OPTIMISATION OF MINING LOGISTICS AT SIYANDA BAKGATLA SPUD SHAFT INCLINES PRODUCTION SECTIONS

By

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Submitted in accordance with the requirements

for the degree of

MASTER OF ENGINEERING

at the

UNIVERSITY OF SOUTH AFRICA

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September 2025

DECLARATION

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W.B. Motlhabane — 07 September 2025

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DEDICATION

I dedicate this work to my family and children, whose time was taken up and mostly sacrificed for this task.

ACKNOWLEDGEMENTS

I would like to first express my sincere gratitude to God Almighty, for the gift of life, good health, grace, and mercy always.

I would also like to thank my family and children for being my motivation.

I also extend my gratitude to my supervisor, Prof Francois Mulenga. This work has been possible because of his constructive feedback, guidance, and expertise.

Lastly, I wish to thank the SIYANDA BAKGATLA management for awarding me a bursary to conduct this research. Secondly, for granting access to the mine which yielded the essential data upon which this work is based.

ABSTRACT

This dissertation investigated the core logistical issues contributing to the poor performance of Siyanda Bakgatla Spud shaft. The study was motivated by consistent underperformance at the mine.

To this end, data was collected through historical performance records, site observations, and meeting interviews with key managers. The analysis entailed statistical techniques and root cause analysis across operational problem categories. These included support installation, drill and blast, equipment, technical services, safety, cleaning, geology, materials and human resources. The following software packages were used for data analysis, Microsoft® Excel®, and RStudio®.

Results revealed a consistent trend of underperformance. The operational inefficiencies are primarily driven by logistical challenges in support installation for stopping and technical services in development. The consistent underperformance relative to planning targets in both stopping (square meters achieved) and development operations (primary metres). Lost blasts are more frequent in stoping operations and are closely associated with delays in support installation practices, equipment breakdowns and poor execution of the drilling and blasting cycle. Similarly, in development, the impact of technical services-related issues, particularly engineering, also contributes significantly to lost blasts.

The root cause analysis has identified gaps in drilling and blasting, support installation, cleaning workflows, geotechnical assessments, equipment reliability, workforce management, supply chain, safety compliance and technical services. Key recommendations include reviewing and auditing current systems on support installation, technical services, drill and blasting, equipment, supply chain, cleaning, geotechnical and safety.

This research contributes to mining logistics by providing a structured framework for analysing and addressing logistical inefficiencies in underground mining environments. The findings have immediate practical implications for Spud Shaft and offer a foundation for further research into system audits, equipment utilization, labour utilisation and maintenance practices.

Keywords: Optimization, logistical inefficiencies, productivity, root cause analysis, lost blasts

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ACRONYMS AND SYMBOLS

Adv	Advance Metres (used for Book Adv, Plan Adv)
DB	Drilling and Blasting
DMPR	Department of Mineral and Petroleum Resources
FOG	Fall of Ground
HR	Human Resources
LHD	Load-Haul-Dump machine
PGMs	Platinum Group Metals
Plan Var	Planned Variance
Pot Var	Potential Variance
RCA	Root Cause Analysis
SBPM	Siyanda Bakgatla Platinum Mine
SQM	Square Metres (used for Book SQM, Plan SQM)
Tech Serv	Technical services
UG2	Upper Group 2 chromitite reef

Chapter 1 Introduction

1.1 Background of the research

Spud shaft is part of the Union mine which is owned by Siyanda Resources and the Bakgatla-Ba-Kgafela Joint Venture. The Union mine was acquired from Anglo American Platinum effective from 1 February 2018. It is located in Swartklip, Northam, Limpopo province in South Africa. The union mine includes the Spud and Richard shafts. The main access to the mining operation is via a vertical shaft nearly 1200 m deep, i.e., down 20 levels. There are three declines below the shaft bottom reaching a depth of 2 100m to access deeper reserves. One of the three declines is dedicated to transporting mining personnel with chairlift systems. The other decline is for material using a rail-bound system. The third decline serves for ore transportation using both rail-bound and conveyor belt systems.

Anglo American has extensively mined the Platinum-bearing Merensky reef for over 20 years. When Siyanda took ownership of the mine in February 2018, only the UG2 reef was left to be mined. The stratigraphy of the mine is shown in Figure 1.1.

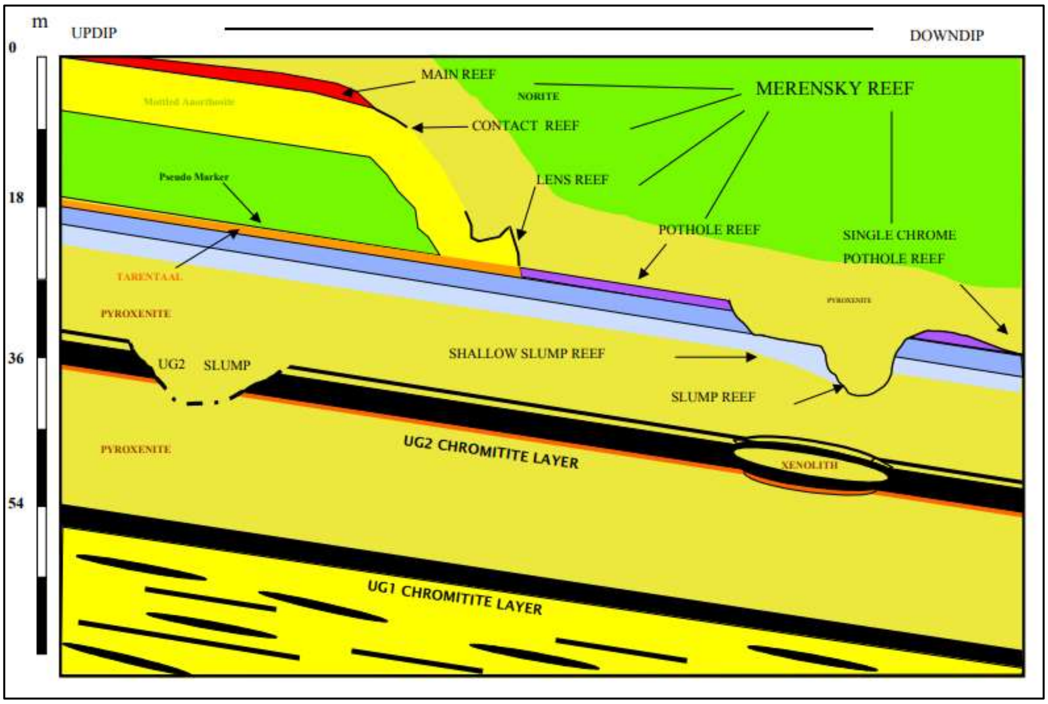


Figure 1.1: Simplified stratigraphy of Union mine (Union mine, 2024)

Figure 1.1 illustrates the general stratigraphy of the Union mine. The PGMs occur in two shallow-dipping orebodies (reefs): the Merensky reef and the Upper Group 2 (UG2) chromitite layer. The Merensky reef is a mineralized pyroxenite. It often forms depressions called potholes, where the reef rests lower than usual. Potholes vary in width and depth, complicating mining operations significantly. Three pothole subtypes exist: contact-type reef, pothole-type reef, and lens-type reef (Watson et al., 2024).

The UG2 Chromitite seam lies 12 m to 400 m beneath the Merensky reef. It is consistently distributed but often shows gentle undulations, rolls, and local potholes. Dips of both reefs range between 3° and 27°, depending on location. Faults, dykes, and structural disturbances frequently affect both orebodies across the mining area (Watson et al., 2024).

Figure 1.2 gives a snapshot of the cumulative performance of the mine as of July 2023. It can be seen that the bar chart compares the cumulative planned tonnage (Progressive Call) against the actual tonnage achieved (Progressive Actual) across four key production sections in July 2023. In every case, actual production fell short of the plan. The underperformance seen in Figure 1.2 may be attributed to recurring logistical bottlenecks that constrain the mining cycle activities such as drilling, blasting, cleaning and support. These operational inefficiencies accumulate, causing sections to consistently underperform against their targets, which justifies the need for systematic research into logistics optimization.

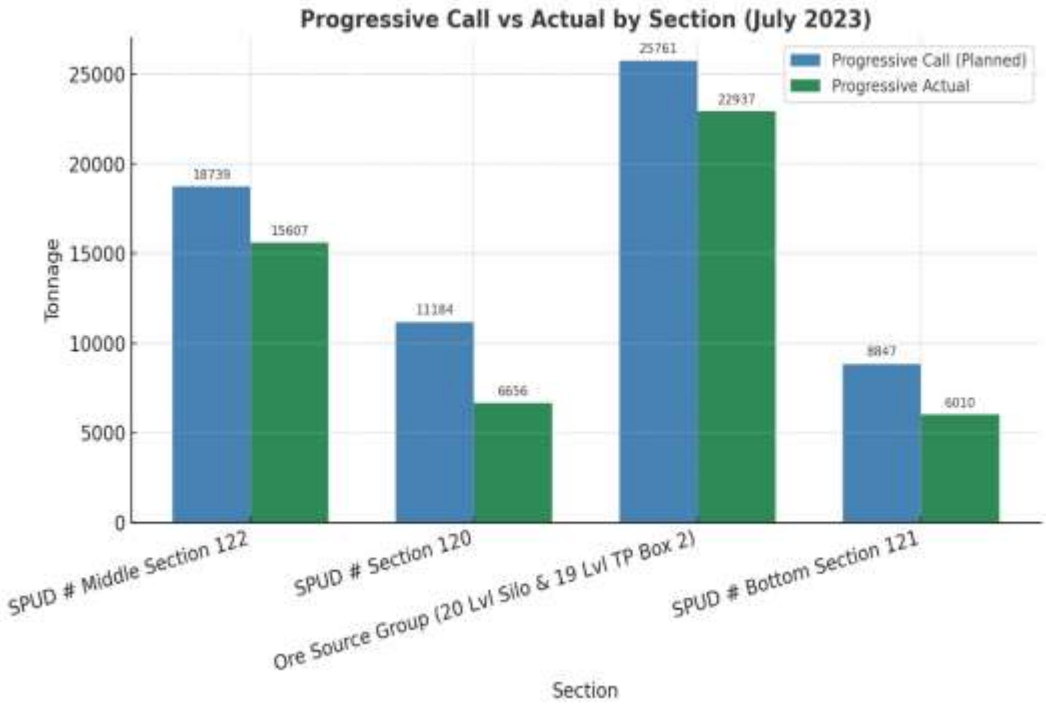


Figure 1.2: Representative cumulative performance of Spud Shaft as of July 2023 showing Planned production (Progressive Call) versus actual production by section (Union mine, 2024).

For this reason, the mine has decided to launch a scientific enquiry into the challenge/s associated with the underperformance noted in Figure 1.2. The focus of the research is limited to the sections below 20 level. These are the levels serviced by the declines. The basic mining layout at Spud shaft is a conventional narrow reef type with raise development and breast mining panels. This is later shown in Figure 3.3 of Chapter 3.

The basic mining processes (stages) of the mine is shown in Figure 1.3. It can be seen from this workflow that the cycle starts with planning, followed by the procurement and allocation of personnel, materials, and services. Once resources are in place, panel preparation and support installation take place. The cycle then proceeds to drilling and blasting. After blasting, ore is cleaned through face and gully scrapers, moving broken rock into the ore pass. From there, hoppers collect the ore and transport it by tramming on rail to conveyor belt chutes. Finally, the ore is hauled out via the conveyor belt system from the decline sections, completing the cycle.

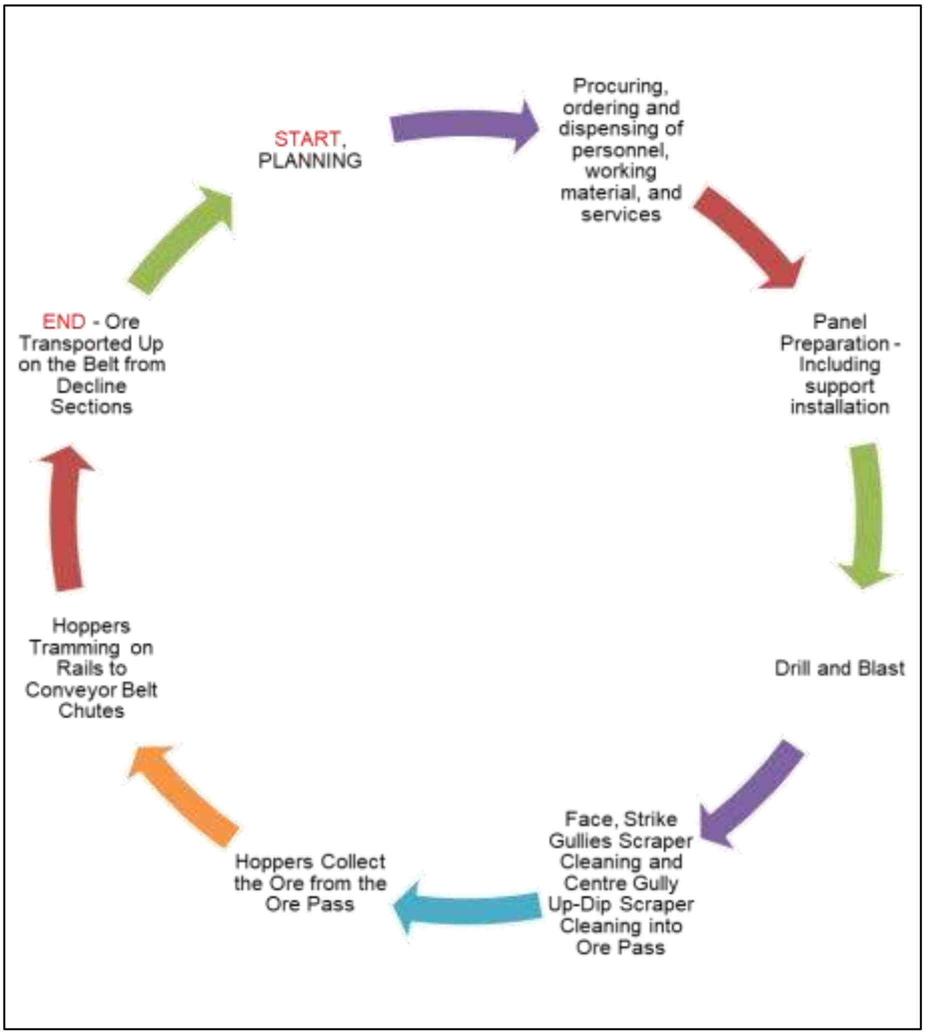


Figure 1.3: Mining process cycle at the decline sections of the Spud shaft

It is understood that underperformance may originate from one or more of the activities identified in Figure 1.3. That is why the logistics of these processes or stages leading up to ore being hoisted were studied in this research project. Site visits and physical observations were conducted to understand these processes in practice and at the same time collect relevant data. The data was then processed and analysed to determine any trends that may reveal logistical bottlenecks in this process flow (i.e., Figure 1.3). Finally, the study also aimed to establish a baseline for improving mining logistics at Spud shaft.

The mining industry is undergoing significant transformation driven by increasing cost pressures, declining ore grades, and heightened global competitiveness (Sánchez and Hartlieb, 2020). The integration of Industry 4.0 technologies, including real-time monitoring systems, digital production tracking, and data-driven decision-making platforms, has intensified the focus on operational efficiency (Bisschoff and Grobbelaar, 2022). In capital-intensive platinum mining operations, productivity shortfalls directly affect operational viability, necessitating systematic approaches to identifying and mitigating operational inefficiencies. Within this broader context, investigations into production variance, lost blasts, and logistical disruptions are increasingly relevant, not only at a site-specific level but also within the wider discourse on sustainable and efficient mining operations.

1.2 Problem statement

In recent times, mining operations have been plagued by increasing operational costs and low productivity. Neingo and Cawood (2014) argued that some of the trends can be lowered by acute managerial skills to turn the inputs into quality outputs. They also highlighted the fact that little effort is made to quantify outputs from inputs such as labour productivity, capital allocation, and mining method efficiency. And when assessing where South Africa stands in terms of productivity, several issues were identified particularly in the platinum sector as unique factors affecting mining productivity. However, Neingo and Tholana (2016) pointed out that legal compliance and labour unrest were the most important. Labour unrest was arguably singled out as hampering continuity and production momentum. Furthermore, with the trend of increasing unit costs, concordant studies are now recommending for mining methods and labour productivity to be constantly revisited and refined to meet escalating costs. Ndlovhu and

Chilese (2020) contended that central to high mining productivity is firstly the optimisation of supervision and maintenance; secondly, technological innovations and continuous enhancements; and lastly, efficient implementation of strategic and tactical plans. The group of researchers explained that the three aforementioned factors must be assimilated and harmonized to work jointly to improve mining productivity. Spud shaft seems to fit the picture alluded to above with continued underperformance likely to result in job losses or mine closure. A scientific enquiry was therefore initiated to gain a better understanding of the causes of low productivity. The idea is then to make informed decision in terms of remedial actions.

1.3 Aim and objectives of the research

The aim of this study was to investigate the core logistical issues contributing to the underperformance and low productivity of the Siyanda Bakgatla Spud shaft.

Failure to meet production targets is a key concern, often indicating misalignment between business and logistical models (Burger et al., 2019). And a major cause for concern to this situation is the constant threat to the survival of the mining business itself. It is therefore necessary for the mine to revisit and study all mining processes involved and their inter-relationship. This is to help determine how these processes bring about poor results. Furthermore, the causes of inefficient processes need to be determined and quantified in terms of their individual contribution to the underperformance of mine. It is in line with the plan of the mine to address the problem that three research objectives were formulated for this study:

- To investigate and outline the logistical problems contributing to the low productivity of the Siyanda Bakgatla Spud shaft.
- To establish intervention strategies that would set the mine back onto a productive course.
- To recommend practical implementation strategies aimed at steadily improving the mine value chain.

Based on the objectives presented above, the guiding research question is as follows: What are the logistical problems contributing to low productivity and underperformance at Siyanda Bakgatla Spud shaft?

The research question is particularly relevant below the 20 level, where there the underperformance (Figure 1.2) provides evidence of prevalence of logistical bottlenecks. Understanding these constraints provides a basis for investigating how each factor contributes to the underperformance of the Spud Shaft and for identifying targeted solutions.

1.4 Scope and limitations of the research

This research is focused on investigating the core logistical issues contributing to low productivity at Siyanda Bakgatla. The issues are identified within the 7 key processes of the mining cycle illustrated in Figure 1.4. By conducting a detailed root cause analysis, the study aims to uncover operational inefficiencies and outline targeted recommendations for logistical optimization in order to bridge the gap between planned and actual production outcomes.

However, this research has certain limitations. In this study, optimisation is conceptualised as process improvement achieved through the systematic identification and mitigation of inefficiencies rather than through the application of prescriptive mathematical optimisation models. Given the capital-intensive nature of mining operations, proposed operational changes are typically justified through demonstrated financial benefit. While this study focused on identifying and analysing logistical inefficiencies and their production impacts, the integration of financial performance indicators would enable a more comprehensive evaluation of cost-efficiency improvements. Accordingly, the findings of this research provide a structured baseline upon which future cost-based or model-driven optimisation studies may be developed.

The study is confined to below the 20th level of the Spud shaft and may not fully capture the complexities or constraints present in other environments of the mine. Additionally, data was limited to historical performance records and current operational observations within a specific time frame. Historical records spanned between March 2023 to February 2024 and March 2024 to May 2024. Operational observations were collected in January 2025 over a period of six months. The latter potentially limited the ability of the study to capture long-term operational variability.

Although operational production and process performance data were available for analysis, detailed supply chain financial data was not accessible within the defined scope of this research. Consequently, the study did not extend to cost-benefit modelling or quantitative financial optimisation techniques. The investigation therefore concentrated on identifying and analysing operational inefficiencies and their measurable production impacts. Future research incorporating financial performance metrics and cost modelling could build upon this foundation to develop a fully integrated cost-efficiency optimisation framework.

Despite these limitations, the research study provides a comprehensive analysis of logistical issues specific to the operational context of the mine thereby offering a framework for continuous improvement.

1.5 Contribution to the body of knowledge

This research contributes to mining logistics by systematically analysing inefficiencies in an underground environment. This thematic area has received limited attention in mining engineering studies. By identifying specific inefficiencies, the research sheds light on how these logistical aspects impact productivity and performance in complex underground settings.

The findings provide a basis for developing targeted strategies for logistical optimization, which can serve as a reference for similar operations facing productivity challenges. In addition to this, the research study lays the groundwork for future studies in predictive maintenance, workforce management, and system audits. This then encourages a holistic approach to analysing and optimizing underground mining productivity. Finally, the findings of this study have the potential to contribute to best practices in similar underground mining settings.

1.6 Organization of the dissertation

This dissertation is organized into six chapters as outlined below.

Chapter 1 introduces the study by outlining the background, problem statement, research objectives, and the scope and limitations of the work. It also highlights the contribution of the study to the field of mining logistics and production optimisation.

Chapter 2 is a review of the existing literature on mining logistics. The chapter begins with an overview of mining logistics, highlighting its evolution from a support activity to a strategic function that directly influences productivity. It then examines the importance of optimizing logistics, with a focus on methods such as simulation, mathematical programming, and scheduling algorithms that have been applied in underground mining contexts. The chapter further discusses factors that constrain mine logistics and contribute to underperformance, such as poor blasting, equipment failures, inadequate cleaning, delays in support installation, geotechnical challenges, shortages of critical materials, and human resource constraints. Gaps are eventually highlighted to situate the study within the broader context of underground logistics optimisation.

Chapter 3 presents the research methodology, Siyanda Bakgatla Spud shaft as the case study, data sources and associated collection protocols, categorisation of operational problems, and the data analysis techniques used. The latter include descriptive statistics, frequency analysis, and root cause analysis (RCA) supported by the RStudio® software tool for data processing and visualisation.

Chapter 4 presents the results of the analysis. It quantifies performance in stoping and development, highlights the frequency and impact of lost blasts, and identifies the most disruptive problem categories. Correlation analysis and RCA are used to assess the operational dynamics contributing to underperformance.

Chapter 5 interprets the results from Chapter 4. It links each key finding to underlying causes and practical consequences for production. The chapter also contextualises the results within current literature and forms the basis for proposed strategies for improved mine logistics.

Chapter 6 provides an overall conclusion and actionable recommendations to address the identified logistical inefficiencies. It also offers suggestions for future research, including system audits, predictive maintenance, and workforce optimisation in similar underground mining operations.

Chapter 2 Literature review

2.1 Introduction

The purpose of this literature review is to locate the present study within existing knowledge. The review allows the identification of previous scholarship that explain how logistics affects mining performance. In mining, logistics is central to the success of production systems. Scholars have shown that poor logistics reduces advance rates, raises costs, and affects safety (Greberg et al., 2016; Rahimdel and Mohammadpour, 2025). Reviewing the literature is therefore essential to understand existing knowledge, evaluate optimisation methods, and highlight gaps relevant to underground mining.

Logistics is more than the movement of ore. It includes the flow of people, equipment, materials, energy, and information across interconnected subsystems that make up the mining cycle (Hartman, 1992; Rahimdel and Mohammadpour, 2025).

The significance of mine logistics is widely acknowledged. Studies show that logistics accounts for more than half of operational costs and remains a primary determinant of productivity, safety, and profitability (Greberg et al., 2016; Fioroni et al., 2014). Logistics inefficiencies also explain why actual mining performance often diverges from planned production, with delays in drilling, blasting, cleaning, and support installation leading to measurable underperformance (Neingo and Cawood, 2014; Sebutsoe and Musingwini, 2017).

Research further highlights that logistics failures are rarely isolated. A breakdown in drilling equipment, for example, reduces blasting efficiency, which in turn delays cleaning and hauling. Similarly, inadequate support installation can halt production and increase safety risks. These interdependencies show why logistics optimisation must be addressed as an integrated system rather than through isolated fixes (Rakiz et al., 2023; Koptev and Kopteva, 2025).

This chapter reviews the literature on mining logistics in five parts. Section 2.2 introduces the basic concepts and roles of mining logistics. Section 2.3 discusses the importance of optimising logistics in underground mines. Section 2.4 reviews methods and tools used for optimisation. Section 2.5 evaluates the main logistical constraints that contribute to underperformance in underground mines. Section 2.6 synthesises the review and identifies knowledge gaps that justify this study.

2.2 Basic concepts of mining logistics

Early work treated logistics as part of material handling primarily focussing on moving ore and waste rock (Hartman, 1992). Modern scholarship sees mining logistics as an integrated system that includes ore transport, personnel movement, supply chains, equipment handling, utilities, and information management (Rahimdel and Mohammadpour, 2025; Koptev and Kopteva, 2025).

Logistics in underground mines covers both horizontal and vertical transport. Horizontal transport includes trucks, conveyors, and rail systems, each with distinct advantages and constraints (Rupprecht, 2019). Vertical transport depends on hoisting systems, which are complex, capital intensive, and critical for safety and production reliability (Hou et al., 2022).

These transport systems are tightly linked. If one subsystem fails, the entire production cycle is affected. For example, poor blasting delays cleaning, which blocks tramming, which in turn overloads hoisting. This interdependence means that logistics must be planned and optimised as a whole rather than through isolated fixes (Rakiz et al., 2021; Ambriško et al., 2015).

Mining technical support services are also part of logistics. Ventilation, compressed air, water, and electricity underpin drilling, blasting, and hoisting. Interruptions in these services delay production and reduce efficiency (Darling, 2011).

Modern mines increasingly rely on information-driven logistics. Digital monitoring and analytics enable real-time visibility of equipment, ore flow, and service reliability (Bag et al., 2020). The adoption of such technologies is reshaping logistics into a strategic driver of efficiency and safety.

The integrated nature of mining logistics means that each subsystem such as transportation, utilities, support services, and monitoring systems together determine whether planned production is achieved. Therefore, a clear understanding of this integrated role is necessary but also the importance of optimisation.

2.3 Importance of optimising mining logistics

Logistics is one of the largest cost drivers in underground mining. Studies show that logistics can account for more than half of total operating costs (Rahimdel and Mohammadpour, 2025). In underground deep mines, where profit margins are narrow, inefficiencies in logistics quickly translate into lost production and higher costs (Greberg et al., 2016).

As mines deepen, logistics becomes more complex. Longer haul distances, and tighter safety requirements create bottlenecks that restrict face availability and reduce advance rates (Fioroni et al., 2014). For example, poor alignment between drilling, blasting, and cleaning increases cycle times and reduces the number of blasts per month. These inefficiencies also increase exposure to risks such as rockfalls and winch accidents (Rupprecht, 2019; Moseme, 2003).

Optimisation of logistics improves efficiency across the production cycle. It lowers unit costs, reduces bottlenecks, and increases throughput (Rakiz et al., 2023; Belov et al., 2020). Improved scheduling and better alignment between subsystems allow mines to meet targets more consistently and reduce variance between planned and actual production (Neingo and Cawood, 2014; Sebutsoe and Musingwini, 2017).

Another important dimension of optimisation is adaptability. Mines must respond to variable ore grades, equipment failures, and labour shortages. Flexible logistics systems allow operations to shift production areas and reallocate resources when disruptions occur (Musingwini, 2007). Without such flexibility, even well-designed plans underperform.

Finally, optimised logistics enhances safety. Efficient transport, reliable support, and proper sequencing reduce accident risks. Safety stoppages, while necessary, are costly. Better planning and monitoring reduce the need for full evacuations and minimise unplanned downtime (Ferreira et al., 2025).

It can be concluded that optimisation of mining logistics is a core determinant of productivity, profitability, and safety in underground mines. Therefore, it is necessary to also understand the available optimization methods and tools.

2.4 Methods and tools for logistics optimisation

Greenhill (1984) explained that the success of a business entity depends on the ability of management to make the right and integrated decisions in sufficient time for the company goals to be achieved. This requires management to review and interrogate, at regular intervals, changes in internal and external factors that could affect the performance of the company. The goal of such an undertaking aimed at integrated logistics is always to find the best layout, the best model, or the best mechanism option to achieve the scheduled production using the lowest capital investment.

Logistics optimisation in mining has advanced through a range of methods. These include simulation, artificial intelligence, mathematical programming, scheduling algorithms, and reliability analysis. Each method addresses constraints in transport, equipment, and planning. The methods aim to reduce delays and increase efficiency.

2.4.1 Simulation optimization methods

Simulation models allow mines to test multiple scenarios without committing resources. Discrete event and Monte Carlo simulations are widely applied to study truck–loader allocation and ore transport uncertainties (Fioroni et al., 2014; Hou et al, 2022). Event-based simulation also helps analyse equipment breakdowns and rescheduling options, supporting better utilisation of limited fleets (Li et al., 2022). Although powerful, simulation requires skilled modelling and can produce varied results if not calibrated correctly (Dindarloo and Siami-Irdemoosa, 2016).

Fioroni et al. (2014) propounded event simulation methods as useful tools that allow for testing and sensitivity analysis of scenarios without actually committing resources. And although simulation tools have proven their usefulness, caution should be exercised in their use. For instance, stochastic, deterministic and experimental model simulations can result in different outputs regardless of the quality of the software package used. Dindarloo et al. (2016) suggested that it is prudent to start by devising a simulation framework to obtain nearly similar outputs for the same inputs regardless of the technique used. Furthermore, they warn against high skill level requirements to construct a model as well as time-consuming tendencies, difficult interpretation and misappropriate use of simulation methods. They proposed the general simulation framework in Figure 2.1 below that must be customized for specific project.

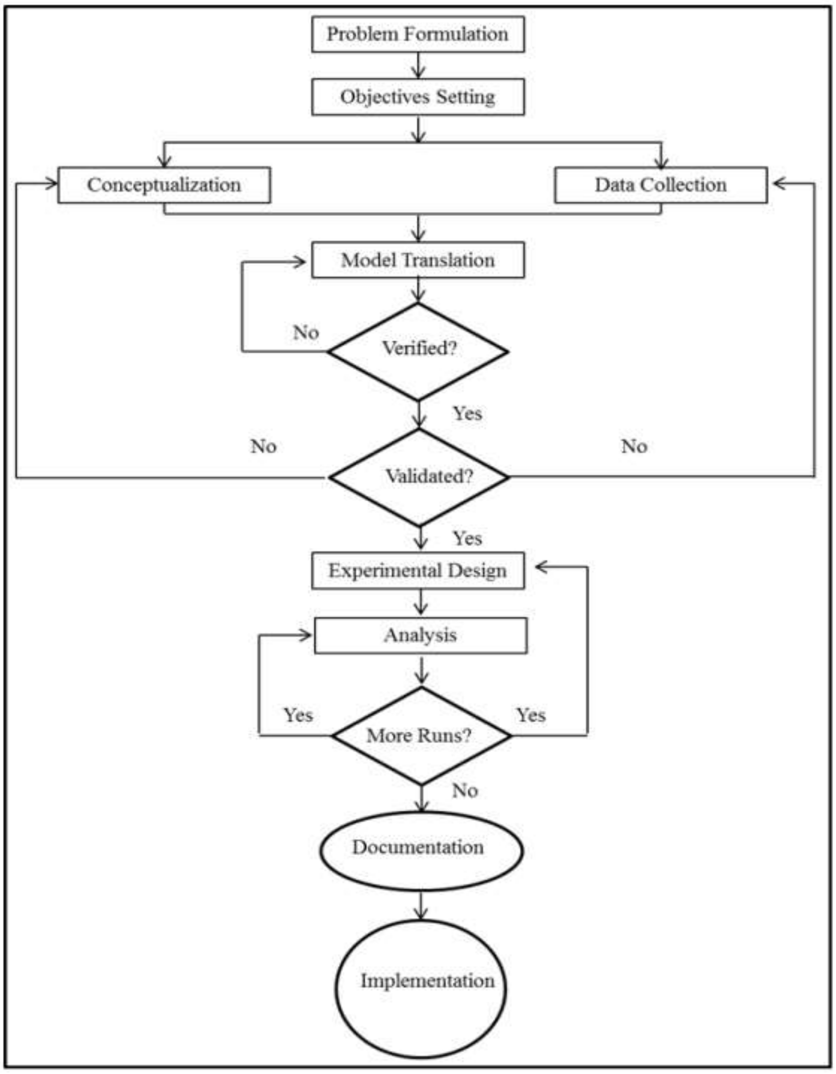


Figure 2.1: General simulation flowchart (Dindarloo and Siami-Irdemoosa, 2016)

Figure 2.1 outlines the steps involved in a general simulation framework. The process begins with problem formulation and setting of objectives, which ensure clarity on what the model aims to achieve. Conceptualization and data collection then provide the foundation for translating the problem into a workable model. The model must be verified to confirm that it has been built correctly and validated to ensure that it reflects reality. Once verified and validated, the model can be used in experimental design, followed by analysis of results and further runs if necessary. Finally, the framework emphasizes documentation and implementation, which are critical for applying simulation outcomes in real-world mining contexts.

