et al. (2021) the queuing theory can be applied to single- or multi-server channels, as illustrated in Figure 1.2. A single-server channel has one server that handles customers one at a time, resulting in potential waiting times. In contrast, a multi-server channel features multiple servers that can process customers concurrently, thereby reducing wait times and enhancing overall system throughput and efficiency.

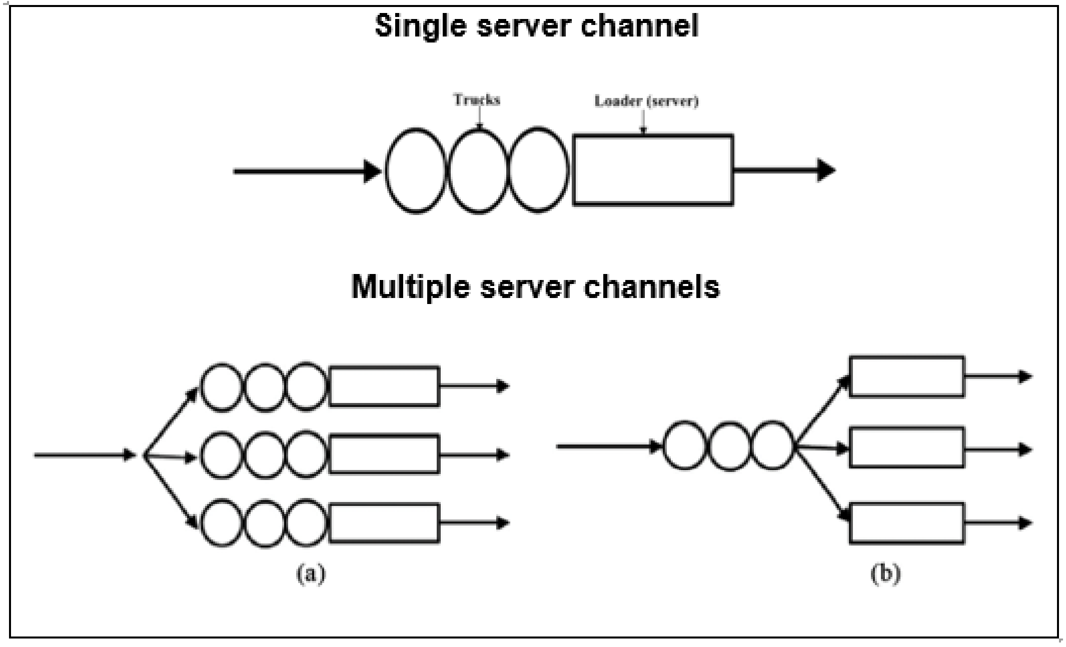


Figure 1.2: Single and multiple server channels in queuing theory.
Source: Adapted from Elijah et al. (2021)

It is also important to note that, when hauling on complex road networks, routing may be prioritised more than scheduling to reduce truck cycle time (Choi et al., 2009). This is because travel time between loading and dumping areas accounts for much of the truck cycle time (Choi et al., 2009). The dynamic nature of mining operations, including loading and hauling operations, is further made complex by the changing geographical characteristics of the extraction processes (Tapia et al., 2021). In addition, the changing number of equipment available at a given time due to maintenance/repairs affects decisions on whether to prioritise a whole track or full bucket system. Adopting a dual strategy to manage operations while equipment is being maintained or on breakdown ensures efficient resource utilisation and maintains operational continuity despite varying equipment availability. When fewer trucks are available, prioritise filling each truck to its maximum capacity. This maximises the payload per trip and reduces the number of trips needed. When loader availability is limited, but more trucks are operational, prioritise filling each loader to its full capacity, which improves each loading cycle's efficiency (Tapia et al., 2021).

## 1.2 Problem Statement

The TSLHS operation at Manungu Colliery did not meet production targets for the 2023 financial year (Manungu Colliery, 2023). As a result, insufficient drilling space was exposed, causing delays in drilling and blasting activities. This, in turn, disrupted the removal of blasted overburden and negatively impacted coal loading and hauling operations. Manungu Colliery's loading and hauling operations account for 40–50% of the operational costs of the mine (Manungu Colliery , 2023).The decline in coal demand puts pressure on the coal price and reduces the profitability of coal mining operations. Therefore, to keep coal mining sustainable, it is necessary to minimise operational costs and maximise production output. To reduce costs and improve the profitability and sustainability of Manungu Colliery, it is essential to enhance the productivity of the TSLHS operation. While this study focuses specifically on improving the TSLHS operation conditions, it is acknowledged that it forms only part of the broader mining value chain. Other activities, including drilling, blasting, coal loading, and maintenance strategies, play interconnected roles in influencing mine-wide productivity. Additionally, although the problem is analysed over a short period, a longer-term review may be necessary to determine whether these challenges are systemic or unique to the year under study.

## 1.3 Justification for Research

The TSLHS operation at Manungu Colliery experienced low productivity in the 2023 financial year, with a 27 % negative variance to the plan (Manungu Colliery, 2023). This underperformance had a significant impact on downstream activities within the mine’s value chain. Specifically, it resulted in drill rigs standing idle due to insufficient drilling space, depletion of blasted material inventory, and the subsequent failure to meet production targets for both blasted material and coal. These cascading effects underscored the urgent need to assess and improve the performance of the TSLHS operation to maintain upstream efficiency and ensure uninterrupted continuity in coal production. Key performance indicators (KPIs) identified for improvement are time utilisation, hauling conditions, loading efficiency factor, and cycle time. Addressing the identified inefficiencies on these KPIs can translate into improved productivity. This information makes improving the TSLHS operation necessary. This is believed to help increase productivity and avoid further downstream effects associated with operational losses. Manungu Colliery can remain profitable despite declining global coal demand and several costly economic, social, technical, and operational challenges if the stripping load and haul fleet maximises productivity. The compounded volume improvement derived from addressing the TSLHS operation’s KPIs is estimated to be above 20%. Undeniably, a production increase within the current operational costs will eventually decrease the unit cost of production, leading to improved financial performance (Pasch and Uludag, 2018). The loading and hauling operations of open pit mines represent a significant portion of the operational expenses that a coal mine incurs. As a result, it is only reasonable to improve this process, which may increase production output within the mine's current operational costs. It is important to note that any inefficiency within the load and haul operations can have a significant bearing on the sustainability of the mine and may make the operational costs too high, such that mining operations may become unsustainable. Enhancing the productivity of the TSLHS operation offers a practical entry point for reducing costs and stabilising production. However, a holistic view of upstream and downstream processes, along with a longer-term perspective, is necessary for future studies to build a more comprehensive understanding of mine performance and sustainability.

## 1.4 Aim and Objectives

This study aims to assess and improve the performance of the TSLHS operation at Manungu Colliery. This focus is driven by the persistent underperformance of the TSLHS operation, which has caused a ripple effect on downstream activities.

The research objectives of this study are as follows:

- To determine the factors influencing the performance of the TSLHS operation at Manungu Colliery and identify areas within the value chain that require improvement,
- To develop and recommend strategies for improving the TSLHS operation,
- To implement an intervention study based on the findings and recommendations of the initial research to evaluate their effectiveness.

## 1.5 Research Motivation

The motivation for this research stems from the critical role that the TSLHS operation plays in the mine value chain at Manungu Colliery. The TSLHS operation serves as the starting point of the mine’s production chain, and its underperformance had a direct and measurable impact on downstream processes, including drilling, blasting, overburden removal, and coal extraction. The 27% negative variance to plan recorded in the 2023 financial year is a clear indication of systemic inefficiencies that require urgent attention. A directive from the Mine Manager further strengthens this focus due to contractual constraints; other equipment on the mine cannot be allocated to topsoil and subsoil mining. As a result, optimising the TSLHS operation is essential for maintaining continuity and efficiency in the broader mining process. This directive positions the TSLHS as a bottleneck operation that must be improved to unlock performance across the production chain.

As global coal demand continues to decline and cost pressures increase, mines are under constant pressure to maximise resource utilisation and reduce operational waste. At Manungu Colliery, loading and hauling operations account for up to 50% of the total operational costs. Therefore, any improvement in the performance of the TSLHS operation directly contributes to cost reduction, improved scheduling, and increased coal availability, ultimately enhancing profitability and sustainability.

This study is further motivated by the potential for practical, measurable improvement. The identification of specific key performance indicators (KPIs) such as time utilisation, hauling conditions, cycle time, and loading efficiency provides a clear path for targeted intervention. Improving these KPIs is not only achievable but could result in an estimated 20% increase in productivity, making a significant impact on the mine's operational performance. Ultimately, this research seeks to contribute to the development of more efficient load and haul practices at Manungu Colliery and support data-driven decision-making to enhance value chain performance.

## 1.6 Structure of the Research Report

The research study was divided into six chapters, which are briefly described below:

*Chapter 1*

Chapter one introduces the research and provides the background and context of the study, including the research problem and objectives. Therefore, it creates a foundation on which the research study was built.

*Chapter 2*

This chapter presents the study's literature review and discusses the theories and concepts relevant to the study. This covers the literature on open pit mine operations, including open pit mining production factors, loading and hauling system, time usage model, and queuing theory.

*Chapter 3*

This chapter outlines the study's research methodology. It describes the research philosophy, research design, the study's target population, sampling techniques, and data collection and analysis procedures.

*Chapter 4*

This chapter presents the results of the initial and intervention studies, which used data collected through observations, shift data sheets and interviews.

Chapter 5

This chapter analyses the results of initial, and intervention studies and reviews the productivity improvements derived from the recommendations of the initial study.

*Chapter 6*

This chapter outlines the conclusions and recommendations of the study, including areas of future research.

# 2 LITERATURE REVIEW

## 2.1 Introduction

This chapter provides a comprehensive review of the literature relevant to the study of loading and hauling operations in open-pit mining. As integral components of the mining value chain, loading and hauling systems directly influence productivity, cost efficiency, and operational sustainability. In open-pit mining, where material movement occurs across vast distances and volumes, the efficiency of these operations is central to the overall performance of the mine. This literature review lays the theoretical and empirical foundation for the study by exploring key themes such as open-pit mining principles, load and haul system configurations, queuing theory applications, technological innovations, productivity metrics, and haul route design parameters. Special attention is given to production drivers such as cycle time, haul route conditions, and time utilisation models, which are central to this study's performance analysis. The chapter also reviews relevant theories—such as queuing theory and systems optimisation—that guide the modelling and interpretation of load and haul efficiencies.

It is important to note that this study is focused specifically on free-digging operations and does not consider fragmentation or blasting practices. Therefore, discussions on rock fragmentation, explosive design, and blast-induced diggability, although highly relevant to mining productivity in general, are not addressed within this chapter. The exclusion of blasted material is a deliberate methodological choice, given the scope and operational context of the research conducted at Manungu Colliery during the assessment period.

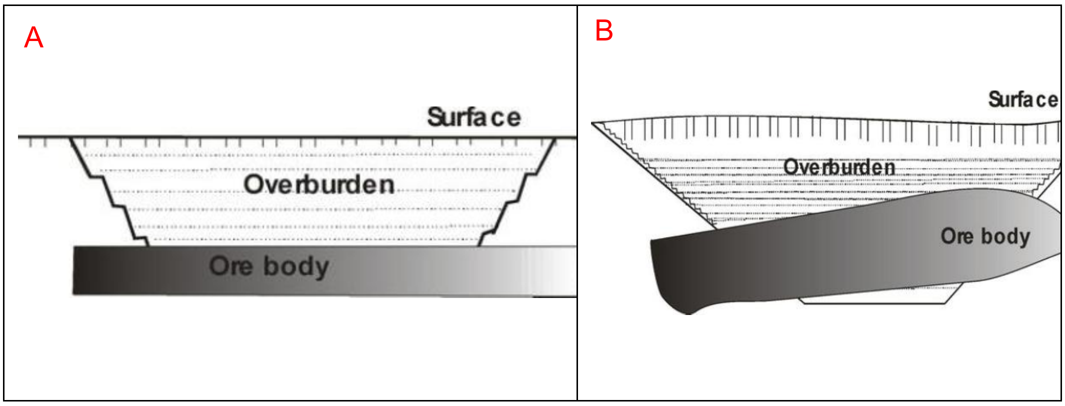
## 2.2 Open Pit Mining

Open pit mining entails mining near-surface ore deposits employing horizontal benches and dumping overburden and waste outside the pit boundary (Altiti et al., 2021). It differs from quarrying by selectively extracting ore, while in a quarry, dimensional stone and aggregate are extracted. This method is used for metallic and non-metallic ores, especially in disseminated ore bodies or steeply dipping veins. Traditionally, in open-pit mining, pits were often left open after mining. However, in some cases, pit design or operational needs have led to partial backfilling to ensure safety and to support future mining activities.

Opet-pit mined voids are gradually viewed as valuable assets that can help reduce costs and minimise land disturbance after closure. Open-pit overburden removal generates waste rock, often exposing materials that could harm the environment. Backfilling mined voids with waste rock, subsoil, and topsoil sequentially to create rehabilitated land offers a cost-effective way to safely cover or contain these materials and reduce post-closure liabilities. However, assessing and planning for backfilling early in the mine planning process is essential to capitalise on this opportunity fully. Land reclamation processes parallel to active mining have gained importance as a strategy to mitigate environmental impacts in open-pit mining operations ( Pearce, et al., 2016).

Open pit mining is typically nonselective, covering high and low quality mineralisation zones, with a mining rate frequently surpassing 20,000 tonnes per day (Altiti et al., 2021). While it requires a substantial capital investment, it generally yields high productivity, good safety conditions, and low operating costs. Open pit involves significant waste removal, with the cost of waste removal constituting the majority of mining expenses (Altiti et al., 2021). Unlike underground methods, open pit mining allows access to the ore body quicker, as extraction can begin immediately after removing waste. The method benefits from the capacity to use large mining equipment, leading to sound technical and economic outcomes (AngloAmerican, 2023). Open cast mining has higher productivity as compared to underground mining, lower production costs, and safe working conditions, (Altiti et al., 2021). While open pit mining contributes substantially to minerals production, it is also a method contributing to the establishment of high capacity quarries (Altiti et al., 2021). Open pit mining is a widely employed method for extracting both metallic (such as iron) and non-metallic (such as coal) ores (Altiti et al., 2021). This traditional mining approach involves creating a cone-shaped pit, though the actual shape may differ depending on the characteristics of the ore body.

Open pit mining is suitable for ore bodies that exhibit pipe-shaped, vein-type, steeply dipping stratified or irregular characteristics. However, there are various open pit and ore body configurations which are classified into five classes which are: **A** – flat-lying seam or bed, flat terrain, **B** – massive deposit, flat terrain, **C** – dipping seam or bed, flat terrain, **D** – massive deposit, high relief and **E** – thick-bedded deposits, with slight overburden as shown in Figure 2.1 (Altiti et al., 2021).



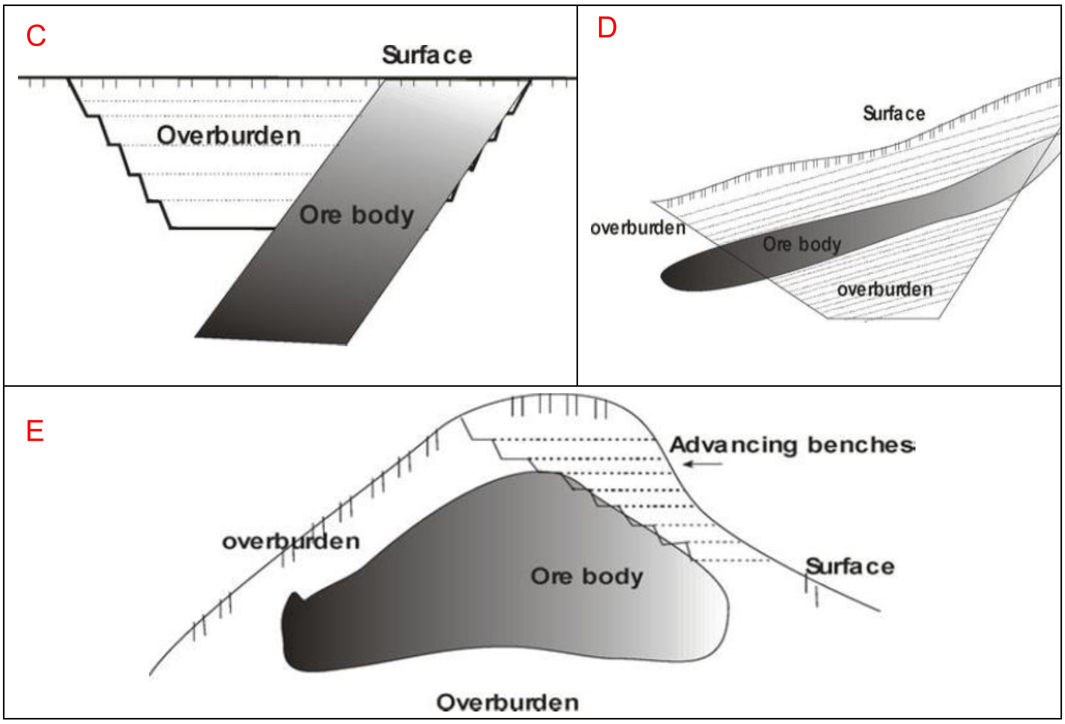


Figure 2.1: Open pit ore and ore body configurations.

Source: Altiti et al. (2021)

Open pit mines vary widely in scale, from small operations processing a few hundred tonnes of ore daily to large operations processing over fifty thousand tonnes. In addition, the production cycle typically involves various activities, including free diggable material stripping, drilling, blasting, and waste removal (Altiti et al., 2021). Graders, wheel dozers, and track dozers are commonly used for ripping and dozing. Ripping enables the fragmentation of hard materials, such as rock, compacted soil, or overburden, by utilising a steel tyne or shank affixed to a ripper of a bulldozer (Pebrianto, et al., 2014). On the other hand, dozing is an earthmoving activity that involves levelling terrain, pushing material from one location to another, creating access roads, and clearing land (Sinclair & Nehring, 2019). Drilling and blasting fracture the rock into a loadable size, with blast hole patterns carefully designed for optimal energy distribution. Loading equipment such as shovels, front-end loaders, and hydraulic shovels is matched with haul trucks (Altiti et al., 2021). Factors like rock hardness influence the choice between tracked shovels and rubber-tired loaders. It is important to note that hydraulic shovels offer flexibility and operator control, while cable shovels have certain limitations in terms of flexibility compared to hydraulic shovels. As such, there is a need to choose the appropriate loading equipment to meet the waste and ore characteristics being mined (Altiti et al., 2021). Haul trucks are vital for transporting ore and waste rock, but some open-pit mines use conveyor belts over long distances. Considering this, some open-pit mines may use haul trucks, conveyor belts, or both, depending on production economics.

A study by Nehring et al. (2018) compares the conveyor system to the truck haulage system. The case study highlights the need for a specialised planning approach for open-pit mining with In-Pit Crushing and Conveying (IPCC) systems. Unlike traditional truck and shovel designs, introducing conveyors brings challenges such as fixed pit walls and reduced flexibility, impacting maneuverability and scalability (Nehring et al., 2018). Flaws in an IPCC mine plan become quickly evident, and there is limited room for adjustments once initiated. While IPCC systems offer lower operating costs, sequencing restrictions require careful planning. Unlike the flexibility of truck and shovel mining, which efficiently accesses high-value material, IPCC systems may prioritise mining larger volumes of waste initially, impacting cash flows and net present value (NPV) maximisation. Given this, the success of IPCC systems depends on factors like orebody horizontal extent and grade distribution. Despite generally lower operating expenses, the economic viability of mining larger material volumes in IPCC systems can contribute to a longer mine life and more remarkable resource recovery (Nehring et al., 2018). As mentioned, the overburden transportation system should be selected based on the unique characteristics of each overburden and orebody for optimal results. While Nehring et al. (2018) offer valuable insights into IPCC challenges, newer studies, such as Nobahar et al. (2024), show how digital mine modelling can improve IPCC planning accuracy. Moreover, Altiti et al. (2021), while useful in establishing the fundamentals of open-pit systems, do not adequately reflect evolving environmental, social, and governance priorities increasingly driving mine design.

While studies have extensively documented the mechanics and cost implications of load and haul systems in open-pit mining, fewer have critically integrated these with evolving mine design strategies or sustainability concerns. For instance, Pasch and Uludag (2018) emphasise cycle time optimisation, while Bozorgebrahimi (2004) stresses the role of haul route design. Integrating these viewpoints underscores that operational productivity cannot be isolated from mine planning, safety, or environmental management. Therefore, a more holistic approach is needed to optimise mining operations in today's regulatory and cost-conscious environment.

## 2.3 Loading and Hauling System

The loading and hauling system in open pit mining is meant to transport material from the loading area to designated dumping sites. The material is loaded from the working face into haul trucks and transported to the dumping area (stockpile, waste dump, void or processing plant) via dedicated haul routes (Aguayo et al., 2021). Haul routes can accommodate large haulage trucks with capacities of up to 450 tonnes. One hauling truck in this elite rank is a BELAZ-7571 series (Krause, 2006, ), (Belaz Equipment, 2024). The loading and hauling process typically constitutes 40–50% of the operational costs of an open pit mine, and as mines advance, longer hauls increase transportation costs (Bakhtavar & Mahmoudi, 2020). Consequently, open pit mining operations face the ongoing challenge of optimising loading and hauling operations while extracting ore at greater depths, thereby enhancing operational efficiency (Hustrulid et al., 2013).

Dumping areas are crucial nodes in the semi-continuous process and require careful consideration to avoid trucks queueing or shovel idle time. The dumping area receives waste material from the trucks and plays a pivotal role in maintaining system efficiency (Bao & Zhang, 2020). Load and haul operations should move enough material to ensure adequate drilling space is consistently available. The approach aligns with the performance benchmark of maintaining uninterrupted mining operations (Oggeri, et al., 2019). In the semi-continuous process, trucks transport overburden of varying nature to the dumping area for backfilling or stockpiling. Regulating the flow of trucks carrying waste ensures a balanced process for exposing the ore body (Bao & Zhang, 2020). Optimising truck flow in an overburden mining process involves meeting production targets, minimising transportation costs, and aligning with loading and dumping capacities (Bao & Zhang, 2020).

## 2.4 Queuing Theory in Loading and Hauling Operations

Queuing theory was created to model systems handling unpredictable service requests. A queuing system is where customers arrive, wait to be serviced, and move on or exit once serviced (Pinsky & Karlin, 2011). The queuing theory was initially developed to manage telephone traffic, and it considers six key characteristics: arrival distribution, service distribution, queue management rules, system limitations, service channel availability, and service stages (Gross, et al., 2008).

Queuing systems involve stochastic arrival processes, and understanding customer behaviours like waiting, baulking, and reneging is crucial. Impatient customers lead to state-dependent arrival distributions (Güneş, 2023). Arrival patterns can be based on frequency or intervals, meaning the number of arrivals within a given time frame or the average time between consecutive arrivals (Gross, et al., 2008). This suggests that the arrival pattern can be deterministic or probabilistic, following a discrete or continuous probability distribution.

A probability distribution is necessary for describing customer service times. Single-service and batch-service options exist, and service processes may be state-dependent or influenced by the queue length (Güneş, 2023). In this regard, the service distribution is ascertained by the number of servers, the arrangement of servers, and the service pattern, as illustrated in Figure 2.2 (Amit & Ghazali, 2018).

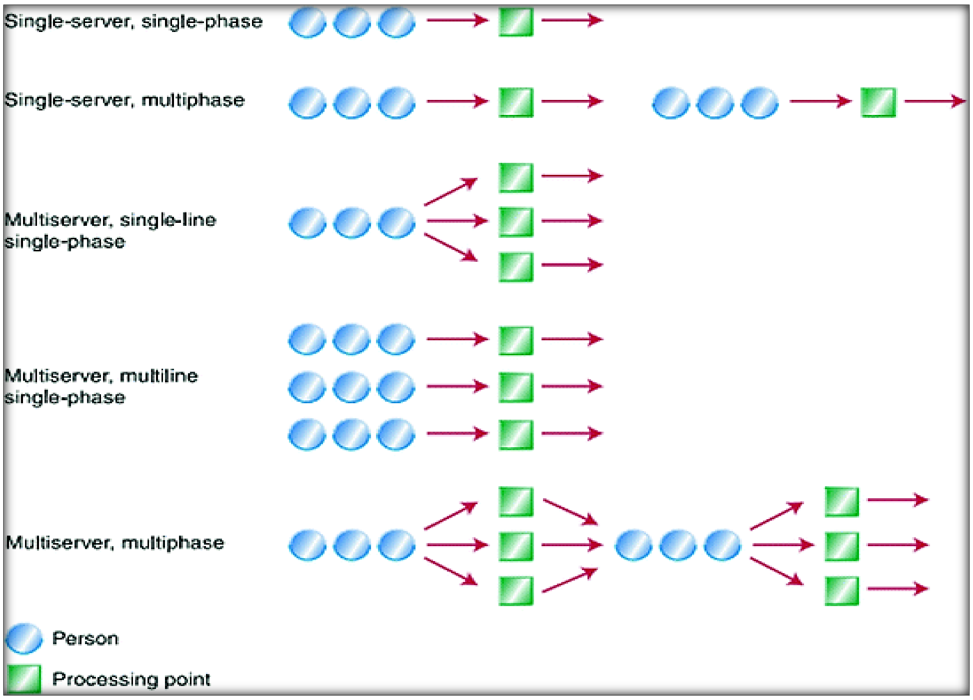


Figure 2.2: Queuing channel and phase configurations.
Source: Amit and Ghazali (2018)

There may be situations where multiple queues can serve the customers instead of a single queue. Typically, the number of queues equals or is less than the number of servers. Implementing additional rules becomes crucial to maintaining proper queue discipline in such scenarios (Hillier & Lieberman, 2005).

Haul routes can be treated as servers, with service distribution assigned, even without forming queues. Cyclic queuing models can include multiple loaders operating in parallel, adjusting for complex mining layouts. As the intricacy of mining operations escalates, a network queuing system is implemented to manage the multiple pathways accessible to haul trucks, thereby sustaining high levels of productivity and efficiency (Gross, et al., 2008).

The performance of queuing systems is important in open pit overburden load and haul operations. Haul trucks transport waste from mining benches to dumping areas, creating a complex queuing environment (Pasch & Uludag, 2018). Efficient performance in this context is essential for maximising productivity, minimising downtime, and ensuring a smooth flow of materials through the loading and hauling system. Waiting time for haul trucks at loading and dumping points significantly impacts the overall efficiency of load and haul operations (Chaowasakoo, et al., 2017). Prolonged waiting can lead to bottlenecks, decreased throughput, and increased operational costs. Therefore, optimising the balance between truck arrivals and loading capacities is crucial to minimise waiting times and enhance the overall performance of the queuing system. On the other hand, service rates are associated with the speed at which loading and tipping services are provided and directly influence the throughput of overburden and coal through the system. Striking the right balance between service rates and equipment capacity is vital to ensure the steady flow of overburden and coal, preventing unnecessary delays and optimising the use of resources (Gross, et al., 2008).

Long queues of trucks waiting to be loaded indicate inefficiencies in the system, leading to increased idle time for trucks (Ta et al., 2013). Monitoring and controlling queue lengths is essential for maintaining a smooth and continuous flow of overburden and coal throughout the load and haul process (Riley, 2004). Proper design, considering factors like service variability and customer behaviour (e.g., truck arrival patterns), is crucial for achieving optimal performance. Additionally, the adaptability of the queuing system to varying demands and operational conditions is vital for effectively managing the dynamic nature of waste loading and hauling operations (Gross, et al., 2008).

Technological advancements, such as automation and continuous monitoring systems, can play a pivotal role in enhancing the proficiency of queuing systems in load and haul operations (Ganiyat, 2022). Automated loading processes, accurate tracking of truck movements, and real-time data analysis improve efficiency and reduce waiting times. In conclusion, the performance of queuing systems in the context of overburden loading and hauling operations is pivotal for the overall success of open pit mining operations. By focusing on time utilisation, hauling route conditions, loading efficiency, and cycle time, mining operations can improve their queuing systems to achieve higher productivity, reduce operational costs, and improve overall efficiency (Gross, et al., 2008).

## 2.5 Technological Advancements and Modern Innovations

Recent technological advancements have significantly transformed open-pit load and haul operations, offering new avenues to improve productivity, safety, and cost-efficiency. Innovations are increasingly being adopted to address longstanding challenges associated with truck dispatching, equipment utilisation, fuel consumption, and operator variability.

One of the most notable advancements is the deployment of autonomous haul trucks. These driverless vehicles, now operational in major mines operated by companies such as Rio Tinto's Pilbara operations, enhance safety by eliminating human error, reduce fatigue-related incidents, and improve fuel efficiency through optimised operational control (Caterpillar, 2025). Autonomous trucks also ensure consistent cycle times, even under adverse weather conditions, contributing to greater operational predictability.

In tandem with automation, fleet management systems (FMS) have become central to modern mining operations. These systems integrate global positioning system (GPS), real-time telemetry, and onboard diagnostics to monitor vehicle performance, location, payload, and cycle times. This allows for real-time visibility into fleet movements and operational bottlenecks, enabling faster decision-making and better utilisation of both loading and hauling equipment (Chanda and Gardiner, 2010). Some FMS platforms also issue alerts on mechanical faults or deviations from optimal routes, reducing unplanned downtime and maintenance costs.

Moreover, the rise of artificial intelligence (AI) and machine learning has introduced advanced analytics and optimisation tools that can learn from historical data to recommend more efficient dispatch patterns. AI-driven algorithms dynamically adjust haul truck assignments based on current site conditions, shovel availability, and queue lengths, resulting in more balanced equipment match factors and lower idle times (Yarmuch et al., 2020). AI tools also support predictive maintenance schedules and simulate different operational scenarios to test the impact of variable inputs on cycle times and fuel usage.

In addition to on-site innovations, digital twin technologies and cloud-based planning platforms now allow for virtual modelling of open-pit operations. These tools enable engineers to simulate haul route designs, equipment interactions, and production outcomes under different configurations without interrupting live operations (Nobahar , et al., 2024).

Collectively, modern technologies are shifting the paradigm from reactive to proactive and predictive mining operations. The integration of automation, real-time monitoring, and AI in open-pit mining not only improves efficiency but also aligns operations with emerging environmental, social, and governance standards by reducing carbon emissions, enhancing safety, and optimising resource use. As technological maturity continues, future mining operations are expected to rely more heavily on integrated smart systems to achieve higher levels of performance and sustainability.

## 2.6 Productivity in Mining Operations

Productivity in mining is a multidimensional construct that refers to the efficiency with which resources are transformed into outputs. It can be categorised into various forms, such as labour productivity (output per unit of labour), capital productivity (output per unit of capital employed), and multifactor productivity (output relative to a combination of inputs) (Du Toit , 2017). In mining, these metrics are particularly relevant given the high capital intensity and variable workforce demands across project phases. Du Toit (2017) argues that productivity is not merely an outcome of operational performance, but a strategic measure shaped by external pressures such as resource scarcity and commodity prices.

A wide range of factors influences productivity in mining operations, and scholars offer diverse interpretations of their relative importance. Technological innovation, for instance, is widely accepted as a critical enabler of productivity improvements. However, Chanda and Gardiner (2010) caution that technological implementation alone does not guarantee productivity gains unless supported by effective change management and workforce training. Du Toit (2017) highlights how automation, digital monitoring, and machine learning have significantly enhanced productivity by reducing variability and optimising equipment usage. This view aligns with Yarmuch et al. (2020), who show that artificial intelligence-based dispatch systems can reduce idle times and improve cycle efficiency by over 10%. However,

Another key determinant is resource depletion and ore grade decline, which poses increasing challenges for sustaining productivity. Tilton & Guzmán, (2016) argue that as higher-grade reserves are exhausted, more waste must be removed to extract the same volume of ore, thereby increasing costs and reducing output per unit input. Du Toit (2017) presents a more optimistic view, suggesting that strategic mine planning and blending techniques can partially offset the effects of resource degradation. Humphreys, (2019), notes that declining ore grades not only drive up energy and equipment usage but also complicate waste management and rehabilitation efforts. Regulatory frameworks further influence productivity, though views diverge on their net effect. On one hand, regulations can drive technological innovation and procedural efficiency, indirectly enhancing long-term productivity (Bozorgebrahimi, 2004). On the other hand, Humphreys (2019) suggests that such stringent safety and environmental laws may introduce operational delays and additional costs, thereby reducing productivity. This tension between compliance and innovation illustrates the dual-edged nature of regulation within mining systems.

