

School of Mining Engineering



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WITWATERSRAND,
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**TEMPORAL AND SPATIAL RECONCILIATION AT STORM MOUNTAIN
DIAMONDS MINE (PTY) LTD**

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

Johannesburg, 2025

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Science in Engineering at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other university.

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



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“Never regret a day in your life. Good days give you happiness and bad days give you experience”

Unknown

ABSTRACT

Storm Mountain Diamonds (Pty) Ltd's Kao Mine has not been consistently achieving its production and grade targets, schedules, and mine call factor compared to the grade control model forecasts. These discrepancies can jeopardise the future of the mine and can lead to inaccurate decision making. Therefore, the aim of this study was to conduct temporal and spatial reconciliation at the mine. This was done to identify sources of variations in mineral resource volumes, tonnages, and grades at the mine. This reconciliation process is crucial for mines as it ensures the alignment of predicted and actual mineral resource extraction. The study was conducted for a period from September 2022 to August 2023.

Various data collection methods were used including truck counts, plant weightometer, advanced vehicle analysis, and global navigation satellite systems to do the reconciliation process. Data such as truck tallies, face mapping, density measurements, exploration drilling data and monthly survey data were utilised in this research.

It was found that the mine's performance during the review period was below expectations. Average temporal and spatial compliance were found to be 8% (between tally and survey measurements) and 75%, respectively. September 2022 notably recorded the lowest spatial compliance of 44% primarily due to low equipment availability averaging 75%. Also, over- and under-breakages of up to 5m from the design were observed. This temporal and spatial underperformance was broadly caused by several reasons including poor blasting practices, unpredictable rainfall, human error and poor understanding of the orebody.

It is recommended that the mine consider using more advanced survey equipment and data analytics technologies to collect and analyse data more accurately. The mine should also improve its accounting practices including spillage management on belt conveyors, maintaining low stockpile levels, regular calibration of weightometers and shifting to daily operational planning. It is also recommended that the mine must involve all relevant stakeholders in the reconciliation process to promote a culture of continuous improvement and accountability.

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LIST OF ACRONYMS AND SYMBOLS

Acronym	Description
amsl	above mean sea level
AVAFMS	Advanced Vehicle Analysis Fleet Management System
B1	Borehole 1
Cpht	Carats per hundred-ton
CSV	Comma Separated Values
DTM	Digital Terrain Map
DXF	Drawing Exchange Format
FK	Fragmental Kimberlite
GK	Gritty Kimberlite
GNSS	Global Navigation Satellite System
Ha	Hectare
KPI	Key Performance Indicator
LDC	Lesotho Diamond Corporation
LEC	Lesotho Electricity Commission
LiDAR	Light Detection and Ranging
LoM	Life of Mine
LQ	Lower Quarry
MCF	Mine Call Factor
NPV	Net Present Value
QK	Quarry Kimberlite
SMD	Storm Mountain Diamonds
tph	tonnes per hour
3D	Three Dimensions
USB	Universal Serial Bus

1. INTRODUCTION

1.1. Chapter Overview

This chapter lays the foundation for the research by first introducing the research background, which provides context and highlights the relevance of the study within its broader field. It then articulates the problem statement, clearly defining the specific issue or gap in knowledge that the research seeks to address. Following this, the research justification is presented, outlining the rationale behind the study and explaining why it is necessary and timely. The significance of the results section discusses the anticipated impact of the findings, detailing how they will contribute to the existing body of knowledge and potentially influence practice and further research. The research objectives and aim are then clearly stated, providing a roadmap of what the study intends to achieve. This is followed by a discussion of the research scope, which delineates the boundaries of the study, specifying what will and will not be covered. Finally, the research structure is outlined, offering a brief overview of the subsequent chapters and how they collectively contribute to addressing the research question.

1.2. Research Background

Storm Mountain Diamonds (SMD) - Kao Mine is located in the Butha-Buthe District in the northeastern area of the Maluti Mountain Range in the Kingdom of Lesotho. Figure 1-1 shows the location of the mine in Lesotho.