2.4.2 Artificial intelligence and machine learning

Machine learning methods adapt to variability in ore grades, haul distances, and cycle times. Applications include optimisation of traffic flows, which have shown improvements in throughput of up to 18% and reductions in energy costs by 14% (Kadyrova et al., 2025). Digital twins combine real-time data with AI to forecast equipment availability and ore flow (Chimunhu et al., 2022). These tools allow operations to respond quickly to disruptions.

2.4.3 Scheduling algorithms

Optimisation algorithms refine activity sequencing and resource allocation. Genetic Algorithms are used to optimise both stope sequencing and equipment dispatching, reducing variance in tonnage and feed grade (Hou et al., 2020; Wang et al., 2020). Other approaches, such as the improved estimation of distribution algorithm, reduce waiting times and transport distances in haulage networks (Li et al., 2022). These methods directly address one of the main causes of underperformance: mismatched schedules and delayed cycles.

2.4.4 Mathematical programming

Mathematical programming supports integrated short- and medium-term planning. Mixed integer programming with flexible time discretisation can incorporate large numbers of activities and operational constraints (Campeau et al., 2022). Multi-stage optimisation models also account for ore grade variability, equipment limits, and blending requirements, providing more realistic production forecasts (Hou et al., 2024).

2.4.5 Reliability and risk assessment

Reliability tools ensure continuity of logistics systems under uncertain conditions. Fault Tree Analysis and Event Tree methods, often combined with fuzzy logic, evaluate the likelihood of equipment failure and its impact on production (Rahimdel and Mohammadpour, 2025). Continuous analysis of failure modes improves maintenance planning and reduces costly downtime.

2.4.6 Conveyor belt optimisation

Conveyor systems are a key part of underground logistics, especially in haulage networks where ore must be transported over long distances. Research has focused on improving both energy efficiency and operational reliability.

At a copper mine in Poland, Krol et al. (2017) proposed to improve conveyor belt systems by developing energy-efficient belts and optimized carrying idlers for new-generation conveyor belts. Their solutions were tested in a specially constructed laboratory. Operational parameters including loading, stresses, strains, energy dissipations, and belt tracking were monitored and recorded. The data collected was then compared to previously collected data on standard conveyors in situ. The results indicated a 20% improvement in the energy efficiency of the belt conveyors. This enabled the group of researchers to also develop an improved method for calculating belt conveyor resistance.

Marais et al. (2008) studied energy-saving mechanisms in South African mines. They tested the “Goodyear Easirider” flexible belt, which regained its shape faster past rollers, saving up to 12% in energy use. They also analysed variable speed drives and motor sequencing, which allowed conveyors to match demand more closely. Their work showed that regenerative braking and load shifting, when integrated with silo and bunker levels, reduced peak-period electricity costs.

Mechanical wear is another challenge. Conveyor belts are prone to damage, which can stop ore flow and delay hoisting. Qu et al. (2021) developed an adaptive deep convolutional network (ACDN) to detect belt tears more accurately than traditional infrared imaging. The ACDN method provided higher detection accuracy, faster results, and stronger generalisation in noisy environments.

These innovations show how conveyor optimisation can directly reduce energy costs, improve belt life, and sustain ore flow. In underground platinum mines, where haulage distances are increasing, such improvements help maintain continuous logistics and reduce bottlenecks.

In summary, optimisation tools provide different ways to manage uncertainty and improve production outcomes. This implies that, each optimisation method is most effective when linked to clear production outcomes. Therefore, it is necessary to understand the constraints that affect mining logistics and in turn lead to underperformance of mines.

2.5 Operational constraints that affect mining logistics

Logistics of most underground mines are constrained by the same factors that affect the mining cycle i.e., drilling, blasting, cleaning, support installation. The other constraints are equipment reliability, geotechnical conditions, safety, and essential services (Huerta et al., 2021). These constraints reduce system efficiency and explain much of the variance between planned and actual production. The underperformance of a mine is rarely due to a single issue. Instead, it arises from interacting constraints.

2.5.1 Mining cycle problems: drilling, blasting, cleaning, and support installation

Poor drilling accuracy and uneven charging cause overbreak, ore dilution, and irregular fragmentation. This disrupts mucking and hauling, raising costs, and increasing cycle times (Bennett et al., 2024; Pomasoncco-Najarro et al., 2022). Distorted face shapes further slow cleaning and require re-establishing layouts, which delays subsequent cycles (Seccatore et al., 2020).

Ineffective blasting also affects logistics directly. Hang-ups in ore passes and panel choking reduce material flow and require secondary blasting or mechanical clearing, interrupting transport schedules (Bennett et al., 2024). A lost blast is a specific event where a planned blasting operation fails to achieve its intended outcome (Magohe et al., 2022). This means that either blasting did not take place or if it happened then it had a poor outcome such as a misfire. Lost blasts directly reduce output and are a central driver of underperformance. To understand why lost blasts, occur, one first needs to understand what is required for a successful blast to take place. A successful blast requires three essential components: adequate preparation, sufficient resources (materials, equipment and crew) and standard execution. If any of these are substandard, a loss of blast is likely to occur. Minerals Council of South Africa (2019) explains that blast success depends on readiness at each step of the mining cycle.

In addition, blasting-induced stress waves weaken surrounding rock, raising support demands and further delaying advance (Li et al., 2022). These failures show how one inefficient step cascades across the logistics chain, lowering advance per cut and extending the production cycle.

Incomplete or delayed cleaning leaves broken ore and waste in stopes, obstructing tramming routes and ore passes. This not only delays new blasts but also increases the risk of hang-ups and production stoppages (Sebutsoe and Musingwini, 2017). Poor cleaning therefore interrupts both horizontal transport and vertical hoisting, reducing the number of blasts achieved per month.

Support systems stabilise excavations, protect workers, and maintain access routes. Delays in support installation can halt the cycle completely, as unsupported areas are unsafe for personnel and equipment (Moss and Kaiser, 2022). In narrow tabular platinum and gold mines, support rates must match advance rates. If not, production faces remain idle, reducing blasts achieved and creating logistical bottlenecks (Andrews, 2019).

2.5.2 Equipment failures, breakdowns, and material shortages

Mining equipment operates in harsh conditions that accelerate wear. Frequent breakdowns reduce availability of drilling, hauling, and cleaning machines, creating delays in ore flow and personnel movement (Hoseinie et al., 2018). Pneumatic drilling systems are especially inefficient due to low energy transfer, poor penetration, and high air consumption (Fraser, 2010; Van Zyl, 2013). Failures in compressed air supply also halt drilling, stalling the cycle. Equipment breakdowns disrupt logistics beyond the immediate equipment. A broken loader, for example, delays transport from the face, which blocks ore passes and forces rescheduling of hoisting (Antosz et al., 2022).

Heyns (2006) reported that the South African rail system in most underground mines is generally in a poor state. These substandard railways cause frequent derailments and accidents. In reaction to this, mines have been decreasing speed which has then hampered production. Heyns (2006) also pointed out prevalent tendency by the mines to ignore the commendable standards and maintenance of rail systems. This non-compliance can be attributed to the reluctance of mining companies to periodically cease production for maintenance purposes. Therefore, there is hardly any scheduled rail maintenance time; yet the creation of a sustainable production environment is closely related to consistent monitoring and maintenance (Antosz et al., 2022).

Services such as compressed air, water, power, and ventilation are vital for mining logistics. Poor air pressure reduces drilling penetration rates; low water pressure slows drilling and reduces dust suppression; power outages stop hoisting and ventilation fans, halting logistics entirely (Wet et al., 2014; Mashingaidze et al., 2025). Ventilation inefficiencies are also costly, as systems often run at peak demand regardless of actual need, consuming up to 40–60% of mine electricity (Chikande et al., 2023).

Interruptions in supply of critical materials such as support, explosives, fuel, and spare parts create delays across multiple subsystems. Without explosives, drilling and blasting stop; without spares, equipment downtime increases; without fuel, loaders and locomotives cannot operate. Each shortage reduces production reliability and raises costs through idle time and rescheduling (Rakiz et al., 2023).

2.5.3 Geotechnical conditions and safety problems

Poor ground conditions increase the need for reinforcement, slow down cycles, and raise safety risks. Seismicity and rock bursts can block access routes, damage haulage systems, and cause extended stoppages (Huo et al., 2022). Each geotechnical event disrupts not only production at the stope but also downstream logistics, including tramming and hoisting.

Safety stoppages, though necessary for legal compliance, are costly. Evacuations after seismic events can halt production for entire shifts, affecting both development and stoping cycles (Ferreira et al., 2025). Stoppages from Falls of ground, accidents or non-compliance with safety standards also cause downtime (Sadeghi et al., 2022).

Moseme et al. (2003) reported that scraper winch accidents in the gold mining sector account for 5% and 9% of platinum within all underground mine-related accidents.

2.5.4 Human resource challenges

Shortages of operators and absenteeism delay drilling cycles, reduce available blasts, and underutilise equipment (Kunkyin-Saadaari et al., 2024). Each missed cycle creates downstream effects on cleaning, tramming, and hoisting. Workforce instability therefore disrupts logistics not only at the face but across the system (Ghasemi et al., 2024).

2.5.5 Organisational and planning inefficiencies

Many mines use static or heuristic-based plans that cannot adapt to disruptions (Chimunhu et al., 2022). This lack of flexibility results in mismatched scheduling, idle time, and underperformance relative to targets (Gliwan and Crowe, 2022). Musingwini et al. (2007) proposed the Flexibility Index to measure the ability of mines to reallocate stopes and sustain output under changing conditions. Without adaptive planning, logistics failures cascade into persistent production shortfalls.

2.6 Concluding remarks

The literature shows that logistics is central to underground mining. It affects productivity, costs, safety, and long-term viability. Logistics failures are not isolated. Breakdowns in drilling, blasting, cleaning, and support installation disrupt the entire production cycle. Failures in services such as compressed air, water, and power compound these disruptions. Human resource shortages, absenteeism, and safety stoppages add further delays. Together, these factors explain much of the gap between planned and actual production in mines (Sebutsoe and Musingwini, 2017; Mashingaidze et al., 2025).

Several optimisation tools have been developed. Simulation models test alternative transport layouts. Machine learning methods improve scheduling and predict equipment failures. Mathematical programming integrates planning horizons. Reliability analysis supports maintenance systems (Chimunhu et al., 2022; Hou et al., 2024; Kadyrova et al., 2025). While these approaches have value, they are often applied in generic or international contexts. Many studies focus on coal mines or large mechanised operations, with limited studies on underground platinum mines in South Africa. Some innovations show how conveyor optimisation can directly reduce energy costs, improve belt life, and sustain ore flow.

Another gap is the limited linkage between logistics inefficiencies and measurable production outcomes. Studies often highlight individual failures, such as poor blasting or equipment downtime, but rarely quantify how these contribute to lost blasts, longer cycles, or plan variance. This weakens the practical relevance of many models for operational managers.

Finally, the literature recognises the importance of flexibility in planning but offers few practical measures for its application in underground platinum mines (Musingwini et al., 2007). Most existing frameworks remain static, making them poorly suited to dynamic underground conditions.

In summary, current literature highlights the importance of logistics but does not fully explain how its failures affect production in platinum mines. There is limited focus on integrated logistics analysis in South African operations, and little work quantifying the contribution of logistical inefficiencies to underperformance. Addressing these gaps is critical for improving

Chapter 3 Research methodology, data collection and analysis techniques

3.1 Introduction

This chapter details the research methodology used to investigate the core logistical issues contributing to underperformance at the Siyanda Bakgatla Spud shaft.

The chapter is structured into five parts. The first part describes the case study and its operational context at Siyanda Bakgatla Spud shaft. It includes an overview of the operational setup, the identified problem, and the context surrounding the identified problem that the research aims to address.

The second section is devoted to the rationale behind the chosen methodological approach in line with the objectives of the study. It discusses how the research design was tailored to effectively investigate the logistical issues at the mine. It also justifies the selection of methods used for data collection and analysis.

The third section focuses on the techniques and protocols used for data collection. It also covers the types, structures and sources of data gathered. Procedures for data cleaning and preparation are also covered in this section.

The fourth section describes the data analysis tools with associated software packages and analytical techniques employed in the study. The section also provides a rationale for the selection of these tools and techniques.

The final section reflects on the overall methodology, discussing what worked well, what did not, and the challenges faced during the research process. Limitations to the work done and adjustments made to the initial research plan to address unforeseen issues are also outlined.

3.2 Presentation of the case study

3.2.1 Operational set up of the mine

This study was conducted at the Spud shaft of the Union mine located in Swartklip, Limpopo province, Republic of South Africa. The location of the mine is shown in Figure 3.1. The Union mine comprises of both underground and surface mining operations extracting platinum group metals (PGMs). The mine is owned by Siyanda Bakgatla Platinum Mine (SBPM), a private company that focusses on the business of mining and processing PGMs. SBPM is a joint venture between Siyanda Resources (Pty) Ltd and Bakgatla-Ba-Kgafela Investment Holdings (SBPM, 2021). Siyanda Resources is a South African resources investment company formed in 2004. Its areas of interest are in PGMs, Chrome, Base Metals, Energy and Battery Metals (SBPM, 2021). Bakgatla-Ba-Kgafela Investment Holdings (BBKIH) is an investment vehicle for the Bakgatla-Ba-Kgafela tribe which resides in the North West province of South Africa under the Moses Kotane Local Municipality (SBPM, 2021). The Union mine was acquired from Anglo American Platinum effective from the 1st of February 2018.

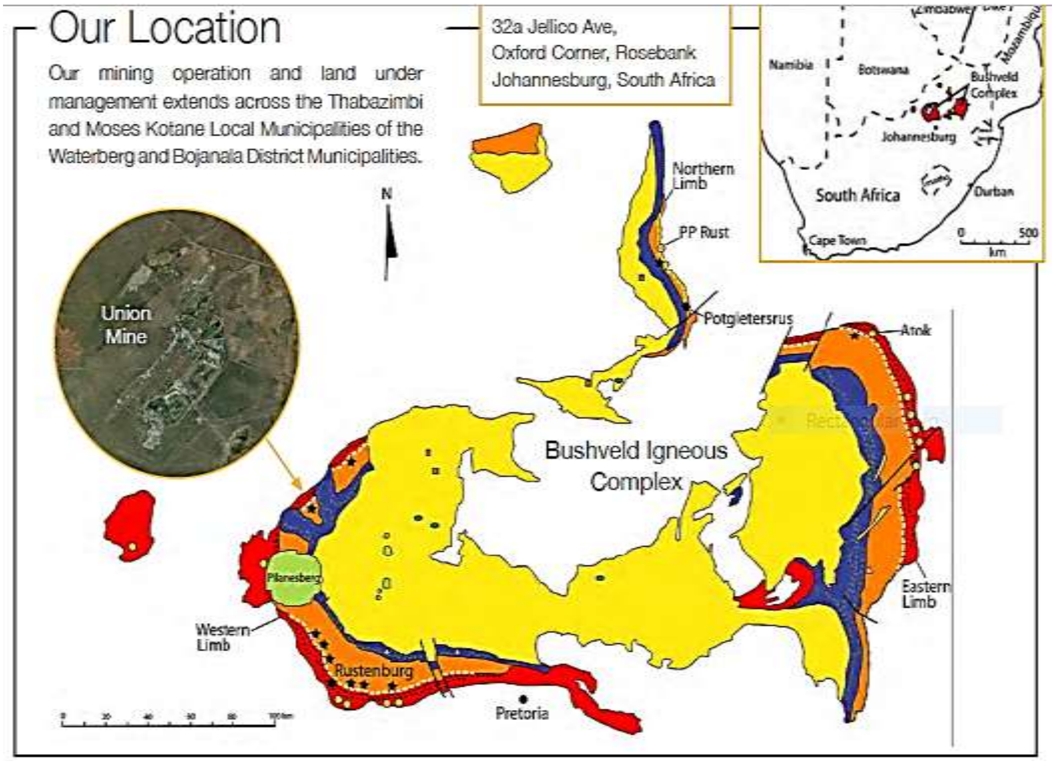


Figure 3.1: Location of the Union mine (SBPM, 2021)

Three quarters of underground resources at SBPM are mined conventionally using stoping with strike pillars. The remainder is mined by combined hybrid mining methods. This hybrid mining approach is used at the declines. This method involves mechanised development, conventional breast stoping, and ore removal using conveyors. Production is focused mainly on the UG2 chromitite reef, mined at an average depth of 850 m. The simplified stratigraphy of the mine was previously shown in Figure 1.1 of Chapter 1.

The main access to the underground mining operation is via a vertical shaft nearly up to 20 levels, i.e., 1 200 m deep. There are three declines below the shaft bottom to access deeper reserves down to 2 100 m. One of the three declines is dedicated for the transport of mining personnel using chairlift systems. The other decline is for the dispatch of material and consumables by means of a rail-bound system. And the third decline serves for ore transportation using both rail bound and conveyor belt systems. The basic mining layout at Spud shaft is a conventional narrow reef type with raise development and breast mining panels as shown in Figure 3.2. The red outlines in the layout are the remaining Merensky pillars (abutments) above the UG2 reef.

Figure 3.2: Layout of the mining panels at the Spud shaft (Union mine, 2024)

The basic mining processes (stages) of the mine was also previously shown in Figure 1.3 of Chapter 1.

The operational set up of Siyanda Bakgatla Spud shaft reflects a typical complex underground mining environment. The use of both conventional and hybrid mining methods makes it vulnerable to logistical challenges. Secondly, as a deep level mine, there are also potential bottlenecks in material handling and personnel movement. The geological complexity, including potholes, faults, and dykes, also adds challenges to mining operations. Each of these factors can contribute to production inefficiencies and underperformance. The next sub-section describes some of the operational problems experienced at Siyanda Bakgatla Spud shaft.

3.2.2 Operational problems at the mine

Records compiled for July 2023 and representative of the performance of the mine can be viewed in Figure 1.2 of Chapter 1. The data suggests one key problem at the mine: consistent underperformance in terms of production targets across various levels and sections. The "Progressive Variance of production" is predominantly negative, showing that the mine is not only missing daily targets but also falling short cumulatively over time. Progressive variance refers to the difference between planned production and the actual production over time. As shown in Figure 1.2, the biggest variance is observed in SPUD # Middle Section 122, with a cumulative shortfall of -4 328 metric tons (t). This is followed by Ore Source Group (20 Level Silo & 19 Level Transfer Box 2), which records a variance of -3244 tons. SPUD # Bottom Section 121 shows a smaller, but still significant, shortfall of -1 322 tons. SPUD # Section 120 shows a variance of -314 tons. This noted underperformance indicates that there are inefficiencies and operational challenges within the mining process that prevent the mine from achieving its production targets consistently. This underscores the need to investigate some of the challenges associated with the underperformance of the mine.

In terms of this research study, the focus has been only on the sections below 20 level. These are the production levels serviced by the declines.

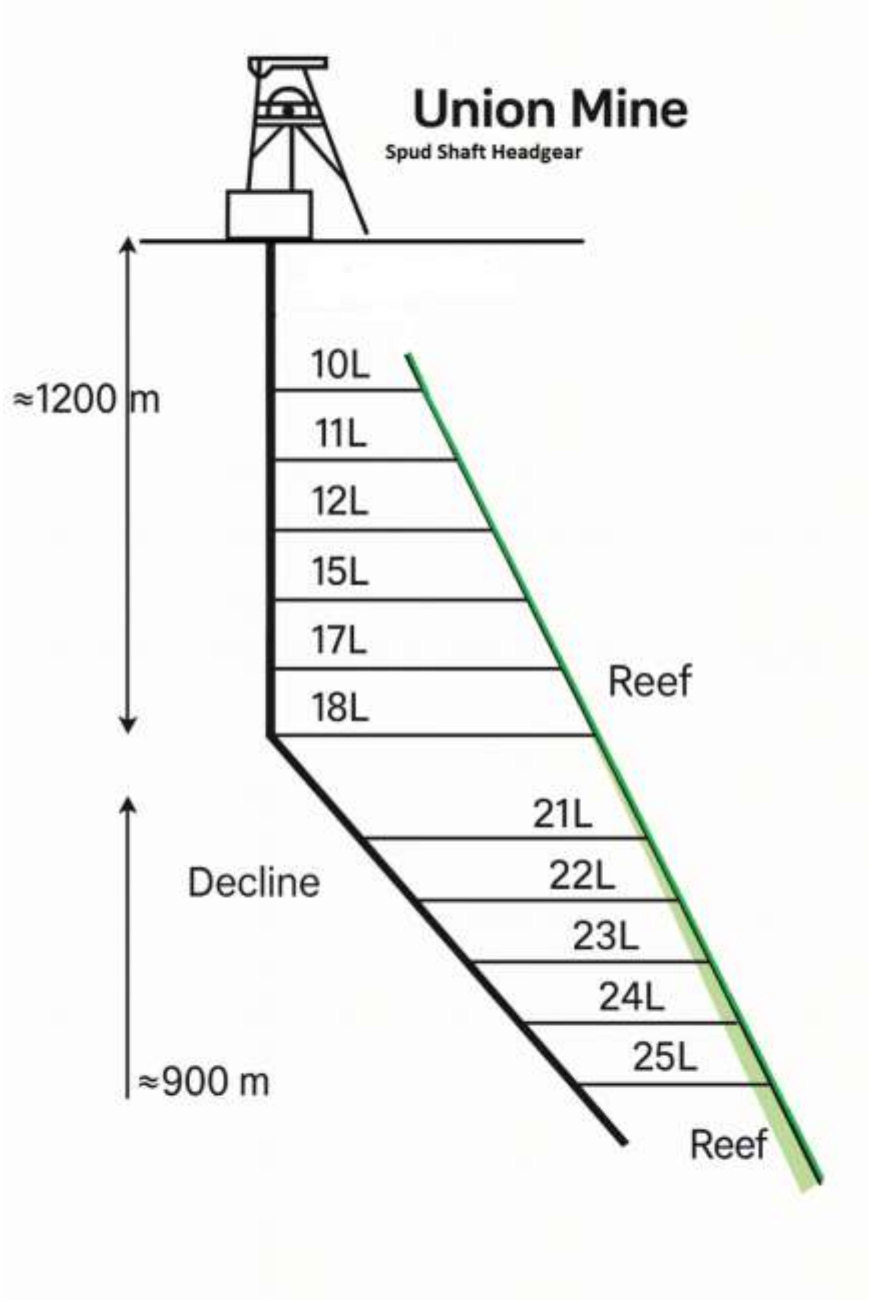


Figure 3.3: A schematic showing the setup of 20 level and the decline starting from the 20L

3.3 Data collection and sources

3.3.1 Data collection process

The data collection process associated with this research study involved 15 physical mine visits to Siyanda Bakgatla Spud shaft, which included meetings with various service department managers.

The first three visits focused on initial engagement and familiarisation. During the first visit, the research purpose and objectives were discussed and agreed upon. This was followed by a tour of the underground facilities and an introduction to various department managers. An overview of the operational setup of the mine was gained from the tour. Afterwards, a schedule of subsequent visits was laid out based on the convenience and availability of relevant managers. During this visit, the mine also pledged resources towards the research such as a laptop and accommodation in the mine village going forward.

The second series of three visits focused on understanding the basic mining process at the decline sections, as previously illustrated in Figure 3.3. This set of visits also allowed for the observation and better understanding of the production system of the mine. During these three visits, it became clear that the mine employees perform daily monitoring and recording of all operational problems across various workplaces using the Syncromine® software. Syncromine® is mine management software developed by Mineware Consulting. It is designed to integrate and report on various functions of the entire mining operation. This includes areas like production, engineering, Finance, safety, and human resources (Mineware, 2024).

A request was then made for operational problem data for stoping and development, production data and supply chain data to be made available as part of the research. Access to the data was granted as evidenced by the snapshot of the permission letter in Appendix A. The datasets included: stoping data, development data, production data for the reporting period 2024, and production data for 2025. The production data was specifically for Stoping 121, Section 125, reef, waste, and total primary metres. The datasets only excluded supply chain information from what was requested. The datasets received were adequate to support the objectives of this study. A detailed description of the datasets and their key elements is later covered in Section 3.3.3.

Other series of visits focused on general discussions with service department managers to understand the manifests of production constraints. These departments included Mineral Resource Management, Engineering, Mining, Ventilation, and Rock Engineering.

Three additional visits were then organised to better understand the structure of the dataset that was given previously. This was for the working definitions of the variables in the data, the quality control process of the data entry, and key issues as to whether there could be duplications and missing values. Note that the data was directly downloaded from the Syncromine® system. The data entry of each logged problem was quality controlled and assured before it was signed off by the Miner and the Mine Overseer. As such, data entries seemingly looking like duplicates accurately reflected the operational logs from the system and did not constitute true duplicates. Removing these would have resulted in the loss of critical information regarding the frequency and consistency of recorded activities. During these visits, explanatory notes were also made to provide context for the data through interacting with Service Department Managers.

Each mine visit lasted between 4 to 8 hours. These mine visits and meetings also underscored the need for this research as this would form the baseline evidence for process improvement in the mining cycle. The understanding was that it would be of significant benefit to go beyond the analysis of the consequences of operational problems and include enablers that contribute to the existence of the root causes of the operational problems.

3.3.2 Key underground observations noted

During the 15 mine visits, it was observed that the underground operations involve a cycle of four broad activities at each workplace. These are: Supporting, Drilling, Blasting, and Cleaning. However, the entire mining process of the decline sections, is a cycle that starts from planning and ends with ore hoisting as illustrated in Figure 1.3.

The second key observation was that the four activities characteristic of the mining cycle (i.e., support, drill, blast, and clean) are constrained by various parameters. For example, cleaning during the night shift as an activity cycle often becomes a constraint due to three possible factors: LHD breakdowns, man-transport unavailability, or absenteeism. When any of these factors interact with the cleaning process, these constrain the cycle and result in an operational problem recorded as "Nightshift Cleaning Incomplete (LHD breakdown)" leading to a loss of blast.

The above observation aligns with previous findings by Sebutsoe and Musingwini (2017) who noted that platinum mine production systems interact with various random variables that can impact the desired outcome of a blast. These random variables may include equipment breakdowns, absenteeism, or blasting misfires. Despite these challenges, Sebutsoe and Musingwini (2017) highlighted that mine management remains in control of four key initial input conditions: Ground (ore reserves), People, Equipment, as well as Materials and Services. Through these inputs, management can make decisions to better achieve the desired outcomes of the production system.

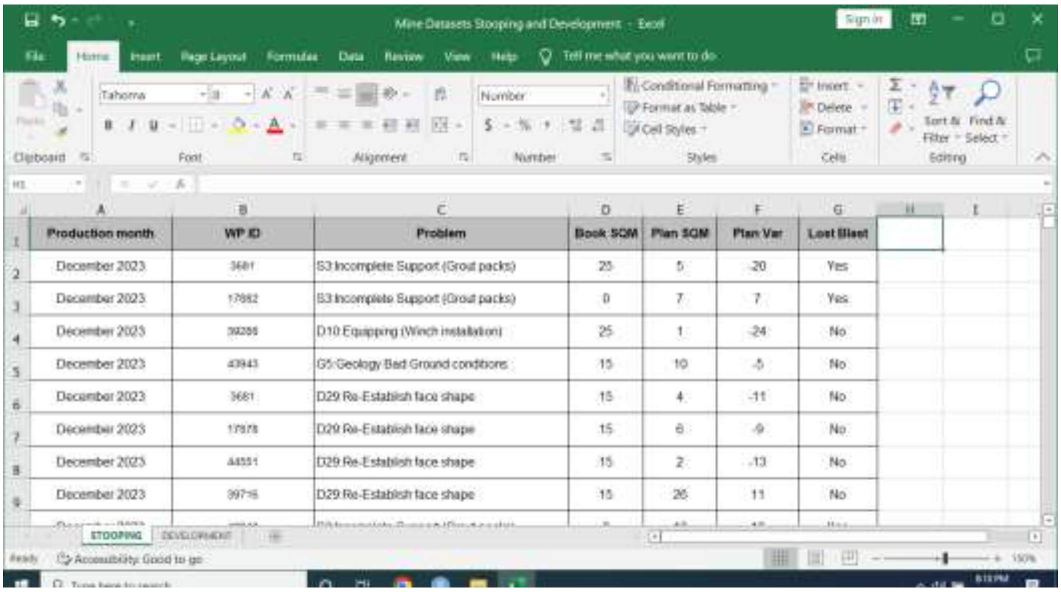
Based on these observations and the framework provided by Sebutsoe and Musingwini (2017), it was decided that the categorisation of all recorded operational problems would be essential for meaningful analysis. This categorization aims to facilitate the aggregation and comparison of data within each category thereby helping to identify the most frequent or impactful causes of lost blasts. The categories, their development, and the rationale behind their definition are discussed later in Section 3.5.2.

3.3.3 Description of the datasets and their key variables

As previously indicated in Section 3.3.1, four datasets were collected from the mine: stoping data, development data, production data for the reporting period 2024, and production data for the reporting period 2025. The following sections provide a description of the datasets and their key components.

3.3.3.1 Stoping data

The first dataset is the Stoping data illustrated in Figure 3.4. The stoping dataset has 7 columns and 1 657 data entries for each column header. The column names are as follows: Production month, WP ID, Problem, Book SQM, Plan SQM, Plan Var, and Lost Blast.



Production month	WP ID	Problem	Book SQM	Plan SQM	Plan Var	Lost Blast
December 2023	3681	S3 Incomplete Support (Grout packs)	25	5	-20	Yes
December 2023	17882	S3 Incomplete Support (Grout packs)	0	7	7	Yes
December 2023	39288	D10 Equipping (Winch installation)	25	1	-24	No
December 2023	43943	G5 Geology Bad Ground conditions	15	10	-5	No
December 2023	3681	D29 Re-Establish face shape	15	4	-11	No
December 2023	17878	D29 Re-Establish face shape	15	6	-9	No
December 2023	44551	D29 Re-Establish face shape	15	2	-13	No
December 2023	39716	D29 Re-Establish face shape	15	26	11	No

Figure 3.4: Screenshot of the original stoping dataset (Spud Shaft Mineral Resources Management Department, 2024)

Table 3.1 provides the working definitions of the column variables and their relevance to the research.

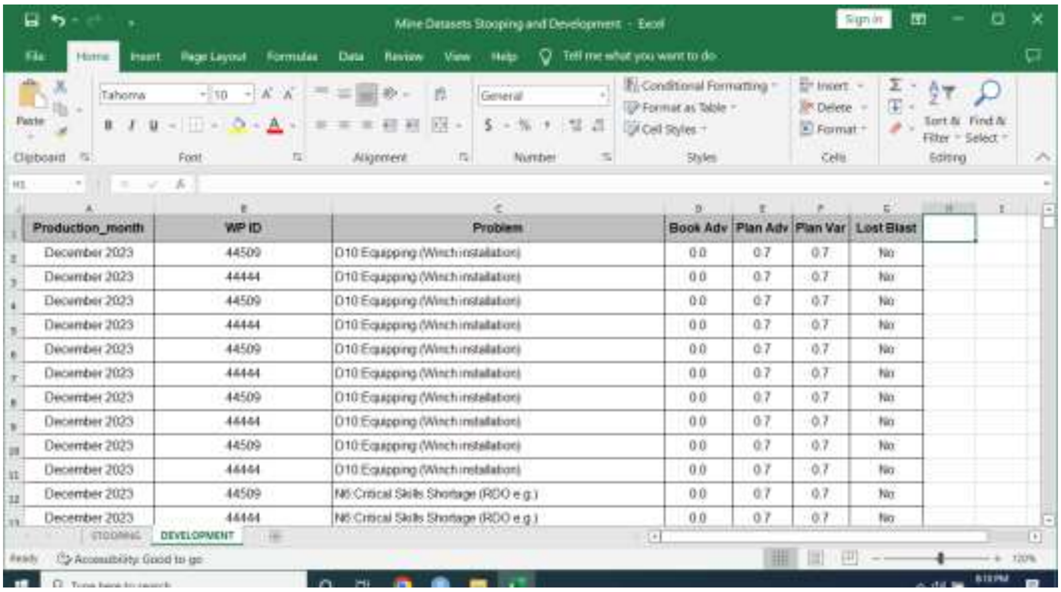
Table 3.1: Working definitions of the column headers in the stoping dataset in Figure 3.4

Column name	Definition and structure
Production month	It specifies the production month of the mine. Typically, months are between December 2023 and June 2024. This is a categorical variable.
WP ID (Workplace ID)	It indicates the specific location of the mine. The stoping has 132 workplaces ID entries. This is a categorical variable.
Problem	It represents the specific operational issue that was recorded in the workplace. Example: • Geology Bad Ground conditions • Misfire • Equipping (Winch installation) • Incomplete Support (Grout packs)
Book SQM (Square Meters)	It represents the actual square meters that have been blasted in a section or workplace within the mine. Example: 25 m^2 This is a numerical variable.
Plan SQM	It represents the anticipated or expected square meters planned to be blasted from a particular section or workplace within the mine. Example: 5 m^2 This is a numerical variable.
Plan Var	It quantifies the discrepancy between the planned blasting (Plan SQM) and actual blasting (Book SQM) metrics. This is a numerical variable. This is obtained by the formula: (Plan SQM) - (Book SQM).