Workforce quality and human capital development are universally recognised as key drivers of productivity. Choudhary (2015) correlates high operator competence with reduced equipment wear and lower variability in cycle times. This is supported by Du Toit (2017) who argues that productivity cannot be sustained without a skilled, motivated, and adaptable workforce. Nevertheless, an overemphasis on human factors can obscure systemic inefficiencies, including poor haul route design or mismatched equipment, where even the most skilled operator would struggle to perform optimally.

Economies of scale and capacity utilisation also play pivotal roles in determining productivity. As Du Toit (2017) explains, larger operations often achieve lower unit costs through more efficient use of capital assets and infrastructure. Yet, this is constrained by the law of diminishing returns; beyond a certain threshold, increasing input does not yield proportionate output due to bottlenecks or underutilisation of equipment (Altiti et al., 2021). In contrast, Tapia et al. (2021) suggest that strategic fleet sizing and optimal match factors can help maintain productivity at larger scales, thereby delaying the onset of diminishing returns.

A critical appraisal of the literature suggests that productivity is multi-factorial, and scholars emphasise structural (technological and regulatory) versus operational (human and process-based) levers. For example, Du Toit (2017) presents a holistic view by integrating macroeconomic and organisational factors, whereas Pasch and Uludag (2018) focus more on cycle time optimisation and equipment efficiency. This diversity underscores the need for context-specific productivity strategies that align with the geological, operational, and institutional realities of individual mines.

In summary, mining productivity is influenced by a complex interplay of internal and external factors. While technological advances, workforce quality, and economies of scale offer opportunities for improvement, constraints such as resource depletion, regulatory burden, and diminishing returns remain significant challenges. A balanced, systems-thinking approach that integrates diverse scholarly perspectives is thus essential for advancing productivity in modern mining operations.

## 2.7 Open Pit Mining Production Factors

### 2.7.1 Cycle time

Load and haul systems are semi-continuous, involving several activities, often termed the load-haul cycle. In load and haul operations, cycle time is a critical performance metric representing the total time to finish an operational cycle. Dump truck cycle time is the total duration needed to complete one full cycle. The truck cycle includes queuing, positioning, loading, hauling (loaded and empty), maneuvering, and tipping. The cycle time of a loader refers to the duration needed to complete a single pass. This includes filling the bucket, swinging to the dump truck, emptying the load, and swinging back empty to refill the bucket (Nday & Thomas, 2019).

Several factors influence cycle time in a load and haul system. These include equipment performance, operator skill level, haul route conditions, and the spatial arrangement of the loading and dumping sites. Equipment efficiency, such as loaders' bucket capacity and haul trucks' payload capacity, plays a role in determining cycle time. Additionally, operator proficiency in maneuvering and operating machinery can significantly impact the duration of each cycle phase (Mnzool, et al., 2024).

Reducing cycle time is crucial for improving operational efficiency and productivity. Shorter cycle times increase throughput, allowing more material to be moved within the same period and costs. This can directly impact the profitability of mining operations, as more efficient cycles mean lower fuel consumption per volume mined and improved labour utilisation (Bozorgebrahimi, et al., 2003). Operational strategies to reduce cycle time include optimising the spatial layout of the loading and dumping sites, improving road conditions, and ensuring reconfiguring haul routes to minimise distance (Chanda & Gardiner, 2010). Technological advancements provide significant opportunities to reduce cycle times. Real-time monitoring systems and telematics allow for continuous tracking of equipment performance and cycle times. Implementing GPS technologies in mining operations enables better route planning and minimises delays caused by suboptimal routing. Automation and autonomous haulage systems reduce cycle times by eliminating human errors and optimising operational efficiency ( Lööw, et al., 2019).

Pasch and Uludag (2018) point out that queuing includes the time an empty truck waits to be loaded and waiting at the dumping area. This shows that not all the time during a shift is utilised for productive purposes during the load-haul cycle. Discussing the time usage model during the load-haul cycle is important.

### 2.7.2 Time Usage Model

Dedicating all shift time to productive activities each day is impossible, as unforeseen events and distractions consume a significant portion of productive time. Considering this, the time within each calendar year can be divided into four parts: standby time, equipment downtime (scheduled and unscheduled), process downtime (scheduled and unscheduled), and operating time, as illustrated in Table 2.1.

Table 2-1: Time usage model

| Calendar year | | | |
|---|---|---|---|
| Standby time | Equipment downtime | Process downtime | Operating time |

Source: Adapted from Pasch and Uludag (2018)

It is important to note that operating time is the total time the load-haul equipment spends performing its planned and intended production function. Choudhary (2015) states that each piece of equipment within a specific production cycle has its expected performance metrics, typically used for performance evaluation and assessment.

### 2.7.3 Equipment Match Factor

The equipment match factor considers how compatible a truck fleet's capacities and loaders are in a load-and-haulage operation, and it measures the productivity of a load-haul fleet (Pasch and Uludag, 2018). It should be distinct from production efficiency, as it only measures the efficiency of the combined load-haulage fleet. Considering this, the equipment match factor should not be used in isolation, but rather in conjunction with other approaches for optimal results. It is computed using equation 2.1, and table 2.2 presents its interpretation.

2-1: *Equipment Match Factor*

$$Equipment\ match\ factor\ (MF) = \frac{No.of\ trucks\ \times\ loader\ cycle\ time}{No.of\ loader\ \times\ trucks\ cycle\ time}$$

*Source: Pasch and Uludag (2018:2)*

- A coupling factor less than 1 (MF < 1), which implies a surplus of the loading fleet (under-trucking) and, consequently, maximum utilisation of the hauling units and low utilisation of the loading units.

- A coupling factor greater than 1 (MF > 1), which implies a surplus of the hauling fleet (over-trucking) and, consequently, maximum utilisation of the loading units and low utilisation of the hauling units.
- A coupling factor equal to 1 (MF = 1), which corresponds to a perfect coupling in terms of the productivity and efficiency of both fleets.

The equipment match factor can be employed to evaluate the productivity performance of the equipment involved in a production operation (Tapia et al., 2021). According to Burt and Caccetta (2018) the equipment match factor shows the relationship between the dump truck arrival rate time to the their service rate. Productive efficiency increases as the match factor approaches a value of one; however, it decreases when the match factor exceeds one. This relationship is illustrated in Figure 2.3, which shows the correlation between production efficiency and the match factor.

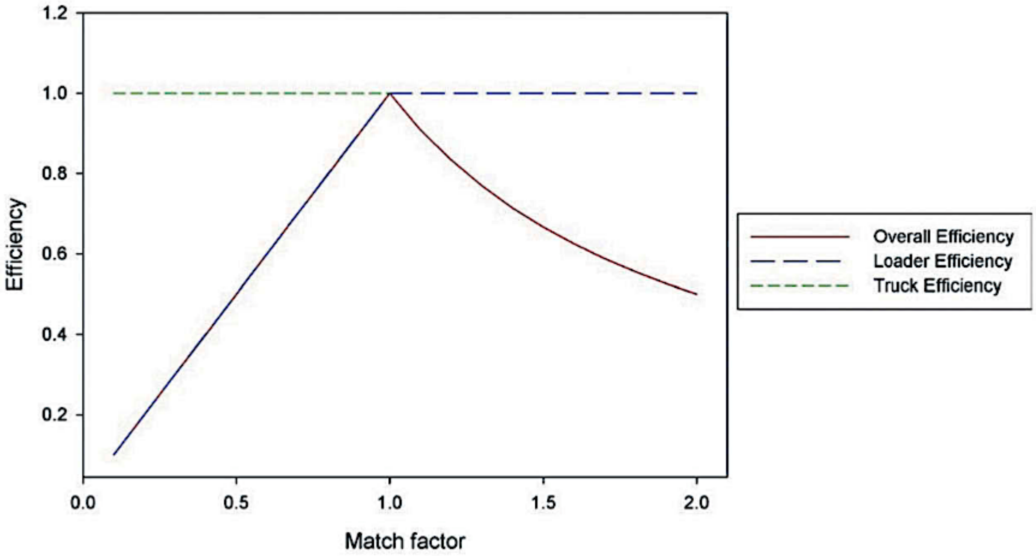


Figure 2.3: Efficiency in terms of equipment match factor.
Source: Tapia et al. (2021:3)

It should be noted that productive efficiency depends on the equipment used and the characteristics of the material being transported. Choudhary (2015) developed a simplified equation that can be employed to determine whether a load-and-haulage operation is over- or under-trucked and is presented in equation 2.2.

*2-2: Loader-to-Truck Matching Formula*

$$No. of\ truck\ required\ = \frac{Total\ truck\ cycle\ time\ (min)}{Sum\ of\ the\ spotting\ time\ and\ loading\ time\ (min)}$$

*Source: (Hartman & Mutmansky, 2002)*

It should be noted that the equation above does not consider queuing times. It's only useful to compare different truck fleet configurations to determine the best option.

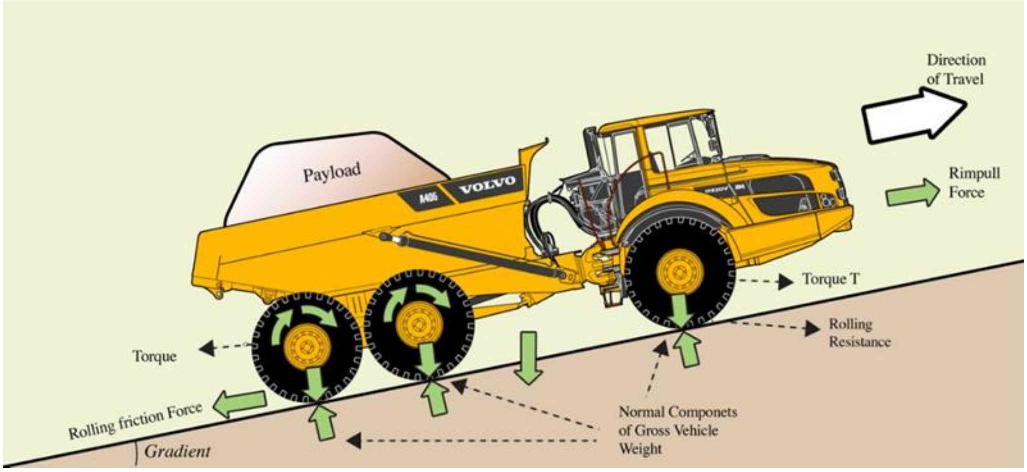
### 2.7.4 Hauling Conditions

The efficiency of hauling trucks is important to achieve overall efficiency and effectiveness in a loading and hauling operation. Load and haul efficiency is influenced by material type, payload, haul route characteristics, distance, equipment conditions, and loader productivity (Joko & Mulyono, 2023). Haul route characteristics central to this study are haul route width, rolling resistance (RR), and gradient. Haul route width is important for operational efficiency in open pit mining load and haul operations. Wide haul routes allow hauling trucks to navigate effortlessly and safely without delays. Narrow haul routes cause congestion, forcing operators to slow down and increase cycle times. They also put more strain on equipment, leading to higher fuel use and faster tyre wear. Properly designed haul route widths fit the size of the hauling trucks, help maintain planned speed limits and meet safety standards. Consequently, well-maintained haul routes reduce delays and minimise risks, increasing efficiency and lowering costs while keeping operations safe and productive (Thompson & Visser, 2003).

Haul road design guidelines recommend road widths based on vehicle dimensions, traffic flow, and safety standards. Typically, the width is calculated to accommodate the largest vehicle used, ensuring enough space for two-way traffic and passing manoeuvres (Thompson, 2010). According to Tannant and Regensburg (2001), a widely used guideline for haul route width suggests that for a single-lane haul route, the minimum width should be two to three times the width of the largest haul truck. For two-way traffic, the haul route width should be three and a half to four times the width of the widest vehicle. This ensures that hauling trucks safely pass each other while maintaining a buffer for operational safety. Wider haul routes may require more excavation, increasing environmental footprint and cost. Therefore, the optimal width should balance operational efficiency, environmental considerations, and economic feasibility (Tannant & Regensburg , 2001).

Hauling systems, particularly those using diesel-powered trucks, significantly contribute to carbon emissions and dust generation (Soofastaei et al., 2015). Alternatives like electric trucks or hybrid conveyor-truck systems are being explored to reduce environmental impacts. Additionally, steep gradients and poorly maintained haul routes present safety risks, increasing the likelihood of haul truck rollovers and brake failures (Thompson & Visser, 2003). Incorporating proactive safety measures and environmental controls is critical in modern pit design and operational planning.

Rolling Resistance (RR) in open pit mining is crucial to hauling operations' efficiency, productivity, and cost performance. RR refers to the force that opposes the motion of vehicles as their tyres roll over the haul route surface, impacting fuel consumption, tyre wear, and overall cycle times, as illustrated in Figure 2.5 (Thompson & Visser, 2003).

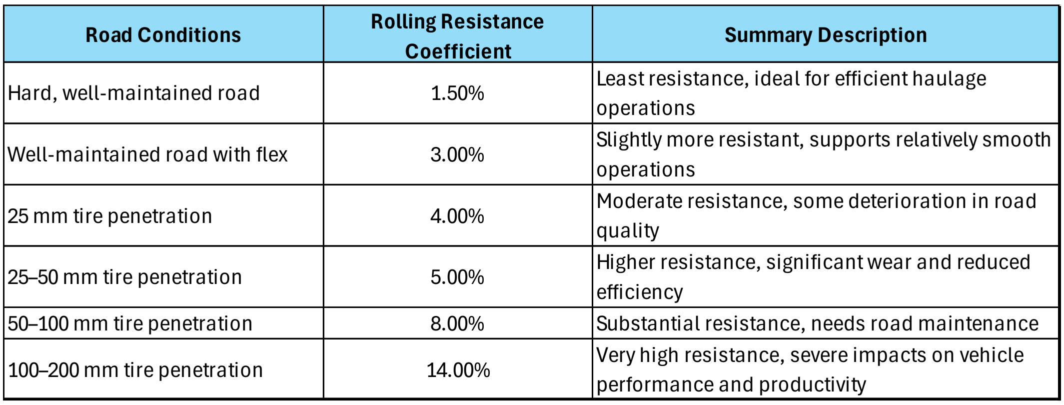


.

Figure 2.4: A schematic diagram illustrating a haul truck and the critical factors contributing to rolling resistance
Source: Soofastaei et al. (2015)

The diagram illustrates the key forces acting on a loaded dump truck as it travels up an incline. It highlights how the truck must generate enough rimpull force through torque to overcome various resistances. These include rolling resistance, caused by tire and surface deformation, and grade resistance due to the uphill slope. It also shows the normal force components acting vertically from the ground to support the vehicle's weight. Table 2.2 presents standard RR coefficient values based on various road conditions.

Table 2-2: Standard Rolling Resistance Values



| Road Conditions | Rolling Resistance Coefficient | Summary Description |
|---|---|---|
| Hard, well-maintained road | 1.50% | Least resistance, ideal for efficient haulage operations |
| Well-maintained road with flex | 3.00% | Slightly more resistant, supports relatively smooth operations |
| 25 mm tire penetration | 4.00% | Moderate resistance, some deterioration in road quality |
| 25–50 mm tire penetration | 5.00% | Higher resistance, significant wear and reduced efficiency |
| 50–100 mm tire penetration | 8.00% | Substantial resistance, needs road maintenance |
| 100–200 mm tire penetration | 14.00% | Very high resistance, severe impacts on vehicle performance and productivity |

Source: Mkhatshwa (2009)

Well-designed hauling routes have a positive linear correlation with high production rates. High RR on haul routes can increase fuel consumption by up to 20%, substantially contributing to operational costs. Factors influencing RR include road surface type, road maintenance practices, and weather conditions. Rough and ungraded road surfaces increase RR as haul trucks experience more friction and tyre deformation. Proper compaction and drainage significantly minimise resistance, particularly in wet conditions where soft ground can double the resistance factor. (Thompson & Visser, 2003). Best practices for reducing RR include regular road grading, compaction, using materials such as crushed gravel, and applying dust suppression agents to maintain a stable and smooth haul route surface (Tannant & Regensburg , 2001). A haul route's Gradient Ratio (GR) in open pit mining is a critical design factor affecting hauling truck performance, fuel consumption, safety, and overall productivity. GR represents the slope of the haul road, expressed as a percentage, and is calculated by dividing the vertical rise by its horizontal length, as illustrated in Figure 2.6 (Thompson & Visser, 2003).

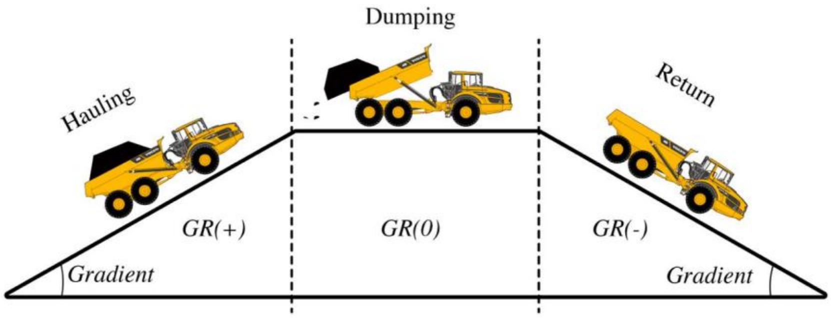


Figure 2.5: Gradient ratio illustration
Source: Soofastaei et al. (2015)

The steepness of a ramp directly influences the efficiency and operational costs of hauling operations, as trucks must work harder to overcome the gravitational pull-on upward slopes (Yarmuch, et al., 2020). In haul route design, selecting appropriate gradients based on equipment capabilities, safety requirements, and cost considerations is important. Ramp gradients in open pit mining are usually designed between 5% and 10% for safety and efficiency. Thompson and Visser (2003) suggest that gradients beyond 10% significantly increase fuel consumption and tyre wear while reducing safety due to increased braking requirements on downward slopes. Steep ramp gradients lead to higher fuel consumption and increased wear on hauling trucks' tyres and brakes. A 1% increase in gradient can raise fuel consumption by 3–5%, as hauling trucks need to exert more power to ascend (Rodovalho, et al., 2016). Ramp gradient directly affects cycle times, slowing down hauling trucks on ascents and descents. Optimal gradient design can improve cycle times by reducing trucks' time navigating steep ramps. Flattening ramps, where possible, can increase speed and thus reduce the time trucks take to complete a cycle, enhancing productivity (Baatarchuluun , et al., 2023).

Efficient hauling is crucial to meeting production targets. In this study, hauling was limited to the stripping operation at Manungu Colliery.

Optimising load and haul operations is essential for smooth and efficient operations. Geological, geotechnical, environmental, and logistical factors influence waste stripping and disposal in open-pit mines. The choice of load and haul methods depends on the volume of material and the distance between the loading bench and the dumping site (Oggeri, et al., 2019).

Optimising hauling routes and proper equipment maintenance can enhance productivity. Chaowasakoo et al (2017) recommend utilising fleet management systems for route optimisation, scheduling, and reducing cycle and idle times. Predictive maintenance techniques and operator training are also suggested to improve equipment efficiency. Based on the study by Arteaga et al (2018) on fleet size selection for open-pit mines, the advice is to balance equipment capital costs against operational running costs. Furthermore, simulation models may evaluate optimal fleet sizes, haulage routes, and scheduling strategies to maximise efficiency. High GR and RR negatively affect fuel consumption and travel time, while inadequate curve radii force trucks to perform complex manoeuvres, posing safety risks and reducing productivity (Bozorgebrahimi, 2004). In this regard, optimising road design can reduce cycle times, fuel consumption, and maintenance costs, leading to overall productivity gains.

Achieving optimal hauling productivity requires a smooth truck flow with minimal hang and queuing times. Some open pit mines use GPS tracking technology to monitor hauling activities and time-related events, enhancing process efficiency. Riyandi and Wibowo (2020) support this approach, emphasising the significance of hauling in the mining industry. Improving loading and hauling processes enables mining companies to attain efficiency and meet targets. In the semi-continuous load and haul mining process, as with the Manungu Colliery, the overall efficiency is constrained by the need to match production capacities across various operations. The truck transportation capacity must not exceed the dumping capacity to ensure continuous waste dumping (Bao & Zhang, 2020). Inefficient truck flow planning can lead to significant idle time at loading and dumping points. Planning and distribution strategies for truck flow can help reduce idle time. Truck flow planning is closely linked to the loading and dumping area configuration (Bao & Zhang, 2020).

## 2.8 Chapter Summary

This chapter presented literature on cycle time, load and haul system, and queuing efficiency in open-pit mining, highlighting strategies to improve each aspect of load-haul operations. Cycle time measures the duration of a complete operational cycle for trucks and excavators, including various stages such as queuing, loading, hauling, manoeuvring, and tipping.

Equipment performance, operator skill, and haul route conditions affect cycle time. Steeper gradients and narrow haul routes increase resistance, slowing travel and increasing cycle time. Improvements to the haul route, such as widening roads and reducing steepness, enhance truck speed, reduce strain, and improve efficiency.

Time utilisation is critical but often hindered by process and equipment downtime. The time usage model categorises productive and non-productive activities to maximise operating time for optimal throughput. Proper layout planning, route adjustments, and maintenance can all shorten cycle time and reduce fuel consumption. The equipment match factor assesses how well truck and loader capacities align, with optimal matches boosting productivity. Misalignment, however, can cause bottlenecks and delays.

Queuing efficiency is vital, especially in high-density operations like overburden removal. Long queues indicate inefficiencies, causing trucks to idle and increase operating costs. Advanced technology—such as automation and real-time monitoring—can reduce waiting times and enhance haul route planning. In summary, managing cycle time, improving haul routes, and optimising equipment compatibility and queuing systems all contribute to lower costs and higher productivity in mining operations.

# 3 RESEARCH APPROACH

## 3.1 Introduction

This chapter is dedicated to the research approach for assessment and improvement of the TSLHS operation at Manungu Colliery. Research methodology guides researchers through investigative endeavours. It is a structured process encompassing the research design, data gathering, and analysis procedures (Kothari & Garg, 2019). The selection of the appropriate methodology is crucial, as different techniques suit varying research settings, contexts, and operational environments. Failing to choose the right combination of research methods can significantly compromise the validity, reliability, and trustworthiness of research findings. (Kothari & Garg, 2019). Pragmatism was chosen as the methodology for this study, which focuses on addressing practical challenges and improving operational efficiency.

## 3.2 Research Design

This study employs the pragmatism research philosophy, and it postulates that a researcher may utilise a philosophical and methodological approach that is most appropriate for the research problem under investigation (Kaushik and Walsh, 2019). The philosophical and methodological approach refers to the foundational beliefs that guide the inquiry and the systematic methods employed to gather, evaluate, and explain the data. These two components shape the overall design and conduct of the research study (Howell, 2012).

According to Saunders et al. (2019), the pragmatism research philosophy emphasises the relevance of concepts in supporting action and reconciles objectivism and subjectivism. In research, pragmatists prioritise addressing practical problems, driven by values and a reflexive process, aiming to provide solutions that inform future practice (Saunders, et al., 2019). Furthermore, it asserts that concepts are only relevant to the extent that they support action (Kelemen and Rumens, 2008). This was necessary as the researcher sought to develop practical and actionable solutions, which this research philosophy supports. The mixed-methods research design was used, combining qualitative and quantitative research designs. Quantitative research studies use numerical data to respond to specific research questions and come up with objective conclusions with the potential of generalising findings to a larger population (Creswell and Creswell, 2017). On the other hand, qualitative research studies use non-numerical data to explore complex situations. They focus on human experiences, behaviours, and social contexts to provide a detailed and in-depth understanding of the subject under investigation. (Creswell and Creswell, 2017). This research design was appropriate for this study as it was aligned with the pragmatic research philosophy.

### 3.2.1 Pragmatism and Mixed-Methods Approach

This study adopted a mixed-methods research framework rooted in the pragmatic research philosophy to investigate and improve the TSLHS operation. The mixed-methods framework incorporates quantitative and qualitative data within one study. The method combines the strengths of both methodologies to offer a more thorough understanding of the research problem (Creswell, 2015). The methods can be used sequentially or concurrently, exploring a problem from different perspectives and making the results comprehensive. Quantitative research gathers numbers and facts through surveys, experiments, or records. The data is analysed using statistics and focuses on how much or how many. Qualitative research looks at people's experiences, thoughts, and feelings. It uses interviews, focus groups, or observation to explore why things happen. It finds themes or stories to understand the deeper meaning behind actions or decisions.

The motivation behind incorporating a mixed-methods approach is its ability to offer detailed insights into the research problem. The pragmatic research philosophy uses the most effective quantitative, qualitative, or both methods to solve real-world problems. It identifies specific issues and selects the best approach to collect data. The analysis aims to find practical solutions, and methods can be adjusted if the results are unclear. The main goal is to produce valuable insights that can be applied directly to improve situations or inform decisions (Creswell & Creswell, 2017). The emphasis on practical outcomes ensures that the research findings can be readily implemented to enhance efficiency, reduce costs, and improve overall productivity. In summary, the pragmatic research philosophy is justified in the context of stripping load and haul mining operations. It provides a tailored and responsive approach to address practical issues, offering solutions immediately applicable in the mining environment.

### 3.2.2 Quantitative Research Design

The quantitative research design examined key operational KPIs related to the TSLHS operation. The KPIs are cycle time, loading efficiency, time utilisation, and hauling conditions (rolling resistance, haul route width, and ramp gradients). The data-driven approach to improving the stripping operation focused on measuring the performance of the study KPIs in enhancing productivity and efficiency. Quantitative data was collected from different sources, including production reports, survey reports, shift data sheets, and real-time observations.

### 3.2.3 Qualitative Research Design

The qualitative research design focused on understanding the human, contextual, and operational dynamics influencing the TSLHS operation. The qualitative approach to improving the operation focused on:

- Human factors and challenges specific to the TSLHS operation.
- Individual experiences of stakeholders of the operation during the day-to-day activities.
- Opinions of machine operators on the influence of operational conditions, such as ramp gradient, utilisation, and haul road quality.
- Adherence to protocols for equipment utilisation and safety standards.
- Interactions and coordination between haul trucks, excavators, and other equipment
- Context to the quantitative data on time utilisation, cycle times, and payload efficiency

Qualitative data was gathered using structured real-time observations, semi-structured interviews, and document review.

### 3.2.4 Integrated Diverse Research Methods for a Holistic Perspective

A dual approach involving qualitative and quantitative data-gathering techniques was employed in the preliminary stages of exploring the study's theme. Qualitative insights were derived from questionnaires (see Appendix A), observations, interviews, and group-based discussions, adding valuable context and support to the predominantly quantitative investigation. Quantitative data, including cycle time data (see Appendix L and M) and reports (production and survey) (see Appendix B to D), provided a structured foundation for addressing specific dimensions of the research questions. Combining qualitative and quantitative approaches enabled a thorough understanding of the stripping operation. Real-time observation of the operation, primarily through a detailed time study, played an essential role in understanding the dynamics of the operation. The researcher documented the stripping operation cycle times through March and May while recording haul route conditions. This approach facilitated capturing multiple 'day-in-the-life-of' scenarios, with specific events logged, offering a comprehensive understanding of the TSLHS operation dynamics.

## 3.3 Data Collection Process

The data collection process was guided by the mixed-methods approach rooted in the pragmatic research philosophy, as discussed in the research design. This section outlines the method employed to gather data, tools, and sources of information used for the study.

### 3.3.1 Quantitative Data Collection

The quantitative component of the TSLHS operation improvement study focused on collecting numerical data on key operational metrics. The primary sources of data included:

- **Production Reports** (see Appendix B to C): Data on tonnage moved, equipment usage, production rates, and time utilisation was collected from daily and weekly production reports.
- **Survey Reports** (see Appendix D): The material moved was quantified through daily tallies and confirmed by survey data to ensure accurate progress reporting in the stripping operation. The survey reports were also utilised to quantify the actual volume in sample buckets as part of the bucket fill factor (BFF) improvement exercise. The survey department also measured ramp gradients and haul route road widths.

- **Shift Data Sheets:** Datasheets from individual shifts recorded cycle times, equipment availability, and other performance indicators.
- **Real-Time Observations:** The researcher conducted time studies by observing the stripping operation in real time, using a stopwatch to record cycle times through March and May. The observations were critical in capturing operational variations, activity durations, time utilisation, haul route conditions and overall cycle time trends.

### 3.3.2 Qualitative Data Collection

The qualitative data collection captured contextual, operational, and human insights that influenced the stripping operation's performance. The sources of qualitative data included:

- **Observations:** Real-time direct observations of the stripping operation highlighted operator behaviours, equipment performance, and adherence to standard operating procedures (SOPs). Observations uncovered non-quantifiable factors such as operator efficiency, equipment interactions, and other human factors influencing operational performance.
- **Interviews:** Interviews were conducted with the stripping operation stakeholders, including line management, equipment operators, and artisans. The interviews gathered insights into experiences, behaviours, and challenges encountered within the operation and suggestions for improving operational efficiency. The study had twenty-five participants, comprising fifteen ADT operators, five excavator operators, and four supervisors, selected using purposive sampling. The selection was guided by operational rosters and involvement in the operation during the study period.
- **Document Review:** The operation’s production reports, short-term mine plans, and SOPs (see Appendix F) were reviewed to

understand targets, operational processes, and strategies. Historical data and plans were essential for understanding the evolution of practices and procedures in the stripping operation.

### 3.3.3 Challenges and Mitigations in Data Collection

The data collection exercise encountered challenges. First, variations in weather, equipment breakdowns, and workforce availability made the data vary. Data was collected over two months to minimise this challenge and capture a representative range of conditions. Another challenge was historical documents which were incomplete or not readily accessible. Document review was supplemented with interviews and real-time observations to fill in the gaps. Lastly, conducting interviews with busy mine employees was difficult. To address this challenge, flexible interview times were implemented, with some interviews being paused and continued when the required stakeholder was available.

## 3.4 Data Validation Process

Data validation ensures the accuracy, reliability, and credibility of research findings. Validation was done to confirm that the collected data was accurate and reflected the reality of the stripping operation. This section outlines the validation techniques applied to the TSLHS operation improvement study.

### 3.4.1 Quantitative Data Validation

The quantitative data was validated through several processes aimed at ensuring consistency, accuracy, and representativeness:

- **Cross-Validation:** The study's multiple data sources were cross-validated to check for consistency. For example, cycle time measurements recorded in real-time were compared with reported data in shift data sheets. Any significant discrepancies were investigated and resolved before the data was included in the final analysis.

- **Triangulation:** Cycle times, production rates, and time utilisation were recorded using different sources within the operation. Time utilisation was recorded manually through time studies and extracted from daily production reports. The alignment of results from these different sources validated the accuracy of the data.
- **Benchmarking** (see Appendix E): The study's outcomes were benchmarked against industry standards and best practices. For instance, production rates, time utilisation, and cycle times were compared with industry norms. Any deviations from expected values were analysed to understand whether they were due to operational inefficiencies, unique site conditions, or data inaccuracies.
- **Statistical Validation:** Variance analysis was used to identify anomalies or inconsistencies in production rates.
- **Data Cleaning and Error Checks:** This process involved identifying and correcting data entry mistakes, inconsistencies in units of measurement, and missing values. Outliers were carefully examined to determine whether they represented valid data points or errors. Only cleaned and validated data was used in the final analysis.

### 3.4.2 Qualitative Data Validation

The qualitative data collected through interviews, observations, and document analysis was validated using the following techniques:

- **Triangulation:** Comparing findings from different techniques, such as interviews, systematic observations, and document review. For example, observations of operator behaviour during operation were cross-checked with interview responses from operators and line management.

- **Participant Validation:** To ensure the accuracy of interview data, participants were provided with summaries of their responses for review and confirmation. This step enhanced the qualitative findings' credibility by ensuring they accurately represented the participants' viewpoints.
- **Audit Trail:** A comprehensive record was kept for observations and document analysis. Data collected was diligently documented, including the times and conditions under which observations were made and ensuring that all relevant documents were reviewed comprehensively.
- **Peer Review:** The qualitative data was reviewed by peers and mine management to ensure that the interpretations and conclusions were logical, unbiased, and reflective of the observed reality. The independent review process added another layer of validation, helping to ensure the trustworthiness of the qualitative findings.

### 3.4.3 Integration of Quantitative and Qualitative Validation

Since this study employed a mixed-methods approach, it was crucial to validate the integration of quantitative and qualitative data:

- **Convergence of Findings:** Quantitative and qualitative data results were compared to verify if they provided a consistent narrative. Data from cycle time studies were compared with operator interviews and observations to confirm if the quantitative measurements were consistent with the workforce's experiences.
- **Discrepancies:** Where discrepancies arose between the quantitative and qualitative data, further investigation was conducted to understand the reasons behind these differences. For example,

quantitative data showed good time utilisation, but interviews suggested significant delays. It was noted that the shift supervisors had a tendency not to report some operational delays, mostly during night shifts.