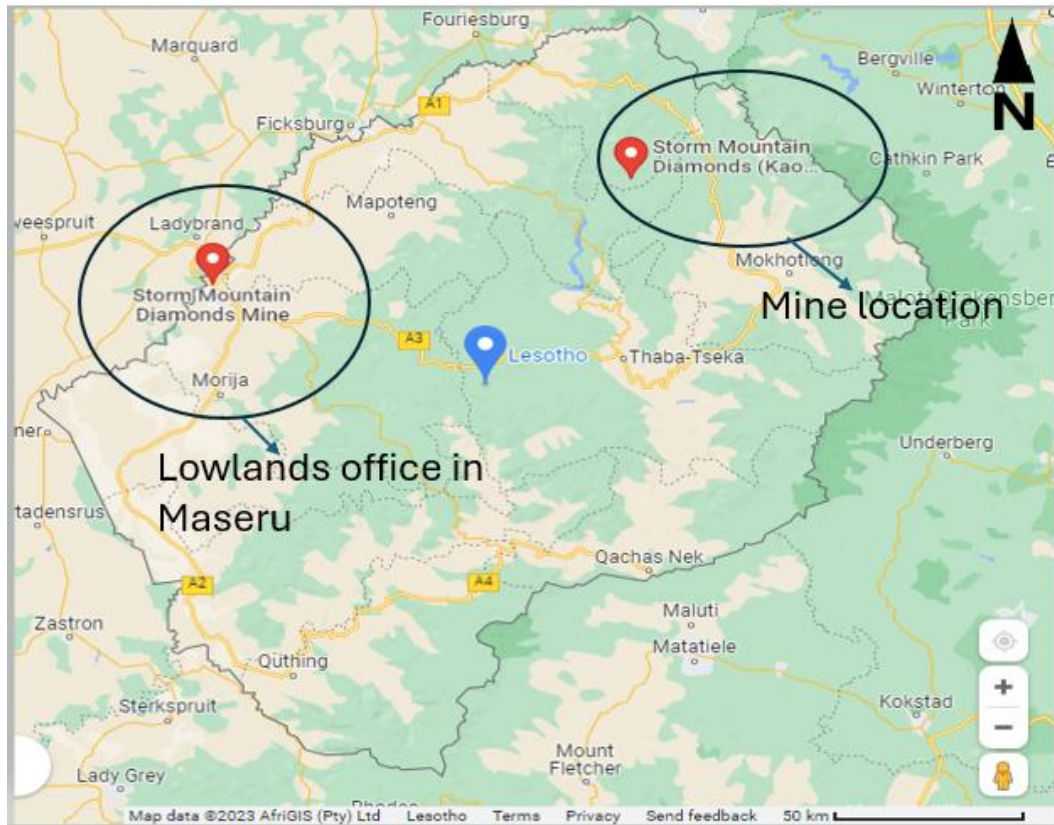


Figure 1-1: The location of Storm Mountain Diamonds Mine in Lesotho

(Source: Google Maps, 2024)

The mine site ranges in elevation from 2500 m to 2700 m above mean sea level (amsl). SMD-Kao Mine is situated 110 km northeast of the capital, Maseru. Additionally, the mine has offices in the lowlands near Ladybrand in Maseru, as shown in Figure 1-1. The mine is an open pit mine which started operation in January 2012 (Solomons, 2016). Initially, Namakwa Diamonds held 62.5% of the company's shares, while the Government of Lesotho held 25% and the remaining 12.5% belonged to Basotho investors through Kimberlite Investment Lesotho Ltd (Namakwa Diamonds Limited, 2012). Currently, Namakwa Diamonds Ltd holds 75% and the Government of Lesotho holds 25% of the shareholding (Storm Mountain Diamonds (Pty) Ltd, 2023a).

1.2.1. History of exploration

The mine had been previously operated for over 60 years by local artisanal miners before the official discovery of the main pipe in 1955 by Colonel Jack Scott (Skinner, 2011). In 1957, the satellite pipe was also discovered by J.B. Dawson and P.H. Nixon and both pipes were mapped (Skinner, 2011). According to Rolfe (1973), Colonel Jack Scott ceased the initial operations in 1959 after recovering 17 567 carats, including notable diamonds such as a 46-carat blue-white diamond, a 387-carat white diamond, and a 33-carat blue diamond.