	Example: 5 m^2 – 25 m^2 = -20 m^2 Please note that the negative sign of the variance represents a favourable deviation as the “actual” exceeds the “plan” indicating an overachievement. A positive sign is an unfavourable deviation indicating underachievement.
Lost Blast	It is an indicator of whether a blast was lost or not (Yes/No). This is a categorical variable.

3.3.3.2 Development data

The development data shown in Figure 3.5 also has 7 columns and 1 271 row entries for each header. The column names are Production month, WP ID, Problem, Book Adv, Plan Adv, Plan Var, and Lost Blast.



Production_month	WP ID	Problem	Book Adv	Plan Adv	Plan Var	Lost Blast
December 2023	44509	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44444	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44509	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44444	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44509	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44444	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44509	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44444	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44509	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44444	D10 Equipping (Winch installation)	0.0	0.7	0.7	No
December 2023	44509	N6 Critical Skills Shortage (RDO e.g.)	0.0	0.7	0.7	No
December 2023	44444	N6 Critical Skills Shortage (RDO e.g.)	0.0	0.7	0.7	No

Figure 3.5: Representative of the original development dataset (Spud Shaft Mineral Resources Management Department, 2024)

Table 3.2 below provides the working definitions of the development data column variables and their relevance to the research.

Table 3.2: Working definitions of the column headers characteristic of the stoping dataset in Figure 3.5

Column name	**Definition and relevance**
Production month	It specifies the production month of the mine. Typical months are between December 2023 and June 2024. This is categorical data.
WP ID (Workplace)	It indicates the development specific location of the mine. The stoping has 110 workplaces ID entries. This is categorical data.
Problem	It represents the specific operational issue that was recorded in the development workplaces. This is categorical data. Example: • Incomplete/slow drilling (Low compressed air) • Inadequate ventilation • Nightshift cleaning incomplete (Winch breakdown) • Incomplete/Slow Drilling (Low compressed air)
Book Adv (advance)	It represents the actual meters advanced after blasting. This is numerical data. Example: 1 m
Plan Adv (advance)	It represents the target meters planned to advance after blasting. This is numerical data. Example: 0.7 m
Plan Var	It quantifies the discrepancy between the planned advance (Plan Adv) and actual advance (Book Adv) metrics. This is a numerical variable. This is obtained by the formula: (Plan Adv) - (Book Adv). Example: 0.7 m – 1 m = -0.3 m

	Please note that the negative sign of the variance represents a favourable deviation as the "actual" exceeds the "plan" indicating an overachievement. A positive sign is an unfavourable deviation indicating underachievement.
Lost Blast	It is an indicator of whether a blast was lost or not (Yes/No). This is categorical data.

3.3.3.3 Production data for the reporting period 2024

The production data for the reporting period 2024 comprises of business plan production metrics from March 2023 to February 2024. It includes information on both actual performance and planned targets across different mining activities, specifically for Stoping 121, Section 125, reef, waste, and total primary metres. Figure 3.6 shows a snapshot of the original production dataset for 2024.

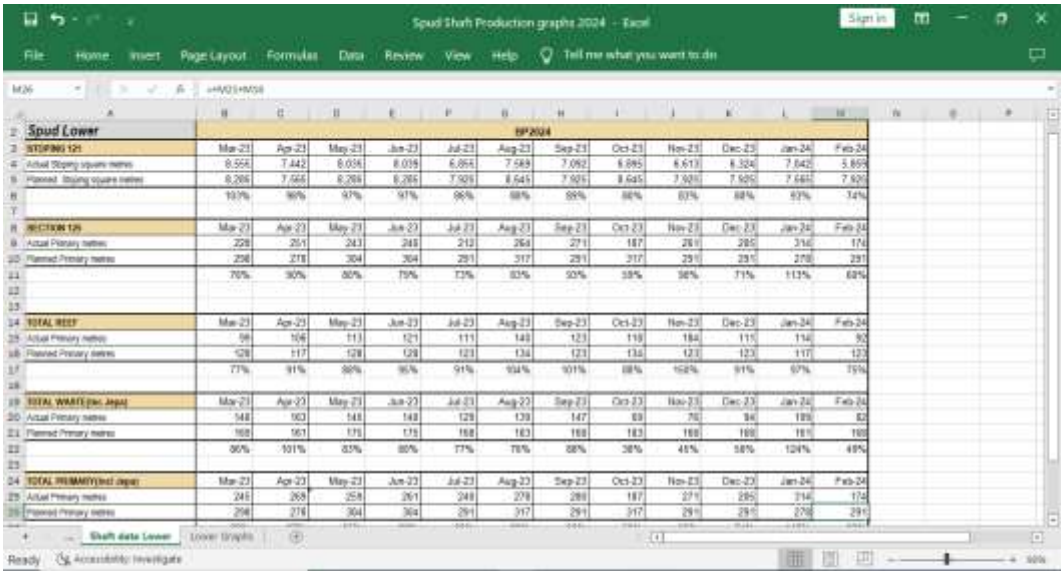


Figure 3.6: Snapshot of the original production dataset for 2024 (Spud Shaft Mineral Resources Management department, 2024)

The key contents of the production data for the reporting period 2024 includes:

Stoping 121: This data compares actual stoping square meters achieved with the planned stoping square metres for each month. The percentage indicates the actual performance relative to the plan. For example, 103% achieved rate in March 2023 means that the actual stoping square metres exceeded the planned stoping square metres by 3%.

Section 125: This data displays actual and planned primary metres for development work in Section 125, with percentages showing the achievement rate. For instance, 90% means that the actual primary metres for development work achieved 90% of the planned metres. This indicates that the development work fell short of its target by 10%.

Total Reef: This metric tracks actual versus planned primary metres mined in reef sections in terms of monthly percentage performance. For instance, 77% achievement rate in March 2023 means that the actual primary metres mined in reef sections reached 77% of the planned metres. This indicates that the mine fell short of its target by 23% for that month.

Total Waste: This data shows actual and planned primary metres for waste rock.

Total Primary: This data represents the sum of the actual primary metres of Total Reef and the actual primary metres of waste rock. It also represents the sum of the planned primary metres of Total Reef and the planned primary metres of waste rock.

3.3.3.4 Production data for the reporting period 2025

Production data for the reporting period 2025 has the same structure and key contents as that for the reporting period 2024. The only unique thing about the 2025 data is that the reporting period is (March 2024 – May 2024). Figure 3.7 shows the structure of the original production dataset for 2025.

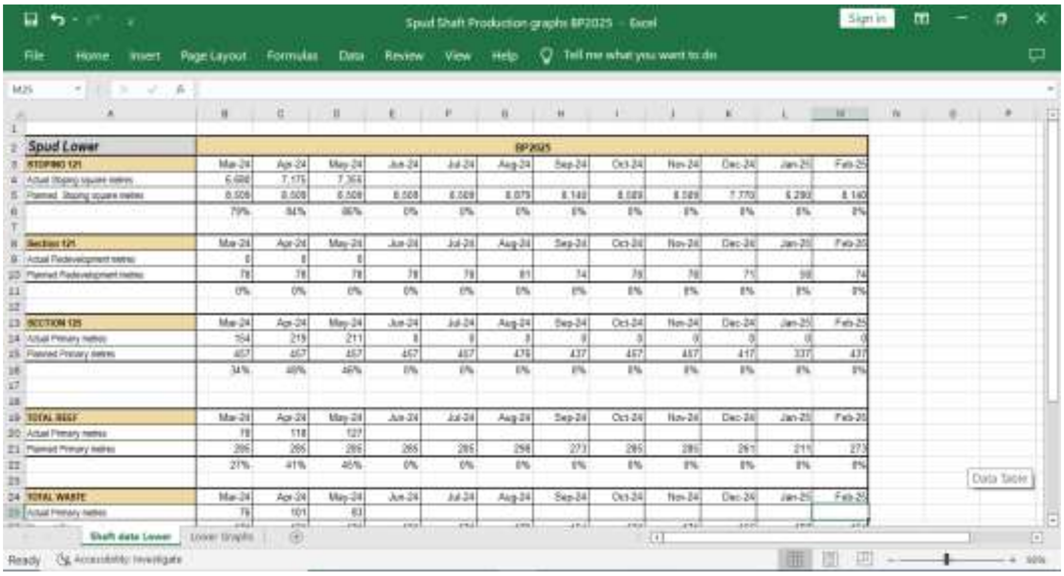


Figure 3.7: Snapshot of the original production dataset for 2025 (Spud Shaft Mineral Resources Management Department, 2024)

The discussed datasets were sufficient to support the objectives of the study. The stoping and development datasets contain numerical data necessary for analysis of operational problems, production performance, and variance. The production datasets for 2024 and 2025 capture actual versus planned outputs. Together, these datasets formed a reliable basis for identifying inefficiencies within the mine. The next section outlines the data cleaning and preparation process prior to analysis.

3.4 Data cleaning and preparation

3.4.1 Data cleaning processes

The datasets provided by the mine and presented in Section 3.3.3 were checked for completeness using the built-in data validation tools available in Microsoft® Excel®. These tools enable one to automatically identify any empty cells across all columns and rows. This involved the following the steps:

Step 1: The entire data range was selected.

The range, including all relevant columns and rows, was highlighted in the dataset.

Step 2: The "Go to Special" feature was used to find blank cells.

The "Go To" dialog box was accessed by pressing Ctrl + G, and the "Special" button was clicked on to open the "Go to Special" dialog box. In this dialog box, "Blanks" was selected, and "OK" was clicked. This action automatically highlights any empty cells within the selected range.

Step 3: The results were reviewed.

The result showed “No cells were found”. This result means that no cells were highlighted thereby confirming that there were no missing values in the dataset. Figure 3.8 illustrates the outcome of the completeness check for stoping data. The development dataset was also checked the same way; no missing values were found in the dataset.

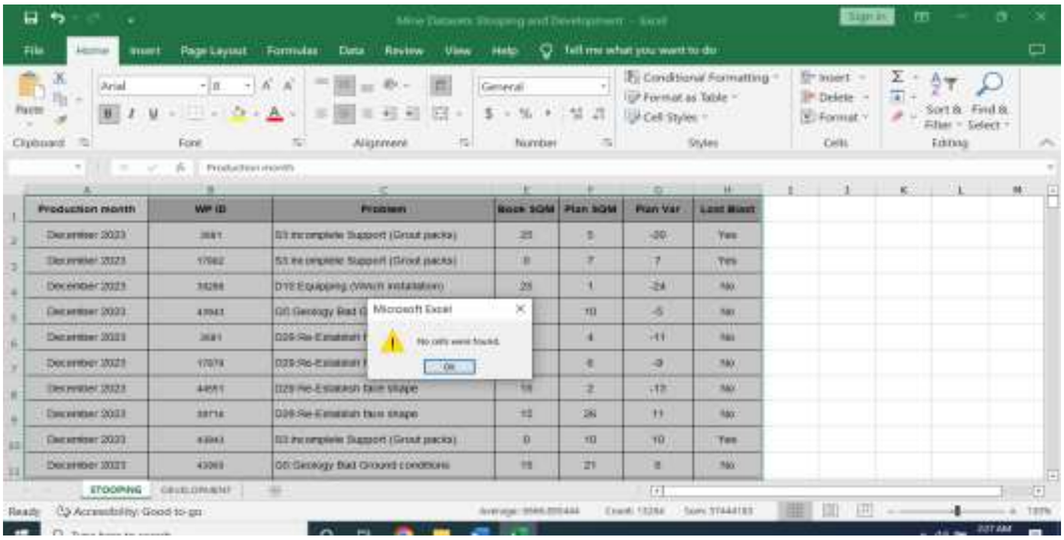


Figure 3.8: Outcome of the completeness check for stoping data

Step 4: Conditional formatting was used for the production data corresponding to the reporting periods 2024 and 2025.

As per Figures 3.7 and 3.8, it can be observed that the design of the production datasets includes intentionally blank cells that separate and organise different sections of the dataset for easier reading. Therefore, conditional formatting in Microsoft® Excel® was used to check for missing values within the cells that are supposed to contain data. Conditional formatting was activated using the following steps:

- The data range was selected.
- The "Home" tab was accessed, and "Conditional Formatting"; then, "New Rule" was chosen.
- "Format only cells that contain" was selected.
- In the "Format only cells with" section, the option was set to "Blanks."
- A pattern colour (RED) was chosen, and a pattern style (Thin vertical stripes) was selected to highlight any blank cells, and "OK" was clicked.

This step confirmed that missing values within the cells that are supposed to contain will be highlighted just as the intentional blanks. The outcome confirmed that there were no missing values as only the intentional blanks were highlighted. This validated the completeness of the data. Figure 3.9 shows the outcome of the completeness check for production data for 2024.

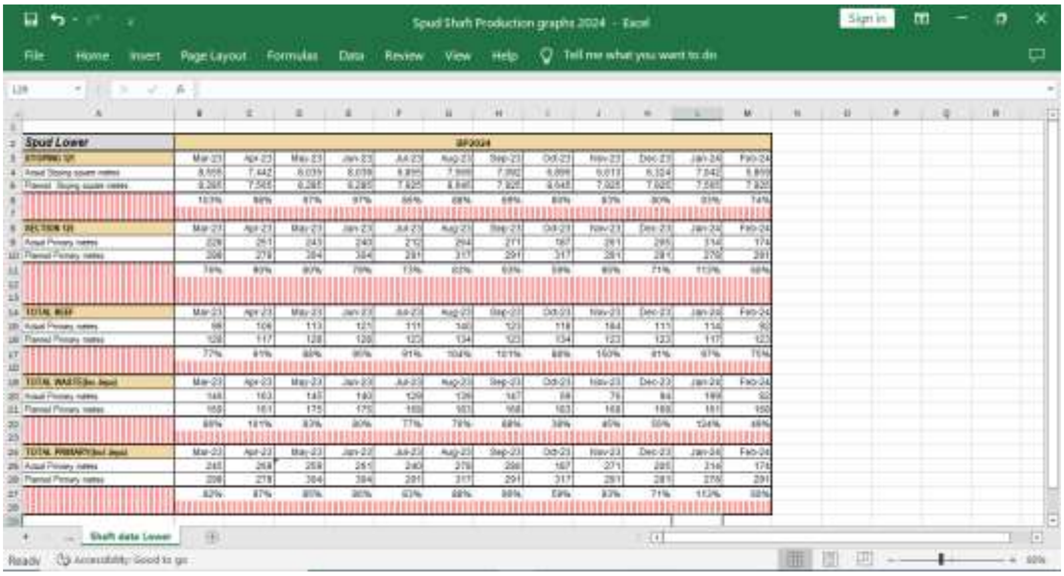


Figure 3.9: Outcome of the completeness check for production data for the year 2024

The combination of the Microsoft® Excel® commands and visual inspection confirmed that there were no missing entries. This ensured that the analysis is based on full data, without the need for advanced techniques to handle missing values.

During the fourth visit, the mine also confirmed that the datasets did not contain any duplicate entries. As a result, the datasets were retained in their original form, ensuring the integrity of the data. Furthermore, the mine confirmed that the data they provided was Automated Format Verified. This means that numerical data columns are formatted as "Number" while date columns were formatted as "Date." Text data were formatted as "Text" to prevent misinterpretation by the software.

3.4.2 Categorisation of operational problems in stoping and development

As part of data preparation for analysis, each operational problem recorded in the “Problem” column for both stoping and development datasets was mapped to a category in a newly created columns called “Problem category”. This “problem category” column is a categorical variable. The categorisation was based on the following groups:

1. Drill and Blast (DB): Direct mining-related problems, e.g., misfires.
2. Support: Operational problems related to installing underground support, e.g., installing planned support (grout packs).
3. Cleaning: These reflect operational problems related to the cleaning cycle within the mine, e.g., sweepings.
4. Geology: These refer to geological or geotechnical conditions affecting mining operations such as fall of ground.
5. Equipment: These include operational problems involving equipment unavailability, malfunctions, or breakdowns, e.g., LHD breakdowns.
6. HR: Human resources-related issues such as labour shortages or absenteeism.
7. Materials: These include shortages of critical materials or consumables, e.g., materials not available at the face.

8. Safety: These refer to safety incidents affecting operations, including compliance matters, e.g., DMPR stoppages, accident investigations
9. Technical Services (Tech Serv): These are key service departments such as engineering, survey, rock engineering. They are critical in providing services such as ventilation, water, power supply, and maintenance. Examples of problems include low compressed air and equipping (winch installation).

The categories reflect the fundamental activities of the mining cycle (i.e., Drilling, Blasting, Supporting, and Cleaning), the initial key inputs that influence the mining system (e.g., Equipment, HR, Geology, Materials), and the critical auxiliary operations (i.e., Safety and Technical services). This alignment ensured that the analysis considers all significant aspects of the mining process while accounting for both operational and systemic factors affecting the production system. A detailed list of the problems (stoping and development) and their categories is presented in Table 3.3.

Table 3.3: List of stoping and development problems and their respective categories

No.	Category	Examples of operational problems
1	DB	• Blasted hanging wall slipping • Gully flushed with the face • End Choked (Long pull) • Panel Choked (Long pull) • End Choked (Box hang up) • Panel Choked (Box hang up) • Panel Choked (Full tips) • Crew Move (End on limit - new workplace not ready) • Re-Establish face shape • Layout Change • Misfire
2	SUPPORT	• End holed (Last support installation)

		• Panel on limit (Last support installation) • Incomplete Support (Sticks support) • Installing secondary support (L/Anchors and straps) • Planned support (Grout packs) • Incomplete Support (Grout packs) • Pumping of Packs delayed
3	CLEANING	• Sweepings (Panel on limit)
4	GEOLOGY	• Crew Move (Bad ground conditions) • Equipping (Footwall lifting) • FOG (i.e., Fall of ground) • Stopped on Geological Feature • Geology Bad Ground • Geology Bad Ground conditions • Installing additional support (Bad ground conditions) • Installing additional support (Geological structures)
5	EQUIPMENT	• End Choked (Belt breakdown) • Nightshift Cleaning Incomplete (Winch breakdown) • Nightshift Cleaning Incomplete (LHD breakdown) • Nightshift Cleaning Incomplete (Man transport unavailability) • Drilling - Drill Rig Breakdown • Man-transporter break down • Winch breakdown • Mining Equipment (e.g., Mono Ropes) • Logistics Equipment (e.g., Non-Loco Like Rails)

6	HR	• Nightshift Cleaning Incomplete (Absenteeism) • Incomplete/Slow Drilling (Absenteeism) • Labour under complement • Labour Absent • Critical Skills Shortage (Rock Drill Operator) • Training
7	MATERIALS	• Materials - Not Available at Face • Materials/Equipment Shortage • Shortage of drilling equipment • Support unavailability (Long anchors) • Support unavailability (Grout packs) • Support unavailability (Bolts)
8	SAFETY	• Safety stoppage • Work Stopped Non standards • DMPR stoppage • Accident investigation
9	TECH SERV	• Inadequate Air Supply/Pressure • Low compressed air • No compressed air • Equipping (Winch installation) • Incomplete/Slow Drilling (Low water pressure) • Incomplete/Slow Drilling (Low compressed air) • Equipping (Service pipes installation) • Inadequate Ventilation • Low water Pressure • Power Failure Mine Supply • Inadequate Water Supply/Pressure • No Survey Notes & Chains

A new column named "Problem category" was added next to the "Problem" column in the original (stoping and development) datasets. A filter was applied to the "Problem" column to display each specific problem. Then, the corresponding category was manually typed into the "Problem Category" column. Once the category was entered for the first occurrence of each problem type, the fill handle was used to drag down and apply the assigned category to all rows with the same problem, ensuring consistency throughout the dataset. The outcome of this categorisation is illustrated in Figure 3.10

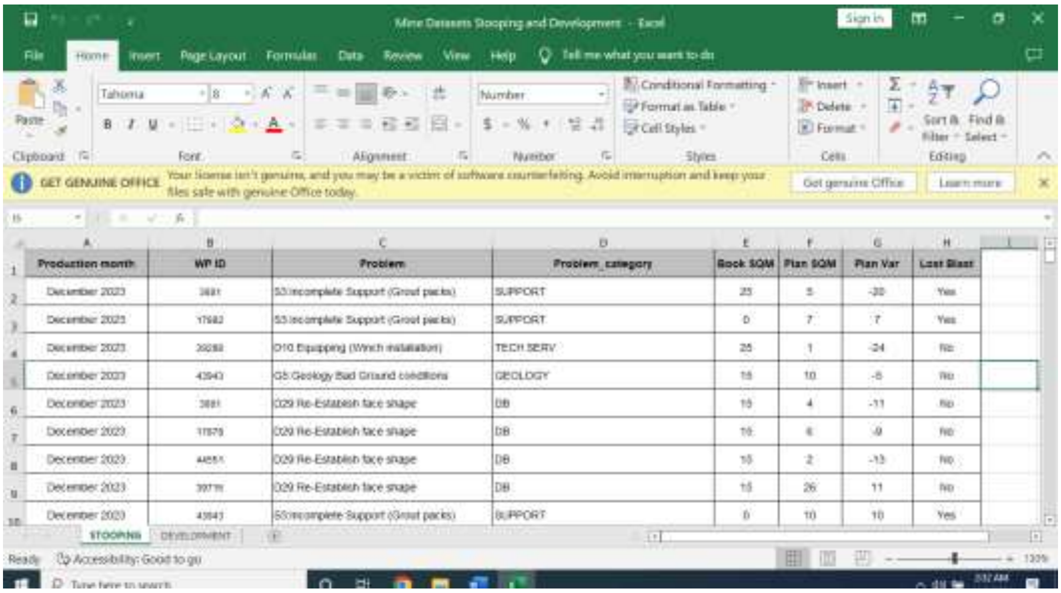


Figure 3.10: Categorisation of problem list

This categorisation offered a structured framework that improved the clarity and depth of the analysis. It also reduced the complexity as the data was organised into manageable groups. This made it easier to identify patterns, understand systemic issues, and develop targeted interventions.

The categorisation of operational problems in the stoping and development datasets concluded the data cleaning and preparation process using Microsoft® Excel® 2016. The pre-processed data was now ready for analysis. The data analysis tools selected for the purpose and the associated analysis techniques used are discussed in Section 3.5 below.

3.5 Data analysis tools and techniques

This section describes the software package and techniques used for data analysis. The data analysis process involved importing the data as well as applying statistical and logical analysis techniques to extract meaningful insights.

3.5.1 Software

Data analysis was performed using two software packages: Microsoft® Excel® 2016 for the production datasets (2024 and 2025) and RStudio® for the stoping and development datasets.

RStudio® is an integrated development environment (IDE) for the R programming language specialising in statistical computing and data visualization. The software was freely downloaded from the official RStudio® website (https://www.rstudio.com). RStudio® version 2024.04.2+764 was used for this research project. RStudio® requires the installation of R first which was also freely downloaded from the official website (https://cran.rstudio.com). The latest version R-4.4.1.tar.gz was selected for download. RStudio® was chosen for its powerful statistical analysis and data visualization capabilities, which are essential for handling complex datasets. It is free, open-source, and widely supported, making it accessible for academic research.

The analysis was conducted on a computer that met the minimum specifications required to run RStudio®: 64-bit Windows® operating system and at least 1 GB of RAM. The computer specifications were Windows® 11 Pro, 64-bit operating system, with an Intel® Core i7, 2.6 GHz processor, 16GB of RAM and 512 GB SSD storage.

The RStudio® user interface consists of four main panes as shown in Figure 3.11.

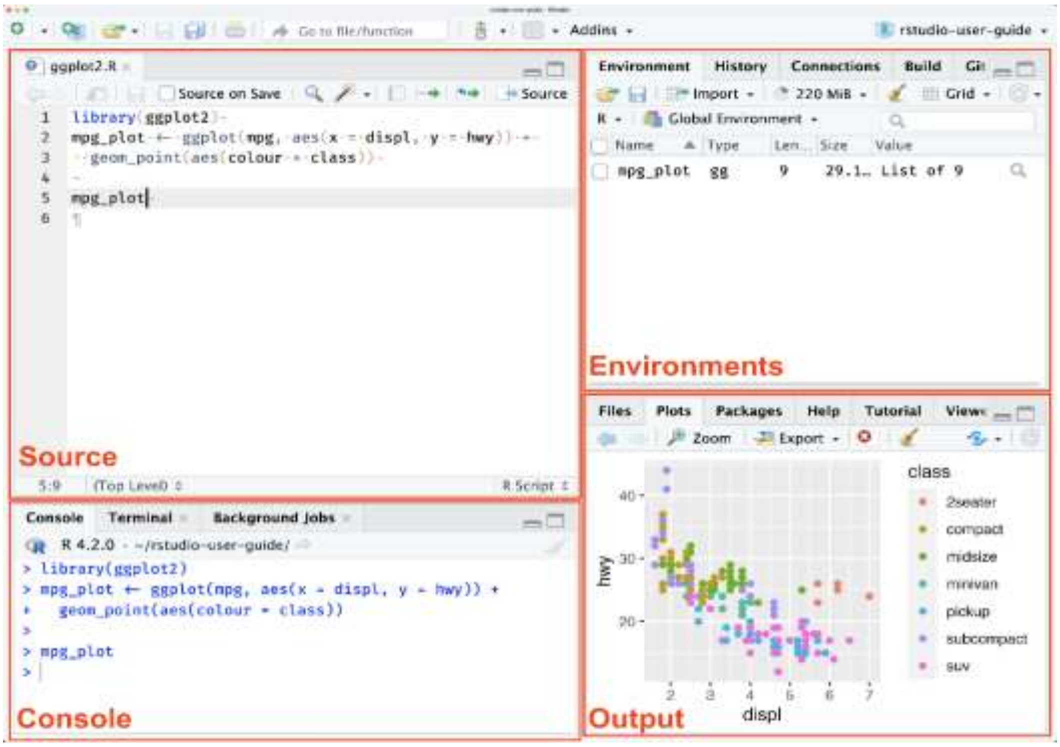


Figure 3.11: The RStudio® user interface (RStudio Team, 2023)

As it can be seen in Figure 3.11, the user interface contains four panes: the Source pane, the Console pane, the Environments pane, and the Output pane. The Source pane is where one writes, edits, and saves code scripts. The Source pane therefore helps manage the R code files under development. The Console pane, on the other hand, is the place where the code is run. In this pane, one can see the results generated by the code or any outputs from the commands entered in the source pane.

As for the Environments pane, this pane contains several tabs including Environment, History, and Connections amongst others. The Environment tab lists all the variables, data, and objects currently in use. History shows a record of all the commands invoked by the user. Connections is for linking directly to databases and data servers. Additional tabs such as Build, VCS, and Tutorial are tools for more advanced use like package development and version control.

The Output pane also has multiple tabs. The Files tab shows files and folders in the working directory. The Plots tab is used to display any charts and create graphs. The Packages tab lists and manages the R packages installed on the personal computer. The Help tab is used to request access to the documentation and help with R functions. Finally, the Viewer and Presentation tab is used to access web-based content or presentations within RStudio® (RStudio Team, 2023).

3.5.2 Loading stoping and development datasets into RStudio®

The datasets were imported from Microsoft® Excel® where they were saved into RStudio®. The process leading to Figure 3.12 involved the following steps:

- Install and load the "readxl" package, which is a specialized R package designed for reading Microsoft® Excel® files.
- The file path for the dataset was then specified to ensure that RStudio® could locate and access the file on the computer. Each sheet within the Excel workbook, "STOPING" and "DEVELOPMENT," was then read into R as separate data frames (tables).
- To verify that the data loaded correctly, the first few rows of each dataset were viewed using the "head ()" function. This allowed a quick check of the dataset structure and values for each sheet.

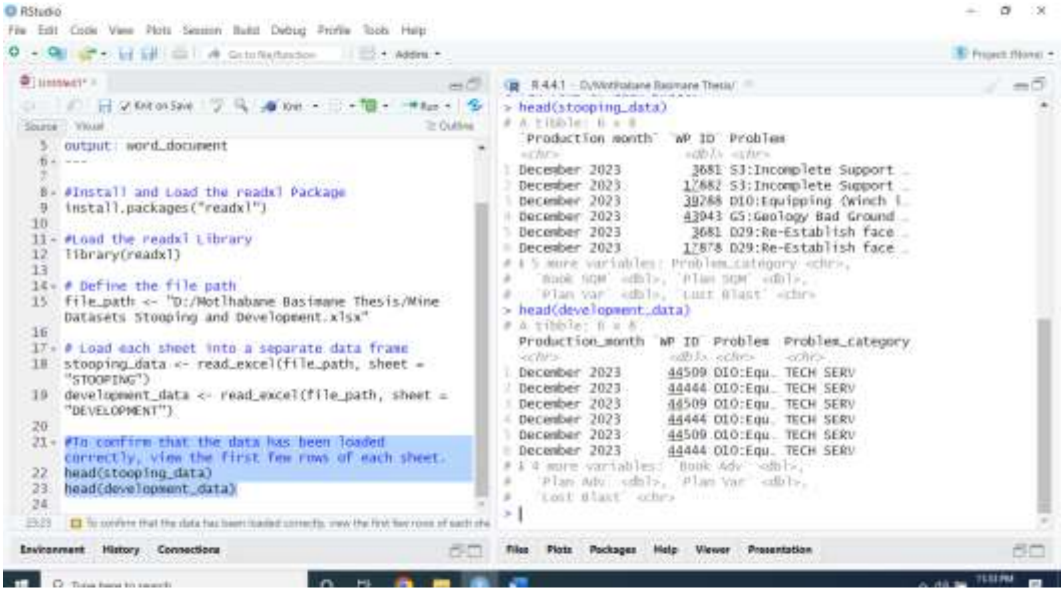


Figure 3.12: Importing datasets into RSTUDIO®

The next step was to validate the data and ensure that it is ready for analysis as presented in the subsequent section.

3.5.3 Validation of the stoping and development datasets in RSTUDIO®

The data validation process in RStudio® is illustrated in Figure 3.13. In this process, the “str()” function was used to display the structure of each data frame, including column names, data types (e.g., numeric, character), and a few sample values for each column. This was to confirm that each column was correctly read and identified.

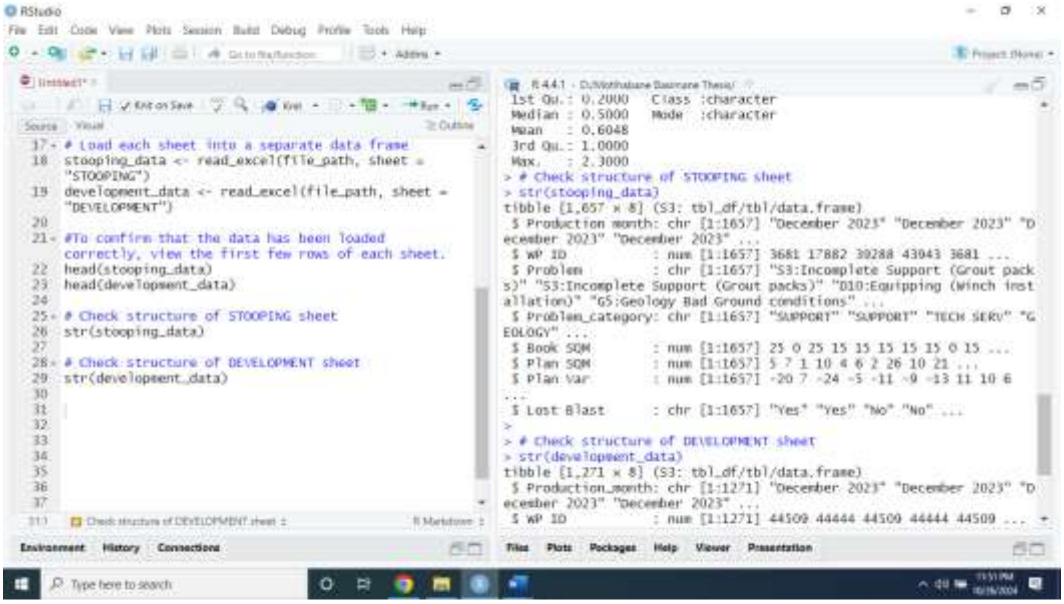


Figure 3.13: Output of validated datasets in RStudio®

The following variables previously defined in Tables 3.1, 3.2 and 3.3 were used for the subsequent statistical analysis of the data:

- Production month
- Problem category
- Book SQM
- Plan SQM
- Book Adv
- Plan Var
- Pot Var
- Lost blast.