### 3.4.4 Addressing Potential Biases

Throughout the validation process, efforts were made to minimise potential biases that could have affected the results:

- **Researcher Bias:** Data was collected using standardised protocols for quantitative and qualitative methods to mitigate researcher bias. Additionally, the mine management review helped ensure that the researcher's interpretations were objective and not influenced by personal views or expectations.
- **Participant Bias:** During interviews and observations, a comfortable environment was created, reducing the likelihood that participants would have responded and behaved in ways they thought the researcher wanted. Anonymity and confidentiality were emphasised and assured to encourage honest and open responses.
- **Data Collection Bias:** Multiple data collection methods and sources were used to ensure no single method dominated the findings. By combining diverse data sources, the study reduced the risk of bias in any method.

## 3.5 Data Analysis Approach

The data analysis for this study was designed to compare the results of the initial investigation conducted in March 2024 with those of the intervention study implemented in May 2024. All references to March and May in this section refer to the year 2024 unless specified otherwise. The initial investigation established the performance of the study’s KPIs and highlighted operational challenges, serving as a reference point for the intervention study. Based on these findings, the intervention study aimed to evaluate the effectiveness of targeted KPI adjustments. Comparing the KPIs before and after the improvements, the analysis sought to measure how these changes influenced the overall efficiency of the TSLHS operation.

### 3.5.1 Quantitative Data Analysis

The study’s KPIs guided the quantitative analysis. The initial study provided the baseline data, while the intervention study focused on measuring the effectiveness of interventions to improve operational efficiency.

- **Descriptive Statistics:** Data from the intervention study was analysed to calculate updated KPI values such as mean cycle time, time utilisation, and BFF. The values were compared to the baseline data collected in March to assess the degree of improvement.
- **Variance Analysis**: Variance analysis was employed to measure fluctuations in production rates and time utilisation, comparing results from the intervention study to the March baseline. This analysis helped quantify the operational improvements resulting from ramp gradients, rolling resistance, and BFF changes.
- **Benchmarking:** The analysis compared March and May data to industry benchmarks. This ensured that the improvements measured during the intervention study were consistent with industry best practices and provided a valid basis for further operational improvement.

### 3.5.2 Qualitative Data Analysis

The intervention study incorporated feedback from operators and supervisors to assess whether the adjustments were practical and sustainable in real-world conditions. Thematic analysis was used to evaluate common themes in operator feedback, focusing on the effectiveness of the operational changes. Themes related to improved haul route conditions and reduced operational strain were compared to the findings from March to ensure that the qualitative feedback aligned with quantitative performance improvements.

### 3.5.3 Data Visualisation and Reporting

The March investigation and the May intervention results were visually presented through charts to demonstrate improved KPIs. These visualisations helped to communicate the effectiveness of the operational changes to stakeholders.

## 3.6 Chapter Summary

This chapter detailed the study's data collection approach to improving the TSLHS operation, covering the research design, data collection, validation, and analysis processes. A pragmatic, mixed-methods design, combining quantitative and qualitative approaches, was selected to tackle operational challenges effectively.

Quantitative methods focused on time utilisation, hauling conditions, loading efficiency and cycle times, using data from production reports and real-time observations. Qualitative research explored the human elements impacting performance, gathering insights from interviews, observations, and document reviews to understand better the employees' experiences, behaviours, and procedural adherence. Quantitative data was gathered from production reports, shift sheets, surveys, and direct observations to track performance across KPIs. Throughout March and May, observations were recorded to capture an in-depth view of the stripping and hauling operation. Qualitative data was collected through interviews with the operation stakeholders, document review and observation.

Data validation was an important part of the research to ensure accuracy and consistency. Quantitative data was cross-verified through multiple sources, statistical checks, and benchmarking against industry standards. Any errors or inconsistencies were carefully managed to maintain data integrity. Qualitative data was validated through triangulation, comparing insights from different sources like interviews, observations, and document analysis. At the same time, participants were given a chance to review and confirm their responses, enhancing reliability.

Weather and incomplete historical records challenged the data collection process. Data was gathered through March and May to account for different operational conditions, and gaps in documentation were filled through additional interviews and observations. Bias was minimised by standardising data collection methods and maintaining a neutral interview environment, encouraging open and honest responses. The analysis compared findings from the initial study in March with results from the intervention study conducted in May to assess the impact of targeted KPI improvements.

Finally, data visualisations such as charts were created to effectively communicate the improvements to stakeholders. This chapter outlined the structured, multi-dimensional approach to gathering, validating, and analysing data to improve the TSLHS operation at Manungu Colliery. The focus on practical solutions and direct applications underscores the pragmatic nature of this research approach, providing the groundwork for improved efficiency and productivity in mining operations.

# 4 INITIAL STUDY: LOAD AND HAUL IMPROVEMENT

## 4.1 Introduction

This section presents data from the study to improve the TSLHS operation, focusing on time utilisation, hauling conditions, loading efficiency, and cycle time. These factors are critical determinants of the performance and cost-effectiveness of a load and haul operation in open-pit mining.

## 4.2 Equipment Specification and Mine Lithology

At Manungu Colliery, a diverse range of equipment is used for loading and hauling operations. This selection ensures optimal performance and efficiency across load and haul benches. Among the equipment utilised are the Hitachi 870 excavators and Volvo A40 articulated dump trucks (ADTs). These machines are deployed primarily for moving free diggable material, which is topsoil and subsoil, referred to as the TSLHS operation. Additionally, the mining operation incorporates heavy-duty equipment to excavate and move blasted overburden and run of mine (ROM). This combination comprises Hitachi 1200 and CAT 6015 excavators, loading into 777 CAT Rigid Dump Trucks (RDTs) and Bell ADTs. The quantity of each type of equipment is shown in Table 4.1.

Table 4-1: Available load and haul equipment at Manungu Colliery

| Equipment Unit | Current Fleet | Bucket Payload ($m^3$) | Material |
|---|---|---|---|
| **Excavators** | | | |
| Hitachi 870 | 4 | 4 | Top-soil and Subsoil |
| Hitachi 1200 | 4 | 7 | Blasted Overburden & ROM |
| CAT 6015 | 4 | 14 | Blasted Overburden & ROM |
| **Dump Trucks** | | | |
| Volvo ADT A40 | 10 | 16 | Top-soil and Subsoil |
| Bell ADT B50 | 7 | 21 | Blasted Overburden & ROM |
| CAT RDT 777 | 24 | 41.9 | Blasted Overburden & ROM |

The TSLHS operation includes a contingency setup supplied by the equipment provider, with two additional ADTs and one extra excavator. This backup equipment is available at no standing time cost, meaning there are no costs when it's not used. The arrangement offers flexibility to handle unexpected breakdowns and increased hauling distances, supporting continuous productivity without incurring standby charges.

In the coal mining operation, stripping of overburden is conducted systematically in multiple stages. Initially, the topsoil and subsoil benches are free diggable. This is followed by the sandstone bench, which requires blasting for excavation, along with subsequent overburden benches. Next in line is the dolerite bench, followed by the shale bench. The coal seam lies beneath these layers. The study focused on the topsoil and subsoil benches, the TSLHS operation. The decision to focus on the TSLHS operation, which accounts for approximately 21% of the total overburden, was driven by operational realities and a directive from mine management.

Due to contractual limitations, no additional equipment from the mine's fleet can be reallocated to this mine value chain section. Accordingly, the TSLHS operation functions independently concerning its designated loading and hauling equipment and occupies a critical position at the commencement of the mine's value chain. Inefficiencies in this segment have significantly delayed downstream processes such as blasted overburden stripping, coal exposure, and production scheduling. For detailed depth information, refer to Figure 4.1.

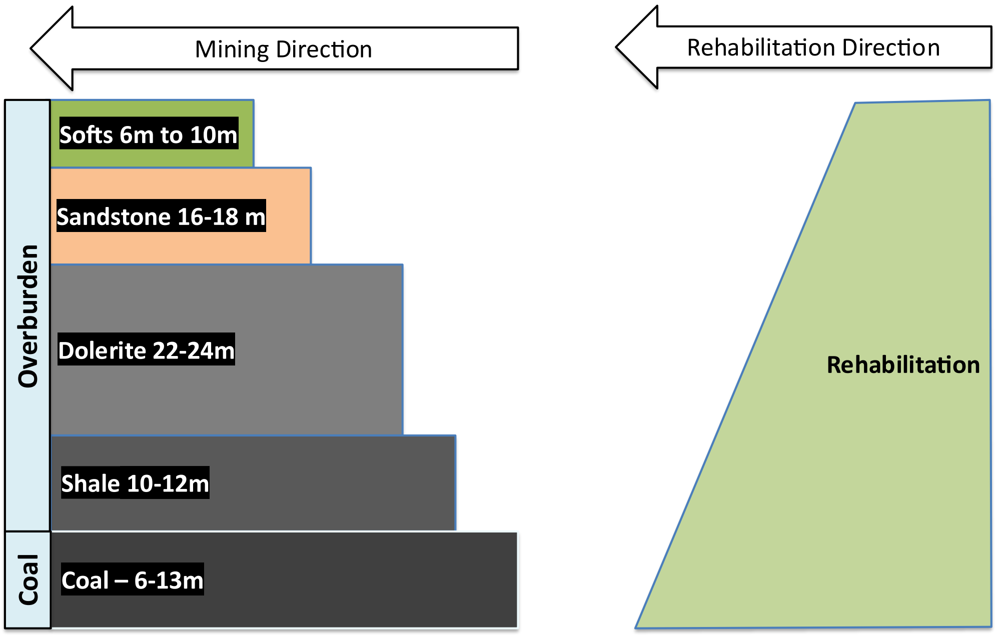

**Section Through Manungu Colliery Mine Benches**

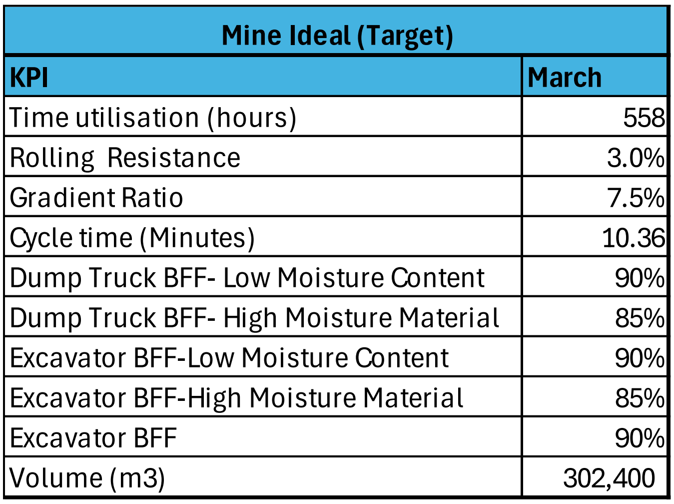
Figure 4.1: Manungu Colliery lithology section

The study was conducted in the central pit of the operation. Observed and recorded KPIs were time utilisation, hauling conditions, loading efficiency, and cycle time. The goal was to identify areas to improve operational effectiveness and productivity. The data presented in this chapter provides insights into the performance of the TSLHS operation in March and May 2024. The March study was valuable in informing the implementation of an intervention study in May 2024, enabling detailed analysis and recommendations that led to significant improvements. All references to March and May in this chapter refer to the year 2024 unless specified otherwise.

## 4.3 Data for the Initial Study

This section presents data from the initial study conducted in March. Table 4.2 presents the operation KPI targets for March, outlining the specific goals set for the period.

Table 4-2: March monthly KPI targets



| **Mine Ideal (Target)** | |
|---|---|
| **KPI** | **March** |
| Time utilisation (hours) | 558 |
| Rolling Resistance | 3.0% |
| Gradient Ratio | 7.5% |
| Cycle time (Minutes) | 10.36 |
| Dump Truck BFF- Low Moisture Content | 90% |
| Dump Truck BFF- High Moisture Material | 85% |
| Excavator BFF-Low Moisture Content | 90% |
| Excavator BFF-High Moisture Material | 85% |
| Excavator BFF | 90% |
| Volume (m3) | 302,400 |

The targets include time utilisation, loading efficiency, and monthly volume. The actual results will be measured against these targets to assess performance and identify areas for improvement.

### 4.3.1 Time Utilisation

The operation runs on a two twelve-hour shift system per day. Shift hours are targeted at nine direct operating hours (DOH) and three hours for planned delays. The planned delays are divided into four: lunch (including blasting operations), toolbox talk, planned maintenance, shift change, and equipment refuelling, as highlighted in Table 4.3.

Table 4-3: Shift time allocation at Manungu Colliery

| Activity | Planned Time Allocated (minutes) | Percentage of Shift Time (%) |
|---|---|---|
| Direct Operating Hours (DOH) | 540 | 75% |
| **Planned Delays** | **180** | **25%** |
| - Lunch (including planned blasting operations) | 60 | 8.33% |
| - Safety Meetings | 15 | 2.08% |
| - Planned Maintenance | 60 | 8.33% |
| - Shift Change | 15 | 2.08% |
| - Equipment Refueling | 30 | 4.17% |
| **Total** | **720** | **100%** |

Figure 4.2 presents time utilisation data for March, showing the daily DOH, unplanned delays, and the target DOH.

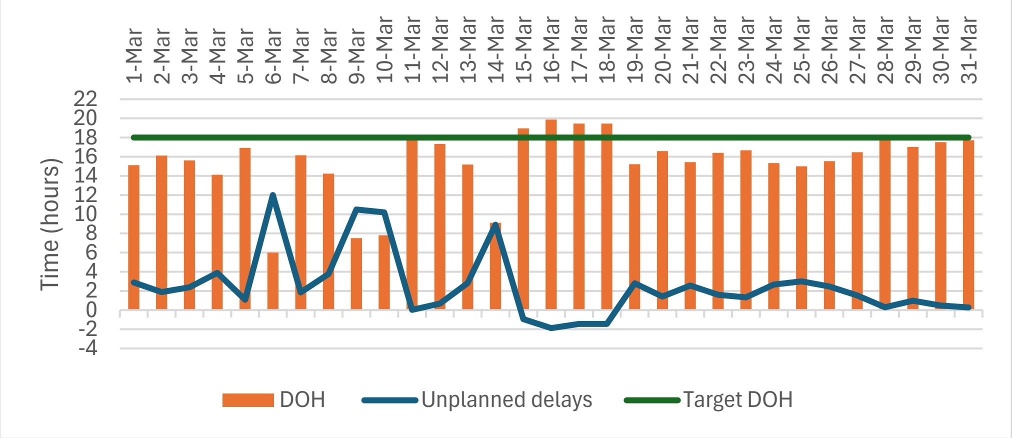


Figure 4.2: March time utilisation

The average DOH was fourteen per cent below target, and the deviation to target was eighty-five per cent of the days due to unplanned delays. The data shows the need for enhanced delay management to align closer to the target DOH and improve operational efficiency. The figure was developed with data from Appendix H. In the context of Figure 4.2, negative unplanned delays indicate days when the operation achieved higher-than-target DOH. Essentially, these negative values mean that the operation took longer than planned, instead of losing time due to delays

Unplanned delays negatively impacted the TSLHS operation efficiency in March. The unplanned delays included rain, extended toolbox talks, haul road construction, and loading face grading, as well as blasting operations that extended beyond their scheduled durations. Blasting operations emerged as the most significant contributor to operational downtime, accounting for 36% of total delays. Although the TSLHS operation involves free digging of topsoil and subsoil material, which does not require blasting, it is situated within the blasting radius of scheduled overburden blasting activities. As per the mine's safety procedures, all operations within the blast radius, including the TSLHS operation, must be evacuated during blasting. Therefore, any delays in blasting, such as those caused by late drilling completion, delays in explosives delivery, or blast misfires (primarily due to faulty initiation systems caused by broken wires or poor connections), result in unplanned stoppages for the TSLHS operation. These interruptions indirectly impact topsoil loading and hauling productivity by extending non-operational time, even though the material itself is not affected by the blasting process.

Rain delays, representing 24% of total delays, also played a considerable role. Rain is an external and uncontrollable element, unlike other factors, making it a unique category among unplanned delays. Rain does impact haul road conditions and limit equipment mobility, leading to operational downtime. Figure 4.3 shows unplanned delays for March, developed using data provided in Appendix H.

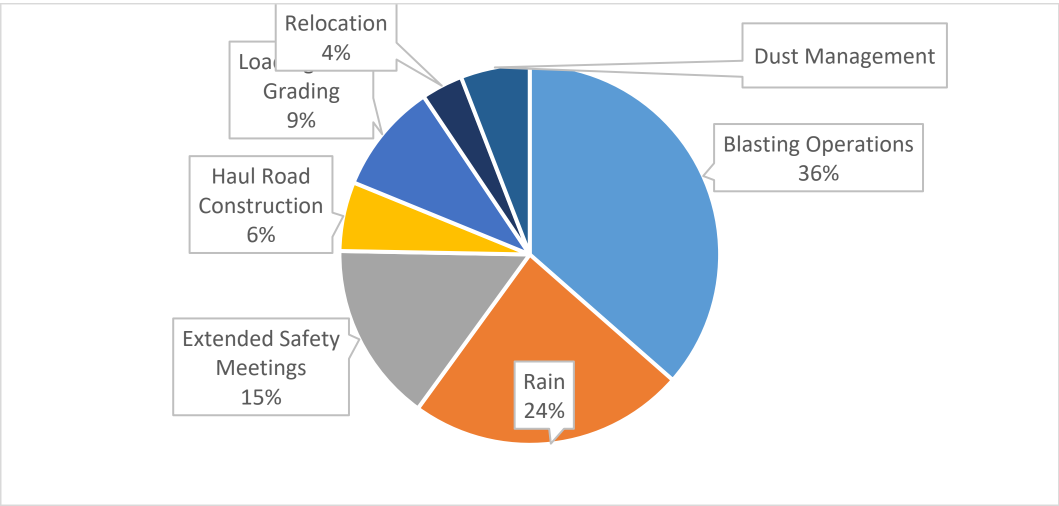
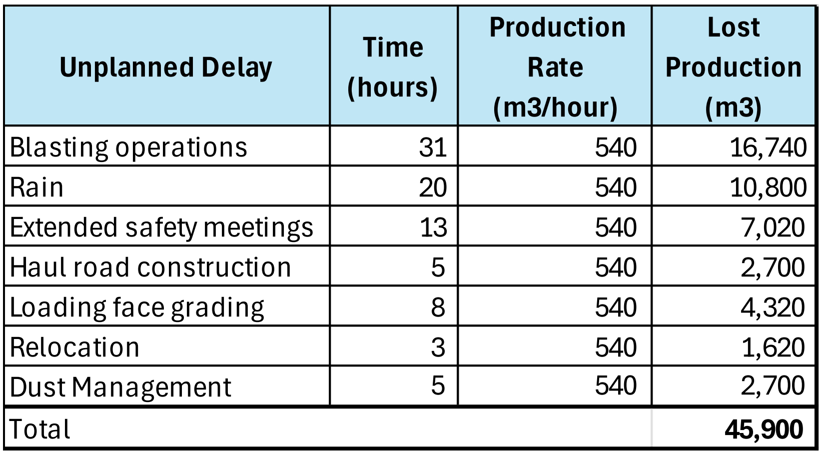


Figure 4.3: March unplanned delays and their percentage contribution

The cumulative effect of unplanned delays in March accounts for fifteen per cent of the stripping operation fleet's production target and above fifty per cent of March’s production deviation from the target. Table 4.4 presents unplanned delays that affected production in March, with each delay's impact measured in hours and lost production in cubic meters.

Table 4-4: March time and production lost



| Unplanned Delay | Time (hours) | Production Rate (m3/hour) | Lost Production (m3) |
|---|---|---|---|
| Blasting operations | 31 | 540 | 16,740 |
| Rain | 20 | 540 | 10,800 |
| Extended safety meetings | 13 | 540 | 7,020 |
| Haul road construction | 5 | 540 | 2,700 |
| Loading face grading | 8 | 540 | 4,320 |
| Relocation | 3 | 540 | 1,620 |
| Dust Management | 5 | 540 | 2,700 |
| Total | | | **45,900** |

### 4.3.2 Hauling Conditions

As discussed in Section 2.5.4, the haulage system is one of the most essential flow paths in an open pit mine value chain. The mine's haul route forms a significant component linking loading and dumping areas. The analysis of hauling conditions focused on haul route width, RR, and GR between the loading bench and the respective dumping area.

At Manungu Colliery, the target RR for haul roads is 3%. This corresponds to slightly resistant conditions on a well-maintained road, as outlined in Table 2.2. Data was collected by dividing the haul route into segments and determining an average RR for each segment. The following guidelines were followed:

- The mine survey department obtained and verified distances and gradients
- Traveling in one of the ADTs while recording section road conditions and speed.
- Applying theoretical principles to determine the haul route RR.

Table 4.5 presents actual results for RR, GR, TR, and average speed across different haul route segments for March.

Table 4-5: Summary of hauling conditions

| Section | Rolling Resistance | Gradient Ratio | Total Resistance | Average speed (Kph) | Speed Limit (Kph) |
|---|---|---|---|---|---|
| A-B | 4% | 0.81% | 4.81% | 36 | 40 |
| B-C | 4% | -10.80% | -6.80% | 24 | 20 |
| C-D | 5% | -12.20% | -7.20% | 25 | 20 |
| D-E | 5% | 0.40% | 5.40% | 18 | 40 |
| E-F | 5% | 2.94% | 7.94% | 18 | 40 |
| F-G | 4% | 12.20% | 16.20% | 13 | 40 |
| G-H | 5% | 0.40% | 5.40% | 35 | 40 |
| H-G | 4% | 0.40% | 4.40% | 33 | 40 |
| G-F | 4% | -12.20% | -8.20% | 21 | 20 |
| F-E | 5% | -2.94% | 2.06% | 26 | 20 |
| E-D | 4% | 2.94% | 6.94% | 24 | 40 |
| D-C | 4% | 12.20% | 16.20% | 14 | 40 |
| C-B | 3% | 10.80% | 13.80% | 16 | 40 |
| B-A | 4% | 0.81% | 4.81% | 35 | 40 |

Figure 4.4 highlights the hauling route from the loading area to the respective dump and back for March, detailing each segment's RR and GR.

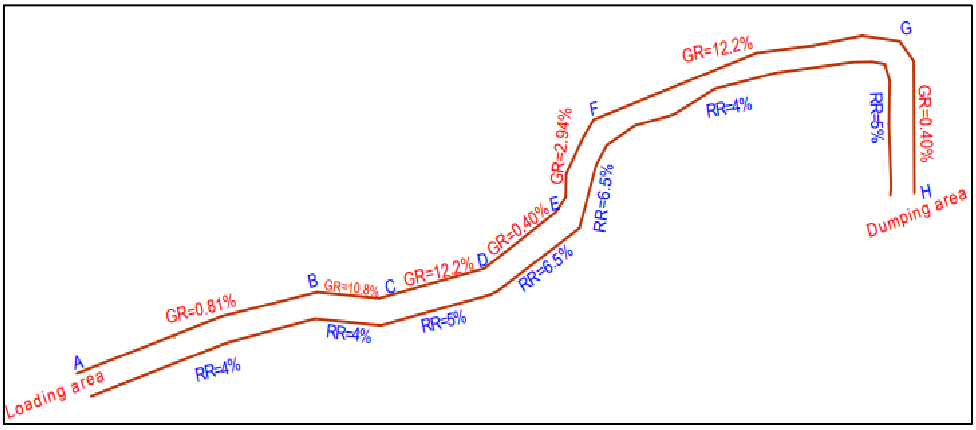
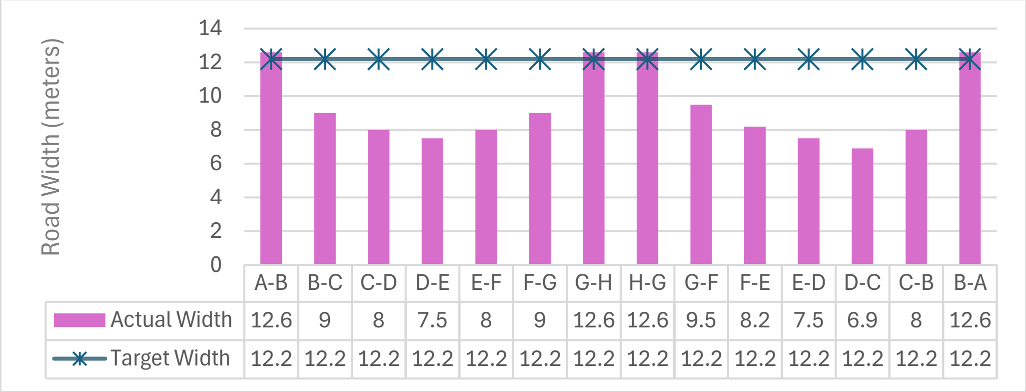


Figure 4.4: March 2024 hauling route

Haul road width measurements were done at fifty-meter intervals, computing an average for each section. The haul roads at Manungu Colliery are designed as one-way lanes. Industry standards for safe and efficient haul road design recommend that the minimum haul route width be two to three times the width of the largest haul truck. This guideline is discussed in Section 2.5.4. The mine's largest haul truck, a CAT 777, has a width of 6.1 meters. Therefore, the recommended haul road width at Manungu Colliery is (6.1x2) which equals 12.2 meters. This design specification ensures ample space for the trucks to move safely, maximising speed limits and improving operational efficiency. Figure 4.5 presents the outcomes of haul route width measurements in both directions for March.



| | A-B | B-C | C-D | D-E | E-F | F-G | G-H | H-G | G-F | F-E | E-D | D-C | C-B | B-A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actual Width | 12.6 | 9 | 8 | 7.5 | 8 | 9 | 12.6 | 12.6 | 9.5 | 8.2 | 7.5 | 6.9 | 8 | 12.6 |
| Target Width | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 |

Figure 4.5: March haul route width actual vs target

Several sections fell short of the target width, with some slightly exceeding it, demonstrating that maintaining the desired road dimensions is possible. The deviations from the target width in numerous sections highlighted potential issues that could be turned into improvement strategies.

### 4.3.1 Loading Efficiency

Loading efficiency data was collected by comparing actual payloads against the rated target payloads to determine whether the excavators and ADTs consistently met their designed capacity. This was done by randomly measuring the actual payloads on excavators and ADTs and comparing them against their rated payloads. The target BFF for this operation is set at 90% and 85% for low-moisture and high-moisture material, respectively.

This is a crucial metric for determining the productivity of the combined fleet and is calculated as shown in Equation 4.-1.

*4-1: Bucket fill factor equation*

$$Bucket\ fill\ factor = \frac{Volume\ of\ material\ in\ the\ bucket}{Rated\ capacity\ of\ the\ bucket} \qquad (2)$$

ADTs randomly tipped loads separately at an identified area during the shift. Similarly, each excavator performed a one-pass load into a dump truck, tipping it separately for survey measurement. The separation allowed for a volume measurement for each load without interference from others. The mine surveyor scanned the stockpiles and used specialised software to calculate the volume of each pile.  This exercise was conducted in March and repeated in May to compare the effects of targeted KPI adjustments on loading efficiency. Figures 4.6 and 4.7 show the ADT BFF for low and high moisture content material in March, respectively.

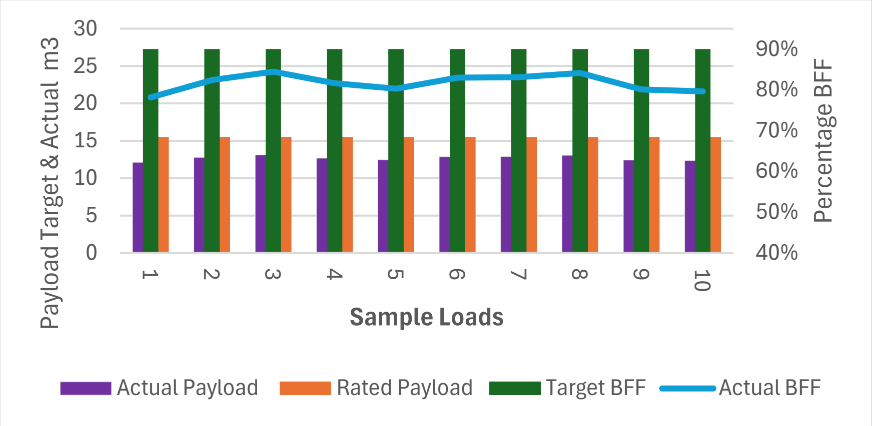


Figure 4.6: March ADT BFF low moisture content material

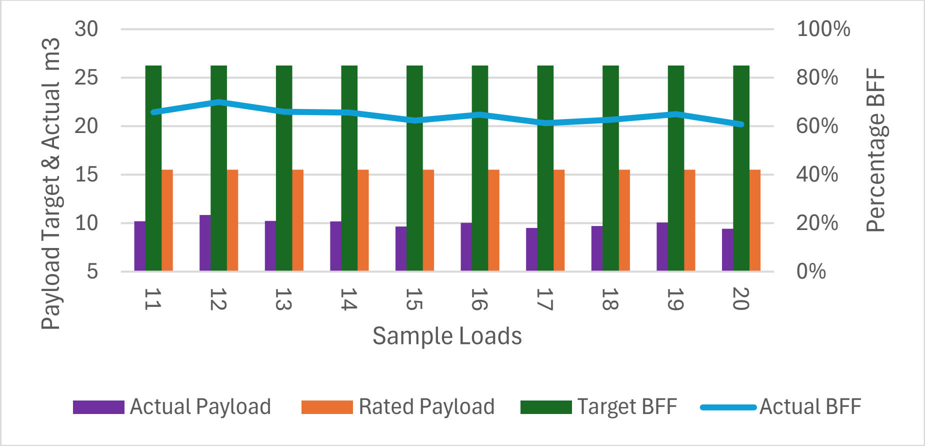


Figure 4.7: March ADT BFF high moisture content material

The figures present the actual and target BFF and the rated and actual payload across ten sample loads for each material type. The actual BFF shows fluctuations below the target BFF, while actual payload volumes are consistently below the rated payload for both materials. The figures were developed from the survey report in Appendix J.

Figures 4.8 and 4.9 show how excavator BFF KPI performed with low and high moisture-content materials in March, respectively.

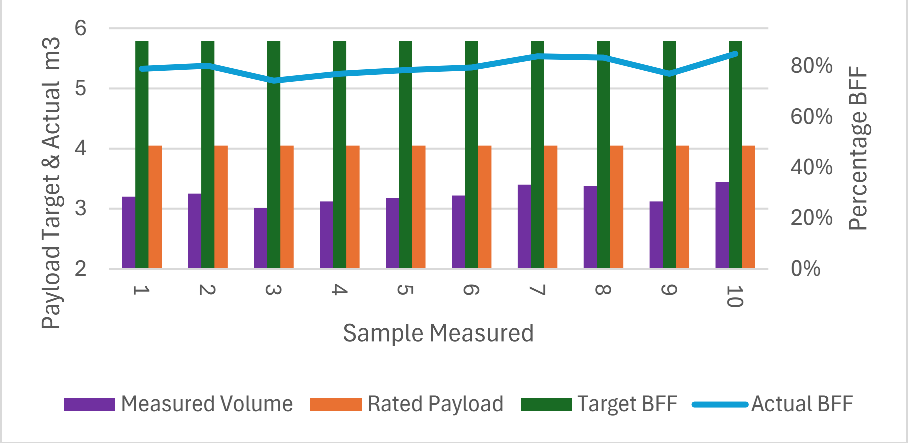


Figure 4.8: March excavator BFF low moisture content material

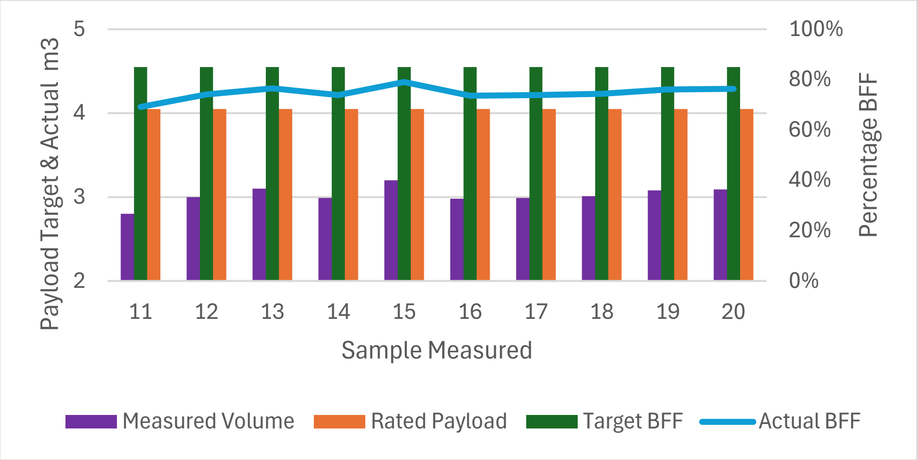


*Figure 4.9:* March excavator BFF high moisture content material

Each figure compares the actual payload, rated payload, and target BFF across ten sample loads per material type. In both cases, the actual BFF varies below the target BFF. Actual payloads are also consistently lower than the rated payload. These figures are based on data from the survey report in Appendix J.