The main pipe underwent exploration by various companies from 1959 to 1962. From 1968 to September 1971, it was operated by licensed artisanal miners. In September 1971, Newmont Mining & US Steel took over operations until the end of 1972 (Skinner, 2011). During that period, pits measuring 12.6 m² and 20 m deep were excavated, yielding 1 500 tonnes of ore each, from which diamonds were recovered using a 12 mm screen, rotary pan, and a grease-belt (Gerryts, 1990).

During the exploration period, a total of 26 holes amounting to 2593 m, as well as seven holes amounting to 739 m, were drilled on the main pipe and satellite pipes, respectively (Skinner, 2011). These drillings provided the geological data used to interpret the geology described in the Lesotho Kimberlites, under the geology of Kao Kimberlite as presented by Rolfe (1973).

The main pipe was again returned to the licensed artisanal miners in 1972. From early 2003 to 2009, the main pipeline was under option to the Lesotho Diamond Corporation (LDC). It was during the LDC's operation that comprehensive mining feasibility studies for all aspects of the project were carried out (Skinner, 2011). A prospecting license was granted to Namakwa Diamonds in 2010, and mining activities commenced in 2012.

1.2.2. Regional geology

The regional geology of northern Lesotho comprises the Upper Karoo Super Group sediments with shales and flat-lying sandstones of the Elliot and the Molteno Formations. These are overlaid by sandstones of the Clarens Formation (Kitching & Raath, 1984). The Karoo sediments are capped by basaltic lavas of the Drakensberg Group, with the base of the lava sequence lying at approximately 1600 m amsl and reaching an elevation of 3200 m amsl in the SMD vicinity (Dawson, 1962).

Following the breakup of the Gondwana Super Continent in the late Jurassic to early Cretaceous period, the Kaapvaal Craton experienced multiple intrusions of kimberlitic material. These intrusions occurred in two primary phases: the early Cretaceous (approximately 108 – 150 million years ago) and the late Cretaceous (approximately 85 – 95 million years ago) (Cox, 1992). A significant number of kimberlites intruded into Lesotho's Karoo Sequence, including Kao/SMD, Letséng, Lemphane, Liqhobong, and Mothae. Some of these intrusions are diamondiferous and have supported artisanal diamond mining in Lesotho (Dawson, 1962).

The main pipe diamond deposit at SMD - Kao Mine is centered around a near-vertical volcanic pipe. Figure 1-2 shows a distinct cylindrical shape of SMD - Kao Mine's main pipe.



Figure 1-2: SMD - Kao Mine's 3-D mineral resource model

(Source: Storm Mountain Diamonds, 2023a)

1.2.3. Local geology

SMD - Kao Mine features two primary kimberlite pipes known as the main pipe and the satellite pipe. These pipes are located in the same region as other prominent diamond-bearing kimberlites in Lesotho, such as Letseng-la-Terae (Bloomer & Nixon, 1973), Lqhobong (Nixon & Boyd, 1974) and Mothae (Galloway *et al.*, 2009). The main pipe forms an irregular oval shape with dyke-like extensions towards the northeast and southeast covering an area of 19.8 ha while the satellite pipe covers an area of 3.2 ha (Clement, 1973). Of the 19.8 ha, only 1.1 ha has a grade of around 18 cpht while the rest of the pipe has a grade ranging between 4 cpht and 7 cpht (Storm Mountain Diamonds (Pty) Ltd, 2023b).

Field mapping of the main pipe had previously resulted in a recognition of a single pipe having six different geological varieties. The six kimberlite varieties (termed K1 to K6) within the main pipe are (Rolfe, 1973):

- K1 Gritty Kimberlite (GK);
- K2 Fragmental Kimberlite (FK);
- K3 Fine fragmental Kimberlite;
- K4 Transitional Kimberlite (Tr);
- K5 Lower Quarry Kimberlite (LQ); and
- K6 Quarry Kimberlite (QK).

Figure 1-3 shows the main pipe with the exploration drill holes drilled during the LDC campaign.