The actual statistical analysis of the data is covered in Section 3.5.4 below.

3.5.4 Statistical analysis of the data

The data analysis entailed nine steps: summary statistics, frequency tables, categorical analysis, problem impact analysis, production loss quantification, proportional analysis, comparison of actual versus planned performance, correlation analysis, and root cause analysis. Each statistical analysis is illustrated with relevant code examples and corresponding outputs.

3.5.4.1 Summary statistics

Summary statistics are numerical values that describe the data using measures of central tendency and measures of dispersion (Peng, 2016). In this study summary statistics were calculated for the stoping and development datasets. These statistics included mean, median, minimum, maximum, and standard deviation.

Figure 3.14 illustrates the process of computing the mean, median, minimum, maximum, and standard deviation for the Book SQM, Plan SQM, and Plan Var columns in the STOPING sheet. It also illustrates the same for the Book Adv, Plan Adv, and Plan Var in the DEVELOPMENT sheet. The summary statistics were compiled into tables in Excel® format showing the central tendency and spread of the data for each metric.

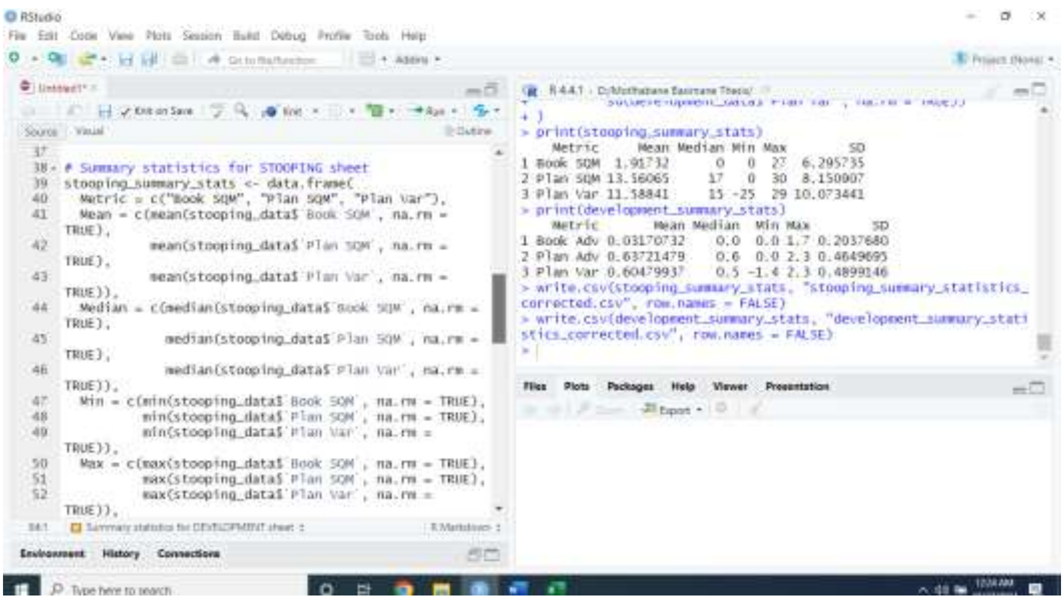


Figure 3.14: Calculation of summary statistics

Table 3.4 illustrates an example of the output of the summary statistics that was computed for the stoping data. For example, the Book SQM had a mean of 1.92 m², a median of 0 m², with values ranging from 0 to 27 m².

The Plan SQM showed a mean of 13.56 m², median of 17 m², with a range between 0 and 30 m². The Plan Var recorded a mean of 11.59 m², median of 15 m², and ranged from -25 to 29 m².

Table 3.4: Output of the summary statistics in the stoping data

Metric	Mean	Median	Min	Max	SD
Book SQM	1.92	0	0	27	6.29
Plan SQM	13.56	17	0	30	8.15
Plan Var	11.59	15	-25	29	10.07

The summary statistics were necessary because they provided an overview of the central tendency and variability in the data.

3.5.4.2 Frequency analysis

Secondly, frequency analysis was performed which involves counting the occurrences of specific categories, values, or events in a dataset. It shows how often different problems or situations arise, helping identify patterns and distributions within the data (Dunn and Davis, 2017). For example, the frequency analysis for Lost Blasts provides counts of instances where blasts were “lost” or “not lost” in Stoping and Development datasets. Figure 3.15 illustrates the process of computing the frequency analysis for lost blasts. A frequency table was created for each dataset, showing the distribution of "Yes" and "No" responses in the Lost Blast column. The display of the output in form of frequency tables helped in understanding the distribution of lost blasts across different categories.

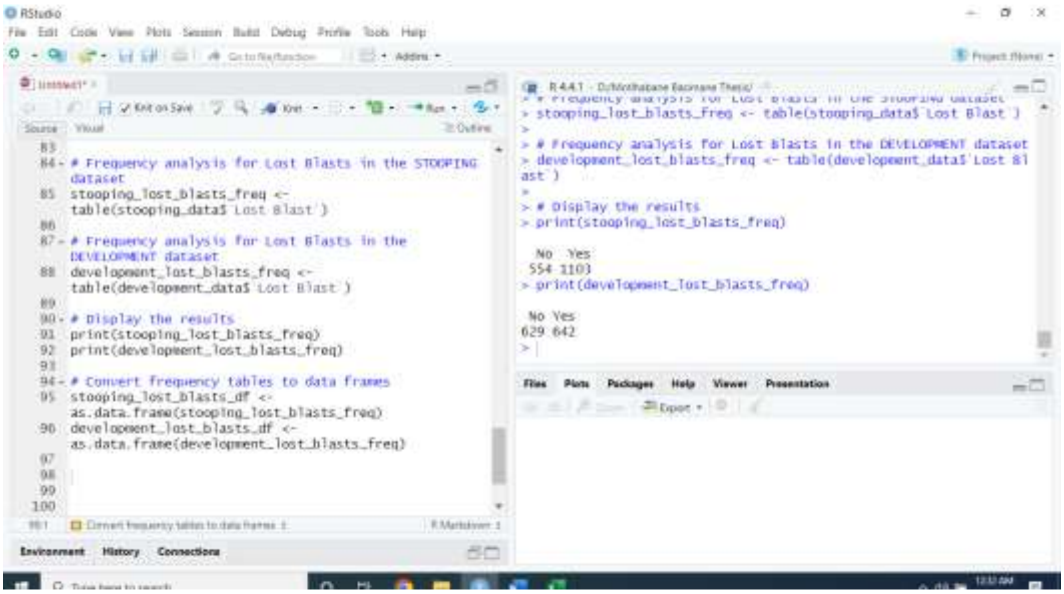


Figure 3.15: Calculation code for frequency table for lost blasts

Table 3.5 shows an output of the frequency table for lost blasts in development. For example, in development, there were 642 recorded instances that resulted in lost blasts.

Table 3.5: Output of the frequency table for lost blasts in development

Lost Blast	Frequency
No	629
Yes	642

Thirdly, frequency tables and bar charts were created for categorical variables (e.g., Problem category) in both datasets. This computation is shown in Figure 3.16 where counts for each category were calculated, and bar plots were generated to visually represent the frequency of each problem category. Figure 3.17 is an output of the computation illustrated in Figure 3.16. This analysis identified the most frequent problem categories affecting the mining operations.

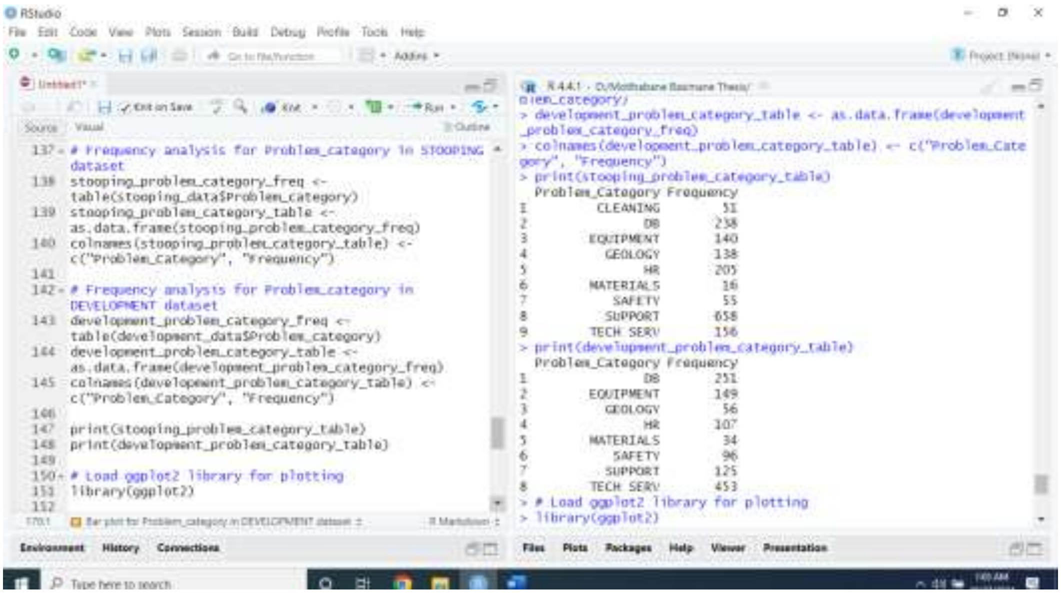


Figure 3.16: Calculation code for frequency table for problem category

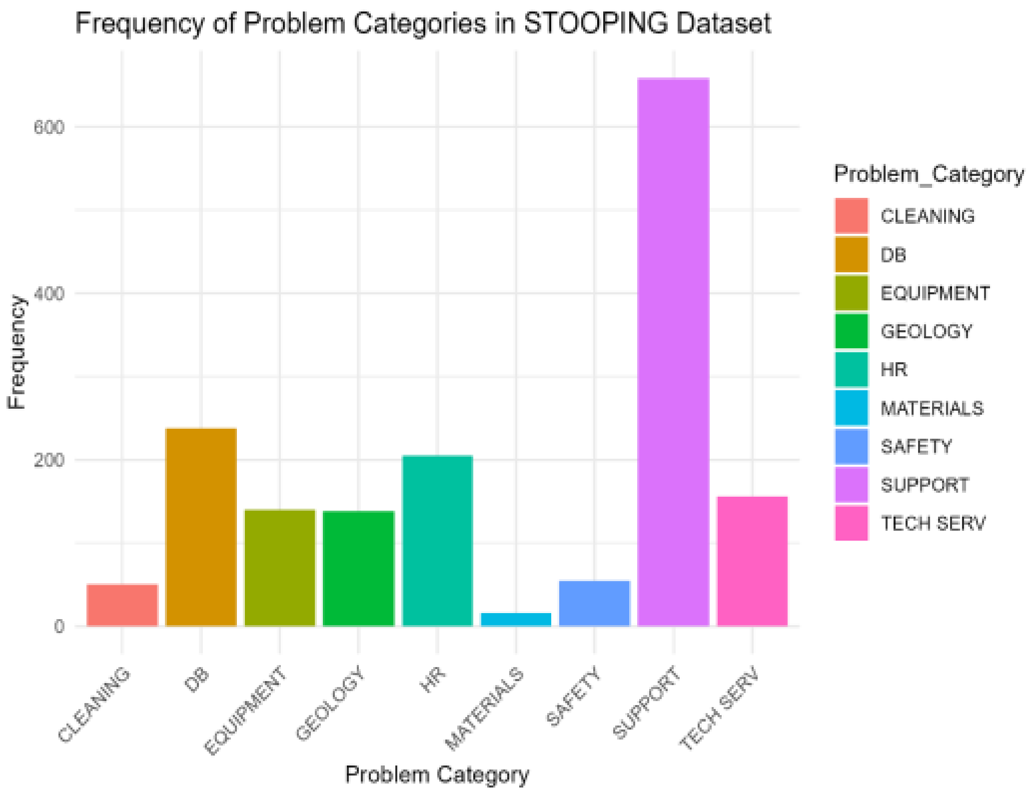


Figure 3.17: Output of the frequency table for problem category in stoping

3.5.4.3 Problem impact analysis

The problem impact analysis was done to understand the impact of various problems. Figure 3.18 illustrates the calculation code for the most frequent and impactful problem categories. The data frames were filtered to include only rows where Lost Blast was recorded as "Yes." The filtered data was grouped by problem category, and the frequency of each category was counted. The total Plan Var for each problem category were calculated while the results were arranged in descending order of frequency.

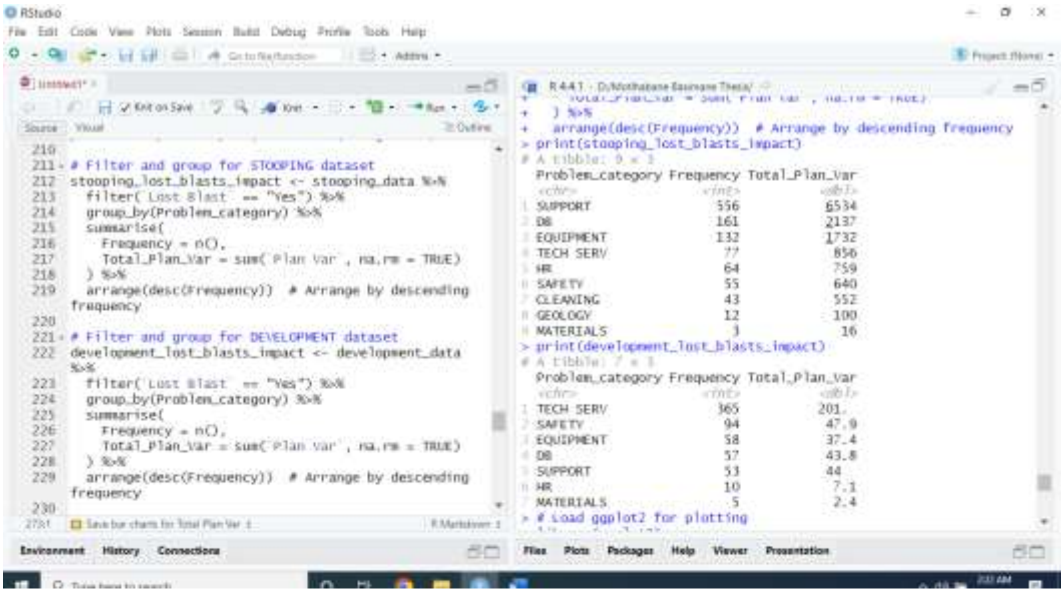


Figure 3.18: Calculation code for the most frequent and impactful problem categories

Bar charts and Pareto charts were produced to visualize the most frequent and impactful problem categories causing lost blasts. For example, Figure 3.19 is a bar chart as an output of the most frequent and impactful problem categories in development.

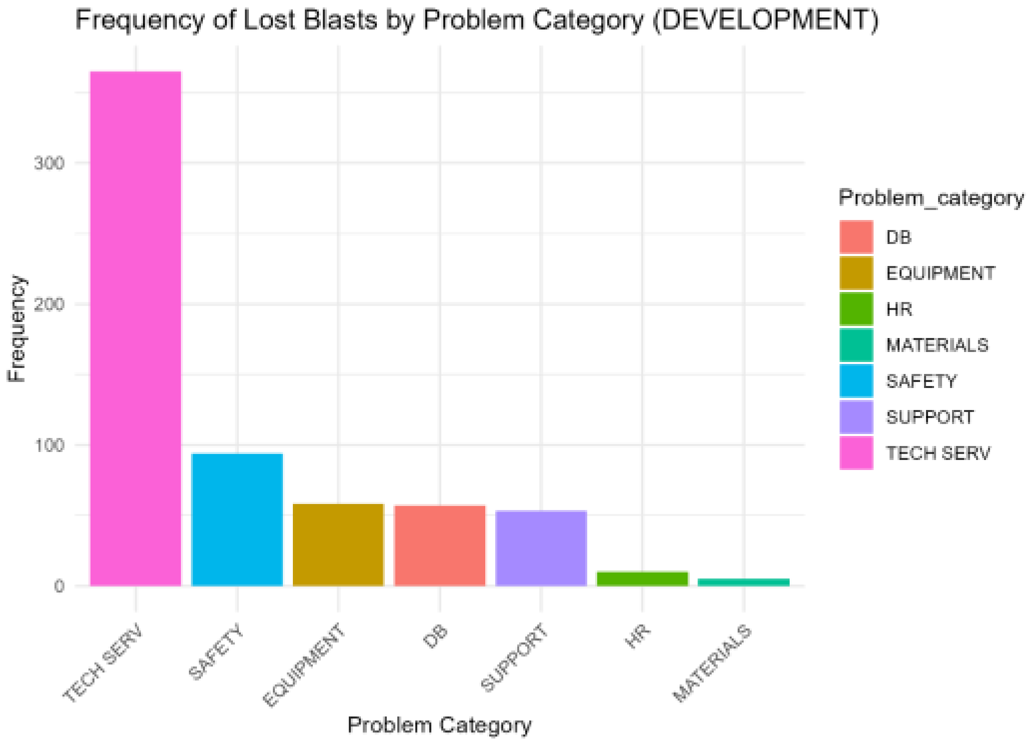


Figure 3.19: Output of the most frequent and impactful problem categories

Note here that the Pareto analysis identifies the problem categories that most frequently cause lost blasts, following the 80/20 rule to prioritize impactful categories (William et al., 2025). For each dataset, cumulative percentages were calculated for the frequency of lost blasts by Problem category. Pareto charts were generated to visualize the cumulative impact of each category. Figure 3.20 illustrates a typical Pareto chart produced showing lost blasts per problem category in Development. It can be seen that "TECH SERV" comes out as the problem category with more lost blasts.

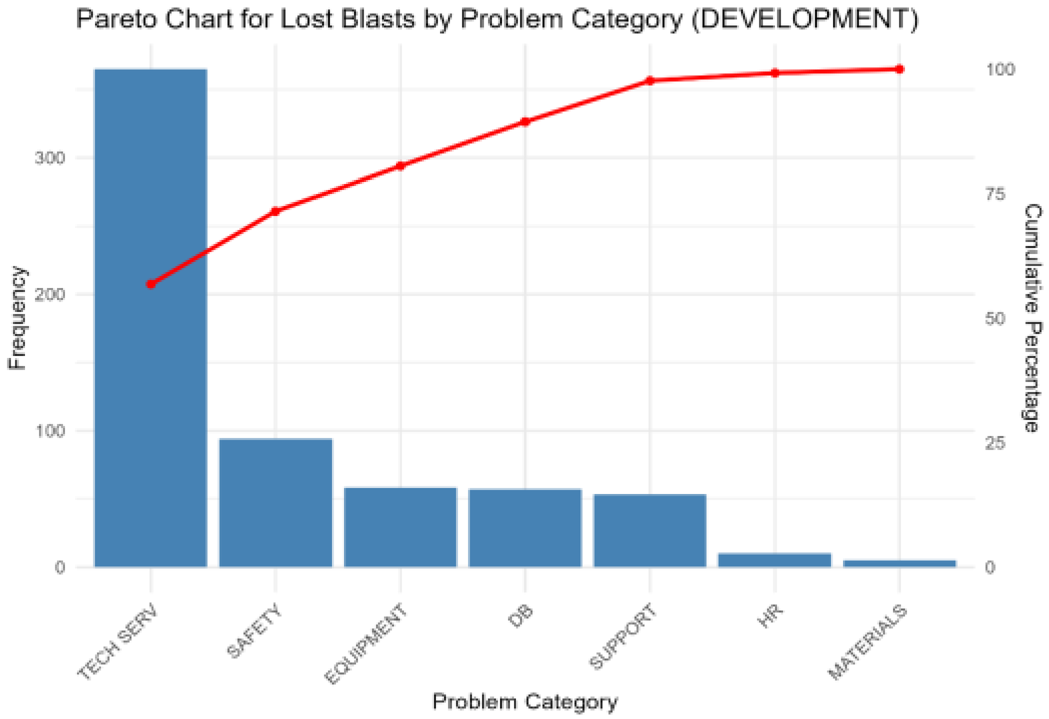


Figure 3.20: Typical output of the Pareto chart produced

The production loss associated with each problem category was quantified. This involved calculating the production loss associated with each problem category as illustrated in Figure 3.21. The total Plan Var (m^2) for each problem category were calculated to understand discrepancies between planned, and actual production. Pie charts similar to what is provided in Figure 3.22 were used to visualize the production losses for Stoping and Development datasets. In this case, Figure 3.22 shows that the Support problem category had a production loss of 7 065 m^2.

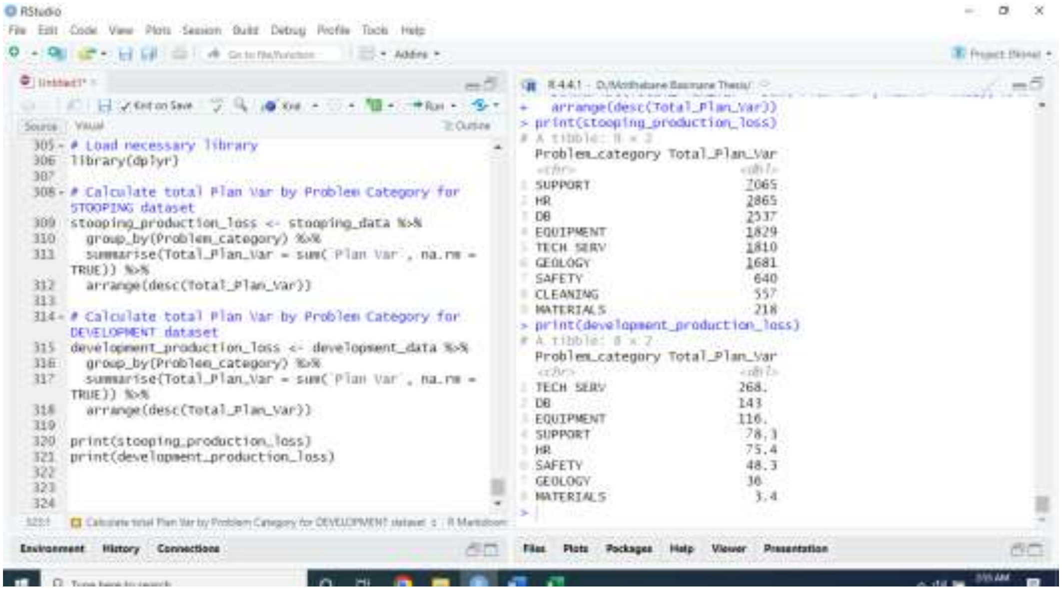


Figure 3.21: Calculation code for the production loss associated with each problem category

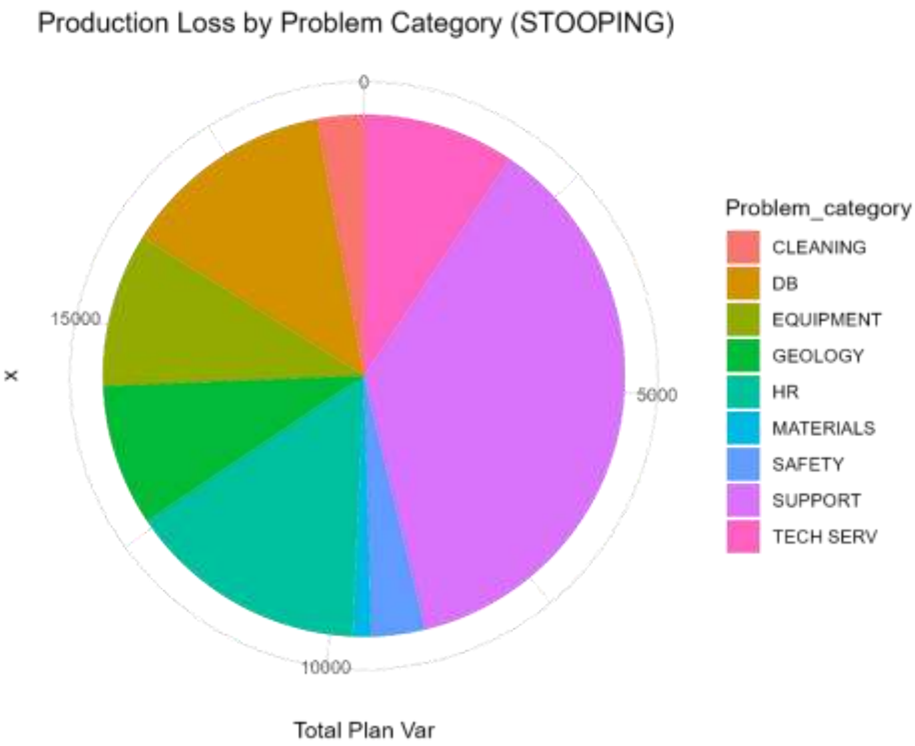


Figure 3.22: Output of the production loss associated with each problem category

3.5.4.4 Proportion of lost blasts

The proportional analysis examined the incidence of lost blasts within each problem category. This involved calculating the proportion of lost blasts for each problem category as illustrated in Figure 3.23. For each problem category, the total instances and lost blast instances were counted.

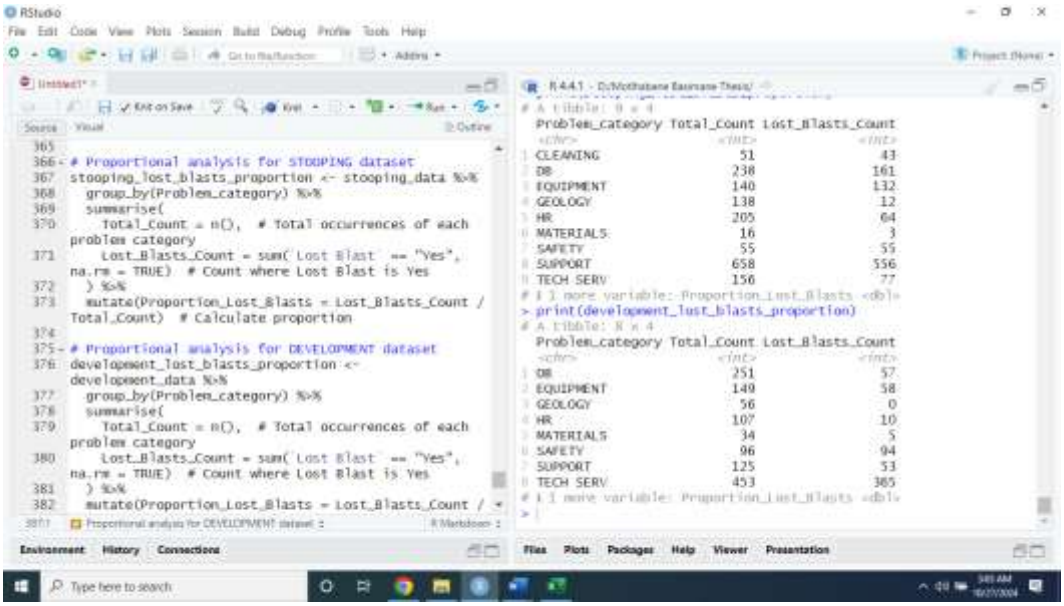


Figure 3.23: Calculation code for the proportion of lost blasts for each problem category

The proportion of lost blasts was then calculated by dividing lost blast counts by total occurrences. The output provided insight into the categories that most frequently lead to lost blasts. The example in Figure 3.24 indicates that "SAFETY" and "EQUIPMENT" are the problem categories with highest incidence of lost blasts in Stoping.

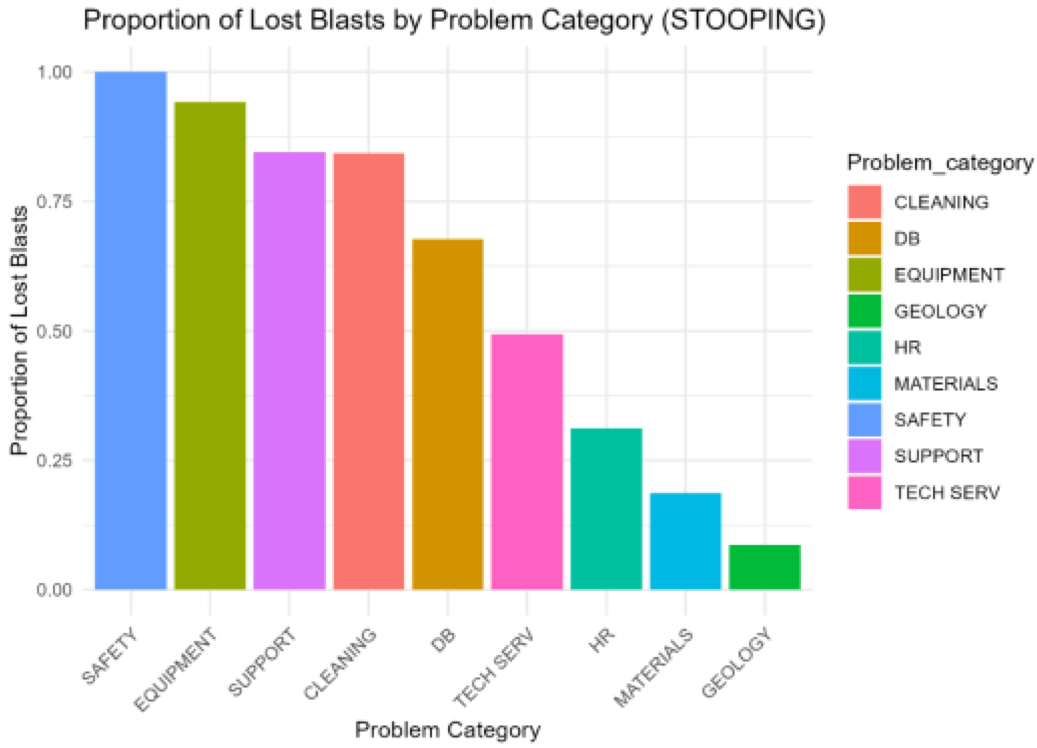


Figure 3.24: Proportion of lost blasts for each problem category

3.5.4.5 Correlation analysis

Correlation analysis was the last statistical analysis that was performed on the stoping and development datasets. Correlation measures the strength and direction of the relationship between two variables, indicating whether they tend to increase or decrease together (Martinson, 2018). The correlation coefficient ranges from -1 to 1, where values close to 1 or -1 indicate a strong relationship while values close to 0 suggest little to no relationship (Martinson, 2018).

Figure 3.25 illustrates how the correlation matrices were generated for numerical variables in both the stoping and development datasets. These correlations were visualized to identify relationships between variables as illustrated in Figure 3.26.

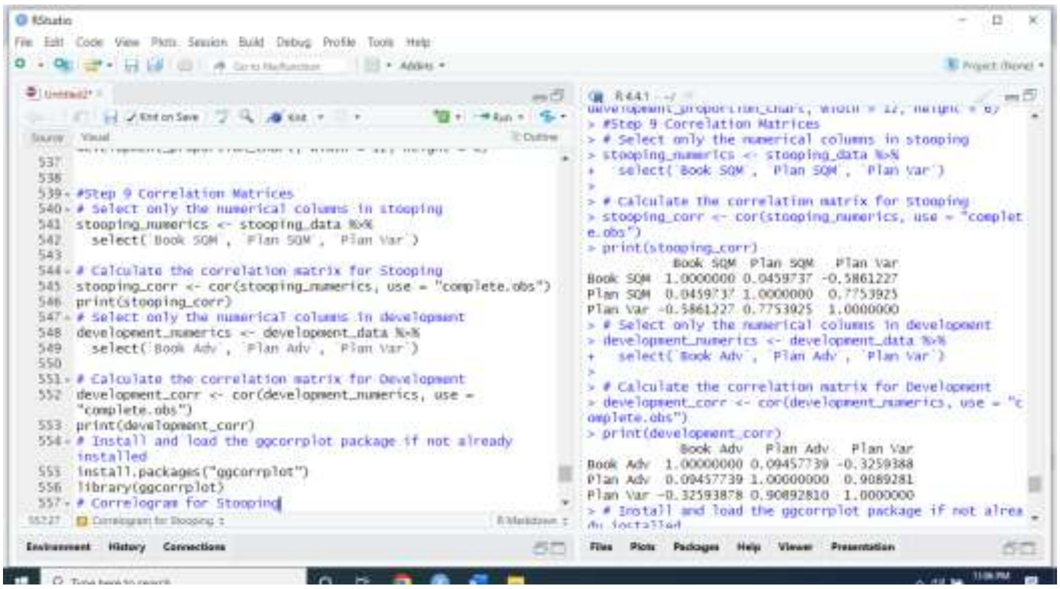


Figure 3.25: Calculation code for correlation matrices

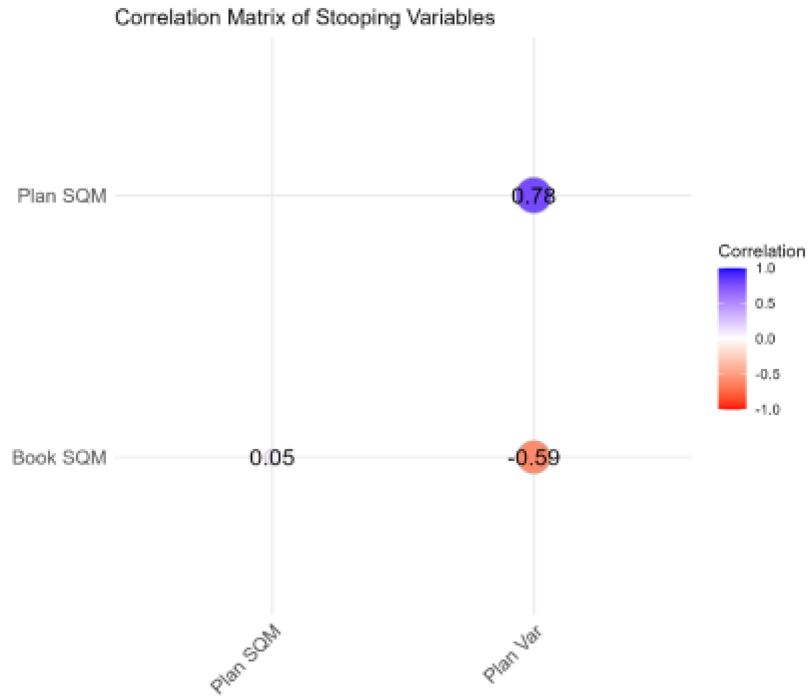


Figure 3.26: Output of the correlation matrices

The next section presents the statistical analysis conducted on the production datasets for the 2024 and 2025 reporting periods. This analysis primarily focused on comparing actual versus planned performance.