The March observations and interviews revealed several key issues affecting the efficiency of the TSLHS operation. The findings provided insights into the failure to meet the targeted BFF, highlighting material and operational factors impacting productivity. The main issues included the skill and awareness of equipment operators, material properties, and site conditions. When the material is damp, it sticks to the beds of the ADTs, so less material is unloaded at the dump site. Figure 4.10 displays how much high moisture material clings to the ADT bed for this operation.

Figure 4.10: ADTs buckets with sticking material

Another issue was that excavators and ADT buckets were often not fully loaded. This issue results from a lack of communication, operator technique, low bench height, poor line management, and lack of standard enforcement. Figures 4.11 and 4.12 show pictures of some of the occurrences observed during the study.

Figure 4.11 : Excavator loading subsoil

**Observations**

- *bucket partially filled*
- *Bench height 1.1 M*

**Interview Highlight**

- *Operator not aware of the BFF target*
- *Operator not aware of the bench height effect on BFF*
- *Supervisor does not check & enforce these KPIs*

Figure 4.12: ADT hauling to the dumping area

**Observations**

- *bucket partially filled*
- *Bench height 1.1 M*

**Interview Highlight**

- *Operator not aware of the dump truck BFF target*
- *Supervisor does not check and enforce this KPI*

### 4.3.2 Cycle Time

Equation 4-2 mathematically expresses the actual cycle time of dump trucks. The cycle of the shovel-truck system is depicted in Figure 4.13.

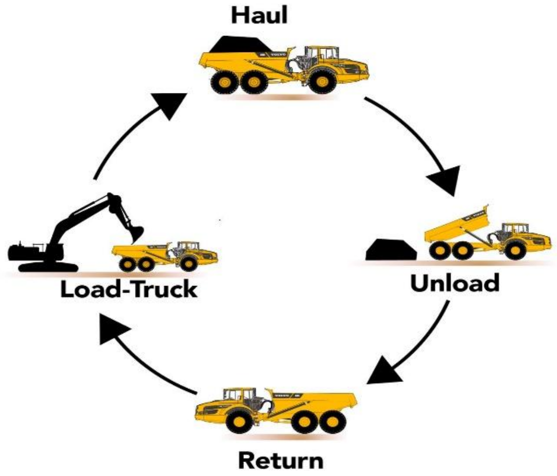


Figure 4.13: Load and haul system

*4-2: Cycle Time Equation*

$$T = td + tte + twl + tml + twd + tmd + tl + ttl$$

were,

T = total cycle time

$td$ = dumping Time

$tte$ = travel time of an empty dump truck

$twl$ = waiting time of a dump truck at the loading area

$tml$ = spotting time at the loader

$twd$ = waiting time of a dump truck at the dump area

$tmd$ = Manoeuvring time at the dumping area

$tl$ = Loading time

$ttl$= Travel time of the loaded dumper

The target total cycle time for the operation is 10.38 minutes, which is aligned with the industry benchmark. The average cycle time recorded for March is 14.14 minutes. Table 4.6 presents the average cycle times for various activities in the stripping operation's shovel-truck system for March, summarising the cycle data available in Appendix M.

Table 4-6: March summary cycle times

| **March** | **T- Total cycle time** | ***td- dumping time*** | ***tte- travel time empty*** | ***twl- waiting time at loading area*** | ***tml- spotting time at loader*** | ***twd - waiting time at dump*** | ***tmd - manoeuvring time at dump area*** | ***tl - loading time*** | ***ttl - travel time loaded*** |
|---|---|---|---|---|---|---|---|---|---|
| | **minutes** | | | | | | | | |
| **Actual** | **14.14** | **0.87** | **3.34** | **1.14** | **0.65** | **0.29** | **0.66** | **2.56** | **4.63** |
| **Target** | **10.36** | **0.55** | **2.35** | **0.85** | **0.60** | **0.25** | **0.40** | **2.01** | **3.35** |
| **Variance** | **3.78** | **0.32** | **0.99** | **0.29** | **0.05** | **0.04** | **0.26** | **0.55** | **1.28** |
| **% Variance** | **37%** | **58%** | **42%** | **34%** | **8%** | **17%** | **66%** | **27%** | **38%** |
| **Contribution to Variance** | | **8%** | **26%** | **8%** | **1%** | **1%** | **7%** | **15%** | **34%** |

The March average cycle time variance to the target is 3.78 minutes, a 37% deviation from the target. The most significant contributors to the total cycle time variance are the travel times when loaded and empty, which account for 34% and 26% of the deviation, respectively. Notable contributions include loading time, waiting at the loading area, and dumping, with minor impacts from spotting at the loader, waiting and manoeuvring at the dump area. Figure 4.14 illustrates the activity percentage contribution to the cycle time deviation to the target.

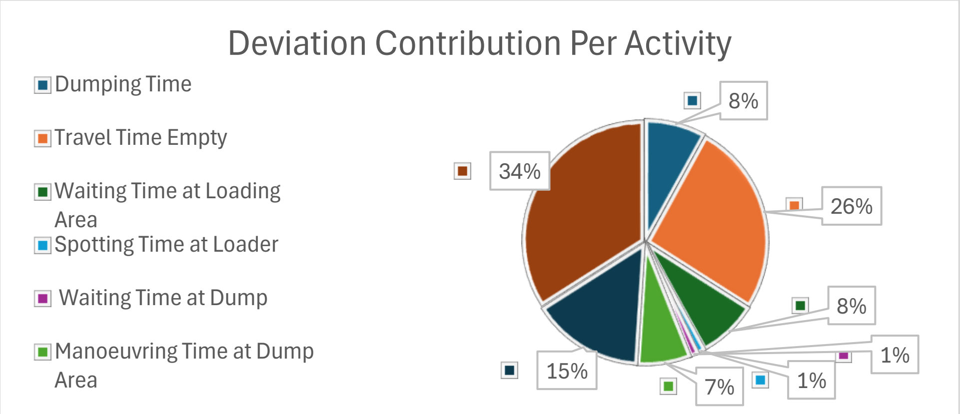


Figure 4.14: March deviation per activity to cycle time

In March, the total truck cycle time was recorded at 14.24 minutes, and the combined spotting and loading time was 3.87 minutes. Using the formula 2.2, the March truck requirement was approximately 3.68 trucks. This means that approximately 4 trucks were required to keep the loader fully utilised in March.

## 4.4 Data for the Intervention Study

This section presents the May intervention study data for KPIs in time utilisation, hauling conditions, loading efficiency, and cycle time. Following the March baseline, specific changes were implemented to improve performance. The data includes measurements after these adjustments, showing progress in various operational metrics. The presentation focuses on improvements in adherence to time targets, haul road conditions, and loading efficiencies across different material moisture levels. Table 4.7 provides the KPI targets for the operation in May, detailing the specific performance objectives established for this period.

Table 4-7: May targets

| **KPI** | **Target** |
|---|---|
| Time utilisation (hours) | 558 |
| Rolling Resistance | 3.0% |
| Gradient Ratio | 7.5% |
| Cycle time (Minutes) | 10.36 |
| Dump Truck BFF- Low Moisture Content | 90 |
| Dump Truck BFF- High Moisture Material | 85% |
| Excavator BFF-Low Moisture Content | 90% |
| Excavator BFF-High Moisture Material | 85% |
| Excavator BFF | 90% |
| Volume (m3) | **302,400** |

The same data collection processes used in March were applied in May, ensuring consistency in the analysis. This approach allowed for a direct comparison between the two periods, maintaining uniformity in how KPIs were assessed and measured.

### 4.4.1 Interventions Implemented to Enhance TSLHS Performance

Following the March baseline assessment, a series of targeted operational interventions were implemented for the TSLHS operation to improve performance across the four key metrics. To improve time utilisation, extended delays associated with blasting operations were addressed through the enforcement of stricter quality control protocols on blasting materials, thereby minimising misfires. Additionally, a short-interval control system was implemented to monitor drilling operations in real-time and facilitate the prompt resolution of issues that could potentially delay scheduled blasts. Extended safety meetings were curtailed through strict adherence to planned durations, and toolbox talks were standardised to ensure discussions remained structured and operationally relevant. Furthermore, auxiliary activities such as road maintenance, loading face grading, and equipment relocation were rescheduled to align with periods of planned delays. This was achieved by realigning the working hours of the personnel responsible for these tasks. To mitigate weather-related downtime, particularly after rainfall, haul roads were redesigned with enhanced drainage infrastructure to allow for quicker drying and prevent waterlogging.

Haul route surfaces were upgraded to reach an RR coefficient of approximately 3%, consistent with industry benchmarks for well-maintained flexible surfaces. GR was reduced within the spatial and operational constraints of the existing haul infrastructure, effectively decreasing GR and enhancing travel efficiency. Moreover, haul road widths were increased following established design guidelines, which recommend that single-lane haul routes be at least two to three times the width of the largest haul truck in operation. This intervention improved traffic flow, reduced delays, and enhanced safety.

To improve loading efficiency, specific interventions were implemented to increase the BFF of both ADTs and excavators. Excavator operators received targeted coaching, training, and supervision to ensure that ADT buckets were consistently filled to their rated capacities and that excavator buckets met loading standards. These sessions emphasised correct bucket positioning, filling techniques, and material handling practices required to maximise payload utilisation across varying material conditions. To address inefficiencies related to high-moisture material, scheduled cleaning of ADT beds was conducted on an hourly basis to remove sticky material that obstructed full loading. Additionally, bench heights were increased to provide better bucket engagement angles, thereby improving fill rates and loading efficiency.

Finally, improvements were made to all phases of the load-haul-dump cycle to reduce overall cycle time. Loading times were reduced through continued operator training and coaching, with an emphasis on consistency and speed. Travel times improved significantly due to enhancements in haul route surface conditions, reduced gradient, and increased road width. Dumping times were also shortened through targeted training and operational standardisation at the dumping areas. Collectively, these interventions contributed to substantial improvements in operational performance and efficiency across the TSLHS value chain.

### 4.4.2 Time Utilisation

In May, the operation still had a two-shift system, each lasting twelve hours daily. The system aimed for nine DOH hours, with three allocated for scheduled delays, as described in Section 4.3.1. Figure 4.15 presents time utilisation data for May, developed from Appendix I, illustrating actual DOH, unplanned delays, and the target DOH

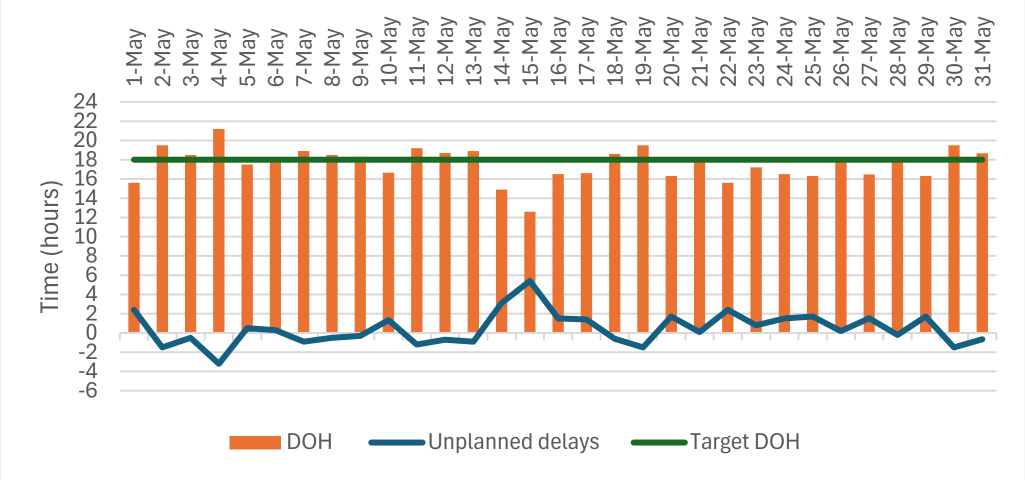


Figure 4.15: May time utilisation

Figure 4.16 illustrates the distribution of time spent on various activities contributing to unplanned delays in May.

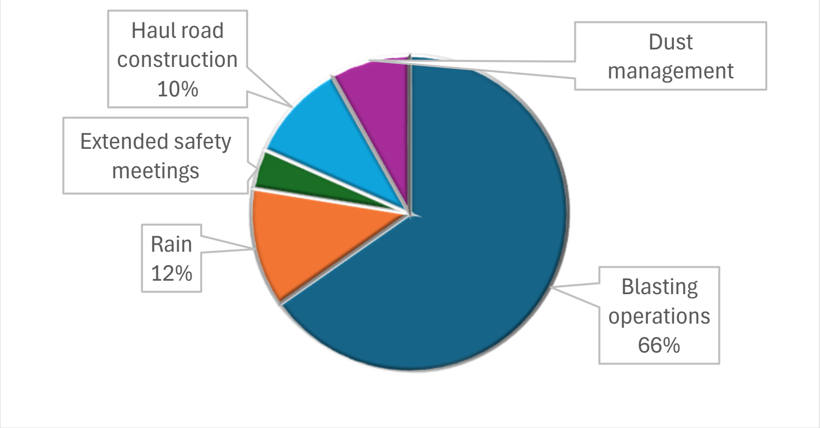


Figure 4.16: May unplanned delays

The largest portion of delays, at 66%, is attributed to blasting operations. Other delay factors include rain at 12%, haul road construction at 10%, dust management at 8%, and extended safety meetings at 4%. This breakdown highlights that blasting operations were the primary cause of unplanned delays, while the impact from other activities remained relatively low. These unplanned delays were significantly reduced compared to March.

Table 4.8 presents an overview of various unplanned delays in May and their impact on production.

Table 4-8: May time and production lost

| **Unplanned Delay** | **Time (hours)** | **Production Rate (m3/hour)** | **Lost Production (m3)** |
|---|---|---|---|
| Blasting operations | 16 | 540 | 8,640 |
| Rain | 3 | 540 | 1,620 |
| Extended safety meetings | 1 | 540 | 540 |
| Haul road construction | 3 | 540 | 1,350 |
| Loading face grading | - | 540 | - |
| Relocation | - | 540 | - |
| Dust management | 2 | 540 | 1,080 |
| Total | **25** | **3,780** | **13,230** |

The data shows a comprehensive picture of time and production losses associated with each unplanned delay in May, summarising the total time lost and the overall production impact. Total volumes lost equates to 4 % of the operation’s May target.

### 4.4.3 Hauling Conditions

Table 4.9 presents data collected for rolling resistance RR, GR, TR, and average speed across different haul route segments for May. In addition to these parameters, the speed limit for each segment is also provided.

Table 4-9: May hauling conditions summary

| Section | Rolling Resistance | Gradiant Ratio | Total Resistance | Average speed (Kph) | Speed Limit (Kph) |
|---|---|---|---|---|---|
| A-B | 4% | 0.90% | 4.90% | 38 | 40 |
| B-C | 3% | 0.80% | 3.80% | 37 | 40 |
| C-D | 3% | 1.50% | 4.50% | 36 | 40 |
| D-E | 3% | 0.50% | 3.50% | 37 | 40 |
| E-F | 3% | 6.60% | 9.60% | 30 | 40 |
| F-G | 3% | 1.80% | 4.80% | 37 | 40 |
| G-F | 4% | 1.80% | 5.80% | 35 | 40 |
| F-E | 3% | -6.60% | -3.60% | 25 | 20 |
| E-D | 4% | -2.94% | 1.06% | 35 | 40 |
| D-C | 4% | 0.50% | 4.50% | 36 | 40 |
| C-B | 3% | 0.90% | 3.90% | 35 | 40 |
| B-A | 4% | 0.80% | 4.80% | 35 | 40 |

The speed limits were important for understanding the operational constraints and ensuring safety and performance standards were met along each route segment. Figure 4.17 presents the hauling route from the loading area to the respective dump and back for May, as provided by the survey department, detailing each segment's RR and GR.

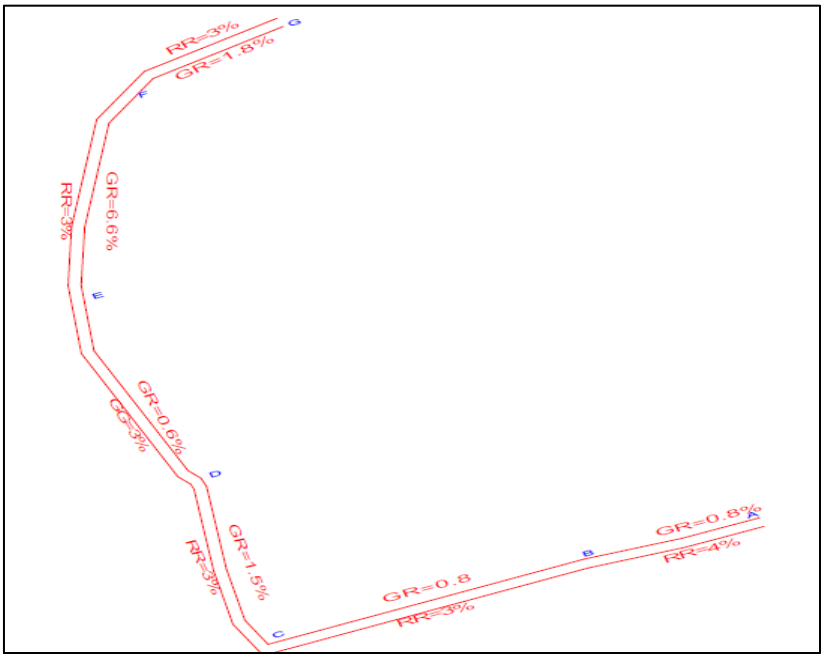


Figure 4.17: May hauling route

Figure 4.18 presents the outcomes of haul route width measurements in both directions for May.

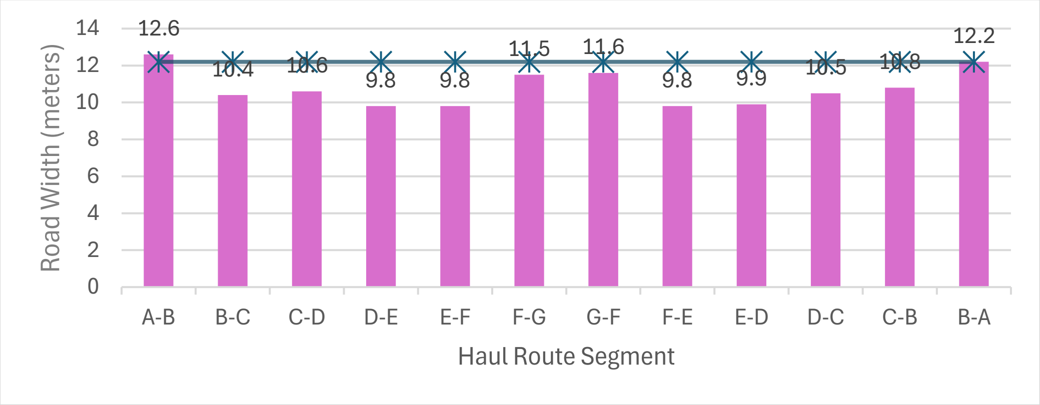


Figure 4.18: May haul route width actual vs target

### 4.4.4 Loading Efficiency

Figures 4.19 and 4.20 show the ADT BFF performance for low- and high-moisture-content materials, respectively, following KPI improvements. They were developed from the survey report in Appendix K.

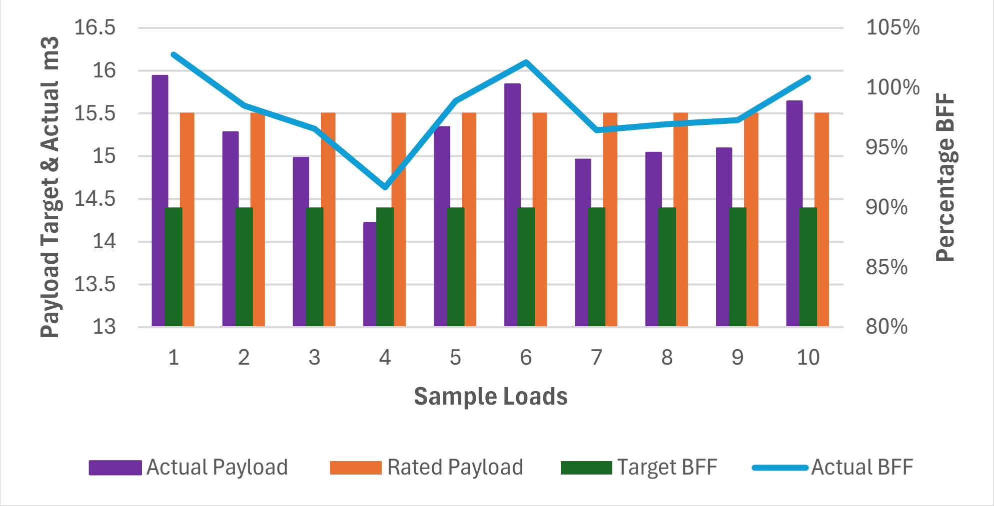


Figure 4.19: May ADT BFF low moisture content material

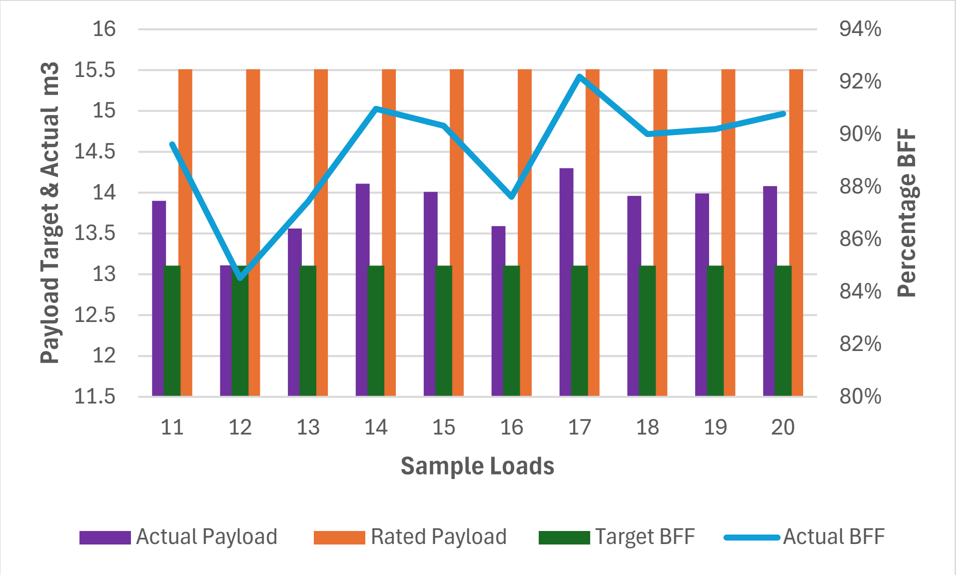


Figure 4.20: May ADT BFF high moisture content material

The data collected in May reflects improved BFF performance for both materials. Actual payloads aligned more closely with targets, and the BFF percentage consistently met or exceeded the targets. This suggests enhanced loading efficiency and KPI improvements positively impacted ADT payload utilisation for low and high-content material mined within the stripping operation.

Figures 4.21 and 4.22 illustrate the excavator BFF performance for low- and high-moisture-content materials, respectively, measured in May following KPI improvements. These figures were developed from data in Appendix I.

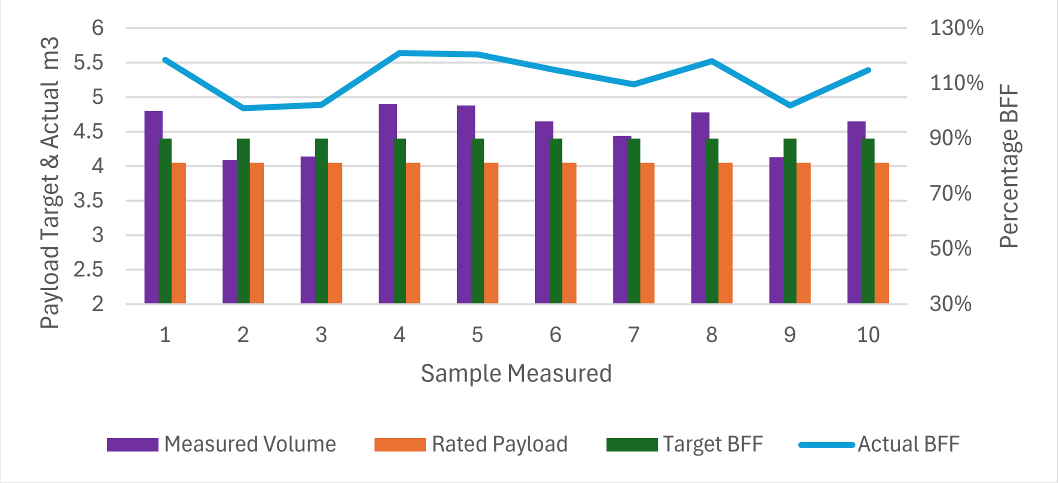


Figure 4.21: May excavator BFF low moisture content material

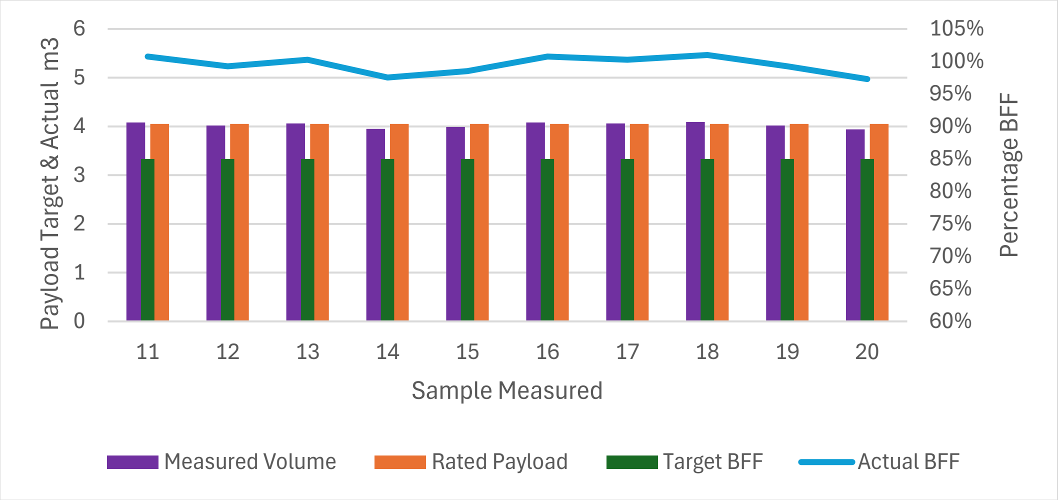


Figure 4.22: May excavator BFF high moisture content material

The May study focused on implementing targeted improvements for each KPI. For loading efficiency, the main objective was to raise workforce awareness about the BFF's impact on the stripping operation. In addition, efforts were directed at strengthening enforcement in the pit to ensure that these standards were consistently applied and followed. Figure 4.23 and Figure 4.24 present observations from May, the observations suggest possible improvements in the BFF utilisation for both the excavators and ADTs.

Figure 4.23: May observations pictures

Figure 4.24: May observations pictures

The images clearly show efforts to remove stuck material from the ADTs' beds when loading high-moisture material. The cleaning was done at least once an hour to improve loading efficiency. Additionally, the bench heights were higher, increasing loading efficiency by enabling bucket fills. These factors reflected positive changes in the TSLHS operation, aligning with targeted KPIs for improved operational efficiency.

### 4.4.5 Cycle Time

Table 4.10, developed from Appendix M, compares actual and target cycle times for various stages of the hauling operation in May. This data was collected after implementing KPI improvements based on March findings, showcasing the impact of those adjustments on operational efficiency.

*Table 4-10: May summary cycle times*

| May | T- Total cycle time | *td- dumping time* | *tte- travel time empty* | *twl- waiting time at loading area* | *tml- spotting time at loader* | *twd - waiting time at dump* | *tmd - manoeuvring time at dump area* | *tl - loading time* | *ttl - travel time loaded* |
|---|---|---|---|---|---|---|---|---|---|
| | minutes | | | | | | | | |
| **Actual** | 9.65 | 0.56 | 2.10 | 0.69 | 0.58 | 0.20 | 0.09 | 1.91 | 3.54 |
| **Target** | 10.36 | 0.55 | 2.35 | 0.85 | 0.60 | 0.25 | 0.40 | 2.01 | 3.35 |
| **Variance** | -0.71 | 0.01 | -0.25 | -0.16 | -0.02 | -0.05 | -0.31 | -0.10 | 0.19 |
| **% Variance** | -7% | 1% | -11% | -19% | -3% | -20% | -77% | -5% | 6% |

After implementing improvements based on March insights, the data collected in May shows clear efficiency gains in the haul cycle. Total cycle time is notably shorter, reflecting quicker task completions. Time spent travelling loaded and empty has decreased, showing gains from the haul route improvements. Loading efficiency improved in May, with faster loading times aligning closer to the target.

In May, the total truck cycle time was recorded at 9.65 minutes, while the combined spotting and loading time was 2.58 minutes. Using Formula 2.2 on page 31, the truck requirement for May was calculated by dividing 9.65 by 2.58, resulting in approximately 3.74 trucks. This confirms that around four trucks were needed to keep the loader fully utilised. Despite the operational efficiency gains, the loader-truck match factor remained consistent in terms of required fleet size, with approximately four trucks needed in both March and May. However, the reduced cycle time in May allowed each truck to complete more trips per hour, thereby increasing the number of loads hauled per truck per hour. This improvement reflects a more efficient utilisation of the same fleet size, ultimately enhancing productivity without the need for additional equipment.

## 4.5 Chapter Summary

The improvement of loading and hauling operations in mining is crucial for enhancing productivity and operational efficiency. This section presented data from the initial (March) and intervention (May) studies of Manungu Colliery's TSLHS operation, focusing on time utilisation, hauling conditions, BFF, and cycle time. These factors are critical determinants of the TSLHS operation's performance and cost-effectiveness. Table 11 summarises the identified KPIs and other performance metrics target vs. actual achieved for the study period.

Table 4-11: March and May compliance with the plan

| Key Performance Indicator | Mine Ideal (Target) | March | | May | |
|---|---|---|---|---|---|
| | | Actual | variance | Actual | variance |
| Time utilisation (hours) | 558 | 479.49 | -79 | 543.19 | -14.81 |
| Rolling Resistance | 3.0% | 4.0% | 1.0% | 3.0% | 0.00 |
| Gradient Ratio | 7.5% | 9.8% | 2.3% | 3.5% | -0.04 |
| Cycle time (Minutes) | 10 | 14.14 | 4.14 | 9.65 | -0.35 |
| Dump Truck BFF- Low Moisture Content | 90% | 82% | -8% | 98% | 8% |
| Dump Truck BFF- High Moisture Material | 85% | 64% | -21% | 89% | 4% |
| Excavator BFF-Low Moisture Content | 90% | 80% | -10% | 112% | 22% |
| Excavator BFF-High Moisture Material | 85% | 75% | -10% | 99% | 14% |
| Volume (m3) | 302,400 | 272,200 | (30,200) | 344,934 | 42,534 |
| Diesel consumed | - | 153,896 | - | 173,363 | |
| Diesel per cubic meter (litres) | 0.52 | 0.57 | 0.045 | 0.50 | (0.017) |

Regarding time utilisation, the mine operates with a shift structure that includes nine hours of DOH and three hours of planned delays. During the March assessment, DOH fell short by about 14%, mainly due to unplanned delays. However, by May, targeted interventions made a difference. Aligning blasting schedules and streamlining toolbox talks helped manage delays better, bringing DOH closer to target and reducing downtime across the shifts. Hauling conditions, particularly the gradient, proved to have a significant impact on ADT speeds.