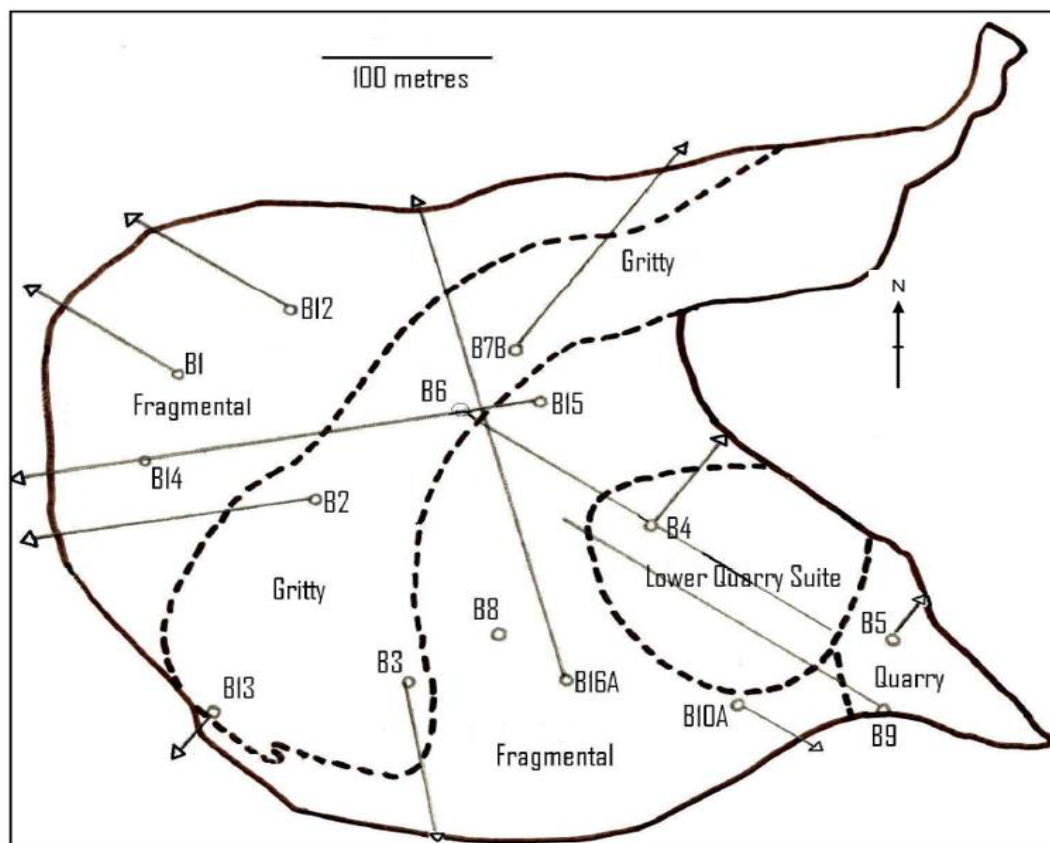


Figure 1-3: Boreholes drilled in the LDC campaign (Marked as B1 to B16A)

(Source: Rolfe, 1973)

The main pipe at SMD-Kao Mine has been the subject of various geological studies, revealing its complex structure. Initial research by Rolfe (1973) identified six kimberlite variabilities, while a more recent study by Skinner (2012) updated the variabilities, identifying five distinct geological bodies. Figure 1-4 shows these five distinct geological bodies. The mentioned

features consist of the Fragmental Kimberlite (FK), which the Gritty Kimberlite (GK) intruded into, and a smaller dyke referred to as K12. There is also a smaller pipe called the Quarry Kimberlite (QK) referred to as K6, as well as another kimberlite intrusion situated between the Quarry Kimberlite and the Fragmental pipe, known as the Lower Quarry (LQ) (Skinner, 2012).