3.5.4.6 Comparison of actual vs. planned performance

Using the production datasets (also known as business plans), graphs were generated in Microsoft® Excel® to compare the actual versus planned production metrics for Section 121 and Section 125. These graphs were analysed for the 2024 (March 2023 – February 2024) and 2025 (March 2024 – May 2024) reporting periods. The following general steps were followed to create the relevant graphs in Microsoft® Excel®:

Step 1: Selected data range

For each metric (e.g., stoping square meters, trammed tons, primary meters), the researcher highlighted the "Actual" and "Planned" data ranges.

Step 2: Inserted column chart with line overlay

A Clustered Column Chart was inserted from the Insert tab to represent the "Actual" values. The researcher then right-clicked the "Planned" data series in the chart, selected “Change Series Chart Type”, and converted it to a “Line Chart” to overlay a line on the columns.

Step 3: Customized chart elements

Axis titles and a legend were added to label the "Actual" and "Planned" series clearly. Colours were adjusted, with distinct colours (e.g., orange for "Actual" columns and a black line for "Planned") to enhance visual distinction.

Step 4: Repeated for each metric and for each dataset

This process was repeated for each metric, resulting in separate charts for Actual vs. Planned Square Metres, Actual vs. Planned Trammed Tons, and Actual vs. Planned Primary Metres.

Figure 3.27 is a typical graph that was produced to illustrate Actual square metres vs. Planned square metres for stoping 121 in 2024.

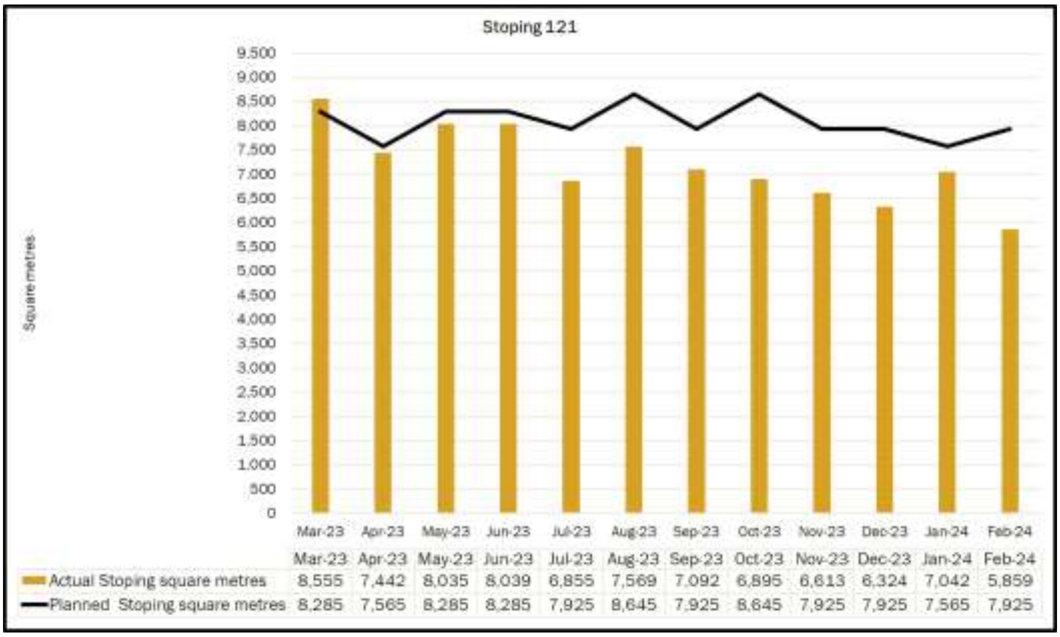


Figure 3.27: Actual and planned square meters corresponding to the stoping of Section 121 during the 2024 business period.

Figure 3.27 shows that for the 2024 plan, actual square meters were generally below the planned targets. Few exceptions where the actual performance either met or exceeded the planned targets were noted in March 2023 for example. However, in the latter months of the 2024 plan (namely, July 2023, to February 2024), the actual production started to fall consistently below planned values.

Lastly, the root cause analysis was done. Root cause analysis (RCA) is a systematic approach used to identify the underlying causes of problems (Latino, 2019). It ensures that interventions target the root issues rather than just the symptoms (Okes, 2019). The application of RCA has been recommended to help improve the drill and blast cycle in conventional narrow tabular orebodies in South African mines (Minerals Council South Africa, 2019). Similarly, Sebutsoe and Musingwini (2017) demonstrated that the application of the RCA on an underground platinum mine requires the mining problems to be categorized under specific headings (e.g., ground conditions, people, materials and services and equipment) to streamline the RCA process. This helps in organizing and directing corrective actions towards the true source of the problem, rather than just addressing symptoms. Therefore, an adaptation of this approach could help identify the root causes of operational problems in the Siyanda Bakgatla Spud shaft mining operations. The RCA methodology is discussed next.

3.5.5 Root cause analysis

A root cause analysis (RCA) was conducted by systematically examining each problem category previously outlined in Table 3.3 (see Section 3.4.2 above). This categorization served as a foundation for the analysis, not only enhancing clarity but also allowing the identification of specific operational deficiencies within the mine that contribute to the existence of the root causes. This was a suitable approach because the recommended solutions as per the objectives of this research study would account for the interconnectedness and within mining operations.

The process started with a step-by-step analysis of each problem category. This approach aimed to uncover both immediate causes (these are observed from the dataset) and underlying causes. Ultimately, the root cause for each problem category was identified.

The following is an example of how the RCA was applied step by step to the EQUIPMENT category operational problems. This same approach was applied to the other 8 problem categories as well.

Step 1: Identify immediate causes of equipment-related problems as per the data.

In the data, the following problems were noted:

- Breakdowns of equipment (e.g., LHDs, winches, Drill Rig, mono)
- Equipment unavailability during operations.

Step 2: Determine underlying causes of immediate problems

The above problems indicate presence of poor maintenance practices, ineffective repairs, issues of spare parts, and equipment reliability.

Step 3: Examine systemic reasons for underlying causes.

The underlying causes in the precedent Step 2 signal the existence of gaps in logistical planning and management within the operational framework of the mine.

Step 4: State the root cause

- Gaps in logistical planning and management.

The structured RCA was applied across all problem categories, where each was evaluated to reveal its immediate and underlying causes. Finally, a summary of all key findings from the data analysis was used to formulate actionable intervention strategies to address these challenges and set the mine on a productive course. Each intervention was designed to tackle specific operational deficiencies, such as enhancing logistical planning, improving equipment maintenance schedules. By linking these strategies with the identified root causes, the interventions were tailored to mitigate the underlying causes, ensuring a more sustainable and efficient operational framework for the mine.

3.7 Summary and challenges encountered

In this chapter, the research methodology used to address the research aim and objectives of the study was described. This section 3.7 also provides a reflection on the adopted data collection as well as the research process. It highlights the successes, challenges, and adjustments made from the initial intended work.

The structured categorization of operational problems was effective, enabling a systematic root cause analysis across key areas such as Equipment, Human Resources (HR), and Technical Services. This approach allowed for a targeted analysis of recurring issues and the formulation of actionable intervention strategies. Additionally, the use of

RStudio® for data analysis and visualization enabled the application of statistical techniques relatively easy and management of large datasets.

Support from the mine, including data access and contextual briefings, strengthened the research process. However, there were some challenges during the research process. The absence of cost data restricted the ability to perform a cost-benefit analysis, limiting recommendations to operational improvements rather than financial optimization.

The initial RCA approach required adaptation to reflect the mine's specific unit operations, ensuring relevance but necessitating a reorientation in the analysis structure.

Access to certain data, such as supply chain information, was restricted due to confidentiality. Additionally, physical time studies were not feasible, impacting detailed analysis of task durations and productivity.

Overall, while the study successfully identified root causes and provided actionable recommendations, limitations in data availability, highlighted the need for methodological flexibility. Future studies would benefit from expanded access to supply chain data to enable a comprehensive analysis and optimisation process. Chapter 4 presents details of how the data was processed and the results from the analysis.

Chapter 4 Identification of root causes associated with the underperformance at Siyanda Bakgatla Spud shaft

4.1 Introduction

This chapter presents the results of the data analysis. The focus is on identifying core logistical issues contributing to underperformance at Siyanda Bakgatla Spud shaft.

This chapter presents results across five key areas. First, it summarises central tendencies and data variability for production metrics such as Book SQM, Plan SQM, Book Adv, and Plan Adv in both stoping and development operations. Second, the analysis examines the distribution of lost blasts and operational problem categories. Third, the impact of different problem categories, such as equipment failures, is quantified in relation to performance metrics. The results also explore relationships among production variables and operational factors to understand how they interrelate. In addition, the analysis assesses the deviation of actual performance from planned targets for metrics like square metres, trammed tons, and primary metres. Lastly, the chapter presents findings from the root cause analysis, which identifies the underlying causes of operational inefficiencies and constraints.

The results presented in this chapter provide the foundation for the subsequent discussion in Chapter 5. The results also informed the recommendations for improvement to set the mine on a productive course.

4.2 Summary statistics on the central tendency and variability of the stoping and development data

Descriptive statistics were calculated to provide an overview of the central tendency and variability of key production metrics in both stoping and development operations. The mean, median, minimum, maximum, and standard deviation for Book SQM, Plan SQM, Plan Var, Book Adv, Plan Adv, and Plan Var were calculated. The summary statistics for stoping and for development are below presented in Table 4.1 and Table 4.2 respectively.

4.2.1 Summary statistics for stoping operations results

Table 4.1 presents summary statistics for key production metrics in stoping operations.

Table 4.1: Summary statistics of key production metrics in stoping

Metric	**Mean**	**Median**	**Min**	**Max**	**Standard deviation (SD)**
Book SQM	1.92m^2	0 m^2	0 m^2	27 m^2	6.30
Plan SQM	13.56 m^2	17 m^2	0 m^2	30 m^2	8.15
Plan Var	11.59 m^2	15 m^2	-25 m^2	29 m^2	10.07

The Book SQM represents the actual square meters blasted in a section or workplace within the mine. The mean Book SQM was 1.92 m^2, while the median was 0 m^2, indicating that most panels had no production. This means that there was no actual production as also shown by a minimum value of 0 m^2. Despite this, some instances achieved up to 27 m^2, as shown by the maximum value. The standard deviation of 6.30 m^2, means that the actual square meters deviate significantly from the average of 1.92 m^2. These figures suggest poor performance in stoping.

The Plan SQM represents the planned square meters for stoping. The average planned square meters was 13.56 m^2, with a median of 17 m^2. This indicates that targets were generally set higher than the actual average square metres (Book SQM) achieved. The large range (minimum of 0 m^2 to maximum of 30 m^2) and standard deviation (8.15 m^2) reveal considerable variation in planning, which could signal inconsistent target-setting or challenges in aligning operational goals with actual performance.

The Plan Var has a mean of 11.59 m^2 and a median of 15 m^2, which shows a general trend of underperformance. However, the minimum value of -25 m^2 indicates that there were instances where the actual performance significantly exceeded the planned targets. This is the case because a negative Plan Var indicates that the actual square meters blasted exceeded the planned square meters, which is considered a favourable deviation. Conversely, a positive Plan Var indicates that the actual square meters fell short of the planned target, which is an unfavourable deviation. It is also important to note that a high degree of variability in the Plan Var, as indicated by the large range of values (-25 to 29), suggests that the performance is inconsistent.

4.2.2 Summary statistics for development operations results

Table 4.2 presents summary statistics for key production metrics in development operations.

Table 4.2: Summary statistics of key production metrics in development

Metric	**Mean**	**Median**	**Min**	**Max**	**Standard deviation (SD)**
Book Adv	0.03m	0	0	1.7m	0.20
Plan Adv	0.64m	0.6m	0m	2.3m	0.46
Plan Var	0.61m	0.5m	-1.4m	2.3m	0.49m

With a mean of 0.03 m and a median of 0 m, Book Adv shows that the actual advancement is minimal across the data, aligning closely with the zero value in many instances. This low advancement rate may indicate operational problems preventing regular progress in mining development work.

The Plan Adv mean of 0.64 m and median of 0.6 m indicate moderate targets for advancement. But the maximum of 2.3 m and standard deviation of 0.46 m reflect variability in planned goals. This suggests that planning might be ambitious or inconsistently set relative to actual conditions.

The Plan Var mean of 0.60 m and median of 0.5 m indicates a positively skewed distribution. This suggests that small deviations from the planned advance occur frequently, while occasional large deviations could also occur. Overall, production performance can be considered generally consistent; however, operational control may have been periodically compromised, resulting in extreme deviations from the planned advance.

4.3. Frequency analysis of categorical variables

The frequency analysis was done to understand the distribution of lost blasts and operational problem categories in both stoping and development operations on the mine.

4.3.1 Frequency analysis for Lost Blasts

Lost blasts were counted to assess their frequency in stoping and development operations.

The results in Figure 4.1 indicates a higher frequency of lost blasts ("Yes") compared to non-lost blasts ("No") in stoping operations. Lost blasts account for a significant portion of production interruptions, suggesting recurring operational challenges that hinder productivity.

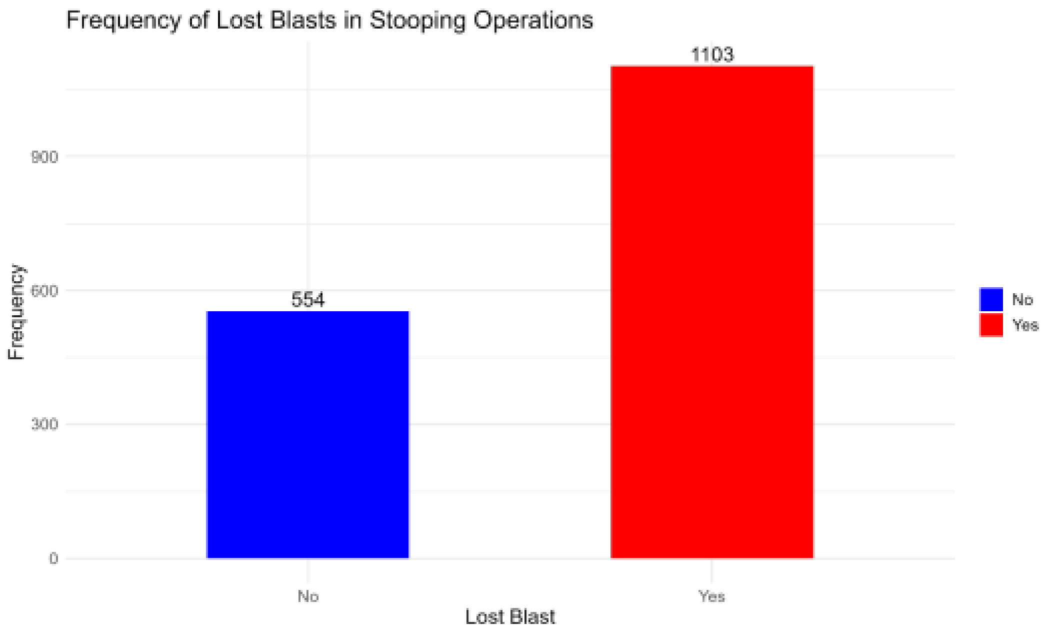


Figure 4.1: Frequency analysis of lost blast in stoping

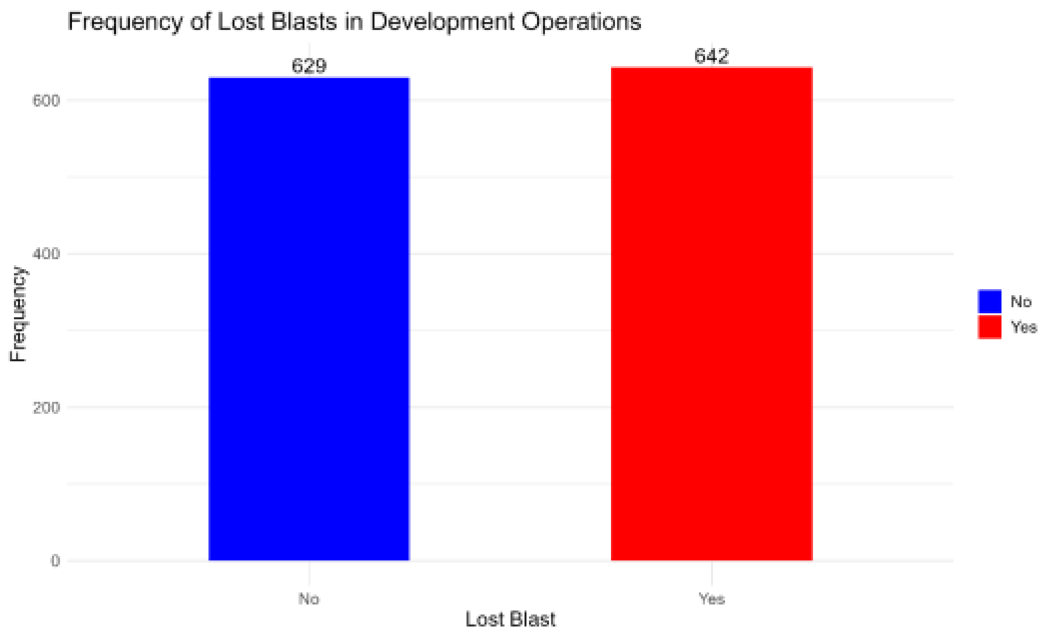


Figure 4.2: Frequency analysis of lost blast in development

Figure 4.2 shows a more balanced distribution between lost blasts ("Yes") and non-lost blasts ("No") in development operations. This indicates that, unlike stoping, development activities experience relatively equal instances of lost and non-lost blasts, although lost blasts still pose an operational concern.

4.3.2 Frequency analysis of operational problem categories

The frequency analysis of problem categories reveals the distribution of different operational issues affecting both stoping and development activities. As shown in Figure 4.3, it can be argued that the support installation problem category is the most frequent problem encountered in stoping, with over 600 recorded instances. Other notable categories include Human Resources (HR) as well as Drilling and Blasting (DB), each with more than 200 instances. Geology and Equipment issues also occur frequently but at a lower rate compared to Support and HR.

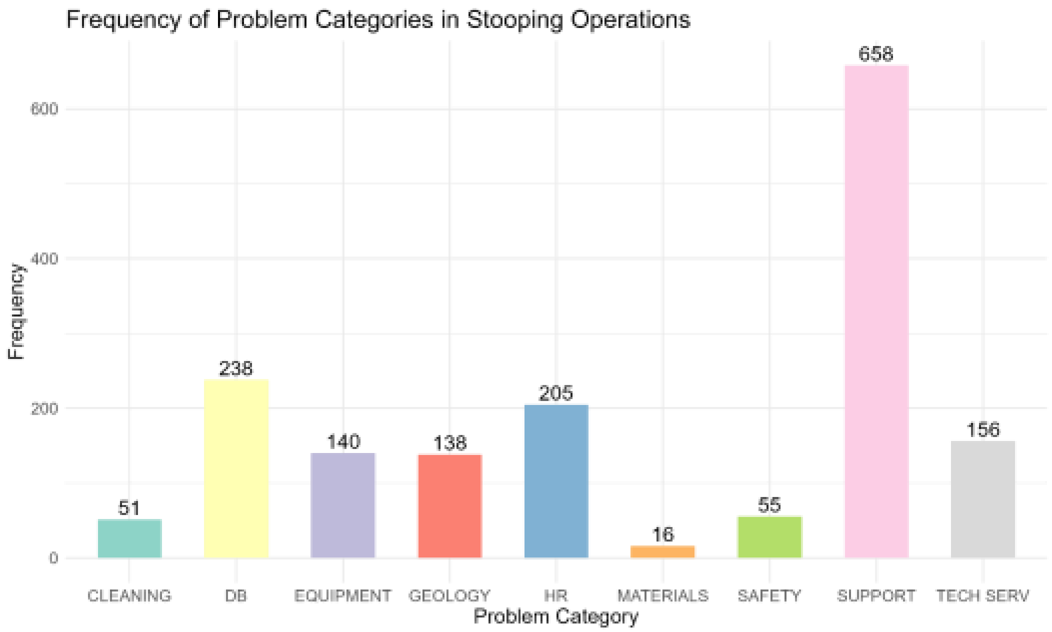


Figure 4.3: Frequency analysis of problem categories in stoping

As for Figure 4.4, Technical Services can be seen to be the most frequent problem category in development, with over 400 recorded instances. DB is also a prominent issue, followed by Support and HR. Other categories, such as Geology, Equipment, and Safety, have comparatively lower frequencies, indicating they are less of a concern in development than in stoping.

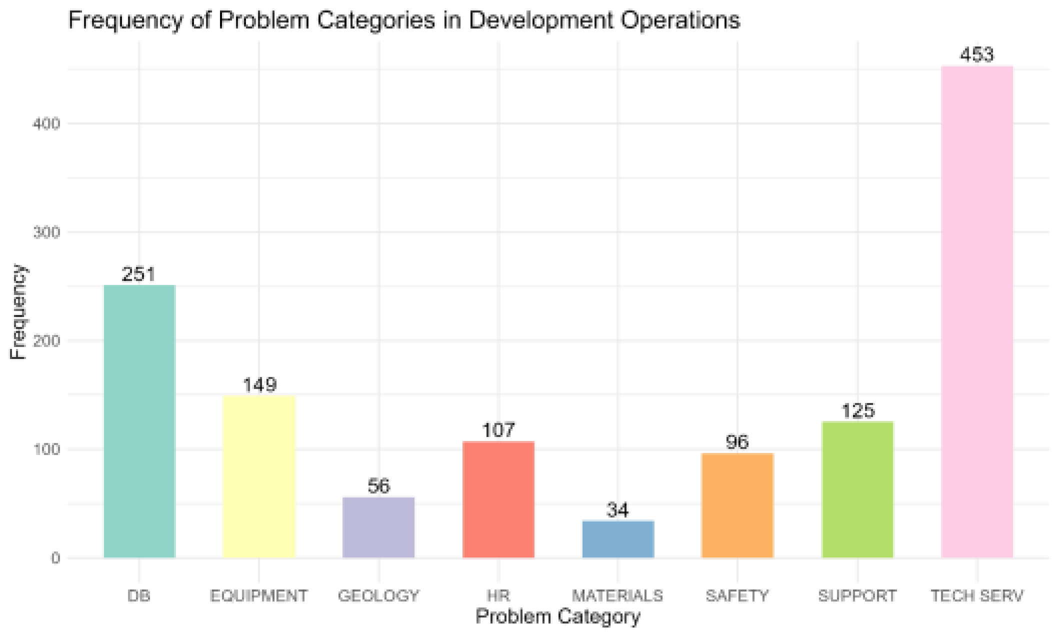


Figure 4.4: Frequency analysis of problem categories in development

4.3.3 Frequency analysis of problem categories resulting in lost blasts

The frequency analysis was done to examine the problem categories that most frequently contribute to lost blasts in both stoping and development operations. The results are shown in Figures 4.5 – 4.8.

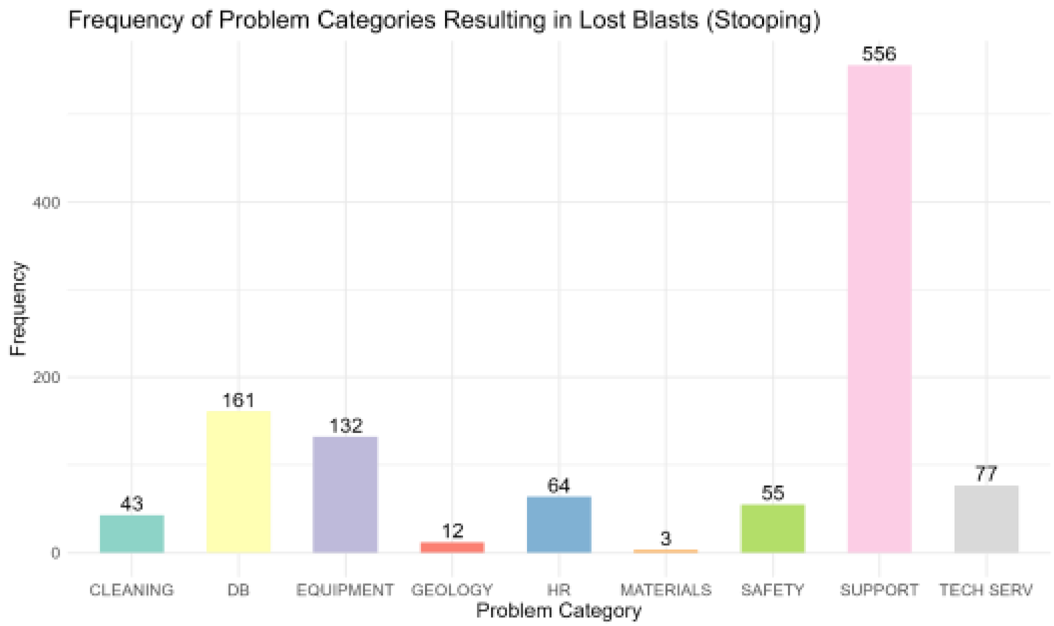


Figure 4.5: Frequency of problem categories resulting in lost blasts in stoping

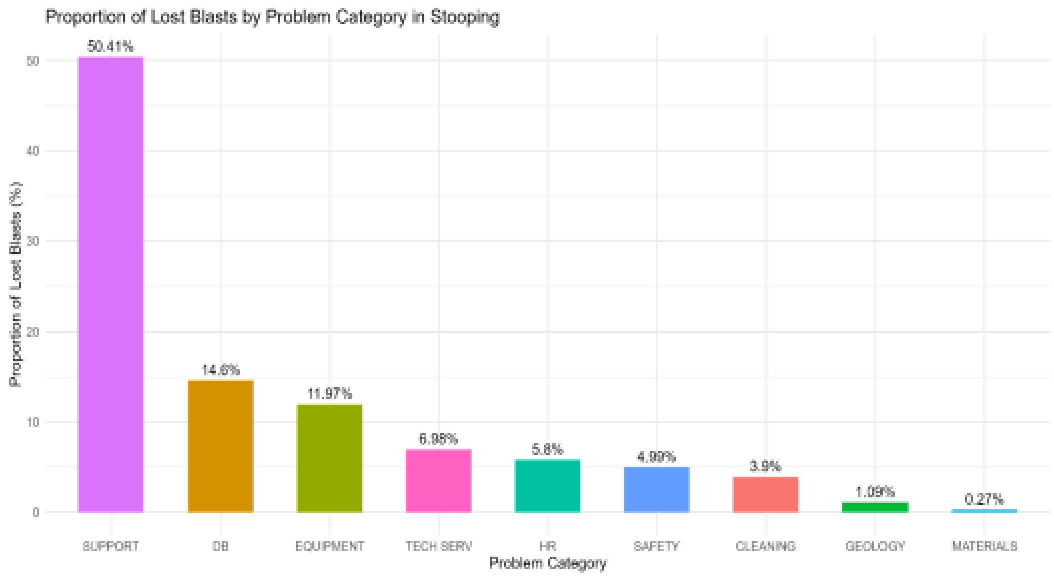


Figure 4.6: Proportion of lost blasts by problem category

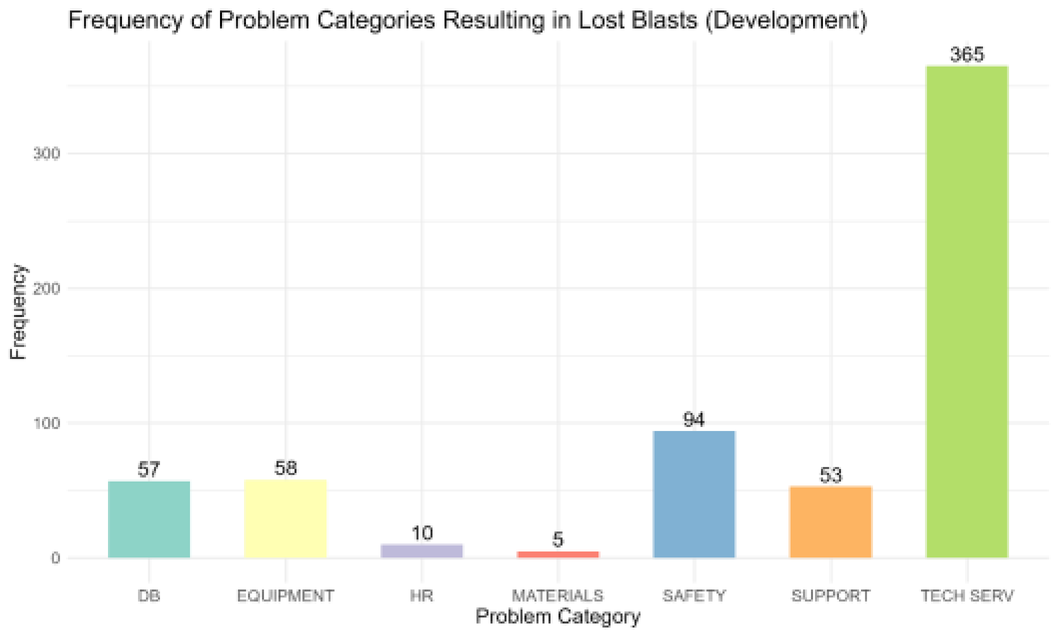


Figure 4.7: Frequency of problem categories resulting in lost blasts in development

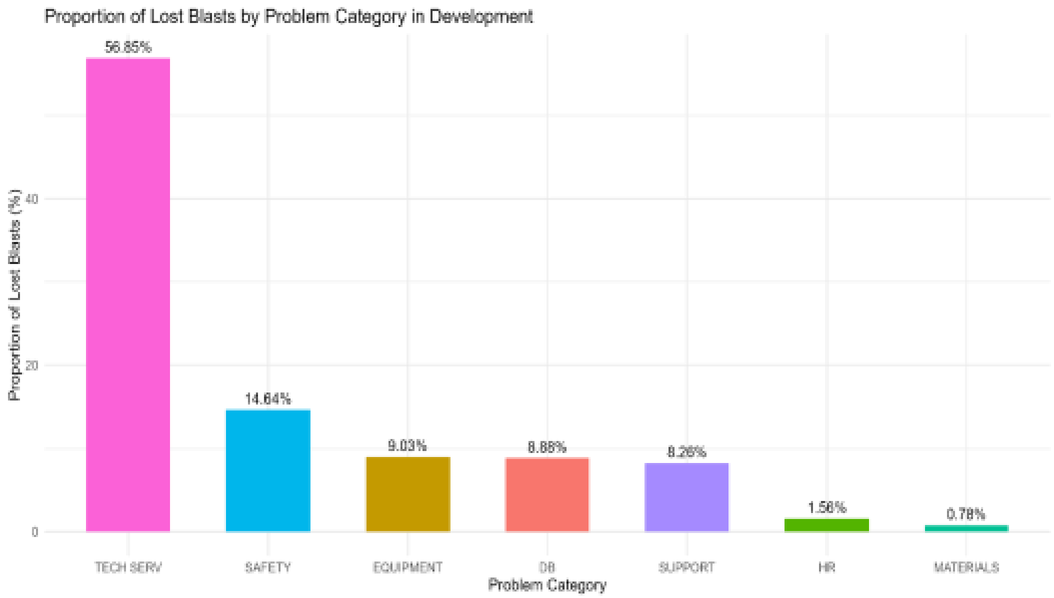


Figure 4.8: Proportion of lost blasts by problem category

Figures 4.5 and 4.6 show that Support is the leading cause of lost blasts in stoping operations, with over 500 recorded instances. This accounts for just over 50% of all lost blasts. Equipment and DB are also notable contributors, each with over 130 instances or above 10% of all lost blasts. Other categories, such as Technical Services, HR, Cleaning and Safety, each account for less than 7% of the lost blasts. Geology and Materials have comparatively lower frequencies and account for less than 2% each of the total lost blasts in stoping.