The March findings revealed that steeper ramps slowed down the ADTs, indicating the need for flatter gradients to improve haul speeds. As a result, maintenance efforts in May included redesigning ramps to lower gradients, which successfully increased ADT speeds, reduced cycle times, and made the operation more efficient overall. In March, bucket fill percentages were below target due to operator technique, limited awareness of BFF targets, and stuck material on ADT buckets. To address these challenges, May saw enhanced enforcement of BFF standards, increased operator training, and more frequent cleaning of ADT load beds. These actions helped align bucket fill levels with target figures, improving loading efficiency for both low and high-moisture materials. Cycle time was another critical area of focus. The March average cycle time exceeded the target of 10.38 minutes, clocking in at 14.14 minutes, primarily due to hauling conditions and loading efficiency. Adjustments in haul route design and efforts to boost operator awareness were introduced in May, and these changes led to shorter cycle times. However, consistently reaching the target remains an area of improvement.

# 5 ANALYSIS AND FINDINGS

## 5.1 Introduction

This chapter analyses the data collected during the study to improve the TSLHS operation at Manungu Colliery in March and May 2024. The analysis of the operation's KPI changes explored the impact of targeted interventions. The chapter comprises five sections: one focusing on volumes mined and diesel usage and four covering the study's KPIs. The analysis employed descriptive statistics and variance analysis to evaluate improvements in operational performance. Data visualisations illustrated the results, offering a narrative of the study's findings.

## 5.2 Volumes Moved and Diesel Usage Analysis

This section presents the relationship between production volumes mined and diesel consumption for March and May. Figure 5.1 compares the target and actual performance for volume mined and diesel consumed in March and May, highlighting diesel usage and production output.

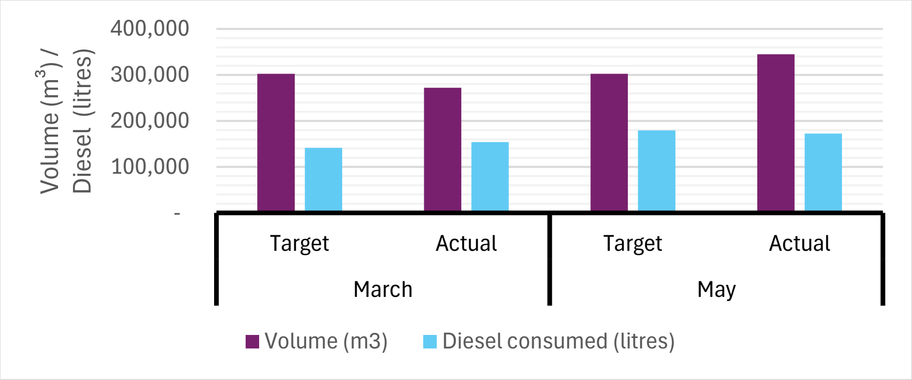


Figure 5.1: March and May Volume Moved and Diesel Consumed

The data shows that production and fuel efficiency improved from March to May. While March showed a gap in meeting volume targets and above target on diesel consumption, May highlights the possible success of the study's KPIs improvement efforts. In May, the actual production output was above the set target, and diesel consumption was below the target for the volumes mined. Figure 5.2 compares the target and actual diesel consumption per cubic meter for March and May.

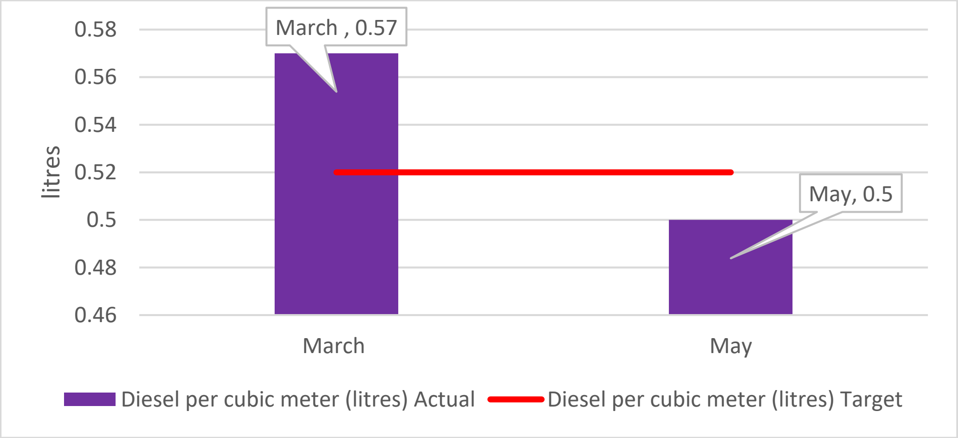


Figure 5.2: Diesel usage per cubic meter

The data reveals that diesel consumption exceeded the target in March by 0.05 litres per cubic meter, indicating inefficiencies in the load and haul system. Significant improvements were observed by May, with diesel consumption reducing to 0.02 litres per cubic meter below the target. Importantly, the average haul distances for both March and May were the same at 1,900 metres, allowing for a fair and direct comparison using the standardised values. The improved diesel consumption per cubic meter was attributed to the combined net effect of the study's KPI interventions, which were:

- Reduced RR and flatter ramps decreased engine load and fuel consumption.

- Widened haul routes enabled smooth traffic flow and reduced fuel-wasting stops.
- Reduced cycle times increased productivity with the same fuel consumption, effectively reducing diesel consumption per unit of material mined.

The reduction in fuel consumption per cubic meter in May, achieved through haul route improvements such as reduced RR and flatter gradients, supports the findings of Thompson and Visser (2003), who identified RR and gradient as critical contributors to fuel use, tyre wear, and haul efficiency.

## 5.3 Time Utilisation Analysis

In the analysis, time utilisation descriptive statistics for DOH were compared between the baseline data collected in March and the intervention study conducted in May. The comparison was meant to measure the impact of operational adjustments on improving time usage within the stripping load-and-haul operation. Figures 5.3 and 5.4 visually represent the descriptive statistics and DOH distribution for March and May, respectively.

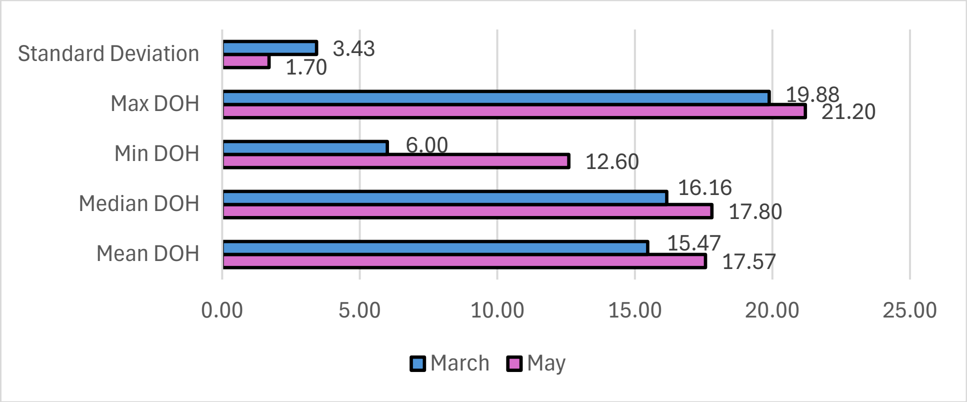


Figure 5.3 Direct operating hours descriptive statistics

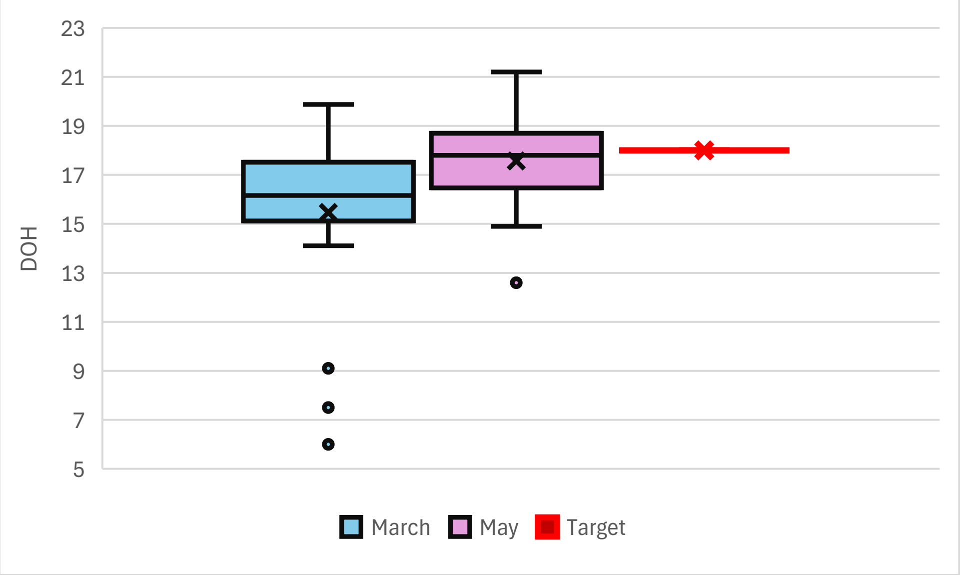


Figure 5.4: March and May DOH distribution

From the figures, the mean DOH improved from 15.47 in March to 17.57 in May, showing better time utilisation. The median also increased from 16.16 in March to 17.80 in May, showing a consistent shift toward improved performance. Maximum DOH rose slightly from 19.88 to 21.20, reflecting extended peak utilisation. Minimum DOH improved significantly, rising from 6.00 in March to 12.60 in May, reducing low-utilisation days. Variability decreased, as shown by the lower standard deviation in May (1.70) compared to March (3.43), implying a more stable operation. The visualisation clearly shows the time utilisation improvements in May compared to March. The data shows that not only did the average DOH increase in May, but the variance dropped by over 75%, indicating greater operational consistency. To determine whether this difference was statistically significant, an independent samples t-test was performed. The results are as follows: t-statistic = 3.05, p-value = 0.0039. Since the p-value is less than 0.05, we conclude that the improvement in DOH from March to May is statistically significant at the 95% confidence level. This confirms that the interventions had a measurable and reliable impact on time utilisation.

Following the implementation of targeted improvements, the data shows alignment with the target DOH in May, although some unplanned delays still impacted the overall time utilisation. The frequency and magnitude of unplanned delays were reduced compared to March, leading to more consistent DOH. The improvement indicates progress towards achieving the target DOH, though more effort is required to eliminate disruptions and fully improve time utilisation. Figure 5.5 compares unplanned delays for March and May.

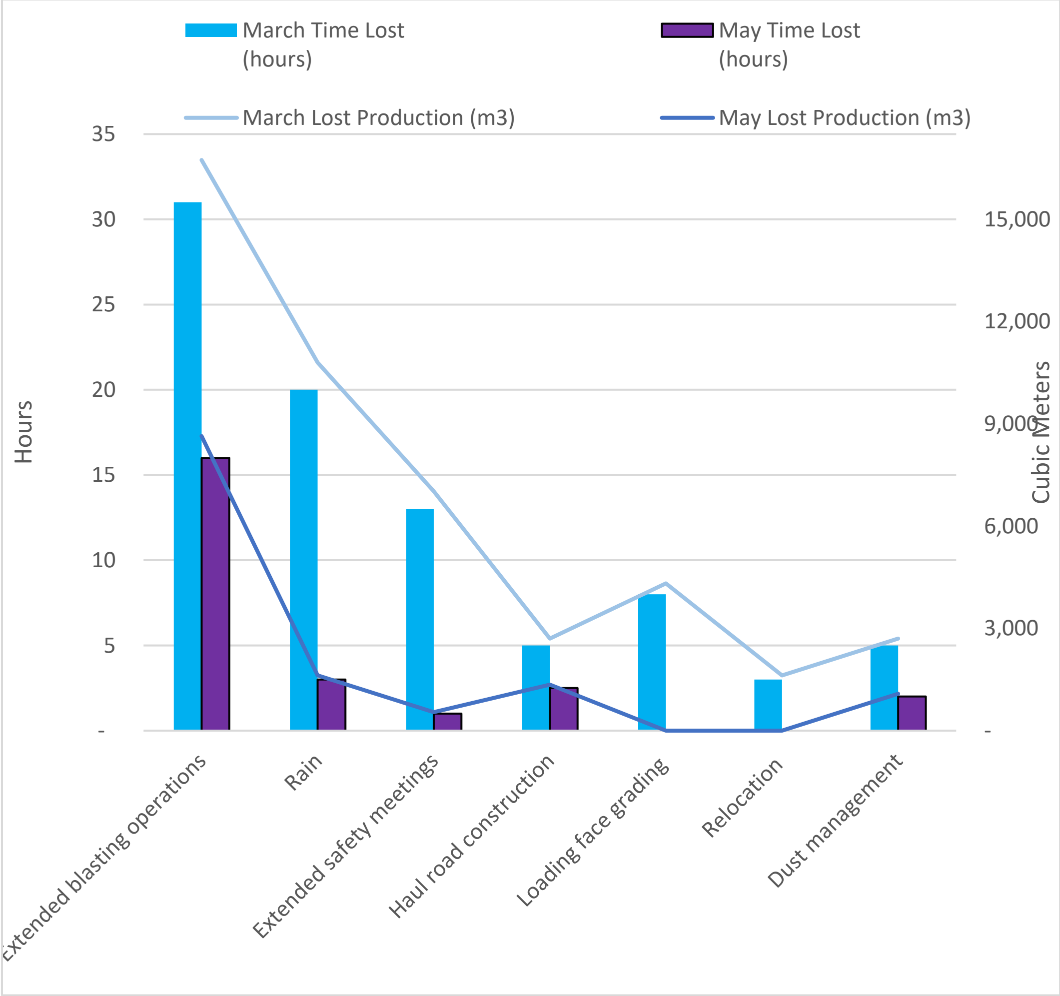


Figure 5.5: March and May lost time and production

In March, unplanned delays caused by extended blasting operations were significantly high, contributing to consistent underperformance in time utilisation. This was largely due to delayed drilling completion, blast misfires, and late delivery of explosives, which caused frequent overrunning of blast planned times. To address these delays, a coordinated approach was implemented in May, strict adherence to the blasting schedule was enforced through engagement with explosives suppliers, ensuring timely delivery and preparation. Additionally, short interval control was introduced to monitor drilling progress, allowing for early identification and resolution of issues that could disrupt the blast schedule. This resulted in a measurable reduction in time lost due to extended blasting in May.

Rainfall also had a considerable impact on March operations, with 65 mm of rain recorded, compared to only 7 mm in May. While rain is a natural and uncontrollable variable, its operational effects can be mitigated. During March, poor road drainage and surface conditions extended the recovery time after rainfall. In response, the mine implemented improved road designs with enhanced drainage to allow for quicker drying and minimal waterlogging, thereby reducing the duration of weather-related delays in May. This suggests that, although lower rainfall in May contributed naturally to reduced delays, infrastructure improvements also played a role in mitigating rain’s impact.

Regarding safety meetings, the extended duration observed in March was attributed to unstructured delivery and a tendency for discussions to diverge from critical safety topics. Toolbox talks were often used informally to address various unrelated concerns, causing them to overrun scheduled times. In May, a revised structure was implemented that focused on concise, task-specific briefings aligned with daily operational priorities. This format not only maintained safety standards but also promoted discipline and time efficiency. Active participation and timekeeping were reinforced through supervision and crew leader accountability. These refinements contributed to the reduction in hours lost to extended safety meetings in May.

For haul road construction, proactive operational changes were also implemented. During May, alternative haul routes were created in advance of scheduled road maintenance activities, allowing operations to continue uninterrupted. Additionally, the planning and execution of these activities were aligned with available workforce capacity and equipment readiness, further improving efficiency.

Relocation and loading face grading activities were another source of delay in March. To reduce their impact, these activities were rescheduled to occur during periods of planned downtime, such as lunch breaks, shift changes, and diesel refuelling. This scheduling adjustment allowed production-critical tasks to proceed without disruption, improving overall time utilisation. Dust management activities, though relatively minor in both months, also benefited from better planning and integration into scheduled non-production time.

In summary, while environmental factors such as rainfall undoubtedly influenced operational delays in March, the significant reduction in lost hours observed in May was not solely due to improved weather conditions. Instead, it was the result of deliberate, structured interventions that improved coordination, time management, task scheduling, and operational discipline. The study’s success in reducing unplanned delays supports the queuing system efficiency model proposed by Chaowasakoo et al. (2017), who stress the importance of synchronising operational phases to minimise system bottlenecks.

## 5.4 Hauling Conditions

The impact of haul route design and maintenance adjustments on the hauling system's performance was evaluated by comparing data from the March baseline investigation to the May intervention study. Figures 5.6 and 5.7 visually present the impact of hauling conditions on average speed across various road sections for March and May, respectively.

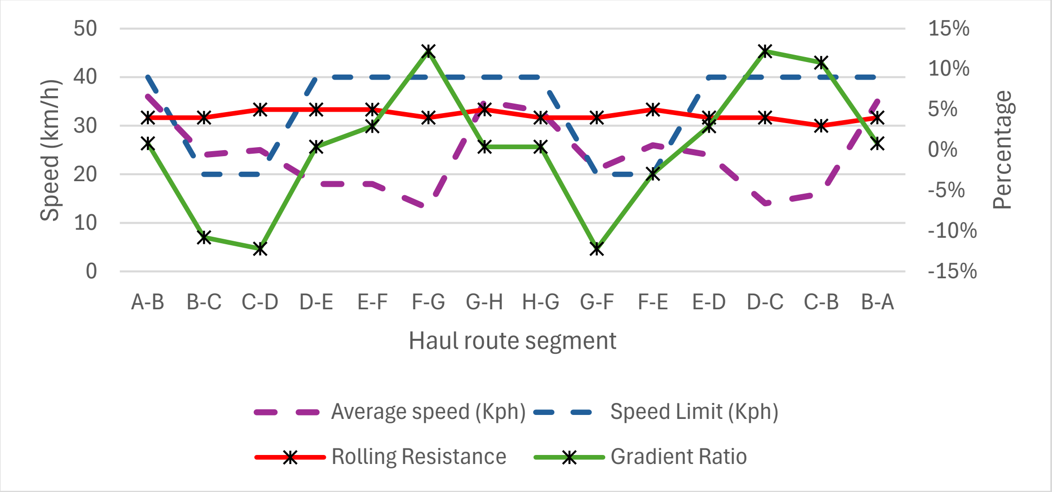


Figure 5.6: March gradient ratio, rolling resistance and average speed

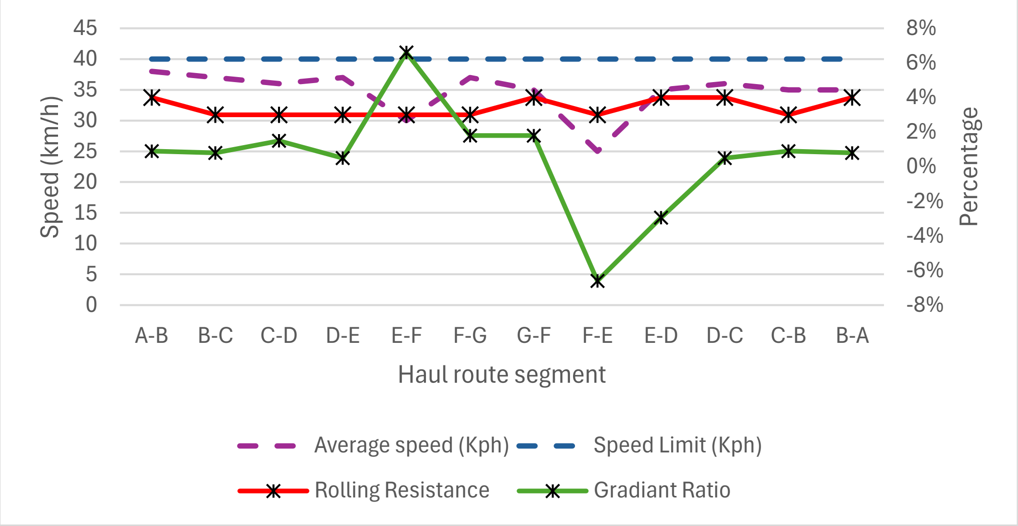


Figure 5.7: May gradient ratio, rolling resistance, and average speed

The comparison between the March and May data highlights significant improvements in hauling conditions and average speeds, reflecting the impact of targeted interventions during the intervention study. In March, RR ranged from 3% to 5%, with higher values observed in most sections, creating inefficiencies in the load and haul operation. By May, RR was uniformly reduced to 3% across most sections, indicating improved hauling route conditions contributing to better fuel efficiency and higher average speeds. GR in March showed significant variation, including steep downhill (up to – 12.20%) and steep uphill slopes (up to 12.20%), hindering uniform speed and adding strain on the ADTs. In May, haul route gradients were smoothed to modest inclines or declines. The smoothing of gradients allowed ADTs to maintain more consistent speeds.

Average speeds in March were inconsistent, often below the planned speed limit, particularly in sections with high RR and steep gradients. An example is section F-G, with an average speed of 13 Km/h versus the planned limit of 40 km/h. In addition to poor road geometry, March was characterised by wet haul roads due to rainfall, which further reduced traction. As a safety precaution at Manungu Colliery, operations are temporarily halted during rainfall and only resume once haul routes are dry and safe for vehicle movement. This protocol effectively limits the influence of wet road conditions on the recorded performance data. In contrast, May data revealed a significant improvement in average speeds across all sections, with ADTs operating closer to the planned speed limits. These improvements can be attributed to targeted interventions aimed at reducing RR and reducing gradients, which collectively enhanced overall haul route conditions. The overall trend indicates that the measures implemented during the intervention study were effective in addressing the hauling inefficiencies observed in March. The improved haul speeds and reduced travel times in May further reinforce the role of road geometry, as emphasised by Baatarchuluun et al. (2023), who found that optimised gradient ratios improve average haul speeds and overall productivity.

The safety procedure at Manungu Colliery stipulates a maximum ramp gradient of 12.5%. The study observed that no ramp exceeds this maximum allowable gradient. However, March results indicate ADT speeds were significantly lower than the planned speed limit on ramps with gradients higher than 7.5%. May's findings supported the assertion that flatter ramps increase ADT speeds, making the haul system more efficient and productive. The enhanced haul route conditions increased average speeds and reduced fuel consumption and equipment strain, translating to faster cycle times and greater overall operational efficiency. Figure 5.6 compares haul road widths across sections in March and May alongside the target width for optimal performance.

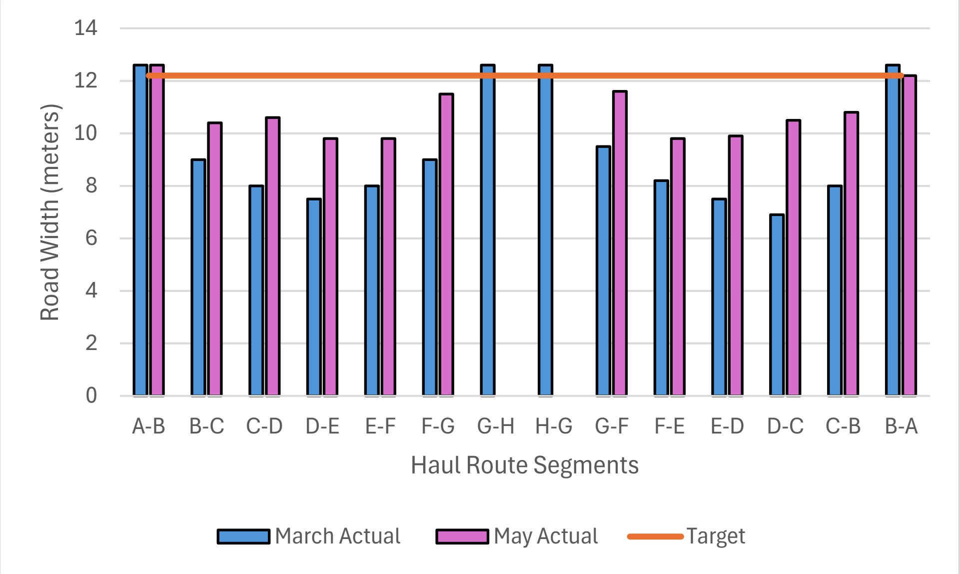


Figure 5.8: March and May haul route width comparison

Several sections fell significantly short of the target haul route width in March, impacting operational efficiency. The road sections with significantly below-target widths accounted for more than 65% of observed congestion and unnecessary braking, hindering traffic flow. However, improvements in May were observed, with haul route widths close to or meeting the target. Despite these improvements, some sections fell below the target, indicating areas for further improvement. Observations in May show significantly reduced congestion and unnecessary braking on the haul route, highlighting the interventions' effectiveness. The improvements also reveal opportunities for further enhancements to improve the operations. The importance and impact of haul route widths were discussed in Section 2.5.4. The enhancements in haul route widths, which reduced congestion and unnecessary braking, correspond with the standards outlined by Tannant and Regensburg (2001), who recommend sufficient width to allow for uninterrupted two-way truck flow.

## 5.5 Loading Efficiency

The loading efficiency analysis evaluated the BFF performance of excavators and ADTs on low and high-moisture materials in March and May. The study intentionally excluded blasted material, as the operation being analysed does not excavate blasted material. As such, material fragmentation resulting from blasting—such as oversized rocks or poorly fragmented zones—did not influence loading performance during this study. Improvement strategies for ADT BFF performance included removing stuck material from ADT beds hourly while mining high-moisture material. Strict enforcement and increased awareness of the need to consistently fill excavator and ADT buckets contributed to the improvements. Figures 5.9 to 5.16 compare the statistical metrics and distributions of BFF performance for ADTs and excavators in March and May relative to the BFF target.

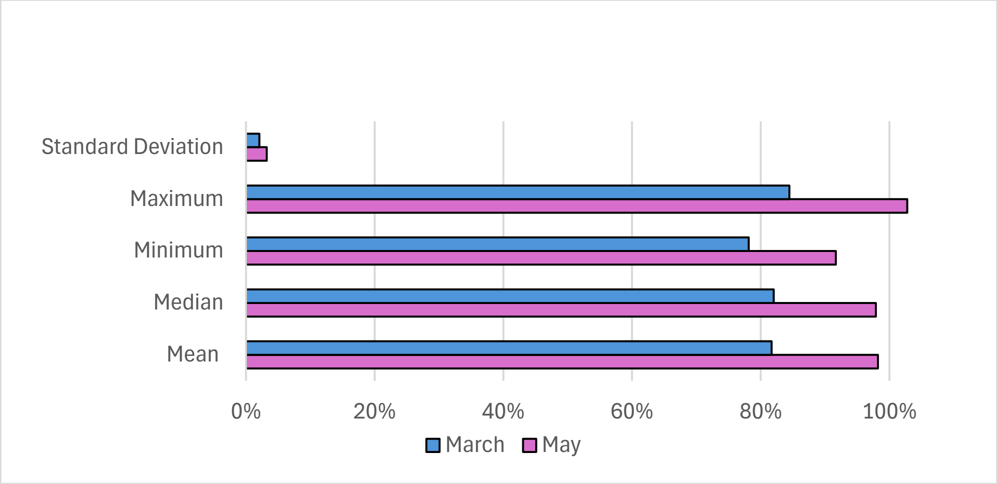


Figure 5.9: March and May low moisture material ADT BFF performance

BFF May's performance while loading low-moisture material shows higher values across all metrics than in March. There was an improvement in May, with the baseline and peak BFF values increasing significantly. The data reflects improved payload utilisation and the value of improvement strategies rolled out while mining low-moisture material during the intervention study.

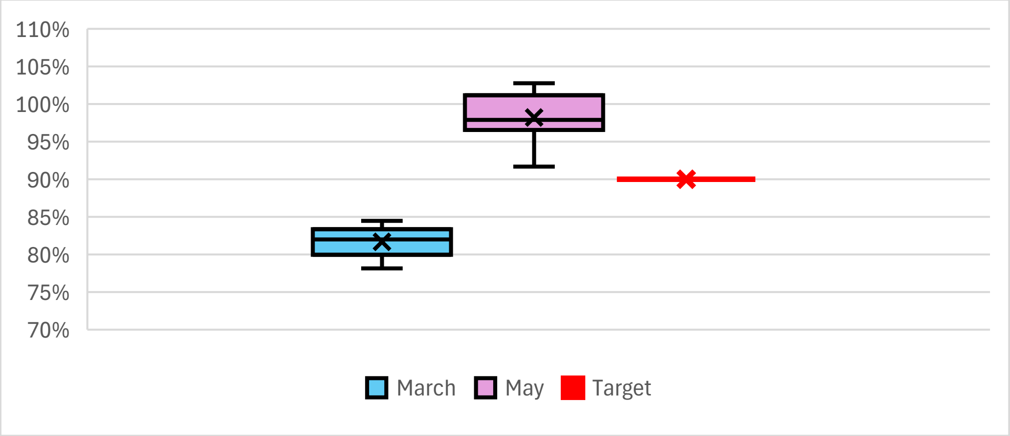


Figure 5.10: March and May low moisture material ADT BFF distribution

Low moisture material ADT BFF distribution in March was generally low and more tightly clustered, while the distribution in May was high and spread out. The May results are above target, with a noticeable shift upwards compared to March. For low-moisture material, the mean BFF increased significantly from 81.6% (SD = 2.01%) in March to 98.3% (SD = 3.23%) in May. An independent samples t-test confirmed that this increase was statistically significant (t = 13.87, p < 0.000000001), validating the effect of improved loading practices.

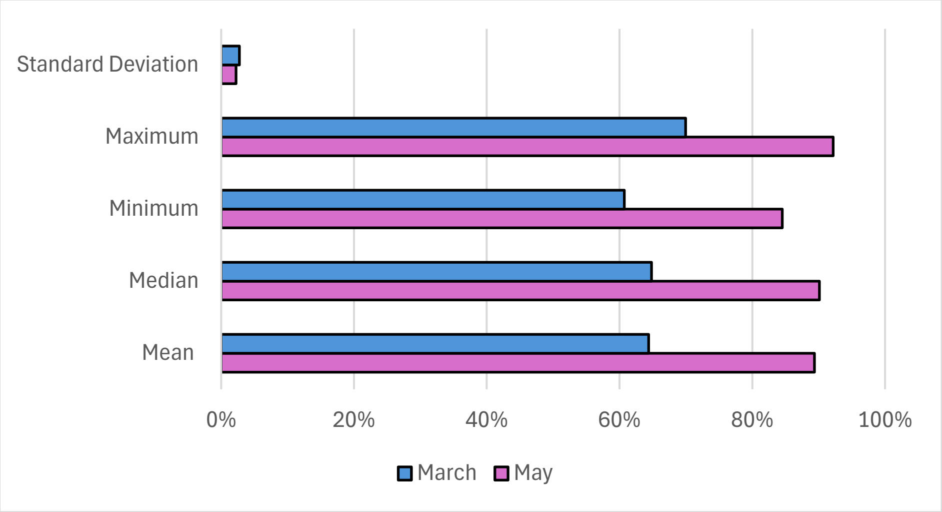


Figure 5.11: March and May high moisture material ADT BFF performance

The ADT BFF performance while mining high moisture material shows that high values were consistently achieved in May across all metrics. The maximum and minimum values for May were higher than those for March, reflecting an improved performance. The standard deviation for both months shows minimal variation in the results.

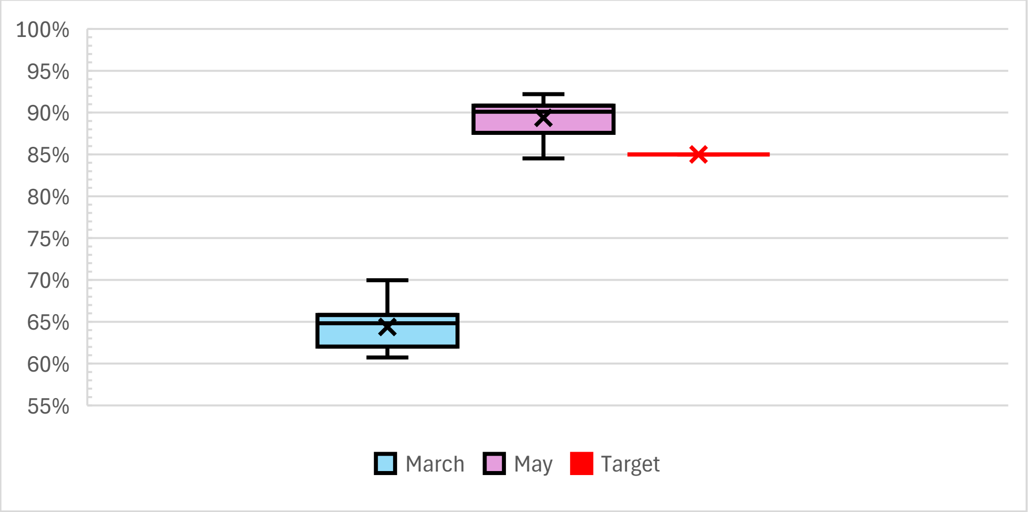


Figure 5.12: March and May high moisture material ADT BFF distribution

While mining high-moisture material in March, the ADT BFF values distribution was lower and more tightly clustered, ranging from around 60% to 70%. In May, the distribution is higher and tightly clustered, with values around 85% to 95%, aligning more with the target BFF. The data indicates an ADT BFF performance improvement from March to May. Improvements were achieved through regular cleaning of material stuck in ADT load bins and stricter enforcement of proper bucket filling during loading. High-moisture material, BFF improved from 64.5% (SD = 2.80%) in March to 89.4% (SD = 2.12%) in May. The t-test again revealed a statistically significant difference ($t = 22.43$, $p < 0.0000000000001$), confirming the intervention's net effect.