Figures 4.7 and 4.8, on the other hand, show that Technical Services is the dominant problem category associated with lost blasts in development, with over 350 recorded instances. This accounts to about 57% of all lost blasts. Safety is second and accounts for about 15% of all lost blasts. Equipment, DB and Support, each account for between 8% and 9% of all lost blasts. HR and Materials have relatively the lowest frequencies and each account for less than 2% of all lost blasts.

4.3.4 Proportion of lost blasts per problem category

The proportional analysis examines the likelihood of each problem category resulting in lost blasts. It therefore highlights problem categories which most frequently result to lost blasts.

In terms of stoping, Figure 4.9 shows that Safety and Equipment are the most significant contributors to lost blasts, with proportions close to 1. These problems almost always caused lost blasts. Support and Cleaning also have high proportions, suggesting that issues in these areas frequently lead to lost blasts. Geology and Materials have the lowest proportions, indicating they are less likely to result in lost blasts compared to other categories.

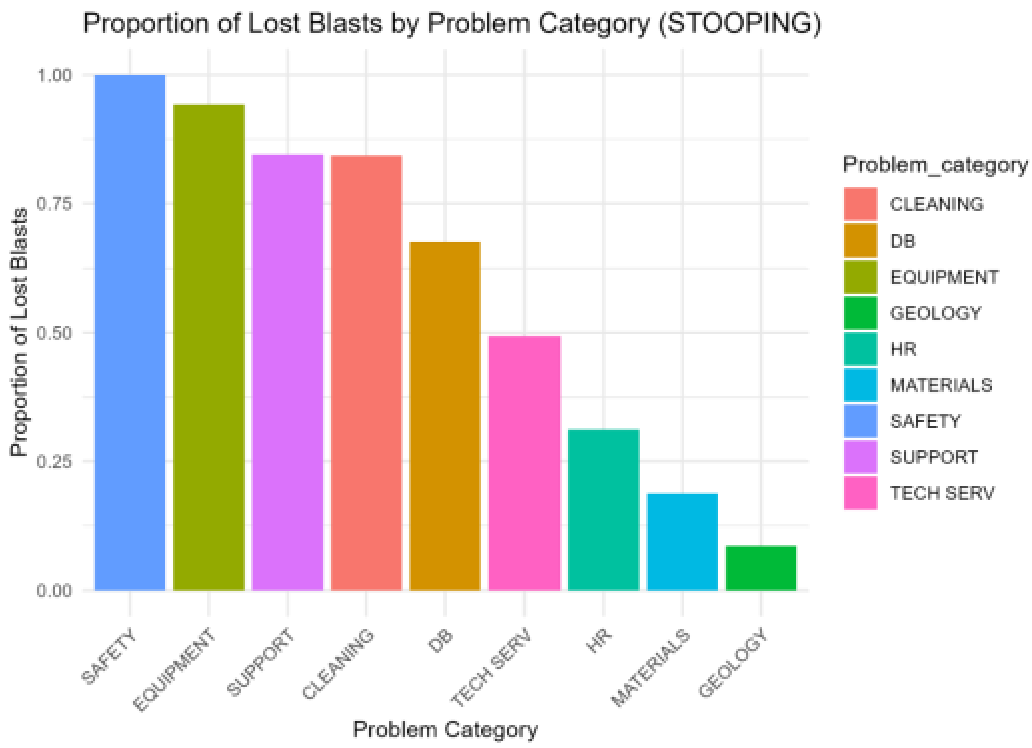


Figure 4.9: proportion of lost blasts per problem category (stoping)

Looking at development, Figure 4.10 shows that Safety and Technical Services are the most significant contributors to lost blasts, with proportions close to 1. Support and Equipment are moderate contributors, while HR and Geology show the least impact on lost blasts.

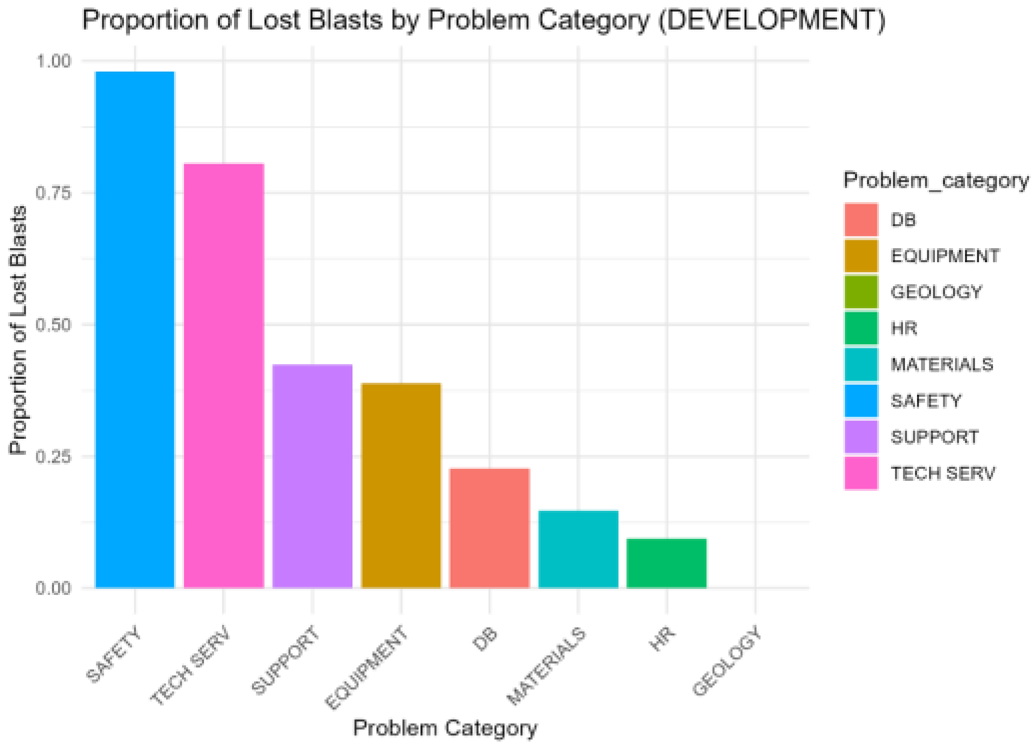


Figure 4.10: proportion of lost blasts per problem category (development)

4.4. Operational problem impact analysis

This analysis quantifies the impact of each problem category on lost blasts. It examines both the frequency and the total Plan Variance (Plan Var) associated with lost blasts. Figures 4.11 and 4.12 illustrate the impact of each problem category on lost blasts in stoping and development operations.

Figure 4.11 shows that Support issues are the most significant contributor to lost blasts, with over 6 500 m^2 in total Plan Var. This category also has the highest frequency, making it the primary source of production variance and lost blasts. DB and Equipment categories follow as substantial contributors with total Plan Vars of 2 187 m^2 and 1 762 m^2 respectively. These two categories also show high frequencies of occurrence, underscoring their impact on lost blasts. Other categories including Technical Services, HR, and Safety show lower total Plan Variances and frequencies. However, they still contribute to the overall lost production.

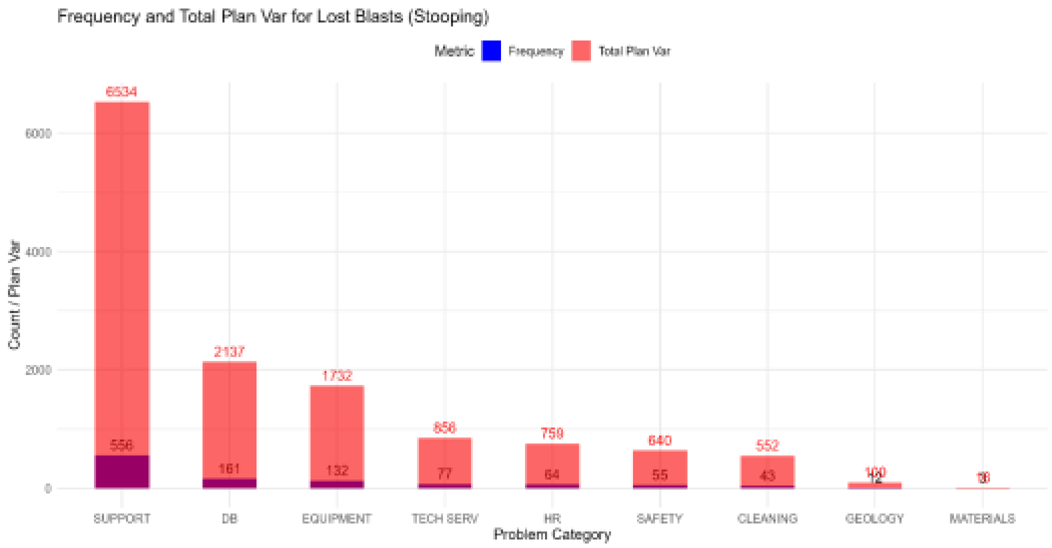


Figure 4.11: Frequency and total plan variance for lost blasts in stoping

When looking at development, Technical Services stands out as the most impactful problem category, with a total Plan Var exceeding 200 m and a high frequency of lost blasts, see Figure 4.12. Safety, Equipment, and DB also show notable impacts, with total Plan Vars of 47.9 m, 37.4 m, and 43.8 m respectively. Support and HR have comparatively lower total Plan Vars with a small contribution to lost blasts.

Figure 4.12: Frequency and total plan variance for lost blasts in development

The Pareto charts in Figures 4.13 and 4.14 provide a view of the most significant problem categories cumulatively contributing to lost blasts.

Figure 4.14 indicates that Support issues are the leading cause of lost blasts in stoping operations, contributing to over 50% of the cumulative impact. DB and Equipment follow, adding substantial contributions to the cumulative total. Together, these three categories account for nearly all lost blasts, highlighting them as critical areas to address. Other categories such as Technical Services, HR, and Safety contribute less significantly and show up later in the cumulative impact curve. These can be considered lower-priority areas for reducing lost blasts in stoping.

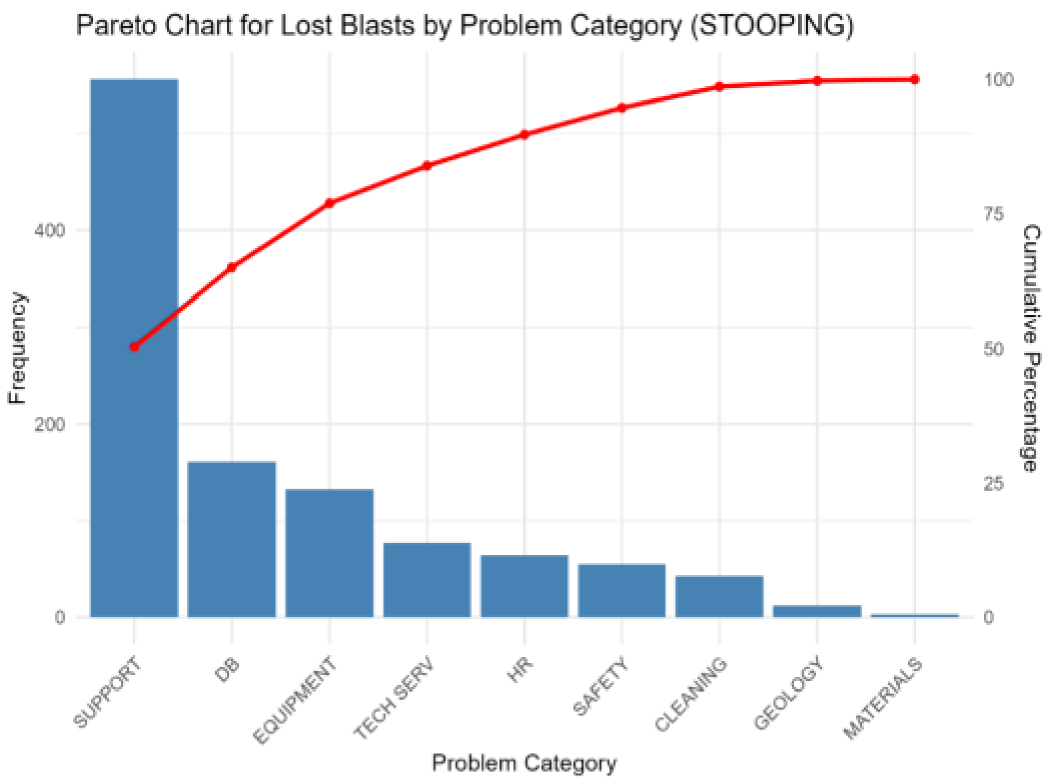


Figure 4.13: Pareto chart for lost blasts in stoping by problem category

As for Figure 4.14 showing the Pareto chart in the development areas, Technical Services is identified as the primary contributor to lost blasts, responsible for over 60% of the cumulative impact. Safety and Equipment follow with contributions of about 20% and 10%, respectively, bringing the cumulative impact to roughly 93%. Categories such as DB, Support, and HR combined, contribute less than 8% to the cumulative impact.

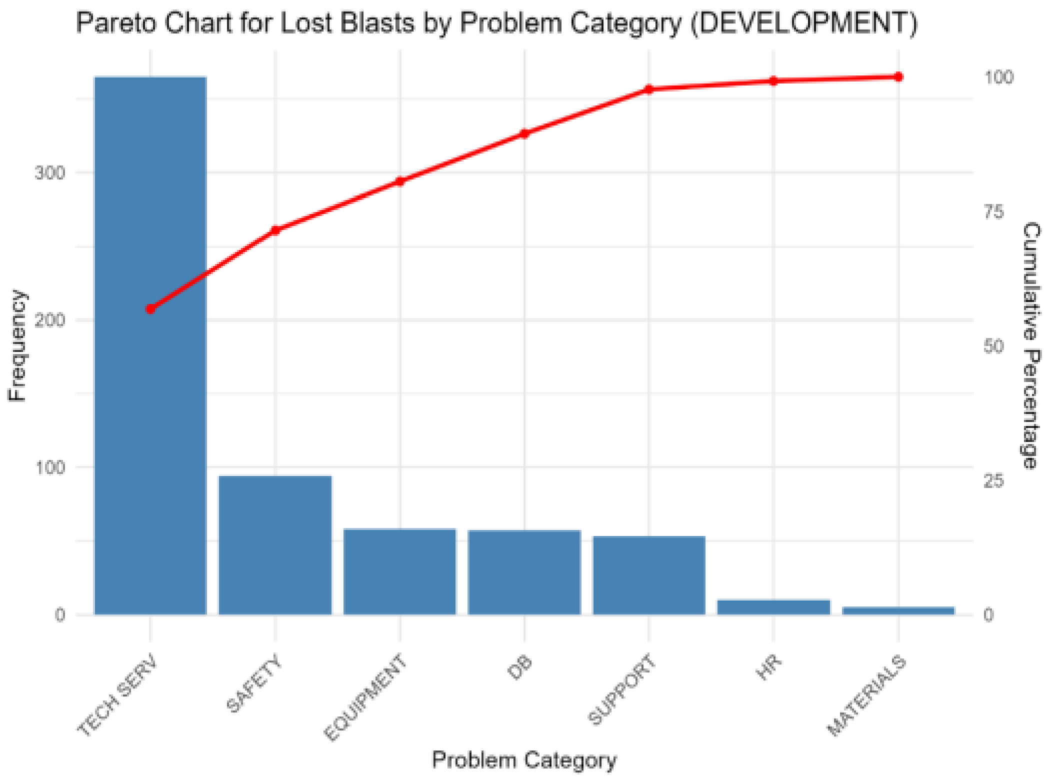


Figure 4.14: Pareto chart for lost blasts in development by problem category

The Pareto analysis illustrated in Figures 4.13 and 4.14 reinforces the findings from the frequency and total Plan Var analyses in Section 4.4, Figures 4.11 and 4.12. It highlights Support as the major area of concern in stoping and Technical Services in development.

4.5. Quantification of production loss in stoping and development operations

The quantification of production loss evaluates the extent of production loss associated with each problem category. The total production loss is measured by Plan Variance (Plan Var). This indicates the problem categories that are responsible for the greatest deviation from planned production targets. Figures 4.15 and 4.16 show the production loss impact by problem category.

It can be seen in Figure 4.15 that Support is the leading cause of production loss in stoping with a total Plan Var exceeding 7 000 m^2. This aligns with previous findings in Sections 4.3.3 and 4.4 where issues around Support were identified as significant contributors to lost blasts in stoping. HR and DB are also major contributors with total Plan Vars above 2 500 m^2 each. Other categories, such as Equipment, Technical Services, and Geology, have moderate production losses but exceeding 1 500 m^2. Safety, Cleaning, and Materials represent relatively smaller contributors to production loss which is less than 700 m^2.

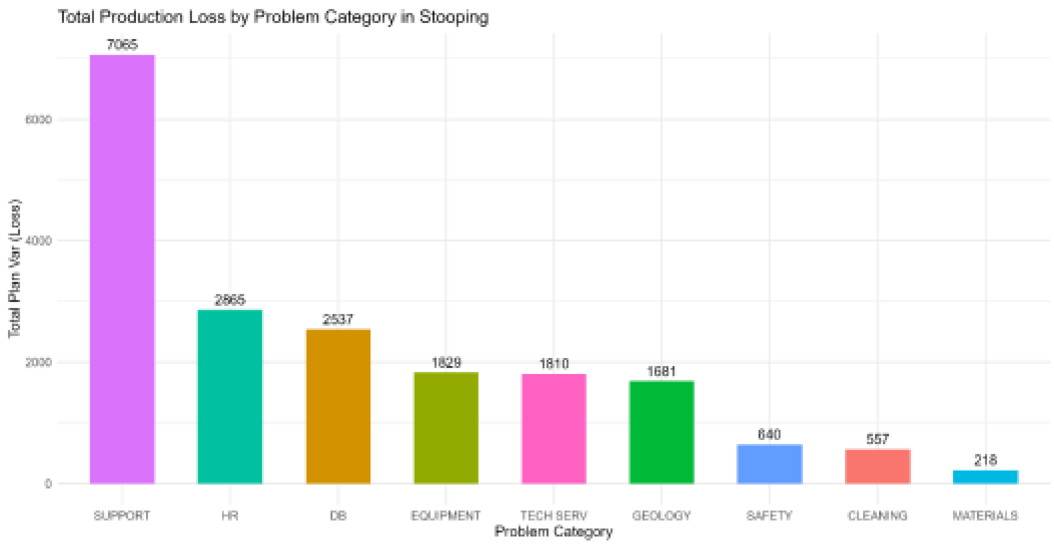


Figure 4.15: Total production loss (variance) in stoping by problem category

Figure 4.16 shows that in development, Technical Services emerges as the primary cause of production loss with a total Plan Var over 250 m. DB and Equipment follow with total Plan Vars of 143 m and 116.2 m respectively. Support and HR show moderate production losses, suggesting that better management in these areas could yield improvements. Categories like Safety and Geology have relatively lower impacts on production loss in development.

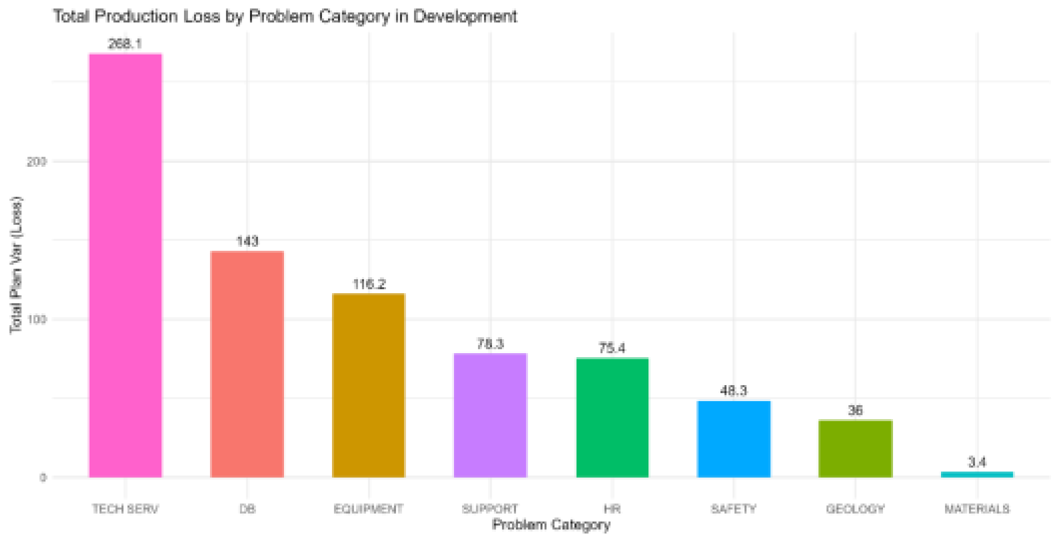


Figure 4.16: Total production loss (variance) in development by problem category

Results in Figures 4.15 and 4.16 highlight the fact that Support in stoping and Technical Services in development are the most impactful categories in terms of deviation from planned production targets.

A cumulative view of the impact of production loss by problem category is provided in the form of Pareto charts in Figures 4.17 and 4.18. Indeed, these two charts illustrate the proportion of total production loss contributed by each category. They further highlight the categories that are responsible for most production deviations from planned targets. The Pareto chart in Figure 4.18 shows that issues of Support associated with stoping alone account for over 50% of the cumulative deviation from planned production targets. This reinforces the role of Support in stoping as the primary driver of lost productivity. HR and DB are the next significant contributors. Equipment, Technical Services, and Geology follow, but their contributions are significantly lower. Safety, Cleaning, and Materials contribute minimally to the cumulative deviation from planned production targets.

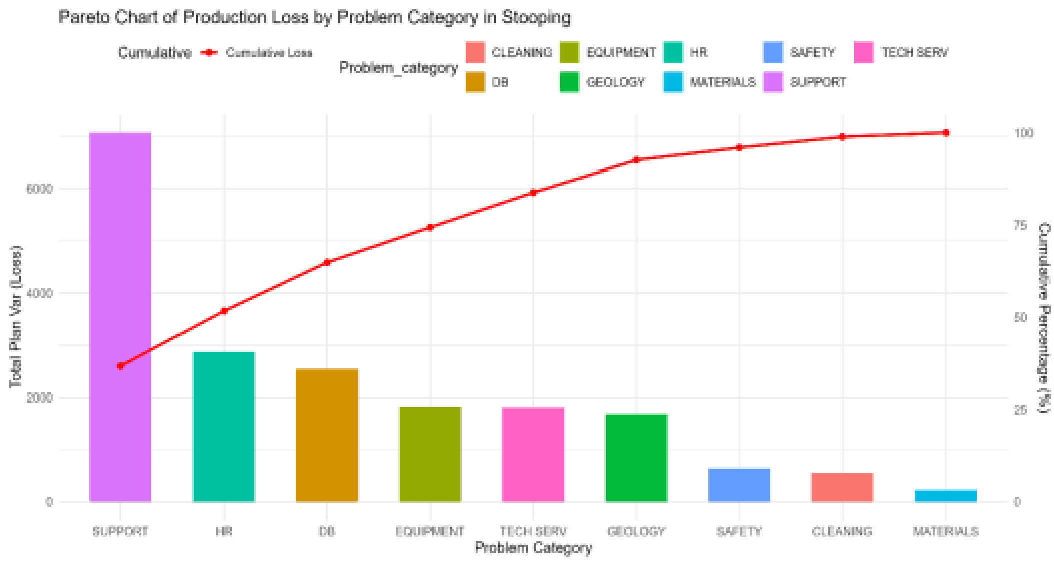


Figure 4.17: Pareto chart of production loss in stoping by problem category

Coming to the Pareto chart in Figure 4.18, in development, Technical Services stands out as the leading cause of production deviations from planned targets. DB and Equipment are the next largest contributors adding significantly to the cumulative production loss. Support, HR, and Safety represent relatively smaller contributions with cumulative impacts levelling off after these categories. Geology and Materials contribute the least to deviation from planned production targets.

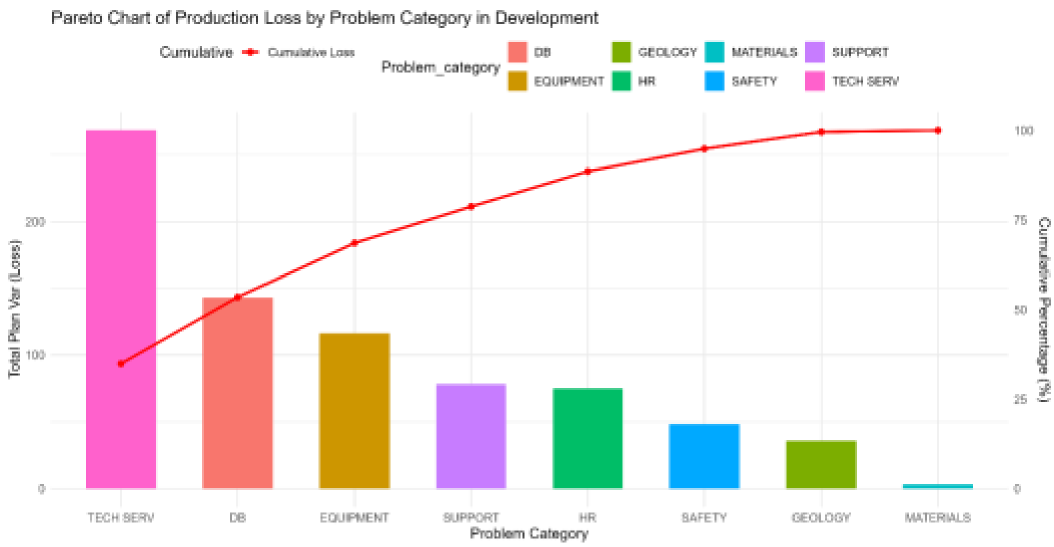


Figure 4.18: Pareto chart of production loss in development by problem category

These Pareto charts (i.e., Figures 4.17 and 4.18) confirm the need for prioritizing Support in stoping and Technical Services in development.

4.6. Correlation analysis of stoping and development operations

The correlation analysis examines the relationships among key production variables in both stoping and development operations. The analysis focuses on Book SQM, Plan SQM, Plan Var in stoping, on the one hand, and Book Adv, Plan Adv, Plan Var in development, on the other.

With reference to Figure 4.19, the correlation matrix for stoping reveals a strong positive correlation (0.78) between Plan SQM and Plan Var. This suggests that as planned square meters increase, the variance between planned and actual results tends to increase as well. In contrast, a positive correlation at 0.5 exists between Book SQM and Plan Var indicating that the actual booked square meters are moderately associated with the deviation from planned targets.

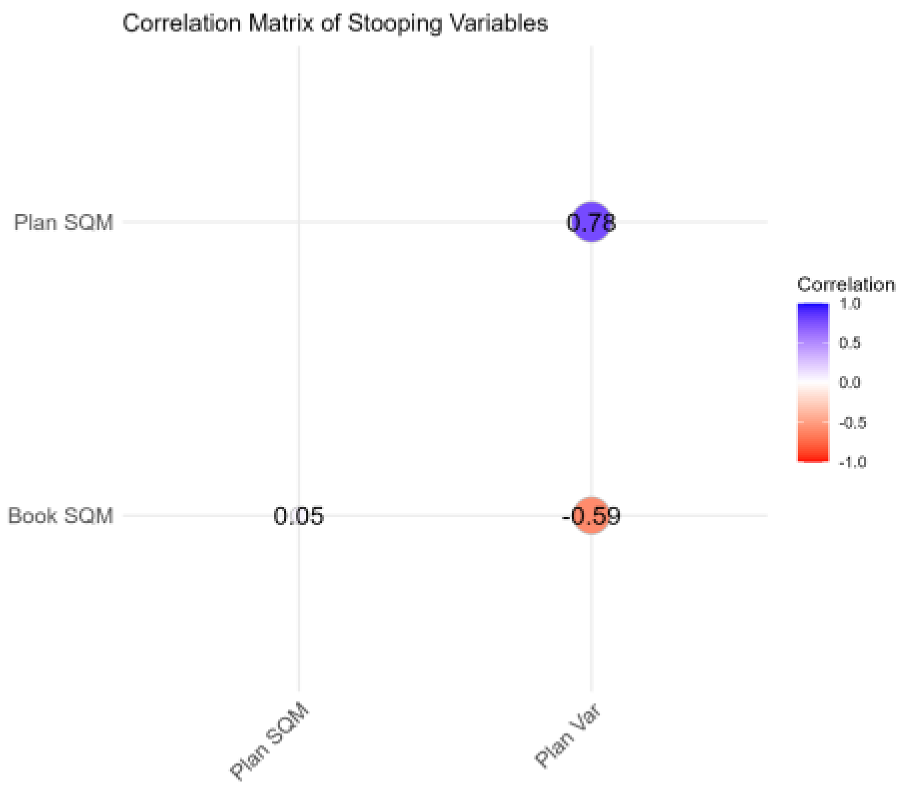


Figure 4.19: Correlation matrix of stoping variables

From a point of view of development operations, Figure 4.20 shows that Plan Adv and Plan Var have a very strong positive correlation (0.9). This suggests that as planned advancements increase, the variance between actual and planned results also increases. There may therefore be a potential issue in setting realistic advancement targets. On the other hand, the correlation between Book Adv and Plan Var is weaker (0.3), indicating a minimal association between actual advancements and the deviations from planned targets.

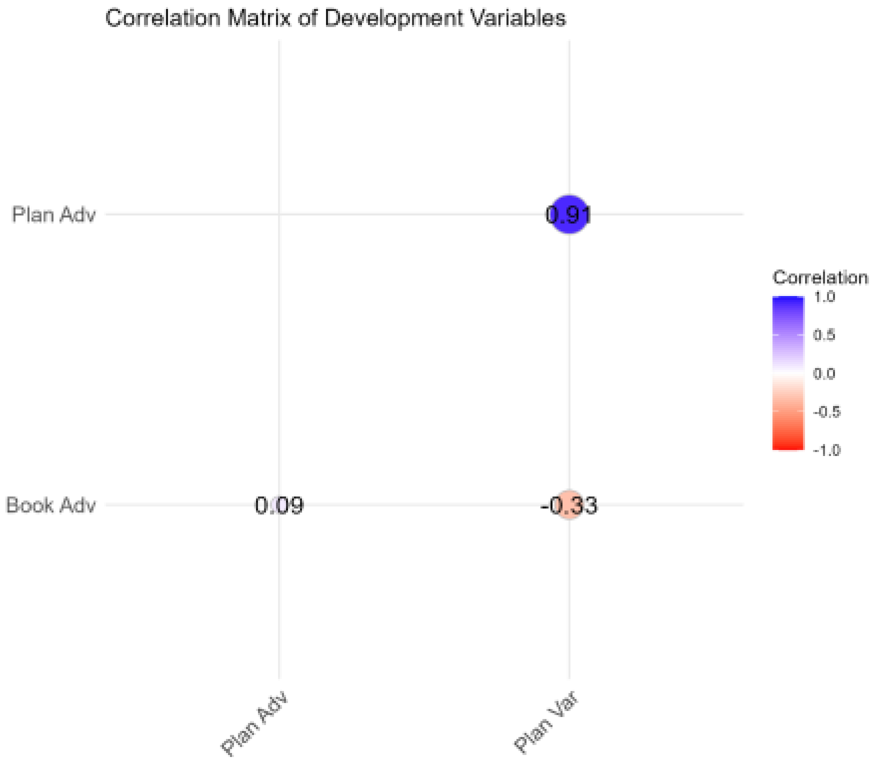


Figure 4.20: Correlation matrix of development variables

In summary, the correlations displayed in Figures 4.19 and 4.20 indicate that higher planned values in both stoping and development are associated with increased variances from actual performance.

4.7. Comparison of production performance in the 2024 and 2025 business plans

This section compares production performance in the 2024 and 2025 business plans. The 2024 plan covered the period from March 2023 to February 2024. The 2025 plan runs from March 2024 to February 2025. Available data for the 2025 plan only includes the months from March to May 2024. The comparison highlights trends and deviations in key metrics such as square metres (m²) in stoping, primary metres (m) in development, and trammed tons (t).

The comparison of stoping performance is presented in Figures 4.21 and 4.22. Figure 4.21 shows that for the 2024 plan, actual square meters were generally below the planned targets. Few exceptions where the actual performance either met or exceeded the planned targets were noted in March 2023 for example. However, in the latter months of the 2024 plan (namely, July 2023, to February 2024), the actual production started to fall consistently below planned values. Similarly, Figure 4.22 shows that for the 2025 plan, the same trend of actual production falling short of planned targets continued between March 2024 and May 2024.

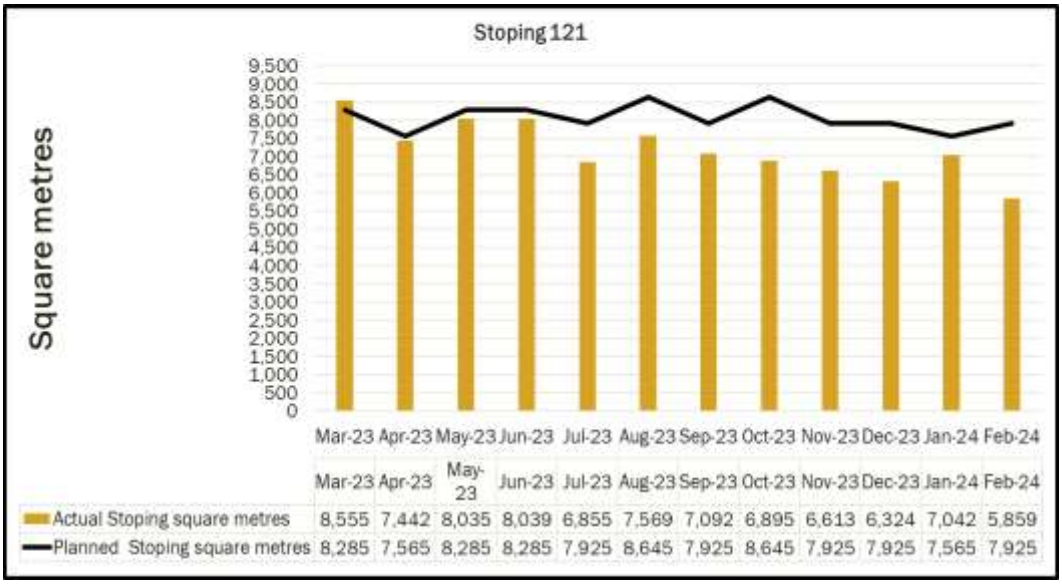


Figure 4.21: Actual and planned square metres corresponding to the stoping of Section 121 during the 2024 business period

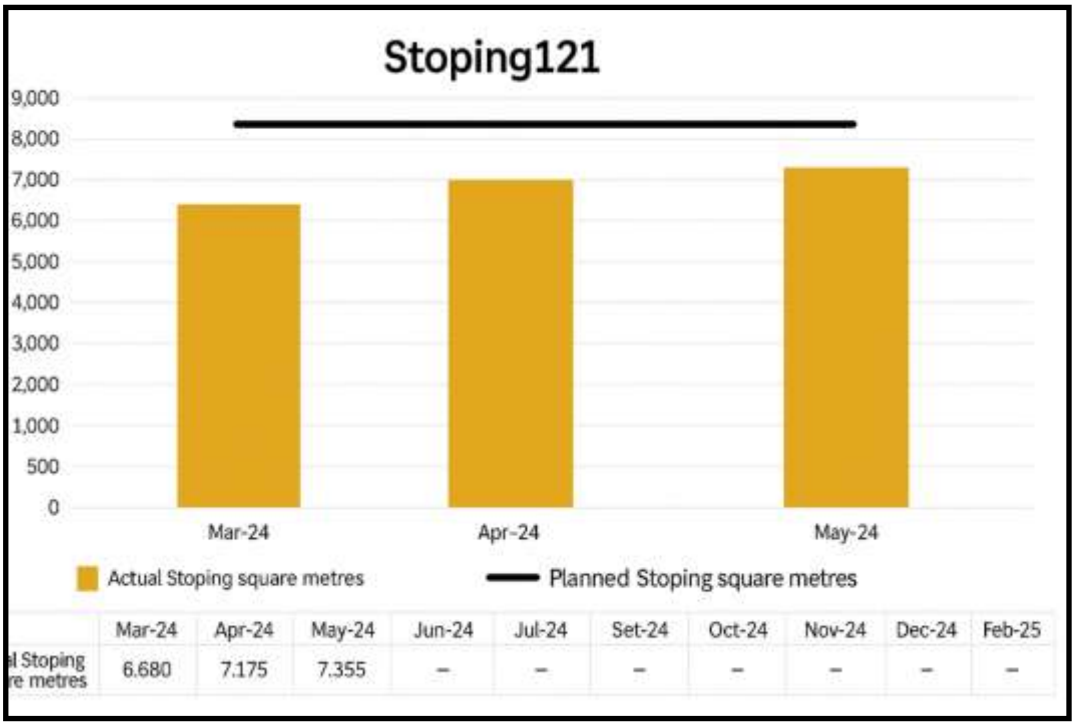


Figure 4.22: Actual and planned square metres corresponding to the stoping of Section 121 during the 2025 business period.

The comparison of Tramming performance is presented in Figures 4.23 and 4.24. Figure 4.23 shows that in the 2024 plan, actual tons trammed fluctuated relative to planned tons. Actual tons trammed exceeded targets in some months (notably March, April, June, and October 2023) while others (July, September, November 2023) fell short. Toward the end of the 2024 plan, actual trammed tons increasingly failed to meet planned values.

Figure 4.24 shows a similar trend that in the 2025 plan, actual trammed tons lagged the planned targets. Therefore, in both periods (2024 and 2025), there is consistent underperformance.

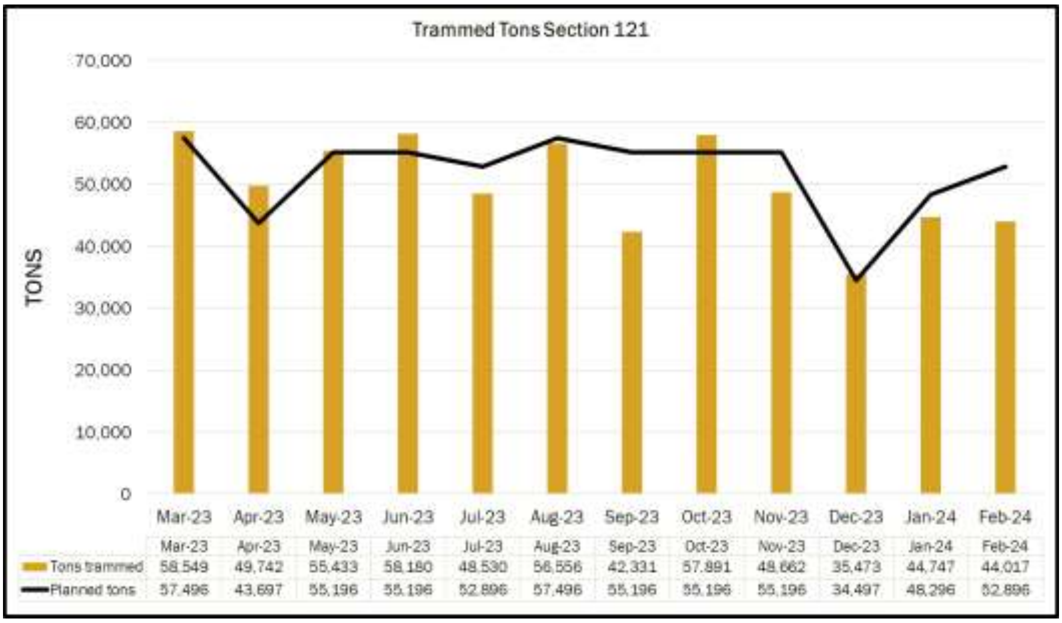


Figure 4.23: Actual and planned trammed tons corresponding to the stoping of Section 121 during the 2024 business period

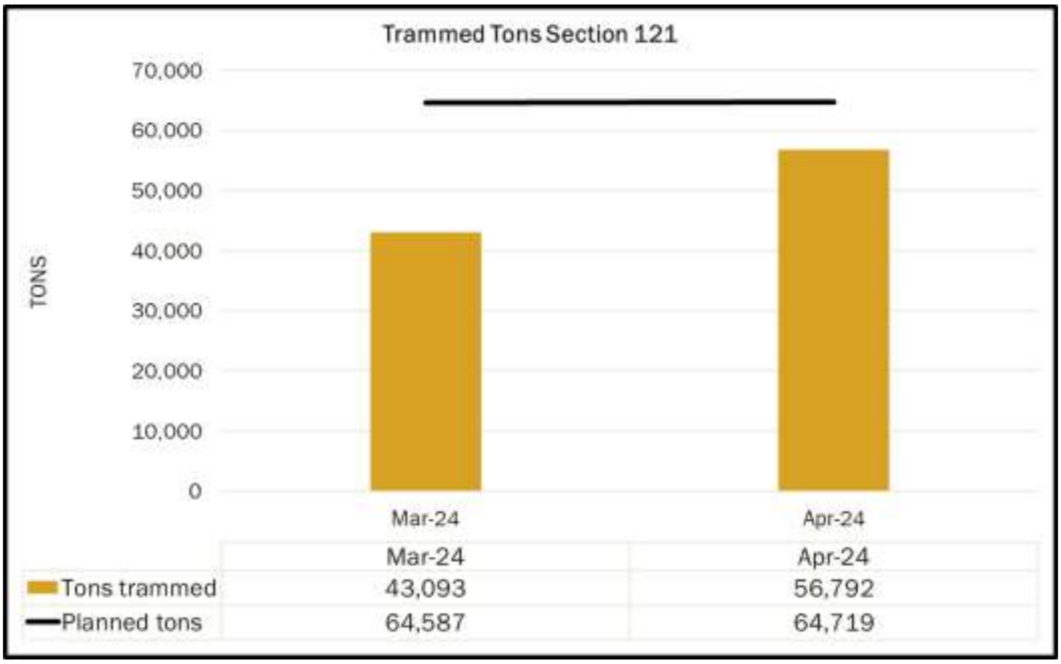


Figure 4.24: Actual and planned trammed tons corresponding to the stoping of Section 121 during the 2025 business period

Figures 4.25 and 4.26 present the comparison of actual versus planned primary metres (m) in development section 125. The results cover both the 2024 and 2025 business plans.

Figure 4.25 shows that during the 2024 period, actual primary meters generally fell below planned target levels. However, there was an exception where the actual performance met or exceeded the planned targets, this was in January 2024. Significant underperformance is also observed in July 2023, October 2023, December 2023, and February 2024.

Similarly, Figure 4.26 shows that actual primary meters generally fell below planned targets. Therefore, in both periods, Section 125 has consistently underperformed as actual primary metres fall below planned targets.

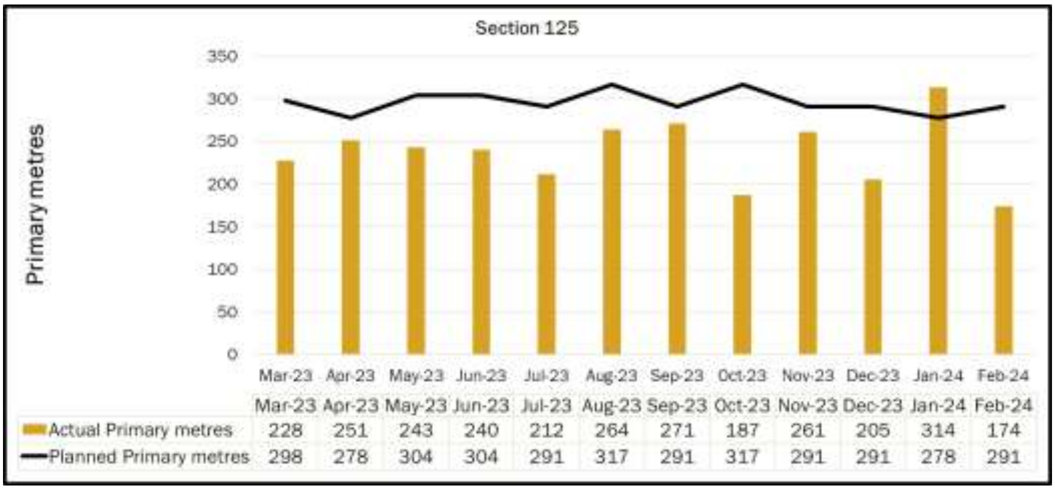


Figure 4.25: Actual and planned primary metres corresponding to the development of Section 125 during the 2024 business period

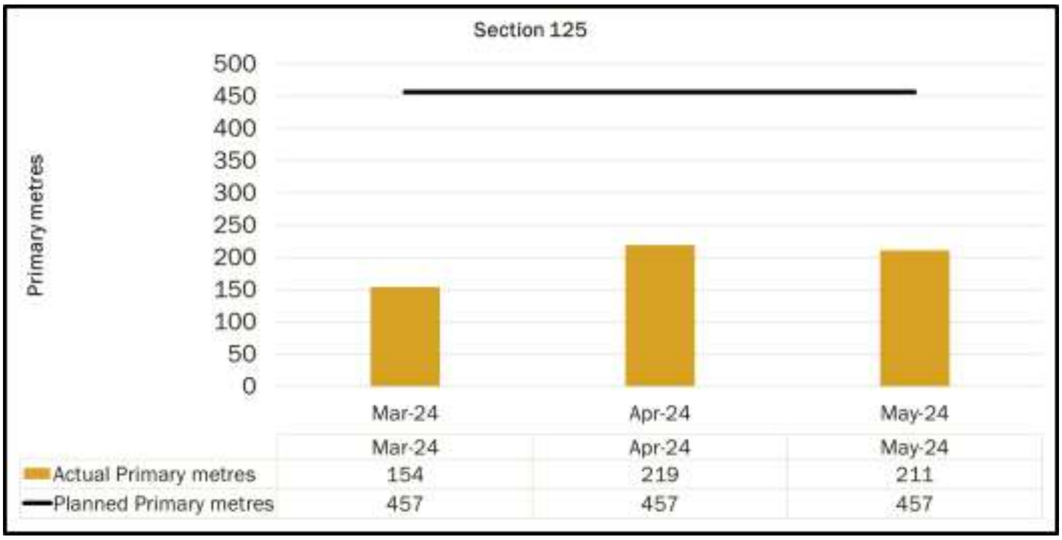


Figure 4.26: Actual and planned primary metres corresponding to the development of Section 125 during the 2025 business period

The comparison between the 2024 and 2025 business plans shows recurring underperformance. Actual performance in key metrics such as square metres (m^2) in stoping, primary metres (m) in development, and trammed tons (t) continued to fall short of targets. Section 4.8 presents the results of the root cause analysis. The aim of this type of analysis was to identify the root causes of the underperformance of the mine.

4.8. Identification of core drivers of production underperformance

The root cause analysis (RCA) focused on identifying the core drivers of production underperformance. Firstly, the RCA identified the immediate causes of the problems. Secondly, the underlying causes which are derived from the interpretation of operational patterns. Finally, the root causes for each problem category, which point to systemic or managerial failures. This approach helped to link observed operational problems with organisational challenges that drive production inefficiencies.

As explained in Chapter 3, Section 3.4.2, all operational problems recorded in the stoping and development were grouped into categories. The names of the categories are: Drilling and Blasting (DB), Support, Cleaning, Geology, Equipment, Human Resources (HR), Materials, Safety, and Technical Services. The categories were chosen to reflect the full spectrum of mining activities, from direct production to auxiliary operations.

Examples of operational problems under each category were also presented in Table 3.3 of Chapter 3. The operational problems were interpreted as immediate causes in the RCA. In Chapter 3, Section 3.5.5 also described the RCA methodology. The immediate, underlying and root causes under each problem category are summarized in Tables 4.3 below.

Table 4.3: List of stoping and development problems and their respective categories

No.	Category	Immediate causes
1	DB	• Blasted hanging wall slipping • Gully flushed with the face • Long pull, Box hang up • Panel Choked (Full tips) • Crew Move (End on limit - new workplace not ready) • Re-Establish face shape • Layout Change • Misfire
2	SUPPORT	• Last support installation • Incomplete Support (Sticks support, Grout packs) • Installing secondary support (L/Anchors and straps) • Planned support (Grout packs) • Pumping of Packs delayed
3	CLEANING	• Sweepings (Panel on limit)
4	GEOLOGY	• Footwall lifting • FOG (i.e., Fall of ground) • Stopped on Geological Feature • Bad Ground conditions
5	EQUIPMENT	• Belt breakdowns: (Winch, LHD breakdown, Man-transporter, Drill Rig, Mono Ropes • Man-transport unavailability
6	HR	• Absenteeism • Labour under complement • Critical Skills Shortage (Rock Drill Operator) • Training

7	MATERIALS	• Materials - Not Available at Face • Materials/Equipment Shortage • Shortage of drilling equipment • Support unavailability (Long anchors, Grout packs, Bolts)
8	SAFETY	• Safety stoppage • Work Stopped: Non standards, DMPR stoppage • Accident investigation
9	TECH SERV	• Inadequate Air Supply/Pressure • Low compressed air • No compressed air • Equipping (Winch installation) • Incomplete/Slow Drilling (Low water pressure) • Incomplete/Slow Drilling (Low compressed air) • Equipping (Service pipes installation) • Inadequate Ventilation • Power Failure Mine Supply • Inadequate Water Supply/Pressure • No Survey Notes & Chains

For the DB category, the immediate causes indicate presence of poor mining practices particularly in blast preparation and execution. These underlying causes directly results into poor blasting outcomes such as misfires. Therefore, the root cause was identified as inadequate drilling and blasting protocols. These protocols failed to ensure consistent blast preparation and execution.

For the Support problems category, the immediate causes included incomplete or delayed support installation, such as delayed pumping of packs, or installation of secondary support. These indicate underlying issues in how support tasks are prioritised, coordinated and scheduled into production cycles. Therefore, the root cause was identified as poor scheduling and coordination in support installation, causing delays and suboptimal support installation practices.

In the Cleaning category, the immediate cause commonly observed was sweepings in panels that had reached their mining limit. This points to ineffective clearance of blasted material before the next mining activity. The underlying causes relate to poor planning of cleaning sequences and delays in assigning cleaning crews to high-priority areas. As a result, the root cause was identified as inefficient cleaning workflows and task prioritisation.

Geology-related operational problems included fall of ground (FOG), poor ground conditions, and additional support requirements due to geological structures. These immediate causes show that ground conditions were often not fully understood or mitigated before mining. This indicates underlying issues in geotechnical planning. Therefore, the root cause was identified as insufficient geotechnical assessments and proactive risk mitigation strategies for challenging ground conditions.

For the Equipment category, immediate causes included frequent breakdowns of winches, loaders, and drill rigs, as well as man transport unavailability and low equipment reliability. These problems reflect to underlying issues of asset management such as a lack of scheduled servicing, poor availability of spares, and equipment monitoring. Hence, the root cause was identified as lack of preventive maintenance planning, spare parts availability, and equipment reliability monitoring.

In the HR category, the immediate causes included high levels of absenteeism, slow drilling due to insufficient labour, and shortages in key skills such as rock drill operators. These problems indicate underlying issues in workforce planning and management. Therefore, the root cause was identified as ineffective workforce management, including inadequate training, absenteeism control, and critical skill shortages.

Material-related delays were driven by shortages of drilling tools and support components such as grout packs, bolts, and long anchors. These problems occurred at the face and directly delayed both support and production tasks. These problems indicated underlying issues in stock control, order lead times, and materials delivery coordination. The root cause was thus identified as poor inventory management and supply chain coordination, leading to critical material shortages.

The Safety category included stoppages due to safety incidents, accident investigations, and regulatory non-compliance. These immediate causes show that production was frequently halted due to inadequate safety readiness and enforcement of safety rules. Therefore, the root cause was identified as insufficient safety protocols and inconsistent compliance monitoring, leading to safety stoppages and increased accident risks.

Technical Service problems included: inadequate ventilation, compressed air shortages, and problems with water supply and winch installation. These immediate causes disrupted production activities such as drilling. Underlying causes were poor infrastructure maintenance and slow response from responsible departments. As a result, the root cause was identified as inadequate maintenance of infrastructure (e.g., air and water supply, power systems) and limited operational support.

The root cause analysis results presented in this section highlight the underlying drivers of inefficiencies across all problem categories. Their implications for mine performance and the development of targeted improvement strategies are discussed further in Chapter 5.

4.9. Summarised findings

Chapter 4 presented the results of the data analysis. It identified core logistical issues contributing to the underperformance of Siyanda Bakgatla Spud shaft. Statistical analysis, frequency analysis, impact analysis, and root cause analysis across various operational categories were used for the purpose. Key findings are summarized in subsequent paragraphs.

First, central tendency and variability of the key production metrics (i.e., Book SQM, Plan SQM, Book Adv, and Plan Adv both for stoping and for development operations) were estimated. Book SQM averaged 1.92 m^2 far below the Plan SQM average of 13.56 m^2. Development advance averaged 0.032 m against a planned 0.64 m. Plan Variance for stoping and development was 11.59 m^2 and 0.61 m, respectively. The results revealed significant discrepancies between planned and actual performance, with underachievement indicating potential inefficiencies in the mining operations.

Second, frequency analysis indicated that lost blasts were more common in stoping (66.5%, n = 1103 where n represents the count or number of occurrences) than in development (50.5%, n = 642). The distribution of operational problems showed that Support installation problem category is the most frequent in stoping (n = 658). This accounts for (50.4%, n = 556) of all lost blasts in stoping. On the other hand, Technical Services was the most frequent problem category in development (n = 453). This accounts for (56.8%, n = 365) of all lost blasts in development. The proportion of lost blasts per problem category showed that, in stoping, Safety and Equipment were the most significant contributors, with proportions close to 1. This indicates that nearly all recorded instances of these problems resulted in lost blasts. In development, Technical Services and Safety displayed similar proportions.

The impact of each problem category on lost blasts in stoping and development operations showed that Support was the most significant contributor in stoping, with a total Plan Variance of 6 534 m^2, accounting for over 50% of the cumulative impact. In development, Technical Services stood out as the most impactful category, with a total Plan Variance of 201.1 m, contributing more than 60% of the cumulative production loss.

Production loss was quantified by problem category to determine which issues caused the greatest deviation from targets. In stoping, Support was the leading cause of production loss, with a total Plan Variance exceeding 7 000 m^2 and contributing to more than 50% of the cumulative shortfall. This confirms that Support is the primary driver of lost productivity in stoping. In development, Technical Services was the leading contributor, with a total Plan Variance over 250 m, accounting for more than 25% of the overall deviation. These findings reinforce the need to prioritise Support in stoping and Technical Services in development when targeting performance improvement.

The correlation analysis in stoping revealed a strong positive correlation (0.78) between Plan SQM and Plan Var. This suggests that as planned square meters increase, the variance between planned and actual results tends to increase as well. In development, Plan Adv and Plan Var have a very strong positive correlation (0.9). This suggests that as planned advancements increase, the variance between actual and planned results also increases.

The comparison between the 2024 and 2025 business plans revealed consistent underperformance. Actual performance in in key metrics such as square metres (m^2) in stoping, primary metres (m) in development, and trammed tons (t) continued to fall short of targets. The results underscoring a need for operational improvements to achieve business objectives.

Last, root cause analysis (RCA) identified root causes for each operational problem category. In Drilling and Blasting, misfires were traced to poor blasting protocols and inconsistent execution. Support delays resulted from poor scheduling and weak coordination of support tasks. Cleaning issues were linked to ineffective task prioritisation and unstructured workflows.

Geology-related problems, including fall of ground, highlighted inadequate geotechnical assessment and risk planning. Equipment failures stemmed from unreliable maintenance practices and spare part shortages. In the

Human Resources category, absenteeism and skill shortages pointed to weak workforce management and training gaps.

Material shortages at the face reflected poor inventory control and delayed supply chains. Safety-related stoppages arose from inconsistent enforcement of safety protocols. Technical Services disruptions were caused by inadequate maintenance of infrastructure such as ventilation, compressed air, and water systems.

The findings from the root cause analysis confirm that production losses were driven by deeper planning, logistical, and systems-level failures. The root causes provide a foundation for targeted recommendations to enhance operational efficiency and productivity.

The results from Chapter 4 set the stage for Chapter 5 where the results are discussed and made sense of. Strategies for addressing the identified root causes are also proposed for performance improvement at the Spud shaft.

Chapter 5 Understanding the contribution of identified root causes to the underperformance of the Siyanda Bakgatla Spud shaft

5.1 Introduction

This chapter interprets the findings presented in Chapter 4 and attempt to provide an explanation of the contribution of the key drivers to underperformance at Spud shaft. Chapter 4 established a consistent and significant gap between planned and actual production performance in both stoping and development. The findings demonstrated that lost blasts are the central operational mechanism through which inefficiencies translated into measurable production shortfalls.

High-frequency problem categories, particularly support installation in stoping and technical services in development, were not only recurrent but also disproportionately disruptive. Their impact extended beyond immediate delays, creating ripple effects that constrained subsequent activities within the continuous mining cycle. This interdependency highlights the importance of viewing mining logistics as an integrated system rather than as independent operational functions.

The strong relationship observed between planning targets and variance further suggests potential misalignment between operational capacity and planning assumptions. Where higher production targets were consistently associated with greater deviations, it raises questions regarding planning realism, resource allocation, and operational readiness.

The comparison between the 2024 and 2025 business plans also revealed consistent underperformance in square metres (m^2), primary metres (m) and trammed tons (t).

Chapter 5 builds the findings in Chapter 4 by explaining why the results look the way they do. Section 5.2 reviews gaps between plan and actual, including 2024 and 2025 plans. Sections 5.3 and 5.4 examine lost blast frequency and impact by category. Section 5.5 presents the root cause analysis, and Section 5.8 leads to Chapter 6 recommendations.

5.2 Discrepancies between planned targets and actual performance in stoping and development

In Chapter 4, Sections 4.2.1 and 4.2.2 revealed that there was a significant shortfall between planned targets and actual production in both stoping and development operations. This section discusses this core finding. It is important to understand this discrepancy because it highlights a pattern of underperformance that can be attributed to how targets are developed, communicated, and operationalised at the mine.

Table 5.1 summarises the differences in stoping and development. In stoping, the average Book SQM was only 1.92 m², far below the planned 13.56 m². Development showed a similar pattern. Book advance averaged 0.032 m compared to a planned 0.64 m. These differences produced significant Plan Variances of 11.59 m² in stoping and 0.61 m in development. The median Book SQM and Book Adv values of zero in both cases confirm that the underperformance was not marginal but structural. This suggests that in many panels, no production occurred during entire shifts.

Table 5.1: Comparison of planned and actual production in stoping and development at Spud shaft

Metric (mean)	Planned	Actual	Variance
Stooping (m^2)	13.56	1.92	11.59
Development (m)	0.64	0.03	0.61

One major reason for this discrepancy is that mine planning assumptions did not fully account for the real constraints faced underground or the current capacity. However, operations below 20 Level at Spud Shaft are affected by the aging infrastructure. This is an old mine whose essential infrastructure has not been revamped. It is vulnerable to logistical challenges. Therefore, there is a disconnect between the planning assumptions and operational realities underground. Previous studies have also highlighted that actual mining performance often deviates from the plan targets due to misalignment between tactical planning and actual mining conditions (Sebutsoe and Musingwini, 2017).

The underperformance in also related to the high occurrence of non-blasting days. As shown in Tables 4.1 and 4.2 of Chapter 4, Book SQM and Plan Adv had a median of 0 m². This suggests that entire panels were unproductive. These non-productive shifts also contribute to the variances between planned and actual production.

Operational inefficiencies in the mining system also contributed to the gap between planned targets and actual output. In Chapter 4, Section 4.3.2, nine operational problem categories are shown to affect both stoping and development operations (see Figures 4.3 and 4.4). These problem categories are: Drilling and Blasting (DB), Support, Cleaning, Geology, Equipment, Human Resources (HR), Materials, Safety, and Technical Services.

Table 5.2 summarises the three most frequent operational problems in each case. In stoping, the three dominant operational problems recorded were support (39.7%), DB (14.36%) and HR (12.37%). In development, Technical Services (35.64%), DB (19.74%) and Equipment (11.72%) were the most frequent problem categories. All the operational problems contribute to the unfavourable deviation between planned targets and actual performance. They disrupt the mining cycle, leading to lost productivity, delays, and lost blasts.

Table 5.2: Top three dominant operational problems in stoping and development at Spud shaft

	1st Problem	**2nd Problem**	**3rd Problem**
Stoping	Support (39.7%)	Drilling & Blasting (14.36%)	Human Resources (12.37%)
Development	Technical Services (35.64%)	Drilling & Blasting (19.74%)	Equipment (11.72%)

The correlation analysis in results in Section 4.6 of Chapter 4 further confirmed the problem of underperformance. In stoping, the correlation between Plan SQM and Plan Variance was 0.78. In development, the correlation between Plan Advance and Plan Variance was even higher at 0.90. This means that higher planned targets were strongly associated with larger performance gaps.

The consistent underperformance suggests that the planning system of the mine is either too optimistic or inflexible. This is because there is no indication of significant adjustments to the planned targets across time. This is seen in the consistent Plan SQM and Plan Adv across 2024 and 2025 despite repeated underperformance (see Figures 4.21 – 4.26).

There is also evidence of times when actual performance exceeded planned targets. For instance, a negative minimum Plan Var of (-25 m^2) in stoping (Table 4.1) and Plan adv of (-1.4 m) in development indicates good performance. This means that in the times of underperformance there were inefficiencies from operational problems. Therefore, it would have been necessary to adjust the planned targets to reflect the operational capabilities.

The need for such adjustments has also been noted by previous studies. For example, Tu et al. (2023) suggested that incorporating dynamic scheduling models could help align planned targets more closely with actual operational capabilities, thereby reducing the observed Plan Var and improving consistency in meeting targets.

The production performance across the 2024 and 2025 business plans (see Chapter 4, Section 4.7), further highlights the consistent underperformance of the mine. Actual performance in in key metrics such as square metres (m^2) in stoping, primary metres (m) in development, and trammed tons (t) continued to fall short of targets.

In stoping (see Figures 4.21 and 4.22), the actual square metres in Section 121 were consistently below the plan. These persistent shortfalls suggest that the operational problems were not resolved between planning periods.

Tramming underperformance (Figures 4.23 and 4.24) was also evident as actual trammed tons in 2024 and 2025 were often below target. The decline in trammed tons reflects incomplete cycles. When blasts are lost or cleaning is delayed, broken ore cannot be transported. This breaks the link between drilling and logistics, reducing overall tonnes moved.

In development (Figures 4.25 and 4.26), actual advance was consistently lower than planned. Section 125 showed underperformance in most months across both business plans. The persistence of this underperformance implies that interventions to the operational problems, if any, were ineffective.

It should be noted that operational problems contribute to underperformance at Spud Shaft. However, the findings discussed above also point to potential failures in planning based on performance data. The next section discusses the incidence of lost blasts in both stoping and development operations.

5.3 Incidence of lost blasts in stoping and development

This section explains why lost blasts occurred so frequently, which problem categories were most responsible, and why some problems almost always led to lost blasts.

Figure 5.1 illustrates the occurrence of lost blasts in stoping and development at Spud shaft. It was found that the incidence of lost blasts was 66.5% in stoping and 50.5% in development. These high frequencies highlight the negative impact of operational problems on production in form of lost blasts. When blasting is missed, the entire mining cycle is delayed, and available shift time is wasted.

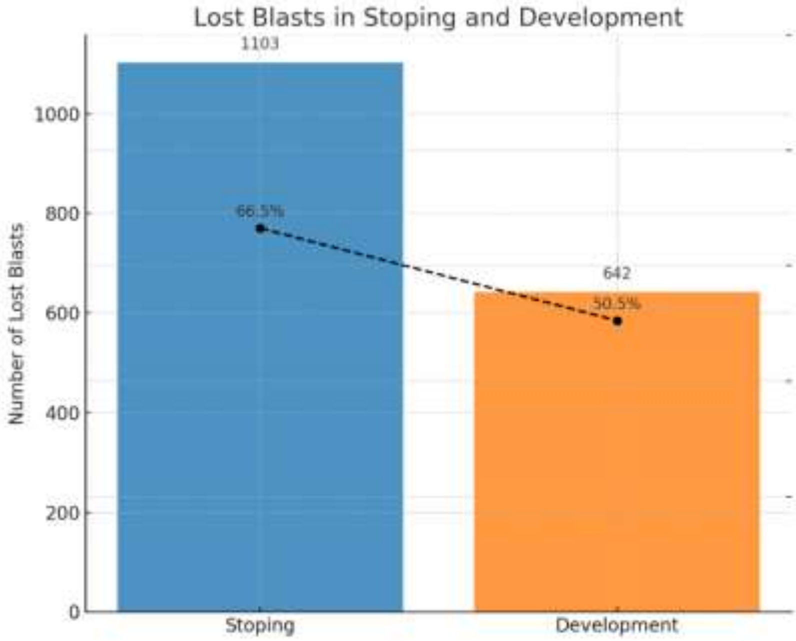


Figure 5.1: Lost blasts in stoping and development at Spud shaft

Figure 5.2 shows that at Spud shaft, Support, DB and Equipment problems account for over 76% of all lost blasts in stoping. On the other hand, technical services, Safety and Equipment problems account for 80% of all lost blasts in development. The occurrence of these problems provides the conditions for a lost blast to happen. Achieving a safe, quality daily blasts (SQDB) require remedying operational lapses in the mining production system (Sebutsoe and Musingwini, 2017). At Spud shaft, all the nine problem categories are the operational lapses in the mining production system (Chapter 4, Figures 4.5 – 4.8).