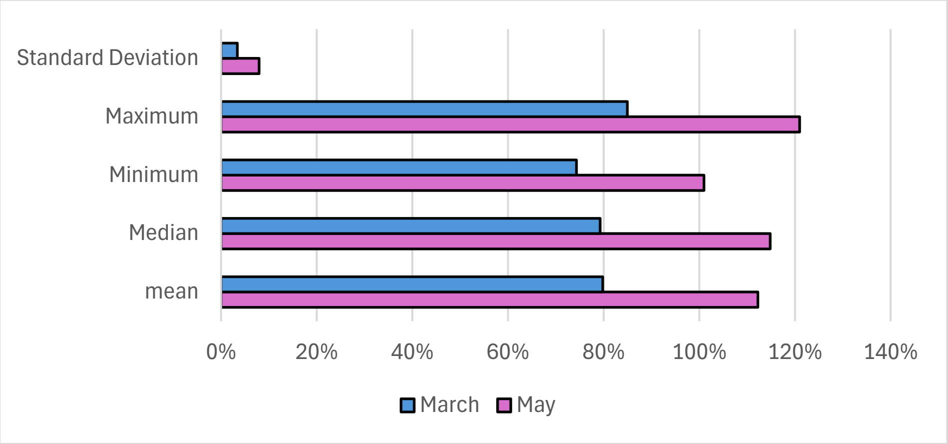


Figure 5.13: March and May low moisture material excavator BFF Performance

In March, the low moisture material excavator BFF performance was lower across all metrics compared to May. The maximum and minimum values increased notably in May, reflecting overall improvement in performance. The variability was minimal for both months, as indicated by standard deviations.

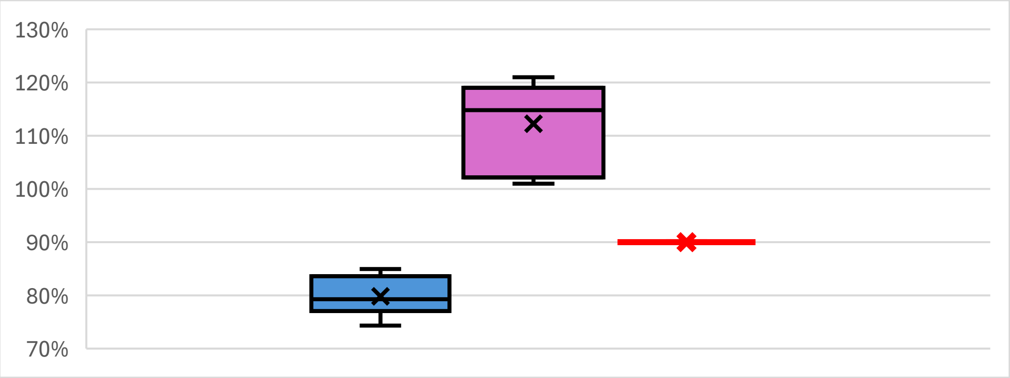


Figure 5.14: March and May low moisture ADT BFF distribution

In March, the distribution of low moisture excavator BFF values was lower and tightly clustered, with all results below the target. In May, the distribution shifted upward, showing higher values and a wider range, with most results exceeding the target. The results show that most excavator scoops consistently achieved or exceeded the rated bucket capacity in May.

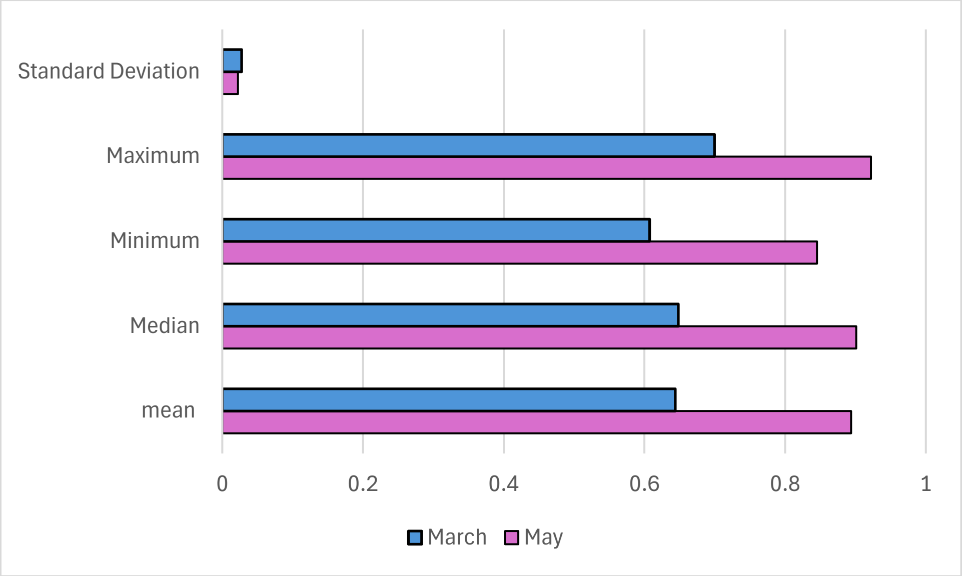


Figure 5.15: March and May high moisture material excavator BFF performance

The high moisture material excavator BFF performance in May was higher across all key metrics than in March. The maximum, minimum, and median values for May were above March's, reflecting significant improvements. The standard deviation remained low for both months, indicating consistent results despite the overall increase in performance.

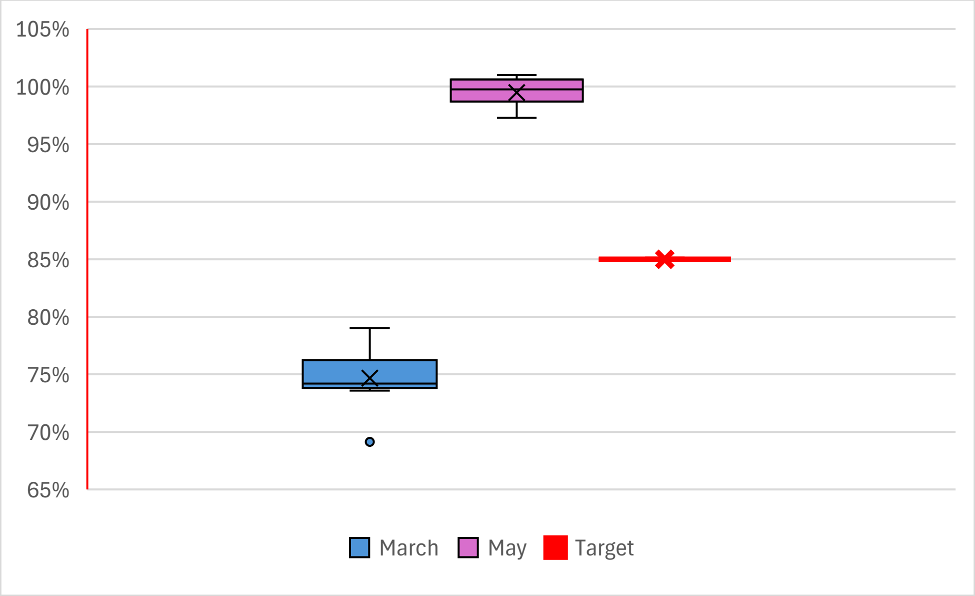


Figure 5.16: March and May high moisture ADT BFF distribution

In March, the distribution of High Moisture ADT BFF values was lower and displayed significant variability, with most results falling below the target. By May, the distribution shifted significantly upward, with values tightly clustered around 100%, exceeding the target.

Performance for both low and high-moisture materials improved significantly from March to May. March results were lower, tightly clustered, and often below targets, while May showed higher values, improved efficiency, and better alignment with targets. Overall, May's performance was driven by improvement strategies, regular cleaning of ADT bins, stricter loading practices, operator training and awareness, and higher bench heights, leading to better efficiency and performance. Improvements in BFF for both ADTs and excavators, achieved through stricter loading practices and regular cleaning of truck beds, demonstrate applied alignment with Bozorgebrahimi et al. (2003), who argue that higher BFF leads to better payload utilisation and reduced per-unit costs.

## 5.6 Cycle Time

The cycle time analysis in Figure 5.17 focused on comparing each cycle activity. The approach offered a detailed activity-level understanding and a statistical perspective on how these predictors influence overall cycle time.

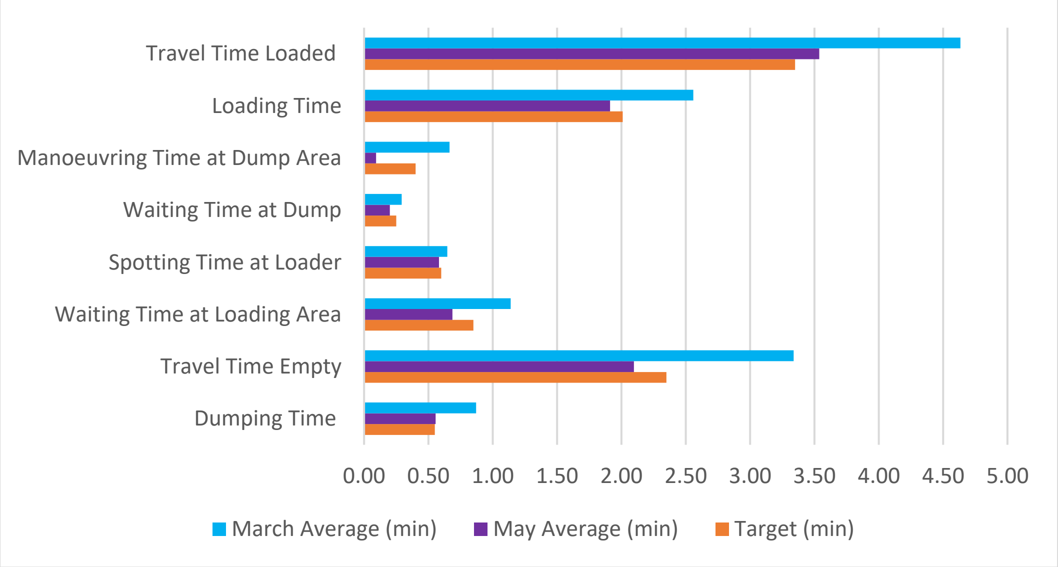
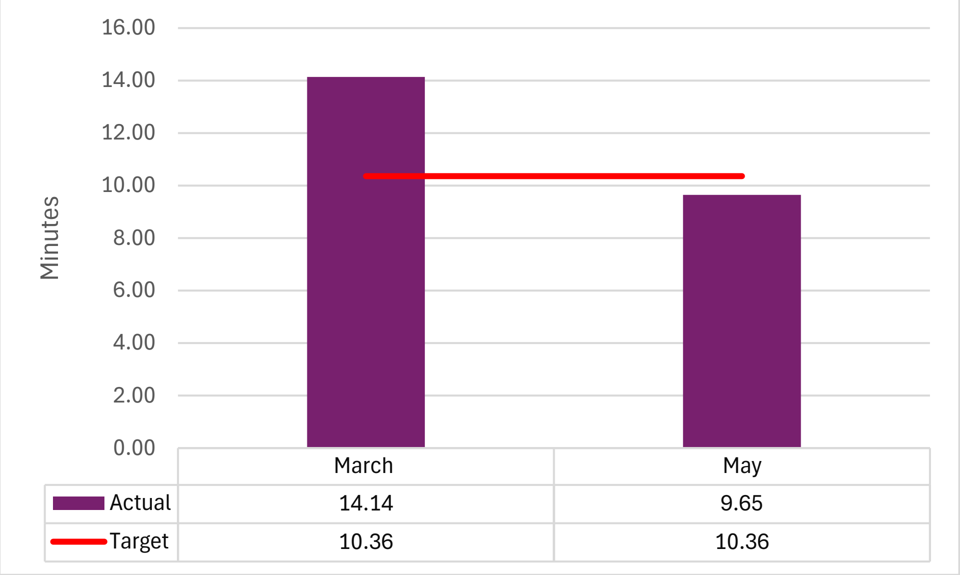


Figure 5.17: March and May cycle time comparison per activity

The OEM specifications indicate that a fully loaded Volvo ADT A40 should have a dumping time of 0.55 minutes. In March, however, the observed average dumping time was 0.87 minutes, a 58% discrepancy from the OEM’s expected performance. Interviews with equipment operators revealed that many were unaware of the optimal use of the ADT’s dump functionality, presenting an opportunity for targeted training. After implementing this training, the May data shows a reduction in average dumping time to 0.56 minutes, much closer to the target.

In March, the travel time for empty ADTs averaged 3.34 minutes, while loaded ADTs took 4.63 minutes. By May, these times were reduced to 2.10 minutes for empty ADTs and 3.54 minutes for loaded ADTs, showing significant improvement. This reduction in travel times is attributed to the improved ramp gradients and road widths on the haul route, which allowed for more efficient hauling. Ramp gradients used in March and May were presented in Sections 4.3.2 and 4.4.2, respectively. The one-way ANOVA test for total cycle time between March and May reveals a statistically significant difference: F-statistic = 253.63. p-value = $3.22 \times 10^{-23}$. Since the p-value is far below 0.05, the null hypothesis is rejected, and the conclusion is that the reduction in cycle time from March to May is statistically significant. This validates the observed operational improvements with strong statistical backing.

Loading time is close to the target in both months, with May showing better performance. Consistently filling the excavator bucket, enhanced truck positioning at loading, and operator training contributed to the reduced loading time. Waiting time at the dump area improved in May due to the availability of a wider dumping area. Similarly, waiting time at the loading area was reduced because of shorter loading times in May. Dumping time improvements in May are linked to training on using the dumping function as per OEM specifications. Spotting time at the loader remains consistent and close to the target. Manoeuvring time at the dump area also decreased in May, moving closer to the target. Overall, May shows better cycle time performance than March. Figure 5.18 illustrates a significant reduction in average cycle times from March to May, with the cycle time improving from being way above the target to below it.



| | March | May |
|---|---|---|
| 🟪 Actual | 14.14 | 9.65 |
| — Target | 10.36 | 10.36 |

Figure 5.18: March and May average cycle times

The improvements resulted from targeted KPI interventions and individual enhancements in cycle time components, such as reduced loading, hauling, and dumping durations. The combined effect of these measures demonstrates the possible success of the improvement efforts in increasing the operational efficiency of the TSLHS operation.

The marked improvement in cycle time performance from March to May validates Pasch and Uludag’s (2018) emphasis on optimising each component of the load-haul cycle to increase operational throughput. For instance, the reduction in ADT dumping time from 0.87 to 0.56 minutes after operator training mirrors the conclusions of Mnzool et al. (2024), who note that equipment efficiency and operator proficiency directly affect productivity.

## 5.7 Chapter Summary

This chapter analysed data collected during the improvement study of the TSLHS operation at Manungu Colliery in March and May 2024. The study integrates quantitative and qualitative data to evaluate KPI changes, focusing on mined volumes, diesel usage, time utilisation, hauling conditions, loading efficiency, and cycle times. Descriptive statistics and variance analysis reveal the impact of targeted interventions on operational performance.

A comparison of March and May data highlights significant efficiency improvements. Production was above target in May, and diesel consumption was lower than planned. Diesel usage per cubic meter dropped from above target by 0.05 litres in March to 0.02 litres below the target in May. This improvement reflects effective KPI interventions.

DOH improved from March to May, with higher mean and median values and reduced variability. Unplanned delays decreased due to better blasting coordination and time management. Haul route maintenance, loading face grading and dust suppression were done during planned downtimes, and the combined improvements reduced unplanned delays.

Hauling conditions improved through reduced RR, smoother gradients, and wider haul roads. RR averaged 3% in May, and gradients allowed consistent ADT speeds. Road widths, initially below target in March, improved in May, reducing congestion and unnecessary braking. The changes created conditions to maintain maximum average speeds, reduced fuel consumption, and increased productivity.

BFF performance for both ADTs and excavators improved in May. Cleaning stuck material and enforcing proper bucket-filling practices yielded better payload utilisation. Excavators consistently exceeded rated capacities in May, particularly with low-moisture material.

Cycle times improved significantly from March to May. Dumping time decreased from 0.87 minutes to 0.56 minutes due to operator training. Travel times also reduced, attributed to better haul route conditions. Other cycle components, including loading, waiting, and manoeuvring times, showed consistent progress. May's average cycle time was below the target, reflecting the success of the interventions.

Targeted improvement efforts in various operational aspects enhanced productivity and efficiency. While May demonstrated notable progress, there is room for improvement from these gains to sustain and maximise productivity. The results underscore the value of ongoing improvement efforts in mining operations.

Although the findings reflect positive outcomes over three months, the short study duration limits the ability to establish long-term trends, particularly under varying seasonal and operational conditions. For instance, rainfall was significantly lower in May, naturally improving some KPIs. A longer study across multiple quarters would enable more robust trend validation and help isolate the sustained impact of intervention strategies from temporary environmental or logistical advantages.

# 6 CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Introduction

This chapter consolidates the findings from the improvement study of the stripping load-and-haul operation at Manungu Colliery. It summarises the study's key contributions, including improving KPIs like time utilisation, cycle time, and bucket fill factor, while highlighting the operational implications. The chapter also identifies research limitations and provides recommendations for future work to address challenges, improve sustainability, and explore advanced technologies for enhanced efficiency.

## 6.2 Summary of Chapters

This report has presented six chapters that cover the following:

- Chapter One introduced the study to improve the TSLHS operation at Manungu Colliery. It presented the research background, problem statement, objectives, and justification. The chapter also introduced the pragmatism philosophy and mixed-methods approach used for the study, supported by data collection methods such as observations, document review, and semi-structured interviews. Finally, it introduced the framework for validating findings to ensure practical, reliable, and actionable recommendations.

- Chapter two reviewed relevant literature, establishing the study's theoretical foundation. It explored critical aspects of open-pit mining, focusing on loading and hauling systems, and examined the application of queuing theory in these operations. The chapter also reviewed the literature on open-pit mining production factors, including cycle time, the time usage model, the equipment match factor, and the queuing system performance.

- Chapter three detailed the research approach adopted for the study. Pragmatism and mixed-methods approach methodology were discussed in detail. The research design overview highlighted the pragmatism philosophy and mixed-methods approach supported by quantitative and qualitative research strategies. Data collection covered quantitative and qualitative methods, the challenges encountered, and their mitigations. The data validation process discussed validation techniques for collected data, their integration, and strategies to address potential biases were presented. Finally, the chapter discussed the data analysis approach, detailing data analysis methods, visualisation, and reporting techniques.

- Chapter four presented data collected from March and May on KPIs for Manungu Colliery's TSLHS operation. Time utilisation in March fell short by 14% due to unplanned delays but improved in May with targeted adjustments. Hauling conditions in March showed that steep ramps slow down ADT speeds, with May data showing faster speeds after gradient re-designs. BFFs in March were below target, but May data showed improvement with stricter standards and training. Cycle times averaged 14.14 minutes in March, exceeding the 10.38-minute target, but May data showed progress with shorter cycle times. Overall, the chapter highlighted changes in KPI metrics between March and May, showing improvements across operational parameters.

- Chapter five presented data analysis from the March and May 2024 improvement study at Manungu Colliery, focusing on the stripping load-and-haul operation. Significant improvements were observed in KPI performance, including reduced diesel consumption, time utilisation, and increased productivity. Hauling conditions improved with smoother gradients, wider haul routes, and reduced RR, enhancing ADT speeds and efficiency. Cycle times dropped below target, with notable dumping and travel times reductions. BFF and payload utilisation improved due to better bucket-filling practices and operator training. These interventions yielded possible measurable progress, but further improvement is necessary for sustained efficiency gains.

- Chapter Six concluded the research study by detailing operational efficiency and productivity improvements achieved through data-driven interventions. It identified limitations such as the short study duration and the need for cost-benefit and environmental impact assessments. Finally, it provided actionable recommendations for future studies, including the exploration of advanced technologies, the extension of the research scope, and the evaluation of long-term impacts to achieve sustained operational excellence.

## 6.3 Research Observations

### 6.3.1 Initial and Intervention Studies

The research was structured around the March baseline and May intervention studies. The studies were designed to evaluate the TSHLS operation's operational performance and identify areas for improvement. The March baseline was a foundational understanding of the study’s KPIs influencing the operation’s cycle times, time utilisation, and productivity. Building on the gathered insights, the May intervention study introduced targeted interventions to address the challenges highlighted. The interventions were designed to test and improve devised solutions, checking their effectiveness and adaptability in real-world conditions.

### 6.3.2 Key findings and observations

The March baseline and May intervention study data analysis revealed several critical insights into the operational performance of the TSLHS operation. The findings reflect the evident improvements achieved through targeted interventions.

- DOH improved from an average of 15.47 hours in March to 17.57 hours in May. The increase was attributed to reduced variability in operational activities and effective mitigation of unplanned delays.
- Implementing time management practices reduced operational downtime and enhanced time utilisation.
- The haul route improvements improved average ADT speeds from 24 km/h in March to 34 km/h in May, effectively reducing cycle times. While seasonal weather differences may have also played a role, the consistent feedback from operators and improved route design suggest that infrastructure upgrades were the main influence. Secondly, as a safety precaution at Manungu Colliery, operations are temporarily halted during rainfall and only resume once haul routes are dry and safe for vehicle movement.
- Increased fuel efficiency was observed; consumption dropped from 0.57 to 0.50 litres per cubic meter, reducing production costs and improving operational profitability. This improvement is notable given that the average hauling distances for both March and May remained the same at approximately 1,900 meters.
- Excavator BFF improved from 80% to 112% for low-moisture material and 75% to 99% for high-moisture material from March.

- ADT bucket payload utilisation improved significantly, with a 16% increase for low-moisture material and a 25% increase for high-moisture material.
- Enhanced loading practices and stricter enforcement of bucket filling drove improvements in the excavator BFF and ADT payload utilisation. Regular monitoring and cleaning of material stuck in ADT load bins necessitated improvements while loading high-moisture material.
- The top three improved cycle time components are loading time, travel time, empty and loaded, reduced by 0.65 minutes, 1.24 minutes and 1.09 minutes, respectively.
- Operator training sessions focused on adherence to OEM specifications were pivotal in reducing dumping time by 58%.
- The reduced time in cycle time components substantially reduced average cycle times by 32%.
- Production increased from 272 200 BCM in March to 344 934 BCM in May, translating to a 27% increase.

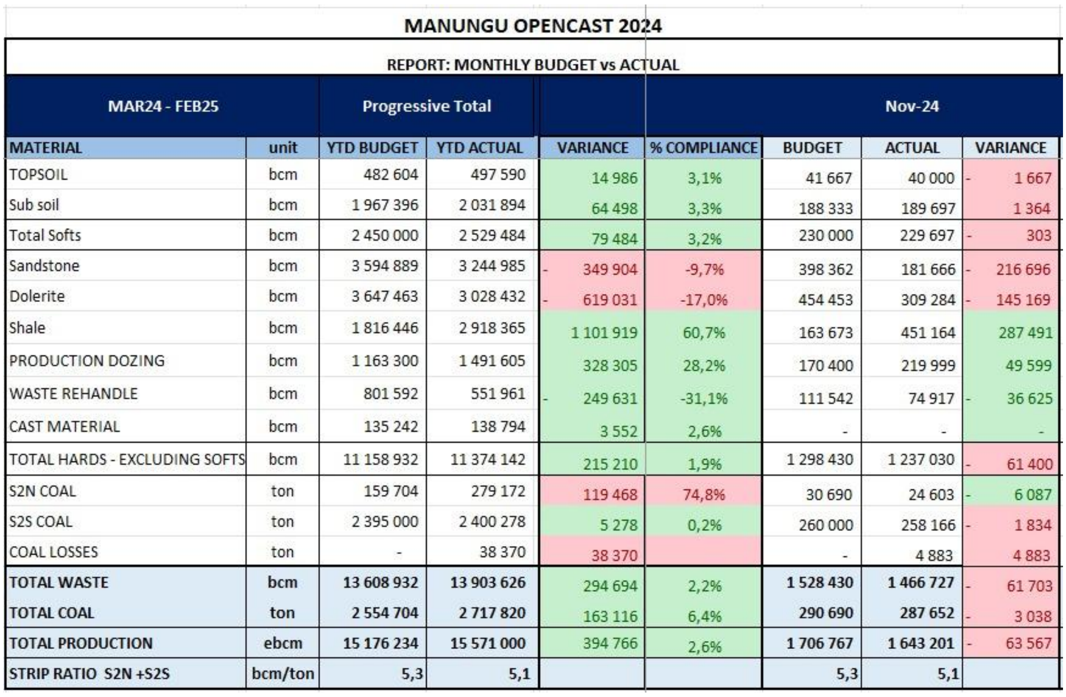
The findings reveal that targeted interventions on key study KPIs enhanced overall operational efficiency. Improved loading practices improved excavator BFFs, ADT payload utilisation, and loading times. Improved hauling conditions increased ADT average speeds, reduced diesel consumption, and decreased cycle times. Effective time management practices improved time utilisation and increased the average DOH. The overlapping impact of these improvements highlights the overall performance of the operation, driven by data-driven strategies and continuous monitoring.

## 6.4 Research Contributions

The study guided the improvements of the TSHLS operation by addressing inefficiencies and providing actionable strategies. It was demonstrated that data-driven interventions improve efficiency, highlighting how systematic analysis guided targeted solutions, such as optimising haul route gradients and refining loading practices. The changes resulted in measurable operational improvements, increased production output through reduced cycle times and better time utilisation. Enhanced haul route conditions improved average ADT speeds, contributing to cycle time reductions while decreasing diesel consumption per volume mined. The research highlighted the impact of key operational metrics on overall productivity, such as time utilisation, BFF, and cycle time efficiency. Increased excavator BFF performance reduced loading times. The reduction in loading time also minimised idling while queuing and unnecessary fuel consumption, contributing to cost savings and environmental sustainability.

A significant contribution was the establishment of a structured framework for systematic KPI monitoring and improvement. This framework provides scalable tools incorporating additional KPIs like fleet match factor and cost and benefit analysis of each KPI improvement, which was not used in this study. By identifying operation-specific inefficiencies, the approach increases productivity while reducing costs, minimising equipment wear and extending operational lifespan. Improved alignment between blasting schedules and production timelines minimised bottlenecks and unplanned delays, streamlining the operation flow. Collaborating with supervisors and operators contributed significantly to the study's success and positive outcomes. The efforts delivered tangible benefits, including increased production output, enhanced diesel efficiency, and improved equipment sustainability, while fostering a more efficient and environmentally sustainable mining operation. November 2024 year-to-date figures are presented in Figure 6.1

Table 6-1: Manungu Colliery production budget vs actual November 2024



MANUNGU OPENCAST 2024

REPORT: MONTHLY BUDGET vs ACTUAL

| MAR24 - FEB25 | | Progressive Total | | | | Nov-24 | | |
|---|---|---|---|---|---|---|---|---|
| MATERIAL | unit | YTD BUDGET | YTD ACTUAL | VARIANCE | % COMPLIANCE | BUDGET | ACTUAL | VARIANCE |
| TOPSOIL | bcm | 482 604 | 497 590 | 14 986 | 3,1% | 41 667 | 40 000 | - 1 667 |
| Sub soil | bcm | 1 967 396 | 2 031 894 | 64 498 | 3,3% | 188 333 | 189 697 | 1 364 |
| Total Softs | bcm | 2 450 000 | 2 529 484 | 79 484 | 3,2% | 230 000 | 229 697 | - 303 |
| Sandstone | bcm | 3 594 889 | 3 244 985 | - 349 904 | -9,7% | 398 362 | 181 666 | - 216 696 |
| Dolerite | bcm | 3 647 463 | 3 028 432 | - 619 031 | -17,0% | 454 453 | 309 284 | - 145 169 |
| Shale | bcm | 1 816 446 | 2 918 365 | 1 101 919 | 60,7% | 163 673 | 451 164 | 287 491 |
| PRODUCTION DOZING | bcm | 1 163 300 | 1 491 605 | 328 305 | 28,2% | 170 400 | 219 999 | 49 599 |
| WASTE REHANDLE | bcm | 801 592 | 551 961 | - 249 631 | -31,1% | 111 542 | 74 917 | - 36 625 |
| CAST MATERIAL | bcm | 135 242 | 138 794 | 3 552 | 2,6% | - | - | - |
| TOTAL HARDS - EXCLUDING SOFTS | bcm | 11 158 932 | 11 374 142 | 215 210 | 1,9% | 1 298 430 | 1 237 030 | - 61 400 |
| S2N COAL | ton | 159 704 | 279 172 | 119 468 | 74,8% | 30 690 | 24 603 | - 6 087 |
| S2S COAL | ton | 2 395 000 | 2 400 278 | 5 278 | 0,2% | 260 000 | 258 166 | - 1 834 |
| COAL LOSSES | ton | - | 38 370 | 38 370 | | - | 4 883 | 4 883 |
| **TOTAL WASTE** | **bcm** | **13 608 932** | **13 903 626** | 294 694 | 2,2% | **1 528 430** | **1 466 727** | - 61 703 |
| **TOTAL COAL** | **ton** | **2 554 704** | **2 717 820** | 163 116 | 6,4% | **290 690** | **287 652** | - 3 038 |
| **TOTAL PRODUCTION** | **ebcm** | **15 176 234** | **15 571 000** | 394 766 | 2,6% | **1 706 767** | **1 643 201** | - 63 567 |
| **STRIP RATIO S2N +S2S** | **bcm/ton** | **5,3** | **5,1** | | | **5,3** | **5,1** | |

This research's significant contribution enabled the stripping, loading, and hauling operation to recover from a 27% production deficit recorded in the 2023 financial year, as shown in Table 1.1. The improved performance of the TSLHS operation had a significant positive impact on the overall production efficiency at Manungu Colliery. November 2024 year-to-date figures show that both topsoil and subsoil volumes exceeded their respective targets by 3.1% and 3.3% respectively. These improvements are not just isolated gains but have unlocked the performance of blasted material load and haul operations, due to the sequential and dependent nature of the mining process. By efficiently moving the top layers, the TSLHS operation facilitated the timely exposure of hard overburden and coal seams, thereby reducing delays in drilling, blasting, and coal loading activities. Additionally, the positive performance in blasted material handling and a strong recovery in S2N coal production (at 74.8% compliance) further demonstrate that upstream improvements in the TSLHS directly contributed to improved coal access and throughput. This reinforces the critical role of the TSLHS operation as an enabler of downstream productivity in the mine's value chain. The operation achieved a remarkable turnaround by implementing data-driven interventions and optimising some processes. The improvement underscores the effectiveness of the research's recommendations in enhancing productivity and achieving sustained operational excellence.

## 6.5 Limitations of the Research Findings

While this study provided useful insights into improving the TSLHS operation at Manungu Colliery, several limitations affect the scope and applicability of the findings. Firstly, the findings are based solely on data collected from the TSLHS operation. The study did not include the loading of fragmented or blasted rock, which is common in most mining operations. As a result, the conclusions related to bucket fill factor, payload utilisation, and loading efficiency may not be directly transferable to contexts involving blasted material, where fragmentation affects diggability, loading rates, and cycle times.

Secondly, the findings reflect conditions observed during a limited three-month period and may not capture the full variability caused by seasonal changes or longer-term operational fluctuations. This timeframe limits the ability to generalise the performance trends or predict their sustainability across different weather and operating conditions. In addition, while instances of overloading ADTs were observed during efforts to maximise payload utilisation, the study did not fully assess the consequences of overloading in terms of mechanical strain, safety risks, or production impacts. Therefore, the findings can only highlight overloading as a concern rather than provide concrete recommendations on acceptable thresholds or mitigation strategies.

The study also observed the potential impact of steep gradients and narrow haul routes on machine performance; however, the findings do not quantify the long-term effects of these conditions on equipment health, such as transmission wear or tyre degradation. This limits the depth of analysis on how haul route design influences equipment longevity.

The study did not conduct a cost-benefit analysis (CBA) at this stage due to time constraints and the prioritisation of urgent operational assessments. The focus was placed on collecting and analysing key performance data to inform immediate improvements. However, a comprehensive CBA is recommended as a follow-up to quantify the financial impact of the implemented interventions more accurately.

Lastly, operator training was in progress during the study period, and its full impact on productivity and compliance was not yet measurable. As such, some findings related to loading precision and payload alignment may not reflect the outcomes of a fully trained workforce. Overall, these limitations suggest that while the findings are valid within the observed context, caution should be exercised when applying them to broader mining scenarios, particularly those involving blasted materials or longer-term operational planning.

## 6.6 Recommendations for Future Research Work

To strengthen the applicability and depth of operational insights, future research should be guided by the limitations identified in this study, with clear prioritisation based on expected operational value.

A key priority is the quantification of overloading impacts. While the study observed instances of ADTs being loaded beyond their rated capacity, it did not assess the resulting strain on mechanical components, safety risks, or productivity losses. Future research should focus on establishing safe payload thresholds and investigating the use of onboard load monitoring systems. This would deliver immediate value by preventing costly equipment failures and improving compliance.

Another high-value area is understanding how steep gradients and narrow haul routes affect equipment health over time. Although the study noted operational inefficiencies in these conditions, it did not quantify impacts on transmission systems, tyre life, or braking performance. Research in this area could inform haul road redesign and maintenance strategies that enhance machine longevity and reduce downtime, making this a high-priority second-tier objective.

Extending the analysis to include blasted material conditions is also critical. The current study focused solely on free-digging subsoil and topsoil, limiting the relevance of its findings to blasted material loading and hauling. Future studies should examine how blast fragmentation influences bucket fill factor, diggability, and loading efficiency. This would broaden the study's applicability across varied mining conditions and improve load planning under real-world scenarios.

A longer observation period is another important direction for research. The three-month duration of the study restricts its ability to capture seasonal effects, such as changes in road condition due to rain, and operational variability across production cycles. A 6–12 month extended study would help validate whether the observed improvements are sustainable and provide a more reliable basis for operational planning.

Finally, the impact of operator training on productivity and payload compliance should be evaluated once training initiatives are fully implemented. While training was ongoing during the study, its outcomes could not be measured effectively. Future research should isolate the influence of human factors on loading accuracy and consistency, which would support long-term workforce development efforts.

By prioritising research into overloading effects and haul route-induced equipment degradation, followed by broader applicability and long-term performance validation, future studies can provide practical, high-impact insights to guide sustainable improvements at Manungu Colliery and similar operations.

.

# REFERENCE LIST

Agnolucci, P., Nagle, P. & Temaj, K. 2023. *Declining coal prices reflect a reshaping of global energy trade* [Online]. Available: https://blogs.worldbank.org/opendata/declining-coal-prices-reflect-reshaping-global-energy-trade [Accessed 19 October 2023].

Aguayo, I. A. O., Nehring, M. & Ullah, G. M. 2021. Optimising productivity and safety of the open pit loading and haulage system with a surge loader. *Mining,* 1(2), pp 167-179.

Akbari, A., Osanloo, M. & Shirazi, M. 2009. Minable reserve estimation while determining ultimate pit limits (UPL) under price uncertainty by real option approach (ROA). *Archives of Mining Sciences,* 54(2), pp 321-339.

Aksoy, M. & Yalcin, E. 2000. A computer program for open pit mine equipment selection: TruckMac. *In:* Panagiotou, G. N. & Michalakopoulos, T. N. (eds.) *Mine planning and equipment selection.* 1st ed. Rotterdam, Netherlands: Balkema.

Altiti, H., Alrawashdeh, R. & Alnawafleh, H. 2021. Open Pit Mining. *In:* Soni, A. (ed.) *Mining techniques: Past, present and future.* London: IntechOpen.

Amit, N. & Ghazali, N. A. Using Simulation to Model Queuing Problem at a Fast-Food Restaurant. 2018 Singapore. Springer Singapore, 1055-1062.

AngloAmerican. 2023. *Open-pit mining definition* [Online]. Available: https://www.angloamerican.com/futuresmart/stories/ourindustry/mining-explained/mining-terms-explained-a-to-z/open-pit-mining-definition [Accessed 4 April 2024].

Arteaga, F., Nehring, M. & Knights, P. 2018. The equipment utilisation versus mining rate trade-off in open pit mining. *International Journal of Mining, Reclamation and Environment,* 32(7)**,** pp 495-518.

Baatarchuluun , E., Batgerel, B.-O. & Ping, C., 2023. Cycle Time Analysis of Open Pit Mining Dump Trucks. *International Journal of Geosciences,* Volume 14, pp. 689-709

Bakhtavar, E. & Mahmoudi, H. 2020. Development of a scenario-based robust model for the optimal truck-shovel allocation in open-pit mining. *Computers & Operations Research,* 115**,** pp 104539.

.

Bao, H. & Zhang, R. 2020. Study on Optimization of Coal Truck Flow in Open-Pit Mine. *Advances in Civil Engineering,* 2020**,** pp 8848140.

Barrera, P. 2023. *Coal market forecast 2023: Top trends that will affect coal in 2023* [Online]. Available: https://investingnews.com/coal-forecast/ [Accessed 19 October 2023].

Bashir, S., Syed, S. & Qureshi, J. A., 2017. *JISR management and social sciences & economics,* 1(15), pp. 31-49.

Belaz Equipment, 2024. *Belaz Equipment.* [Online] Available at: https://m.belaz.by/en/products/products-belaz/dumpers/dump-trucks-with-electromechanical-transmission/dumpers-series-7571/ [Accessed 20 February 2024].

Bozorgebrahimi, E. 2004. *The evaluation of haulage truck size effects on open pit mining.* PhD thesis in Mining Engineering, University of British Columbia.

Bozorgebrahimi, E., Hall, R. A. & Blackwell, G., 2003. Sizing equipment for open pit mining - A review of critical parameters. *Transactions of the Institution of Mining and Metallurgy, Section A: Mining Technology,* 112(3), pp. 171-179.

Bravus Mining & Resources. 2021. *What technology is involved in gathering or using coal?* [Online]. Available: https://www.bravusmining.com.au/what-technology-is-involved-in-gathering-or-using-coal/ [Accessed 4 December 2023].

Burt, C. N. & Caccetta, L. 2018. Methodology: Preliminaries and Background. *In:* Burt, C. N. & Caccetta, L. (eds.) *Equipment Selection for Mining: With Case Studies.* 1st ed. Cham: Springer International Publishing.

*Mining and Metallurgy, Section A: Mining Technology,* 112(3), pp. 171-179.

Caterpillar, 2025. *www.caterpillar.com.* [Online] Available at: https://www.caterpillar.com/en/news/caterpillarNews/2022/500-autonomous-trucks.html
[Accessed 22 06 2025].

Chanda, E. & Gardiner, S., 2010. A comparative study of truck cycle time prediction methods in open-pit mining. *Engineering Construction & Architectural Management,* 17(5), pp. 446-460.

Chaowasakoo, P., Seppälä, H., Koivo, H. & Zhou, Q. 2017. Digitalization of mine operations: Scenarios to benefit in real-time truck dispatching. *International Journal of Mining Science and Technology,* 27(2), pp 229-236.

Choi, Y., Park, H. D., Sunwoo, C. & Clarke, K. C. 2009. Multi-criteria evaluation and least-cost path analysis for optimal haulage routing of dump trucks in large scale open-pit mines. *International Journal of Geographical Information Science,* 23(12)**,** pp 1541–1567.

Choudhary, R. P. 2015. Optimization of Load-Haul-Dump Mining System by OEE and Match Factor for Surface Mining. *International Journal of Applied Engineering and Technology,* 5(2)**,** pp 96-102.

Creswell, J. W., 2015. *SAGE Handbook of Mixed Methods in Social & Behavioral Research.* 2 ed. Thousand Oaks: SAGE Publications, Inc.

Creswell, J. W. & Creswell, J. D., 2017. *Research design: Qualitative, quantitative, and mixed methods approaches..* 4 ed. Newbury Park: Sage Publications.

Du Toit , A., 2017. Evaluation of productivity trends in the South African coal mining industry, Johannesburg: University of the Witwatersrand.

Elijah, K., Joseph, G., Samuel, M. & Mauti, D. (2021). Optimisation of shovel-truck haulage system in an open pit using queuing approach. *Arabian Journal of Geosciences,* 14(11)**,** pp 973.

Ercelebi, S. G. & Bascetin, A. 2009. Optimization of shovel-truck system for surface mining. *Journal of the Southern African Institute of Mining and Metallurgy,* 109(7)**,** pp 433-439.

Evans, M. A. & Ramani, R. V. 2023. *Coal mining* [Online]. Available: https://www.britannica.com/technology/coal-mining [Accessed 19 October 2023].

Ganiyat, S. (2022). *The impact of disruptive technology on the manufacturing process and productivity in an advanced manufacturing environment* PhD in Mechanical Engineering Thesis, University of KwaZulu-Natal.

Gross , D. et al., 2008. *Fundamentals of Queueing Theory.* 4th ed. New Jersey: Wiley-Interscience.

Güneş, M. (2023). Ch. 8 Queueing Models. Available: https://www.mi.fu-berlin.de/inf/groups/ag-tech/intern/19540-V-Simulation/08_Queueing_Models.pdf [Accessed 4 December 2023].

Hillier , F. S. & Lieberman, G. J., 2005. *Introduction to Operations Research.* 8th ed. Boston: McGraw-Hill Education.

Howell, K. E., 2012. *An Introduction to the Philosophy of Methodology.* London: Sage Publications Ltd.

Hustrulid, W., Kuchta, M. & Martin, R. 2013. *Open pit mine planning and design*, 3rd ed., Boca Raton: CRC Press.

Jaradat, R. & Abutabenjeh, S., 2018. Clarification of research design, research methods, and research methodology: A guide for public administration researchers and practitioners. *Teaching Public Administration,* 36(3), p. 237–258.

Joko, G. & Mulyono, N. B. 2023. Optimizing Coal Hauling Operations: A Strategic Plan for Increased Productivity at PT Borneo. *Logistic and Operation Management Research (LOMR),* 2(1)**,** pp 63-82.

Kaushik, V. & Walsh, C. A. 2019. Pragmatism as a Research Paradigm and Its Implications for Social Work Research. *Social Sciences,* 8(9)**,** pp 255.

Kelemen, M. L. & Rumens, N. 2008. *An introduction to critical management research*, 1st, London: Sage.

Kothari, C. R. & Garg, G., 2019. *Reserach Methodology - Methods and Techniques.* 4th ed. New Delhi: New Age International.

Krause, A. J. (2006). *Shovel-truck cycle simulation methods in surface mining.* Master of Science in Engineering, University of Witwatersrand.

Lööw, J., Abrahamsson, L. & Johansson, J., 2019. Mining 4.0—the Impact of New Technology from a Work. *Mining, Metallurgy & Exploration,* Volume 36, pp. 701-707.

Manungu Colliery (2023). *Company archives*: South Africa.

May, M. A. (2012). *Applications of queuing theory for open-pit truck/shovel haulage systems.* Master of Science in Mining & Minerals Engineering Thesis, Virginia Polytechnic Institute and State University.

Minerals Council South Africa. (2023). *The coal mining life cycle* [Online]. Available: https://www.miningforschools.co.za/lets-explore/coal/the-coal-mining-life-cycle [Accessed 19 October 2023].

Mnzool, M. et al., 2024. Optimization of cycle time for loading and hauling trucks in open-pit mining. *Mining of Mineral Deposits,* 18(1), pp. 18-26.

Nday, I. N. & Thomas, H., 2019. Optimization of the cycle time to increase productivity at Ruashi Mining. *The Southern African Insitute of Mining and Metallurgy,* Volume 119, pp. 631-639.

Nehring, M., Knights, P., Kizil, M. & Hay, E. 2018. A comparison of strategic mine planning approaches for in-pit crushing and conveying and truck/shovel systems. *International journal of mining science and technology,* 28(2)**,** pp 205-214.

Nobahar , P., Xu, C., Dowd, P. & Roohollah , S. F., 2024. Exploring digital twin systems in mining operations: A review. *Green and Smart Mining Engineering,* 1(4), pp. 474-492.

Oggeri, C., Fenoglio, . T. . M., Godio, A. & Vinai, R., 2019. Overburden management in open pits: options and limits in large limestone quarries. *International Journal of Mining Science and Technology,* Volume 29, p. 217–228.

Otto, T. J. & Lindeque, G. C. (2021). Improving productivity at an open-pit mine through enhanced short-term mine planning. *Journal of the Southern African Institute of Mining and Metallurgy,* 121(11)**,** pp 589–598.

Owolabi, A. (2019). Loading and haulage equipment selection for optimum production in a granite quarry. *Int. J. Min. Sci,* 5(2)**,** pp 35–40.

Pasch, O. & Uludag, S. 2018. Optimization of the load-and-haul operation at an opencast colliery. *Journal of the Southern African Institute of Mining and Metallurgy,* 118(May)**,** pp 449-456.

Pearce, S., Orr, M., Grohs, K. & Pearce, J., 2016. Progressive rehabilitation — Martabe Gold Mine as a case study. Perth, Australian Centre for Geomechanics.

Pebrianto, R., Asof, M., Susilo, B. K. & Gofar, N., 2014. Evaluation of factors affecting ripping productivity in open pit mining excavation. *Electronic Journal of Geotechnical Engineering,* Volume 19, pp. 10447-10456.

Pinsky, M. A. & Karlin, S. 2011. 9 - Queueing Systems. *In:* Pinsky, M. A. & Karlin, S. (eds.) *An Introduction to Stochastic Modeling (Fourth Edition).* Boston: Academic Press.

Riley, L. B. (2004). *Reducing the total cost of ownership of mining haul trucks.* Master of Science in Engineering Sciences, University of Stellenbosch.

Riyandi, I. & Wibowo, M. B. Optimizing the Use of Heavy Equipment by Using Unlock System-Fleet Management System (FMS) Dispatch Modular Study Case. Proceedings of the PERHAPI Annual Professional Meeting, 2020 PT Bukit Makmur Mandiri Utama Job Site Lati. 145–154.

Rodovalho, E. . d. C., Lima, H. M. & Tomi, G. d., 2016. New approach for reduction of diesel consumption by comparing different mining haulage configurations. *Journal of Environmental Management,* Volume 172, pp. 177-185.

Saunders, M. . N., Lewis, P. & Thornhill, A., 2019. Research Methods for Business Students. 8th ed. Harlow: Pearson.

Sinclair, N. & Nehring, M., 2019. Dozer side-cutting' versus excavator side-casting on the highwall in dozer bulk push operations. *Journal of the Southern African Institute of Mining and Metallurgy,* 119(1), pp. 71-80.

Soofastaei, A., Aminossadati, S., Kizil, M. S. & Knights, P., 2015. The Effect of Rolling Resistance on Fuel Consumption and Greenhouse Gas Emissions by Haul Trucks in Surface Mines. *Tribology International Journal,* pp. 1-30.

Ta, C. H., Ingolfsson, A. & Doucette, J. 2013. A linear surface mining haul truck allocation model incorporates shovel idle probabilities. *European Journal of Operational Research,* 231(3)**,** pp 770-778.

Tannant, D. D. & Regensburg , B., 2001. *Guidelines for Mine Haul Road Design ,* Canada: University of British Columbia.

Tapia, E., Salazar Araya, A., Saavedra, N., Nehring, M. & Mora, J. 2021. An analysis of full truck versus full bucket strategies in open pit mining loading and hauling operations. *International Journal of Mining, Reclamation and Environment,* 35(1)**,** pp 1-11.

Thompson, R., 2010. *Mine haul road design and management best practices for safe and cost-efficient truck haulage.* Phoenix, Arizona, Society for Mining, Metallurgy and Exploration, pp. 1-10.

Thompson, R. J. & Visser, A. T., 2003. Mine haul road maintenance management systems. *The Journal of The South African Institute of Mining and Metallurgy,* 103(5), pp. 303-312

Tilton, . J. E. & Guzmán, I. J., 2016. *Mineral economics and policy.* 1st ed. Abingdon: RFF Press.

Trivedi, R., Rai, P. & Nath, R. (1999). Shovel-truck optimization study in an open-cast mine queueing approach. *Indian Journal of Engineering & Materials Sciences,* 6**,** pp 153–157.

Yarmuch, J. L., Brazil, M., Rubinstein, H. & Thomas, D. A., 2020. Optimum ramp design in open pit mines. *Computers and Operations Research,* 115(104739), pp. 1-9.

# APPENDIX A. Questionnaire

**INTERVIEW QUESTIONNAIRE GUIDE**

1. How long have you been working for your organisation?

2. What is the current performance status of your load and haulage system?

3. What factors influence the performance of your loading and hauling operations?

4. What challenges are you currently facing in loading and hauling operations?

5. What areas do you think need improvement in the load and haulage system to increase productivity?

6. What steps have you taken to improve the operational efficiency of your load and haulage system?

7. Do you have any other information you would like to share about your load and haulage system?

Additional questions
What role does equipment efficiency play in influencing the performance of loading and hauling operations at Manungu Colliery?

How do workforce skills and training impact the efficiency and productivity of loading and hauling activities at the colliery?

To what extent do external factors, such as weather conditions and logistical challenges, contribute to variations in the performance of loading and hauling operations?

What influence do maintenance protocols and equipment downtime have on the overall effectiveness of loading and hauling processes at Manungu Colliery?

How does the integration of advanced technologies in loading and hauling operations affect their efficiency and contribute to improved performance?

In what ways do management strategies and safety measures impact the overall productivity and performance of loading and hauling activities at the colliery?

To what degree does the alignment of operational processes with industry best practices contribute to the success of loading and hauling operations at Manungu Colliery?

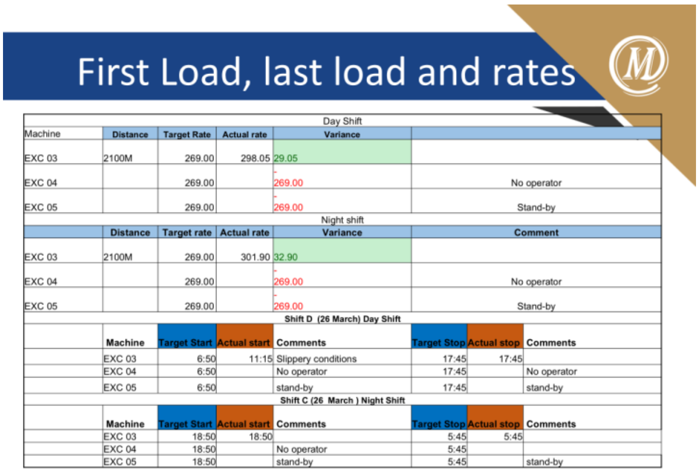
What is the impact of variability in coal demand on the performance of loading and hauling processes, and how does this influence operational efficiency?

# APPENDIX B. Daily Production Report 26 March 2024

Manungu
Softs Production

26 March 2024

MBUYELO
COAL



## First Load, last load and rates

Day Shift

| Machine | Distance | Target Rate | Actual rate | Variance | |
|---|---|---|---|---|---|
| EXC 03 | 2100M | 269.00 | 298.05 | 29.05 | |
| EXC 04 | | 269.00 | | - 269.00 | No operator |
| EXC 05 | | 269.00 | | - 269.00 | Stand-by |

Night shift

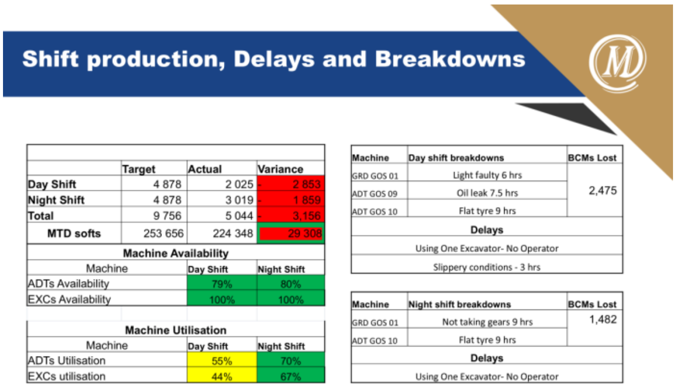
| | Distance | Target rate | Actual rate | Variance | Comment |
|---|---|---|---|---|---|
| EXC 03 | 2100M | 269.00 | 301.90 | 32.90 | |
| EXC 04 | | 269.00 | | - 269.00 | No operator |
| EXC 05 | | 269.00 | | - 269.00 | Stand-by |

Shift D (26 March) Day Shift

| | Machine | Target Start | Actual start | Comments | Target Stop | Actual stop | Comments |
|---|---|---|---|---|---|---|---|
| | EXC 03 | 6:50 | 11:15 | Slippery conditions | 17:45 | 17:45 | |
| | EXC 04 | 6:50 | | No operator | 17:45 | | No operator |
| | EXC 05 | 6:50 | | stand-by | 17:45 | | stand-by |

Shift C (26 March ) Night Shift

| | Machine | Target Start | Actual start | Comments | Target Stop | Actual stop | Comments |
|---|---|---|---|---|---|---|---|
| | EXC 03 | 18:50 | 18:50 | | 5:45 | 5:45 | |
| | EXC 04 | 18:50 | | No operator | 5:45 | | |
| | EXC 05 | 18:50 | | stand-by | 5:45 | | stand-by |



## Shift production, Delays and Breakdowns

| | Target | Actual | Variance |
|---|---|---|---|
| **Day Shift** | 4 878 | 2 025 | - 2 853 |
| **Night Shift** | 4 878 | 3 019 | - 1 859 |
| **Total** | 9 756 | 5 044 | - 3,156 |
| **MTD softs** | 253 656 | 224 348 | 29 308 |

**Machine Availability**

| Machine | Day Shift | Night Shift |
|---|---|---|
| ADTs Availability | 79% | 80% |
| EXCs Availability | 100% | 100% |

**Machine Utilisation**

| Machine | Day Shift | Night Shift |
|---|---|---|
| ADTs Utilisation | 55% | 70% |
| EXCs utilisation | 44% | 67% |

| Machine | Day shift breakdowns | BCMs Lost |
|---|---|---|
| GRD GOS 01 | Light faulty 6 hrs | 2,475 |
| ADT GOS 09 | Oil leak 7.5 hrs | |
| ADT GOS 10 | Flat tyre 9 hrs | |

**Delays**

Using One Excavator- No Operator

Slippery conditions - 3 hrs

| Machine | Night shift breakdowns | BCMs Lost |
|---|---|---|
| GRD GOS 01 | Not taking gears 9 hrs | 1,482 |
| ADT GOS 10 | Flat tyre 9 hrs | |

**Delays**

Using One Excavator- No Operator

## APPENDIX C. March (2024). Weekly Production Report

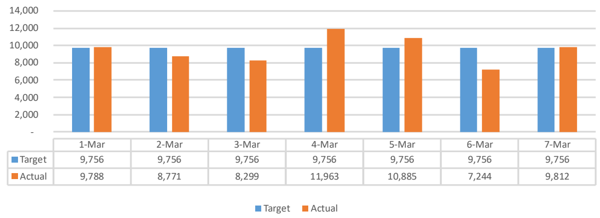
jjjj

Softs Production

MBUYELO
COAL

# Weekly review

Week ending 10 March 2024



| | 1-Mar | 2-Mar | 3-Mar | 4-Mar | 5-Mar | 6-Mar | 7-Mar |
|---|---|---|---|---|---|---|---|
| ■ Target | 9,756 | 9,756 | 9,756 | 9,756 | 9,756 | 9,756 | 9,756 |
| ■ Actual | 9,788 | 8,771 | 8,299 | 11,963 | 10,885 | 7,244 | 9,812 |

## Week Performance

| | |
|---|---|
| **Week production target** | 97,560 |
| **Week Production actual** | 89,225 |
| **Variance** | - 8,335 |

## Month Performance

| MTD | | | |
|---|---|---|---|
| | **Target** | **Actual** | **Variance** |
| **Week 1** | 97,560 | 89,225 | - 8,335 |
| **Week 2** | | | - |
| **Week 3** | | | - |
| **Week 4** | | | - |
| **MTD softs** | 97,560 | 89,225 | - 8,335 |

# APPENDIX D. March and May 2024 Survey Report

**MANUNGU COLLIERY**

Tshedza Mining Resources (PTY) Ltd.

| Monthly Survey Report Volume Comparison | |
|---|---|
| Mining Contractor | GOSSA Holdings |
| Measuring Month | APRIL_2024 |

Mbuyelo Coal (Pty) Ltd
a subsidiary of Mbuyelo Group (Pty) Ltd

| URVEYOR | MBUYELO COAL | | | GOSSA HOLDINGS | | | | COMPARISON | |
|---|---|---|---|---|---|---|---|---|---|
| NIT | Current | Previous | Monthly | Current | Previous | Monthly | Mean | Volume | % |
| ESCRIPTION | Progressive | Progressive | Removal | Progressive | Progressive | Removal | Removal | Diff | Diff |
| | m³ | m³ | m³ | | | m³ | | m³ | |
| OFTS | 271,785.00 | - | 271,785.00 | 272,658.00 | - | 272,658.00 | 272,222 | - 873.00 | 0% |
| AND STONE | | - | - | | - | - | - | - | |
| OLERITE | - | - | - | - | - | - | - | - | |
| ARDS MINED | | - | - | - | - | - | - | - | |
| OTAL COAL MINED(t) | | - | - | | - | - | - | - | |
| ON-SELECT MINED(t) | - | - | - | - | - | - | - | - | - |
| OAL Loss(t) | - | - | - | - | - | - | - | - | - |
| SEAM SELECT MINED(t) | - | - | - | - | - | - | - | - | - |

| DISTANCES (m) | | | | | | |
|---|---|---|---|---|---|---|
| 0-500 | 500-1000 | 1000-1500 | 1500-2000 | 2000-2500 | 2500-3000 | 3000-3500 |
| | | | | | | |
| m³ | m³ | m³ | m³ | m³ | m³ | m³ |
| | - | 98,452.00 | | 173,333.00 | | |
| - | | | - | | | |
| | | - | | | | |
| | | | | | | |
| | | | | | | - |
| | | | | | | |
| | | | | | | |

SIGNATURES FOR ACCEPTANCE & APPROVAL

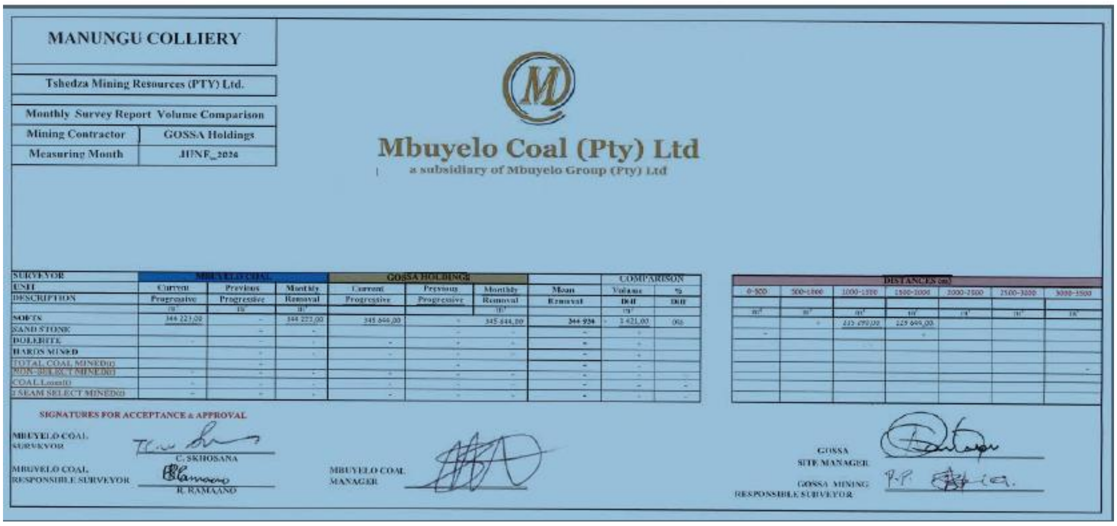
MBUYELO COAL SURVEYOR — C. SKHOSANA

MBUYELO COAL RESPONSIBLE SURVEYOR — R. RAMAANO

MBUYELO COAL MANAGER

GOSSA SITE MANAGER — PP

GOSSA MINING RESPONSIBLE SURVEYOR



**MANUNGU COLLIERY**

Tshedza Mining Resources (PTY) Ltd.

| Monthly Survey Report Volume Comparison | |
|---|---|
| Mining Contractor | GOSSA Holdings |
| Measuring Month | JUNE_2024 |

Mbuyelo Coal (Pty) Ltd
a subsidiary of Mbuyelo Group (Pty) Ltd

| SURVEYOR | MBUYELO COAL | | | GOSSA HOLDINGS | | | | COMPARISON | |
|---|---|---|---|---|---|---|---|---|---|
| UNIT | Current | Previous | Monthly | Current | Previous | Monthly | Mean | Volume | % |
| DESCRIPTION | Progressive | Progressive | Removal | Progressive | Progressive | Removal | Removal | Diff | Diff |
| | m³ | m³ | m³ | | | m³ | | m³ | |
| SOFTS | 344 223,00 | - | 344 223,00 | 345 644,00 | - | 345 644,00 | 344 934 | - 1 421,00 | 0% |
| SAND STONE | | - | - | | - | - | - | - | |
| DOLERITE | - | - | - | - | - | - | - | - | |
| HARDS MINED | | - | - | - | - | - | - | - | |
| TOTAL COAL MINED(t) | | - | | | - | | - | - | |
| NON-SELECT MINED(t) | - | - | - | - | - | - | - | - | |
| COAL Loss(t) | - | - | - | - | - | - | - | - | - |
| 2 SEAM SELECT MINED(t) | - | - | - | - | - | - | - | - | - |

| DISTANCES (m) | | | | | | |
|---|---|---|---|---|---|---|
| 0-500 | 500-1000 | 1000-1500 | 1500-2000 | 2000-2500 | 2500-3000 | 3000-3500 |
| | | | | | | |
| m³ | m³ | m³ | m³ | m³ | m³ | m³ |
| | - | 215 690,00 | 125 649,00 | | | |
| - | | | - | | | |
| | | - | | | | |
| | | | | | | |
| | | | | | | - |
| | | | | | | |
| | | | | | | |

SIGNATURES FOR ACCEPTANCE & APPROVAL

MBUYELO COAL SURVEYOR — C. SKHOSANA

MBUYELO COAL RESPONSIBLE SURVEYOR — R. RAMAANO

MBUYELO COAL MANAGER

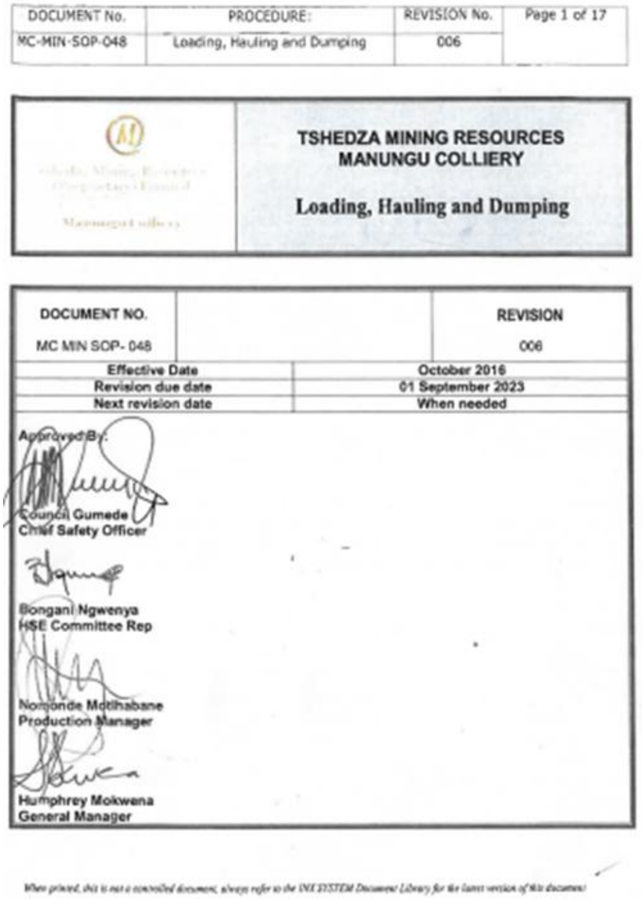
GOSSA SITE MANAGER

GOSSA MINING RESPONSIBLE SURVEYOR — P.P.