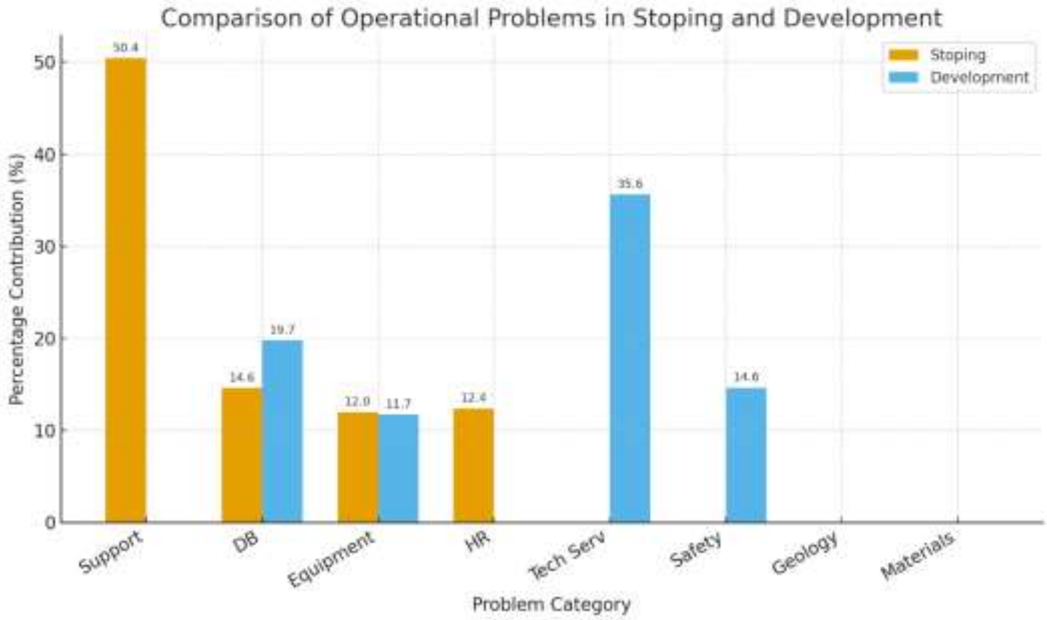


Figure 5.2: Compares the dominant operational problems percentage contribution to lost blasts in stoping and development

The higher rate of lost blasts in stoping compared to development is due to several interrelated operational factors (Figure 5.1). Stoping relies on completion of prior tasks in a strict order. The face has to be inspected and supported. Thereafter, the face has to be drilled, blasted and then cleaned. If any one of these steps is missed or delayed, the blast cannot proceed.

Support operational problems were the most frequent contributor to lost blasts in stoping, accounting for over 50% of cases (see Figure 4.6). Support in stoping is labour-intensive and technically demanding due to narrow panels, challenging ground conditions, and limited space for crews and equipment. These conditions increase the likelihood of delays. In contrast, development typically involves fewer faces and fewer interdependent crews. It also relies on most machinery therefore it is more sensitive to infrastructure failures.

It should also be noted that the operational problems at the spud shaft are interlinked within the continuous mining cycle. A disruption in one area almost always causes a ripple effect, leading to bottlenecks and lost blasts. The mining cycle typically involves a sequence of activities: Drilling, Blasting, Cleaning (Mucking), and Support. All other functions (i.e., HR, Equipment, Materials, Safety, Technical Services, Geology) are enablers or constraints on this core cycle.

HR provides the necessary skilled labour; Equipment provides the tools; Materials provides the consumables; Technical Services (or Tech Serv) provides the vital infrastructure (air, water, power, ventilation, survey); and Geology dictates the environment and its challenges. Safety acts as the ultimate arbiter, capable of halting any operation that poses a risk, regardless of the cause. Therefore, an attempt to address one problem in isolation without considering its links to others is likely to be ineffective in preventing lost blasts.

The frequency and distribution of lost blasts at Spud shaft reflect confirms that lost blasts are the main mechanism driving underperformance. They point to underlying drivers of inefficiencies across all nine problem categories. These are discussed further in the two sections that follow.

5.4 Impact of operational problem categories on production performance in stoping

The results in Figures 4.11 and 4.12 (Chapter 4) also reveal the impact of lost blasts on the plan variance stemming from each problem category. This adds to the discussion in Section 5.2 above. Support installation in stoping exceeds 7 000 m^2 of lost production. This reflects the high frequency of support-related issues. It also highlights the critical role of support installation in stoping. Any delays or incomplete support means that drilling and blasting will not take place. Neigno and Cawood (2014) have argued that neglecting support installations in favour of more measurable factors like immediate production outputs leads to increased Plan Variance and underperformance.

In development, Technical Services issues accounted for more than 250 m of lost advance (Figure 4.12). In the previous Section 5.3, it was noted that development requires reliable infrastructure such compressed air, water supply, and power. Therefore, technical service failures tend to have more impact on loss of advance.

Mashingaidze et al. (2021) confirm that unreliable compressed air lines increase idle time and reduce penetration rates. At Spud Shaft, breakdowns in these systems meant that drill crews could not advance. Hoseinie et al. (2018) note that underground environments accelerate equipment wear, necessitating preventive maintenance of the infrastructure.

It is important to note that the impact of the Safety problem category in stoping and development. Nearly every safety-related problem resulted in a lost blast (Figures 4.9 and 4.10). These included formal stoppages by the Department of Mineral and Petroleum Resources (DMPR), accident investigations, and non-standard work conditions (Table 4.3). Once a safety issue is flagged, work is often stopped. This explains why the proportion of lost blasts within this category was 1. This indicates that safety incidents had a near 100% likelihood of resulting in lost blasts.

Figure 5.3 shows that stoping recorded a total variance of 10,934 m², while development recorded 579.7 m due to lost blasts. This confirms that lost blasts in stoping had a disproportionately greater effect on production losses compared to development.

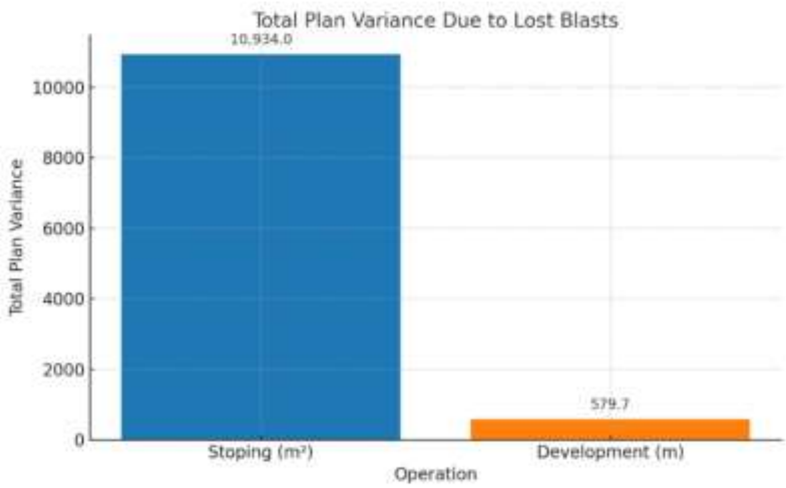


Figure 5.3: Total plan variance in stoping and development due to lost blasts

The impact of the operational problems in terms of production loss, further cements the core argument that the occurrence of the operational problems brings inefficiencies and drive consistent underperformance through lost blasts. This is visible in both stoping and development. Section 5.6 explores the deeper reasons behind these patterns using the root cause analysis findings from Chapter 4.

5.5 Root cause analysis of logistical and operational inefficiencies

The RCA had identified root causes within each problem category that enable operational problems to persist and affect the performance of the mine (Chapter 4, Section 4.8). Each problem category was analysed through three levels: immediate causes, underlying problems, and root causes. This section discusses each operational problem category based on Table 4.3 of Chapter 4.

5.5.1 Contribution of drilling and blasting inefficiencies to underperformance

In the DB category, misfires and poor blast outcomes were traced to inconsistent execution and inadequate preparation. The root cause was identified as inadequate blasting protocols (Chapter 4, Section 4.8). These protocols failed to ensure that blast preparation, and execution followed a standardised process. This suggests that procedural compliance is not enforced, or supervisors fail to verify the work. The problems listed in Table 4.3 illustrate how technical shortcomings in drilling and blasting result in lost blasts.

A hanging wall slip immediately after a blast creates an unsafe workplace and delays the next cycle. Similarly, when a blast flushes a gully, the gully must be repaired before blasting can resume. Long pulls and choked ends indicate that the blast failed to fragment rock effectively. These conditions prevent cleaning and delay the next round.

Box hang-ups and full tips prevent cleaning and create backlogs, leading to lost blasts. Poor blasting practices may also lead to irregular face shapes. Time is then spent reshaping the face instead of drilling, resulting in missed cycles. In some cases, repeated blast failures force a layout change (Seccatore et al., 2020). This leads to long-term production losses and capital costs. Misfires are a direct form of lost blast, with work halted until the area is declared safe. Misfires also increase hazards for crews, necessitating workplace moves and additional safety measures (Li et al., 2022).

5.5.2 Contribution of support installation inefficiencies to underperformance

The root cause of support installation problems stems from poor scheduling and coordination in support installation, causing delays and suboptimal support practices. Examples from support installation problems the mine confirm this (Table 4.3).

If the last support installation is incomplete in an end that is already drilled, safety regulations prohibit blasting. Similarly, if a panel has reached its limit but final support is not installed, blasting cannot proceed. Incomplete stick support or grout pack installation means the workplace is considered unstable, which leads to a lost blast.

Even if the packs are planned, delays in pumping prevent the support from being finalised. Secondary support tasks such as installation of long anchors or straps consume time from the cycle. If not accounted for, they delay blast preparation. All these conditions result in work stoppages until support is complete, directly causing lost blasts.

The literature also highlights that installing support systems is essential to stabilize excavations, maintain continuous production and protect workers

(Moss and Kaiser, 2022). Delays in support installation or inadequate support can lead to unplanned rehabilitation, production stoppages, and increased costs. In narrow tabular mining, the rate of support installation must match the mining advance to avoid production bottlenecks (Andrews, 2019).

5.5.3 Contribution of cleaning inefficiencies to underperformance

Cleaning problems stem from inefficient task sequencing and prioritisation. In a well-managed cycle, cleaning should be completed during nightshift to prepare the face for the next blast. Delays reflect poor planning or lack of accountability. As with support, cleaning is a scheduled activity. If it causes production delays, it points to substandard practices.

At the mine, sweepings were often left incomplete. While minor in volume, the time spent completing sweepings delayed the close-out of panels and prevented timely preparation of new workplaces. This created bottlenecks in face availability. In some cases, panels could not be closed because sweepings were pending. This led to delays in resulting in indirect lost blasts. Sebutsoe and Musingwini (2017) have previously argued that support installation and cleaning should not be a cause of lost blasts because these are scheduled activities. If they do; then, they point to substandard mining practices.

5.5.4 Contribution of geotechnical conditions to underperformance

The root cause of the Geology problems is attributed to insufficient geotechnical assessments and proactive risk mitigation strategies for challenging ground conditions. Geotechnical conditions require proactive monitoring. They reflect on the operating flexibility of the mine. It is therefore important that the planning department should ensure that there are enough panels to allow crews to move to another workplace in case there are bad geotechnical conditions.

Examples of geology problems at the mine (Table 4.3) show that crews often encountered bad ground and had to move without a prepared alternative. This caused lost blasts due to idle time. Footwall lifting disrupted infrastructure installation, delaying service extension to active ends. Fall of Ground (FOG) incidents halted production for days or weeks.

Encounters with geological features may require redesign of drill patterns and layout, leading to lost blasts. Poor ground conditions delay drilling or made it unsafe, requiring additional scaling or reinforcement. Additional support required in these areas delayed the blast cycle, especially around faults or dykes. Each of these conditions reduced cycle readiness and contributed to lost blasts.

5.5.5 Contribution of equipment inefficiencies to underperformance

Lack of preventive maintenance planning, spare parts availability, and equipment reliability monitoring is the main root cause of the equipment operational problems. At the mine, equipment problems repeatedly interrupted the mining cycle (Table 4.3).

A belt breakdown caused chokes at ends and transfer points. Cleaning could not proceed, and the next round could not be drilled. Winch breakdowns left blasted rock uncleared. LHD failures had the same effect in mechanised sections.

If man-transport systems failed, nightshift crews could not reach cleaning areas, and the face was not cleaned. Some crews arrived late or not at all, delaying every task. Drill rig breakdowns prevented blast hole drilling.

Failure of essential support equipment such as mono ropes or haulage systems prevented material movement and cleaning. Even if not at the face, logistics equipment failures stopped supply flow. Without drill bits, support packs, or explosives, blasting could not proceed. Each of these failures resulted in lost production.

The literature also highlights that frequent equipment breakdowns and poor maintenance lead to longer cycle times and lower production rates than planned (Mashingaidze et al., 2025). Machine breakdowns, and underutilization, reduce the number of meters drilled per day, leading to measurable production losses (Talan et al., 2018). Therefore, it is important for maintenance systems to optimise and improve equipment reliability (Åstrand et al., 2018).

5.5.6 Contribution of human resource inefficiencies to underperformance

Human resources problems stem from ineffective workforce management, including inadequate training, absenteeism control, and critical skill shortages.

At the mine, most common HR issues are noted in Table 4.3. Due to absenteeism, cleaning crews did not complete their tasks during nightshift. Day shift crews could not drill or blast because the face remained dirty. Absenteeism also affected drilling. With few trained operators present, hole preparation was slow or incomplete.

Labour under-complement meant tasks were not finished on time. Even if no one was absent, too few workers were available. General absenteeism reduced crew capacity, especially among skilled roles such as drillers or support installers.

The shortage of Rock Drill Operators meant that no faces could be prepared. In some cases, training diverted experienced staff from production duties. These delays affected the mining cycle and resulted in lost blasts.

The literature also highlights that shortage of skilled workers (e.g., rock drill operators) and high absenteeism rates can cause delays in critical mining activities, leading to reduced ore extraction and missed production targets (Ghasemi et al., 2024). This shortage often results in underutilization of equipment and increased downtime, as there may not be enough qualified personnel to operate or maintain machinery efficiently (Kunkyin-Saadaari et al., 2024). Therefore, improving the workforce planning and management through skills training, recruitment of critical skills and retention of those skills can help to address the human resources problems.

5.5.7 Contribution of material shortages to underperformance

Poor inventory management and supply chain coordination, leading to critical material shortages is the root cause for the material problems. This is also reflected in the literature, as Phillis and Gumede (2011) reported that 30% of lost blasts in most shafts can be attributed to shortages of critical material and/or equipment. Therefore, this implies that it is necessary to have logistical planning and supply chain management systems that ensure the mine has critical consumables and equipment.

Table 4.3 shows that the most direct problem was lack of materials at the face. Without explosives, drill bits, or support materials, the mining cycle could not continue. Even when some materials were available, shortages of other items caused work to stop. A general shortage affected multiple sections, forcing crews to prioritise certain workplaces over others.

In some cases, drilling could not start due to a lack of drill rigs or parts. Unavailability of long anchors, grout packs, or bolts prevented support installation. Without support, no blasting could proceed. These issues reflect logistical failures that caused lost blasts.

5.5.8 Contribution of safety stoppages to underperformance

Safety problems at the mine are rooted in the presence of insufficient safety protocols and inconsistent compliance monitoring, leading to safety stoppages and increased accident risks. The safety issues noted in Table 4.3 stem from safety incidents, or regulatory actions, which directly resulted in lost blasts.

A safety stoppage immediately freezes all work in the affected area. If a face is being drilled, charged, or prepared for blasting, these activities must cease. No blast can be initiated until the unsafe condition is addressed and the area is declared safe. Safety stoppages are described as very costly, especially for marginal mines (Ferreira et al., 2025).

Similarly, if work related to preparing for a blast (drilling, charging, support) is found to be "non-standard," it must be stopped immediately. The blast cannot proceed until the correct standards are implemented and the work is redone safely.

A DMPR stoppage means that no work can occur in the specified area until all conditions set by the inspector are met and the notice is formally lifted. This means that any planned blasts in that area are postponed, leading to production losses until compliance is achieved. A DMPR stoppage is a legal order issued by a DMPR inspector to halt all work in an area (or even the entire mine) due to serious safety violations or conditions that pose an immediate danger to life. These are formal Section 54 or Section 55 notices under the Mine Health and Safety Act of the Republic of South Africa. According to the Mine Health and Safety Act (MHSA), Section 54 gives a mining inspector the power to halt a mine's operations if there is a risk to health and safety, while Section 55 allows an inspector to issue a compliance notice when a mine fails to comply with the Act. This means that Section 54 is an immediate safety stoppage, while Section 55 is a formal requirement for the mine to correct non-compliance with the regulations.

Following any accident or serious incident (e.g., a fall of ground, equipment malfunction resulting in injury, an unplanned event with high potential for harm), a formal "accident investigation" is launched. The area where an accident occurred is immediately declared a crime scene (in effect) and becomes a no-go zone for normal mining operations until the investigation is complete. If the accident happens at or near an active working face, all activities (drilling, charging, blasting) are halted. This directly causes a lost blast for the affected area, as the mine cannot proceed with its production cycle until the investigation concludes.

5.5.9 Contribution of technical service inefficiencies to underperformance

Technical service issues were often caused by poor maintenance of essential infrastructure like air supply, water pipes, and electricity. For example, when compressed air was unavailable, crews could not use drills, leading to work stoppages and missed blasts (Table 4.3).

Compressed air is powers pneumatic rock drills, winches for mucking, and various other hand tools. "Inadequate," "low," or "no" compressed air means there is not enough air at the required pressure to operate this equipment effectively or at all. Rock drills cannot operate effectively (or at all) with insufficient air pressure, leading to "Incomplete/Slow Drilling." Without drilled holes, no blast can be set up.

Pneumatic winches used for cleaning blasted rock rely on compressed air. If air supply is low or absent, the face cannot be cleared, preventing the next drill cycle.

Compressed air is also used for auxiliary ventilation in some areas, and its absence can compromise air quality, potentially leading to safety stoppages that then cause lost blasts. Therefore, issues with compressed air supply constrain the mining cycle.

Winch installation is a critical prerequisite for cleaning in conventional stopes. If a new face or panel is developed, or if a winch needs to be moved to follow the advance, and its installation is delayed, then the subsequent cleaning of blasted material cannot occur. This directly prevents the preparation of the face for the next blast, leading to a lost blast until the winch is fully installed and operational.

Problems of low water pressure results in drilling being not completed or slow. If water pressure is low, drill cuttings cannot be effectively removed, causing the drill bit to bind or "mud up" in the hole. This slows down drilling significantly and can damage drill bits or even the drill itself. This means the blast holes are not ready in time, directly leading to a lost blast for that shift.

Problems of low water pressure and inadequate water supply also indicate a general problem with the water reticulation system of the mine. There was not enough water volume or pressure delivered to the working faces. Beyond drilling, water is important for dust suppression during mucking and drilling (a safety requirement). If water is unavailable or at low pressure, safety regulations might prevent drilling or cleaning due to dust.

There were also problems or delays in installing "service pipes," which carry vital utilities like compressed air, water, and sometimes pumping lines, to the working faces. Service pipes are the lifelines to the working areas. If their installation is delayed, then the necessary air and water (and sometimes power if cables are run alongside) cannot reach the drilling and cleaning equipment at the face. This directly prevents the preparation for and execution of blasts, leading to lost blasts in those affected areas. It's a critical logistical and infrastructure bottleneck.

Another noted problem was inadequate ventilation (refer to Table 4.3). Ventilation is the system that supplies fresh air to underground workings and removes hazardous gases, dust, and heat. Inadequate ventilation means there was not enough airflow to maintain a safe and breathable atmosphere.

If there is a build-up of toxic gases, miners cannot safely enter the area to drill or charge, preventing a blast. After a blast, large volumes of noxious fumes are produced. Inadequate ventilation means these fumes will take too long to clear. Miners cannot re-enter the area to begin cleaning and drilling for the next round until the air is safe, leading to lost blasts for that face.

The problem of power failure mine supply meant that there was a loss of electrical power from the main mine supply. This causes lost blasts because power is essential for: compressors, pumps, ventilation fans, lighting, Material handling equipment (Mashingaidze et al., 2025). A power failure immediately stops almost all mining activities. Therefore, no drilling, no cleaning, no charging can occur, leading to lost blasts.

The problem of “No Survey Notes & Chains” means the surveyors haven't provided the necessary marks or data, or their equipment is unavailable/faulty. Surveying is important for the accuracy and safety of drilling and blasting. Without precise survey marks: Drill holes cannot be placed correctly (leading to poor blast results like "long pull," "gully flushed," or damaging the hanging wall).

5.6 Concluding remarks

The current study reveals that the occurrence of the operational problems brings inefficiencies and contributes to underperformance of the mine in stoping and development. The problem categories are: Drilling and Blasting (DB), Support, Cleaning, Geology, Equipment, Human Resources (HR), Materials, Safety, and Technical Services.

The operational problems disrupt the mining cycle, leading to lost productivity, delays and lost blasts. These lost blasts are the main mechanism driving underperformance. The impact of these problems is seen in the unfavourable deviation between planned targets and actual performance.

The operational problems are interlinked within the continuous mining cycle. A disruption in one area almost invariably causes a ripple effect, leading to bottlenecks and, most critically, lost blasts.

Support installation problems in stoping and technical services in development are the primary drivers of deviation of actual performance from planned targets. These findings align with the literature, which highlights the importance of targeted interventions in these areas to enhance overall mining efficiency.

The study underscores the need for improved drilling and blasting practices, work scheduling, maintenance, supply chain management and workforce management to address the observed production deviations effectively. Addressing these root causes is acknowledged to be critical to achieving the production goals of the mine and improving its operational efficiency.

Chapter 6 provides a conclusion to the research done; it also offers actionable recommendations for the optimisation of mining logistics at Siyanda Bakgatla Spud shaft for consideration.

Chapter 6 Conclusions and recommendations

6.1 Introduction

The main objective of this thesis was to investigate the core logistical issues causing underperformance at Siyanda Bakgatla Spud shaft. The other objective was to outline potential intervention strategies and remedial actions to address the logistical issues.

To achieve this, historical data from the mine was analysed by means of statistical techniques, root cause analysis and on-site observations. Subsequently, operational challenges and their root causes were identified within mining processes, from drill and blast, support installation, equipment, cleaning, material supplies, technical services, safety, and geology.

The results of the analysis were presented in detail in Chapter 4 and a discussion of the findings was covered in Chapter 5. This chapter summarizes the key findings of the dissertation. It also proposes actionable recommendations tailored to the logistical challenges identified, and suggestions for future research to enhance productivity in similar mining operations.

6.2 Summary of the dissertation

This study set out to investigate the core logistical issues contributing underperformance at Siyanda Bakgatla Spud shaft. The main research question was: *What are the logistical problems contributing to low productivity and underperformance at Siyanda Bakgatla Spud Shaft?*

Three objectives were used to guide the research each of which was achieved during the study.

The first objective was to investigate and outline the logistical problems contributing to the low productivity of the Siyanda Bakgatla Spud shaft. This objective was achieved through a quantitative analysis of the data (Book SQM and Plan SQM in stoping, and Book Adv and Plan Adv in development) using RStudio® software. The analysis revealed consistent underperformance relative to planning targets, highlighting a gap between planned targets and actual operational capacity. A frequency analysis was conducted to quantify lost blasts in both operations, revealing that a significant portion of planned blasting operations were unsuccessful. The impact of lost blasts was further examined in relation to the variance, underscoring their contribution to operational inefficiencies and production deviations.

The second objective was to establish and outline intervention strategies to set the mine on a productive course. Using frequency analysis, this study classified operational problems into categories, including Support, Equipment, Technical Services, and Human Resources, among others. Each category was examined for its effect on production metrics, identifying high-impact categories (support installation and technical services) that consistently contributed to underperformance.

The third objective was to recommend implementation of these strategies. The study conducted a root cause analysis to identify the underlying causes of inefficiencies within each problem category. Findings revealed systemic issues in drill and blast protocols, support installation, maintenance, resource allocation, and operational flexibility that contribute to production disruptions.

All three objectives were achieved, providing an overview and understanding of the logistical challenges at Siyanda Bakgatla Spud shaft. The findings serve as a foundation for actionable recommendations tailored to the logistical challenges identified to improve operational efficiency and productivity of the mine.

And in terms of the research question highlighted above, this research has found that the occurrence of the operational problems brings inefficiencies and contributes to underperformance in stoping and development. The problem categories are: Drilling and Blasting (DB), Support, Cleaning, Geology, Equipment, Human Resources (HR), Materials, Safety, and Technical Services. They disrupt the mining cycle, leading to lost productivity, delays, and lost blasts. The lost blasts are the main mechanism driving underperformance. The impact of these problems is seen in the persistent unfavourable deviation between planned targets and actual performance. These inefficiencies are primarily driven by logistical challenges in Support installation for stoping and Technical Services in development. The consistent underperformance relative to planning targets in both stoping (square meters achieved) and development operations (primary metres), reveals a significant misalignment between planned goals and on-ground realities. This is compounded by operational challenges within drill and blast, cleaning, human resources, equipment, safety, materials, and geology. The operational problems are interlinked within the continuous mining cycle. A disruption in one area almost invariably causes a ripple effect, leading to bottlenecks and, most critically, lost blasts.

6.3 Overall conclusion

This thesis concludes that at Siyanda Bakgatla Spud shaft, there is a trend of underperformance both in stoping and development operations. The operational inefficiencies are primarily driven by logistical challenges in Support installation for stoping and Technical Services in development.

The consistent underperformance relative to planning targets in both stoping (square metres achieved) and development operations (primary metres), reveals a significant misalignment between planned goals and on-ground realities. Additional inefficiencies stem from challenges in drill and blast, cleaning, human resources, equipment, safety, materials, and geology.

Lost blasts are widespread, particularly in stoping. They are closely linked to delays in support installation, poor blasting practices, and equipment breakdowns. Similarly in development, they are most linked to technical services-related issues particularly, engineering.

The root cause analysis has identified gaps in drilling and blasting protocols result in the poor blasting outcomes. Poor scheduling and coordination in support installation, causing delays and suboptimal support practices.

The cleaning problems in the mining cycle stem from inefficient cleaning workflows and task prioritization. The Geology problems result from insufficient geotechnical assessments and proactive risk mitigation strategies for challenging ground conditions.

Lack of preventive maintenance planning, spare parts availability, and equipment reliability monitoring is the main root cause of the equipment operational problems. Human Resources problems stem from ineffective workforce management, including inadequate training, absenteeism control, and critical skill shortages.

Poor inventory management and supply chain coordination, leading to critical material shortages is the root cause for the material problems. Safety problems at the mine are rooted in the presence of insufficient safety protocols and inconsistent compliance monitoring, leading to safety stoppages and increased accident risks. Technical Service problems stem from inadequate maintenance of infrastructure (e.g., air and water supply, power systems) and limited services support.

Addressing these problem areas and implementing targeted interventions, Siyanda Bakgatla Spud shaft can improve its operational performance, reduce production losses, and align more closely with planned production targets.

6.4 Actionable recommendations for the mine

The recommendations focus on reviewing and auditing current systems before implementing new measures. This ensures the mine can make targeted, informed decisions based on a thorough understanding of what is working well and what needs adjustment.

Support installation should be reviewed and restructured to minimise delays in stoping. Coordination between crews must be improved to prevent bottlenecks. This includes KPI accountability for underperformance.

It is also recommended for the mine to review its workforce management for critical skills. The aim is to address workforce shortages and skill gaps that impact productivity. The mine should audit its recruitment, training, and retention practices, with a specific focus on high-impact roles such as drillers and equipment operators.

The mine should evaluate its technical services departments to identify gaps in infrastructure and equipment reliability. The aim is to improve the reliability of technical services (engineering, ventilation, power, survey) and equipment availability. The mine should review the capabilities and coordination of technical services and the maintenance program for critical equipment.

It is also recommended to review safety compliance and monitoring. This aims to enhance safety adherence and reduce stoppages due to compliance issues. The mine should audit the current safety and compliance monitoring processes to identify gaps in enforcement, training, and reporting.

6.5 Recommendations for further research

Based on the findings presented in this dissertation, the following areas to be explored in future studies have been identified:

- Future research should assess how regular technical service audits influence productivity in underground mining. This may help define best practices for audit timing, scope, and follow-up actions.

- Future research should explore how underground material handling and transport can be improved. This includes identifying efficient, low-cost logistics strategies to reduce delays and ensure consistent material flow.
- Future studies should assess equipment utilisation by analysing downtime and capacity use. This can help improve planning and reduce costs through more efficient use of critical machinery.

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APPENDICES

APPENDIX A: PERMISSION LETTER

SBPM

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Blackwell Highway
Swartklip
Limpopo
0370

07 September 2023

Dear Mr. Motlhabane,

SBPM herewith acknowledge that Mr. Wellbeloved Basimane Motlhabane has been given a bursary in line with doing his Msc engineering research. He is currently busy with a research project on optimizing the logistical model at Spud Shaft, one of our operations at SBPM. The research will span across two years, 2023 – 2024.

The candidate details are as follows: Student Number: 19812588; ID Number: 7710105793084.

The student has full permission to acquire data from the mine for the purposes of his research. The candidate will also provide the mine with the official document of the outcomes of his research and will also be required to present to the mine.

Yours in safe profitable production,

Mduduzi Mtshali
Snr. HR Manager

8 September 2023
Date

APPENDIX B: ETHICS APPROVAL

UNISA university of south africa

College of Science, Engineering and Technology_ School of Engineering_ERC

Date: 18/01/2025

Dear: Mr Wellbeloved Basimane Motlhabane

Ref #: 6180
Name: Mr Wellbeloved Basimane Motlhabane
Student #: 19812558
Staff #: NA

Decision: Ethics Approval from 18/01/2025 to 18/01/2028 (Non-human)

Researcher: Mr Wellbeloved Basimane Motlhabane

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Supervisor: Professor Francois Mulenga mulenfk@unisa.ac.za

OPTIMISATION OF MINING LOGISTICS AT SIYANDA BAKGATLA SPUD SHAFT INCLINES PRODUCTION SECTIONS

Qualification: MEng

Thank you for the application for research ethics clearance by the College of Science, Engineering and Technology_ School of Engineering_ERC for the above mentioned research study Ethics approval is granted for three years.

The **negligible risk application** was **reviewed** by College of Science, Engineering and Technology_ School of Engineering_ERC on 18/01/2025 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the College of Science, Engineering and Technology_ School of Engineering_ERC.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.

5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.

6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data requires additional ethics clearance.

7. No field work activities may continue after the expiry date (18/01/2028). Submission of a completed research ethics progress report will constitute an application for renewal, for Ethics Research Committee approval.

Additional Conditions

1. Disclosure of data to third parties is prohibited without explicit consent from Unisa.
2. De-identified data must be safely stored on password protected PCs.
3. Care should be taken by the researcher when publishing the results to protect the confidentiality and privacy of the university.
4. Adherence to the National Statement on Ethical Research and Publication practices, principle 7 referring to Social awareness, must be ensured: "Researchers and institutions must be sensitive to the potential impact of their research on society, marginal groups or individuals, and must consider these when weighing the benefits of the research against any harmful effects, with a view to minimising or avoiding the latter where possible." Unisa will not be liable for any failure to comply with this principle.

Note

The reference number 6180 should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.

Kind regards,

Dr W Hussien
Chair of College of Science, Engineering and Technology_ School of Engineering_ERC
E-mail: hussiwam@unisa.ac.za

Executive Dean / Prof SJ Johnston, By delegation from the Executive Dean of College of Science, Engineering and Technology_ School of Engineering_ERC
E-mail: johnssj@unisa.ac.za