# APPENDIX E. Industry Benchmarks Table

| Metric | Industry Benchmark | Description |
|---|---|---|
| **Cycle Time (minutes)** | 10–12 | Ideal range based on upper quartile data. |
| **Bucket Fill Factor (BFF)** | 90–95% | Measures the efficiency of excavator loading relative to bucket capacity. |
| **Payload Utilisation (%)** | 90–100% | Percentage of rated payload utilised by ADTs or trucks. |
| **Hauling Speeds (km/h)** | 25–40 (flat);<br>15–20 (ramp) | Speed ranges for loaded and empty ADTs, considering terrain conditions. |
| **Equipment Availability (%)** | 85–90% | Reflects the proportion of time equipment is operational and available. |
| **Utilisation (%)** | 80–90% | Percentage of time equipment is effectively used out of available time. |
| **Fuel Consumption (L/bcm)** | 0.3–0.6 | Liters of fuel consumed per bank cubic meter (bcm) moved, depending on material density and haul distance. |
| **Operator Efficiency (%)** | 80–90% | Assesses operator adherence to operational protocols and efficiency targets. |
| **Ramp Gradient (%)** | ≤9% | Optimal ramp inclination to improve hauling conditions and reduce delays. |
| **Breakdown Rate (%)** | <2% | Frequency of equipment breakdowns relative to operational hours. |
| **Loading Efficiency (loads/hr)** | 4–6 | Average number of truckloads filled per hour by an excavator. |

## APPENDIX F. Front Page Load and Haul SOP



| DOCUMENT No. | PROCEDURE: | REVISION No. | Page 1 of 17 |
|---|---|---|---|
| MC-MIN-SOP-048 | Loading, Hauling and Dumping | 006 | |

**TSHEDZA MINING RESOURCES**
**MANUNGU COLLIERY**

**Loading, Hauling and Dumping**

| DOCUMENT NO. | | REVISION |
|---|---|---|
| MC MIN SOP- 048 | | 006 |

| | |
|---|---|
| **Effective Date** | **October 2016** |
| **Revision due date** | **01 September 2023** |
| **Next revision date** | **When needed** |

**Approved By:**

**Council Gumede**
**Chief Safety Officer**

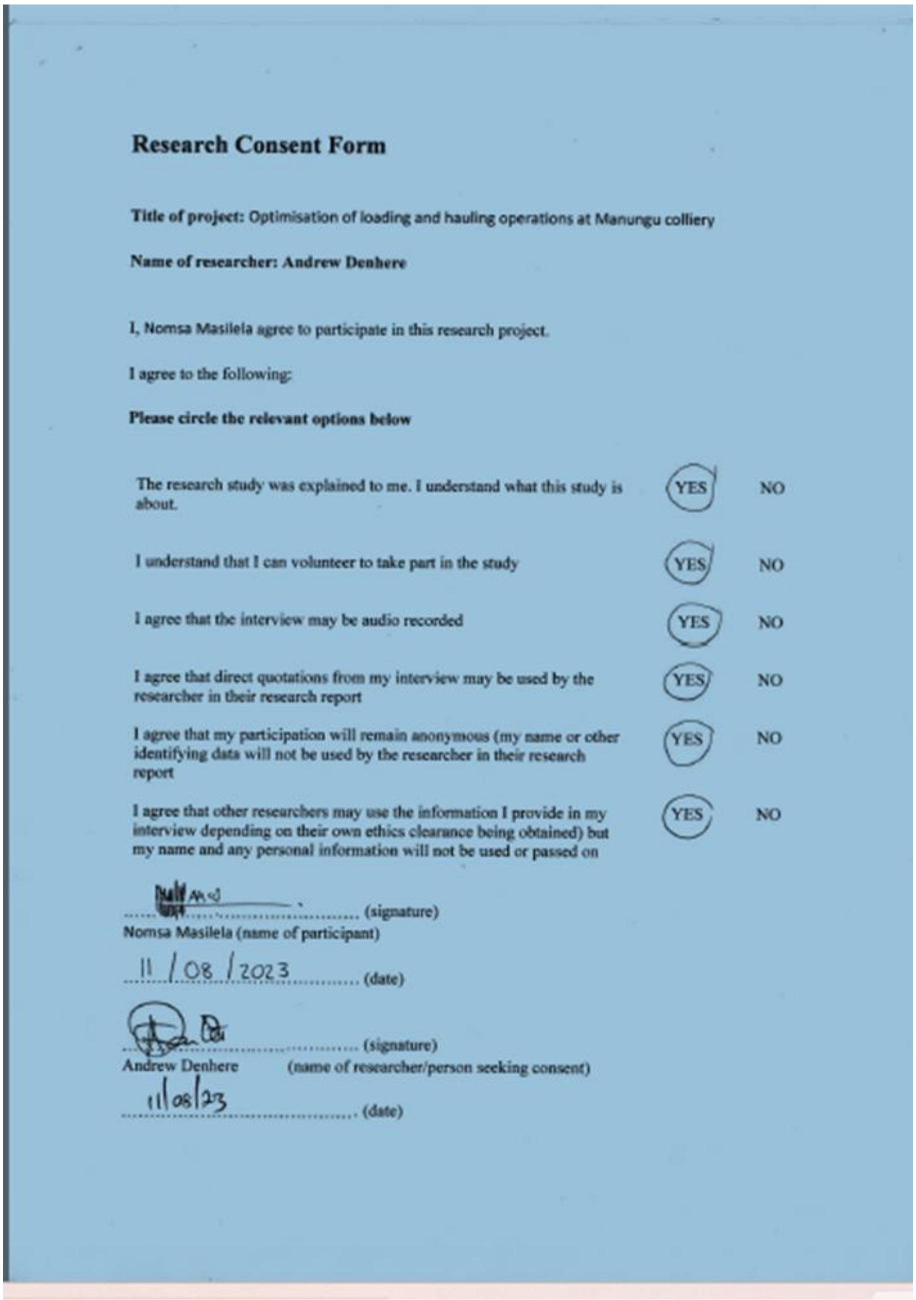
**Bongani Ngwenya**
**HSE Committee Rep**

**Nomonde Motlhabane**
**Production Manager**

**Humphrey Mokwena**
**General Manager**

*When printed, this is not a controlled document, always refer to the INX SYSTEM Document Library for the latest version of this document*

# APPENDIX G. Sample Signed Consent Letter



## Research Consent Form

**Title of project:** Optimisation of loading and hauling operations at Manungu colliery

**Name of researcher: Andrew Denhere**

I, Nomsa Masilela agree to participate in this research project.

I agree to the following:

**Please circle the relevant options below**

| | | |
|---|---|---|
| The research study was explained to me. I understand what this study is about. | [✓ YES] | NO |
| I understand that I can volunteer to take part in the study | [✓ YES] | NO |
| I agree that the interview may be audio recorded | [✓ YES] | NO |
| I agree that direct quotations from my interview may be used by the researcher in their research report | [✓ YES] | NO |
| I agree that my participation will remain anonymous (my name or other identifying data will not be used by the researcher in their research report | [✓ YES] | NO |
| I agree that other researchers may use the information I provide in my interview depending on their own ethics clearance being obtained) but my name and any personal information will not be used or passed on | [✓ YES] | NO |

................................................ (signature)

Nomsa Masilela (name of participant)

11 / 08 / 2023 ............ (date)

................................................ (signature)

Andrew Denhere (name of researcher/person seeking consent)

11/08/23 ............ (date)

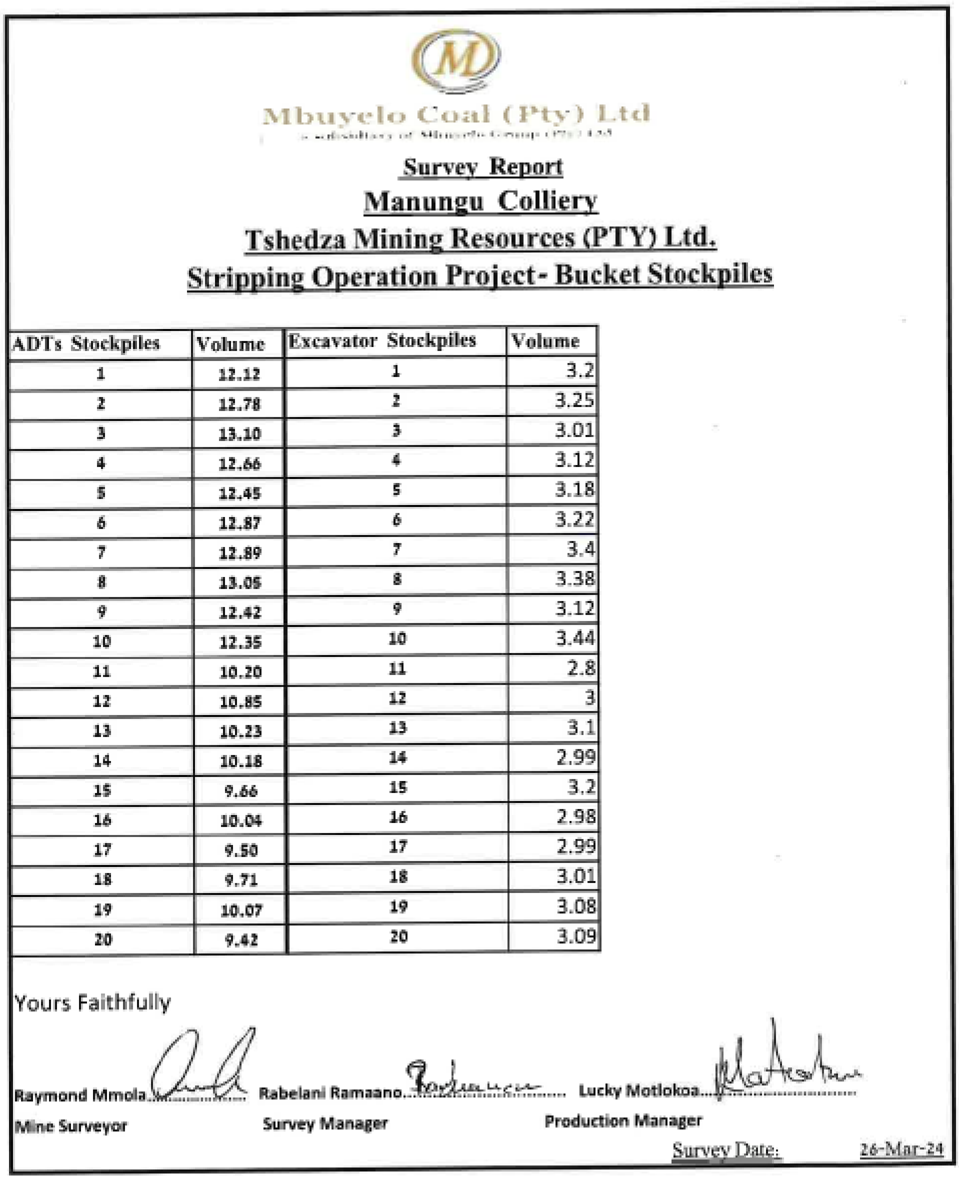
## APPENDIX H. Stripping Operation March Time Utilisation

| **Date** | **Unplanned delays** | **DOH** | **Target DOH** |
|---|---|---|---|
| 1-Mar | 2.88 | 15.12 | 18 |
| 2-Mar | 1.88 | 16.12 | 18 |
| 3-Mar | 2.38 | 15.62 | 18 |
| 4-Mar | 3.89 | 14.11 | 18 |
| 5-Mar | 1.08 | 16.92 | 18 |
| 6-Mar | 1.9 | 16.1 | 18 |
| 7-Mar | 1.84 | 16.16 | 18 |
| 8-Mar | 3.77 | 14.23 | 18 |
| 9-Mar | 0.12 | 17.88 | 18 |
| 10-Mar | 3.5 | 14.5 | 18 |
| 11-Mar | 0.03 | 17.97 | 18 |
| 12-Mar | 0.67 | 17.33 | 18 |
| 13-Mar | 2.82 | 15.18 | 18 |
| 14-Mar | -1.2 | 19.2 | 18 |
| 15-Mar | -0.95 | 18.95 | 18 |
| 16-Mar | -1.88 | 19.88 | 18 |
| 17-Mar | -1.45 | 19.45 | 18 |
| 18-Mar | -1.45 | 19.45 | 18 |
| 19-Mar | 2.79 | 15.21 | 18 |
| 20-Mar | 1.42 | 16.58 | 18 |
| 21-Mar | 2.57 | 15.43 | 18 |
| 22-Mar | 1.6 | 16.4 | 18 |
| 23-Mar | 1.33 | 16.67 | 18 |
| 24-Mar | 2.67 | 15.33 | 18 |
| 25-Mar | 3 | 15 | 18 |
| 26-Mar | 2.46 | 15.54 | 18 |
| 27-Mar | 1.53 | 16.47 | 18 |
| 28-Mar | 0.29 | 17.71 | 18 |
| 29-Mar | 0.98 | 17.02 | 18 |
| 30-Mar | 0.48 | 17.52 | 18 |
| 31-Mar | 0.28 | 17.72 | 18 |
| **Total** | **41.23** | **516.77** | **558** |

# APPENDIX I. Stripping Operation May Time Utilisation

| May-24 | | | |
|---|---|---|---|
| **Date** | **Unplanned delays** | **DOH** | **Target DOH** |
| 1-May | 2.4 | 15.6 | 18 |
| 2-May | -1.5 | 19.5 | 18 |
| 3-May | -0.5 | 18.5 | 18 |
| 4-May | -3.2 | 21.2 | 18 |
| 5-May | 0.5 | 17.5 | 18 |
| 6-May | 0.3 | 17.7 | 18 |
| 7-May | -0.9 | 18.9 | 18 |
| 8-May | -0.5 | 18.5 | 18 |
| 9-May | -0.3 | 18.3 | 18 |
| 10-May | 1.34 | 16.66 | 18 |
| 11-May | -1.2 | 19.2 | 18 |
| 12-May | -0.7 | 18.7 | 18 |
| 13-May | -0.9 | 18.9 | 18 |
| 14-May | 3.1 | 14.9 | 18 |
| 15-May | 5.4 | 12.6 | 18 |
| 16-May | 1.5 | 16.5 | 18 |
| 17-May | 1.4 | 16.6 | 18 |
| 18-May | -0.6 | 18.6 | 18 |
| 19-May | -1.5 | 19.5 | 18 |
| 20-May | 1.7 | 16.3 | 18 |
| 21-May | 0.1 | 17.9 | 18 |
| 22-May | 2.4 | 15.6 | 18 |
| 23-May | 0.8 | 17.2 | 18 |
| 24-May | 1.5 | 16.5 | 18 |
| 25-May | 1.7 | 16.3 | 18 |
| 26-May | 0.2 | 17.8 | 18 |
| 27-May | 1.53 | 16.47 | 18 |
| 28-May | -0.2 | 18.2 | 18 |
| 29-May | 1.7 | 16.3 | 18 |
| 30-May | -1.5 | 19.5 | 18 |
| 31-May | -0.66 | 18.66 | 18 |
| **Total** | **25.07** | **544.59** | **558** |

## APPENDIX J. BFF Survey Report March 2024



Mbuyelo Coal (Pty) Ltd

**Survey Report**

**Manungu Colliery**

**Tshedza Mining Resources (PTY) Ltd.**

**Stripping Operation Project- Bucket Stockpiles**

| ADTs Stockpiles | Volume | Excavator Stockpiles | Volume |
|---|---|---|---|
| 1 | 12.12 | 1 | 3.2 |
| 2 | 12.78 | 2 | 3.25 |
| 3 | 13.10 | 3 | 3.01 |
| 4 | 12.66 | 4 | 3.12 |
| 5 | 12.45 | 5 | 3.18 |
| 6 | 12.87 | 6 | 3.22 |
| 7 | 12.89 | 7 | 3.4 |
| 8 | 13.05 | 8 | 3.38 |
| 9 | 12.42 | 9 | 3.12 |
| 10 | 12.35 | 10 | 3.44 |
| 11 | 10.20 | 11 | 2.8 |
| 12 | 10.85 | 12 | 3 |
| 13 | 10.23 | 13 | 3.1 |
| 14 | 10.18 | 14 | 2.99 |
| 15 | 9.66 | 15 | 3.2 |
| 16 | 10.04 | 16 | 2.98 |
| 17 | 9.50 | 17 | 2.99 |
| 18 | 9.71 | 18 | 3.01 |
| 19 | 10.07 | 19 | 3.08 |
| 20 | 9.42 | 20 | 3.09 |

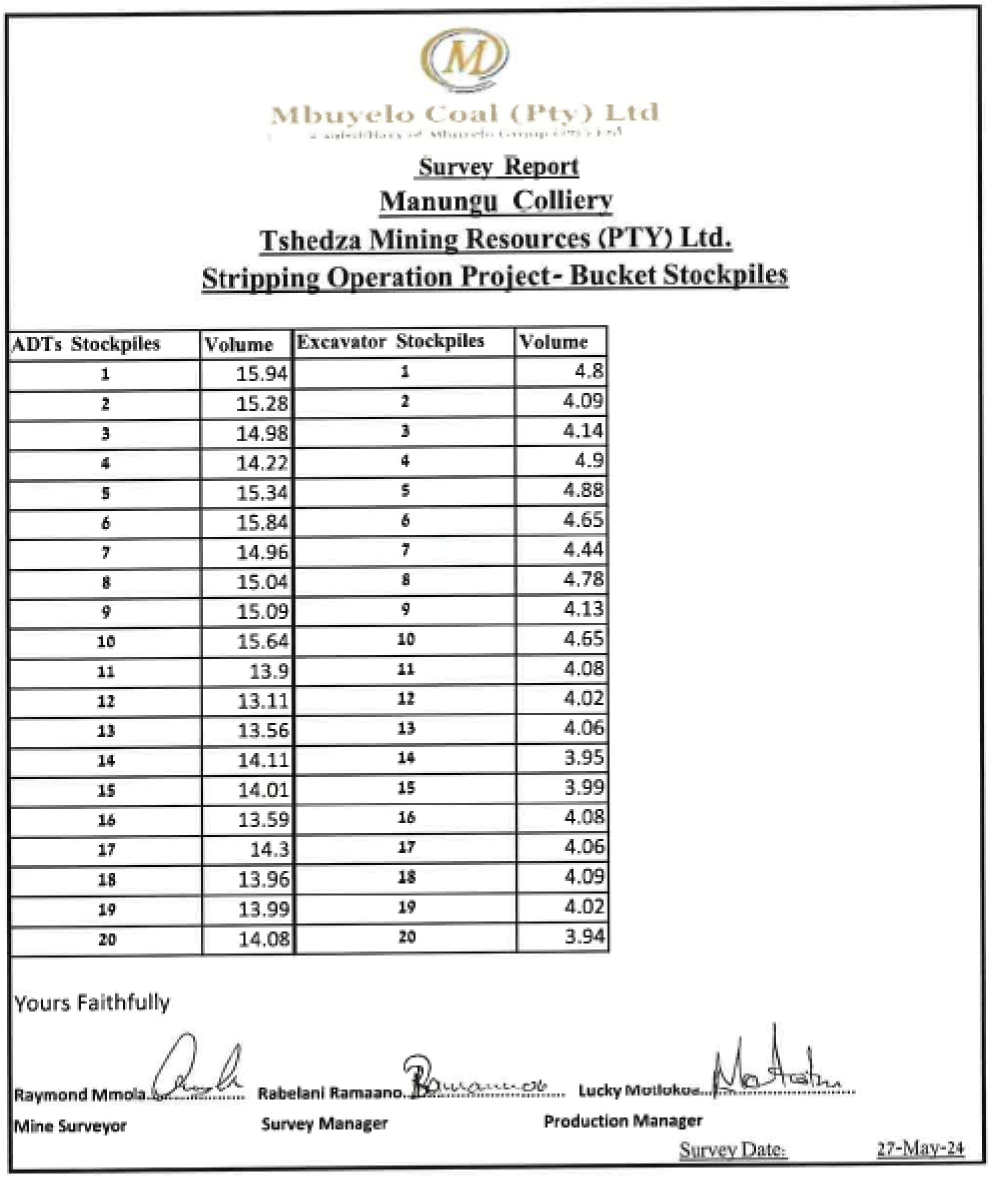
Yours Faithfully

Raymond Mmola........ Rabelani Ramaano.................. Lucky Motlokoa............................

Mine Surveyor Survey Manager Production Manager

Survey Date: 26-Mar-24

# APPENDIX K.  BFF Survey Report BFF May 2024



Mbuyelo Coal (Pty) Ltd

**Survey Report**

**Manungu Colliery**

**Tshedza Mining Resources (PTY) Ltd.**

**Stripping Operation Project- Bucket Stockpiles**

| ADTs Stockpiles | Volume | Excavator Stockpiles | Volume |
|---|---|---|---|
| 1 | 15.94 | 1 | 4.8 |
| 2 | 15.28 | 2 | 4.09 |
| 3 | 14.98 | 3 | 4.14 |
| 4 | 14.22 | 4 | 4.9 |
| 5 | 15.34 | 5 | 4.88 |
| 6 | 15.84 | 6 | 4.65 |
| 7 | 14.96 | 7 | 4.44 |
| 8 | 15.04 | 8 | 4.78 |
| 9 | 15.09 | 9 | 4.13 |
| 10 | 15.64 | 10 | 4.65 |
| 11 | 13.9 | 11 | 4.08 |
| 12 | 13.11 | 12 | 4.02 |
| 13 | 13.56 | 13 | 4.06 |
| 14 | 14.11 | 14 | 3.95 |
| 15 | 14.01 | 15 | 3.99 |
| 16 | 13.59 | 16 | 4.08 |
| 17 | 14.3 | 17 | 4.06 |
| 18 | 13.96 | 18 | 4.09 |
| 19 | 13.99 | 19 | 4.02 |
| 20 | 14.08 | 20 | 3.94 |

Yours Faithfully

Raymond Mmola.................. Rabelani Ramaano.......................... Lucky Motlokoa..........................

Mine Surveyor  Survey Manager  Production Manager

Survey Date: 27-May-24

# APPENDIX L. March Cycle Time

| March | T- Total cycle time | *td- dumping time* | *tte- travel time empty* | *twl- waiting time at loading area* | *tml- spotting time at loader* | *twd - waiting time at dump* | *tmd - manoeuvring time at dump area* | *tl - loading time* | *ttl - travel time loaded* |
|---|---|---|---|---|---|---|---|---|---|
| | **minutes** | | | | | | | | |
| 1 | 15.88 | 0.97 | 3.24 | 1.35 | 0.58 | 0.35 | 0.88 | 3.50 | 5.01 |
| 2 | 13.61 | 0.98 | 3.44 | 0.91 | 0.75 | 0.22 | 0.78 | 2.33 | 4.2 |
| 3 | 12.26 | 0.78 | 3.33 | 0.98 | 0.44 | 0 | 0.2 | 2.41 | 4.12 |
| 4 | 13.11 | 0.88 | 3.66 | 1.09 | 0.66 | 0 | 0.1 | 2.54 | 4.18 |
| 5 | 13.01 | 0.96 | 3.84 | 0.78 | 0.99 | 0 | 0.21 | 1.9 | 4.33 |
| 6 | 11.68 | 0.56 | 3.4 | 0.81 | 0.4 | 0 | 0.1 | 2.1 | 4.31 |
| 7 | 16.19 | 0.99 | 3.38 | 0.92 | 0.66 | 1.1 | 1.8 | 2.35 | 4.99 |
| 8 | 13.99 | 0.85 | 3.55 | 1.24 | 0.88 | 0 | 0.12 | 3.2 | 4.15 |
| 9 | 11.76 | 0.76 | 3.4 | 1.28 | 0.45 | 0 | 0.18 | 1.8 | 3.89 |
| 10 | 14.71 | 0.92 | 3.25 | 1.94 | 0.68 | 0.44 | 1.1 | 1.6 | 4.78 |
| 11 | 13.94 | 0.89 | 3.12 | 1.28 | 0.58 | 0 | 0.14 | 3.4 | 4.53 |
| 12 | 12.31 | 0.88 | 3.28 | 0.76 | 0.59 | 0 | 0.13 | 1.89 | 4.78 |
| 13 | 14.2 | 0.85 | 3.18 | 1.34 | 0.78 | 0 | 0.1 | 3.5 | 4.45 |
| 14 | 14.01 | 0.99 | 3.51 | 1.56 | 0.3 | 0.24 | 0.88 | 1.88 | 4.65 |
| 15 | 12.91 | 0.95 | 3.1 | 0.81 | 0.5 | 0.12 | 0.35 | 1.98 | 5.1 |
| 16 | 15.14 | 0.65 | 3.45 | 1.25 | 0.48 | 0.45 | 0.98 | 3.2 | 4.68 |
| 17 | 14.09 | 0.98 | 3.31 | 0.9 | 0.52 | 0.38 | 0.92 | 2.1 | 4.98 |
| 18 | 13.53 | 0.88 | 3.46 | 0.84 | 0.47 | 0.29 | 0.84 | 1.98 | 4.77 |
| 19 | 13.5 | 0.9 | 3.22 | 0.98 | 0.49 | 0.18 | 0.78 | 2.3 | 4.65 |
| 20 | 12.7 | 0.87 | 3.16 | 1.4 | 0.67 | 0 | 0.12 | 1.98 | 4.5 |
| 21 | 15.79 | 0.89 | 3.41 | 0.88 | 0.71 | 0.98 | 1.65 | 2.4 | 4.87 |
| 22 | 16.08 | 0.97 | 3.14 | 0.89 | 0.64 | 1.2 | 1.98 | 2.5 | 4.76 |
| 23 | 15.01 | 0.77 | 3.04 | 1.36 | 0.85 | 0.1 | 0.28 | 3.5 | 5.11 |
| 24 | 14.67 | 0.88 | 3.67 | 1.41 | 0.65 | 0 | 0.14 | 3.7 | 4.22 |
| 25 | 14.39 | 0.78 | 3.2 | 1.1 | 0.98 | 0 | 0.11 | 2.98 | 5.24 |
| 26 | 13.2 | 0.89 | 3.22 | 1.56 | 0.87 | 0 | 0.1 | 1.88 | 4.68 |
| 27 | 12.39 | 0.75 | 3.14 | 0.85 | 0.76 | 0 | 0.12 | 1.99 | 4.78 |
| 28 | 17.86 | 0.98 | 3.24 | 1.32 | 0.88 | 1.2 | 1.9 | 3.5 | 4.84 |
| 29 | 16.49 | 0.69 | 3.31 | 1.34 | 0.45 | 0.8 | 1.6 | 3.44 | 4.86 |
| 30 | 15.84 | 0.95 | 3.67 | 1.18 | 0.72 | 0.67 | 1.3 | 2.9 | 4.45 |
| 31 | 14.27 | 0.94 | 3.18 | 1.01 | 0.68 | 0.35 | 0.7 | 2.6 | 4.81 |
| **Actual** | **14.14** | 0.87 | 3.34 | 1.14 | 0.65 | 0.29 | 0.66 | 2.56 | 4.63 |
| **Target** | **10.36** | 0.55 | 2.35 | 0.85 | 0.60 | 0.25 | 0.40 | 2.01 | 3.35 |
| **Variance** | **3.78** | 0.32 | 0.99 | 0.29 | 0.05 | 0.04 | 0.26 | 0.55 | 1.28 |
| **% Variance** | **37%** | 58% | 42% | 34% | 8% | 17% | 66% | 27% | 38% |
| **Contribution to Variance** | | 8% | 26% | 8% | 1% | 1% | 7% | 15% | 34% |

# APPENDIX M. May Cycle Time

| May | T- Total cycle time | *td- dumping time* | *tte- travel time empty* | *twl- waiting time at loading area* | *tml- spotting time at loader* | *twd - waiting time at dump* | *tmd - manoeuvring time at dump area* | *tl - loading time* | *ttl - travel time loaded* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.43 | 0.57 | 1.75 | 0.55 | 0.67 | 0.21 | 0.02 | 1.83 | 3.83 |
| 2 | 9.69 | 0.5 | 2.31 | 0.89 | 0.72 | 0.2 | 0.06 | 1.79 | 3.22 |
| 3 | 10.37 | 0.59 | 2.3 | 0.89 | 0.54 | 0.19 | 0.09 | 2.1 | 3.67 |
| 4 | 9.84 | 0.61 | 2.32 | 0.89 | 0.68 | 0.21 | 0.06 | 1.7 | 3.37 |
| 5 | 10.02 | 0.54 | 2.38 | 0.77 | 0.42 | 0.2 | 0.01 | 1.99 | 3.71 |
| 6 | 9.63 | 0.62 | 2.01 | 0.51 | 0.49 | 0.21 | 0.19 | 1.85 | 3.75 |
| 7 | 8.85 | 0.58 | 1.98 | 0.57 | 0.67 | 0.21 | 0 | 1.74 | 3.1 |
| 8 | 9.16 | 0.5 | 2.11 | 0.5 | 0.6 | 0.19 | 0.03 | 1.98 | 3.25 |
| 9 | 9.5 | 0.6 | 2.12 | 0.66 | 0.53 | 0.19 | 0.08 | 1.97 | 3.35 |
| 10 | 10.01 | 0.54 | 2.48 | 0.53 | 0.43 | 0.19 | 0.12 | 1.98 | 3.74 |
| 11 | 9.88 | 0.61 | 2.47 | 0.64 | 0.55 | 0.2 | 0.18 | 1.78 | 3.45 |
| 12 | 10.03 | 0.56 | 2.44 | 0.5 | 0.56 | 0.2 | 0.08 | 1.97 | 3.72 |
| 13 | 10.08 | 0.55 | 2.23 | 0.83 | 0.7 | 0.2 | 0.01 | 1.82 | 3.74 |
| 14 | 9.82 | 0.51 | 2.06 | 0.74 | 0.52 | 0.21 | 0.06 | 1.87 | 3.85 |
| 15 | 8.9 | 0.59 | 1.72 | 0.67 | 0.49 | 0.21 | 0.13 | 1.8 | 3.29 |
| 16 | 8.48 | 0.59 | 1.85 | 0.5 | 0.44 | 0.21 | 0.03 | 1.71 | 3.15 |
| 17 | 9.8 | 0.56 | 1.92 | 0.63 | 0.61 | 0.19 | 0.17 | 2.01 | 3.71 |
| 18 | 9.32 | 0.6 | 1.92 | 0.71 | 0.44 | 0.19 | 0.13 | 2.02 | 3.31 |
| 19 | 10.11 | 0.5 | 2.37 | 0.74 | 0.63 | 0.2 | 0.1 | 1.75 | 3.82 |
| 20 | 9.98 | 0.49 | 2.11 | 0.65 | 0.7 | 0.19 | 0.16 | 2.05 | 3.63 |
| 21 | 10.04 | 0.52 | 2.14 | 0.82 | 0.62 | 0.21 | 0.13 | 1.89 | 3.71 |
| 22 | 9.83 | 0.5 | 2.02 | 0.72 | 0.71 | 0.19 | 0.1 | 1.92 | 3.67 |
| 23 | 9.54 | 0.6 | 1.79 | 0.88 | 0.42 | 0.21 | 0.08 | 2.1 | 3.46 |
| 24 | 9.67 | 0.6 | 1.94 | 0.81 | 0.72 | 0.19 | 0.04 | 1.99 | 3.38 |
| 25 | 9.02 | 0.52 | 1.86 | 0.83 | 0.47 | 0.19 | 0.06 | 1.88 | 3.21 |
| 26 | 9.58 | 0.61 | 1.81 | 0.65 | 0.52 | 0.19 | 0.13 | 1.98 | 3.69 |
| 27 | 9.78 | 0.5 | 2.05 | 0.51 | 0.61 | 0.2 | 0.1 | 2.03 | 3.78 |
| 28 | 9.96 | 0.58 | 2.45 | 0.67 | 0.68 | 0.2 | 0.09 | 2.05 | 3.24 |
| 29 | 9.76 | 0.56 | 1.8 | 0.68 | 0.71 | 0.2 | 0.17 | 2.05 | 3.59 |
| 30 | 9.36 | 0.5 | 1.97 | 0.62 | 0.62 | 0.21 | 0.17 | 1.7 | 3.57 |
| 31 | 10.15 | 0.55 | 2.31 | 0.72 | 0.59 | 0.21 | 0.11 | 1.98 | 3.68 |
| **Actual** | **9.65** | **0.56** | **2.10** | **0.69** | **0.58** | **0.20** | **0.09** | **1.91** | **3.54** |
| **Target** | **10.36** | **0.55** | **2.35** | **0.85** | **0.60** | **0.25** | **0.40** | **2.01** | **3.35** |
| **Variance** | **-0.71** | **0.01** | **-0.25** | **-0.16** | **-0.02** | **-0.05** | **-0.31** | **-0.10** | **0.19** |
| **% Variance** | **-7%** | **1%** | **-11%** | **-19%** | **-3%** | **-20%** | **-77%** | **-5%** | **6%** |