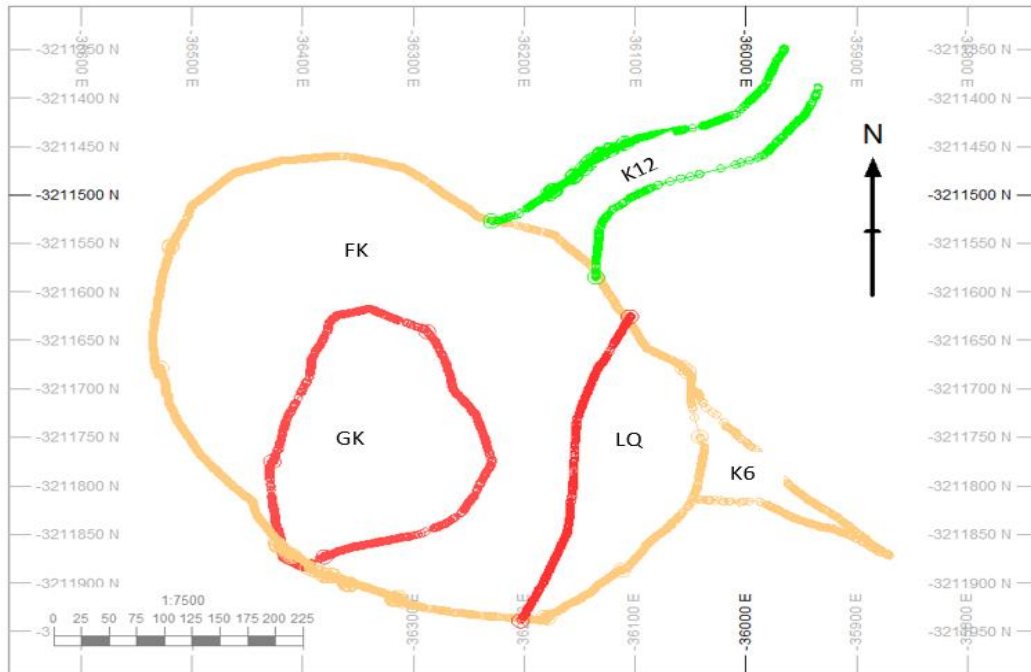


Figure 1-4: SMD - Kao Mine's main pipe with five geological kimberlite varieties

(Source: Storm Mountain Diamonds, 2023b)

FK is the largest kimberlite within the main pipe, intersecting the Karoo basalt at slope angles of 82° as indicated by drilling (Skinner, 2012). The three kimberlite types that were identified as Fragmental, Fine-Fragmental and Transitional in earlier works although with apparent differences, did not fit within the boundaries as indicated by Rolfe (1973). Skinner (2012) classified them all under FK.

GK is an irregular kimberlite pipe that intruded into the core of FK. GK is an unusual, pelletal-rich volcanoclastic kimberlite with elevated spherical to elliptical structures of mantle xenolith and garnet, with fine-grained olivine phenocrysts. These striking features range in size from less than 0.1 mm to 7 mm (Skinner, 2012).

LQ is a coherent kimberlite, possibly a transition between hypabyssal and the diatreme facies that forms a suite comprising at least three kimberlite types. LQ is characterised by segregatory microcystic kimberlite. It contains abundant olivine macrocrysts and phenocrysts. There is highly altered xenolith country rock present. The groundmass is finer-

grained and consists of phlogopite and perovskite. This is set in a base of calcite and serpentine (Rolfe, 1973).

QK is the early pyroclastic to volcanoclastic kimberlites preserved in a structurally controlled sidewall wedge of the South-Eastern corner of the main pipe. It is referred to as K6 kimberlite. QK consists of olivine grains surrounded by thin selvages with very fine-grained, granular, serpentinised moticellite, phlogopite laths and perovskite (Skinner, 2012).

K12 is the kimberlite forming the northeast appendage. K12 was originally mapped as part of the Fine Fragmental (K3) kimberlite type. However, later work removed this downward tapering into its facie which was later named the K12. No work has been undertaken on K12.

1.3. Problem Statement

Mining is a business that is built around estimated geological models that predict reality to a certain degree of confidence (Morley, 2014a). The challenge with the predictive models is that they always deviate from reality in terms of volumes, tonnages and grades received. SMD - Kao Mine is facing challenges whereby targets which are set based on estimated models, are consistently not being met. Figure 1-5 shows planned carats compared to carats achieved per month.

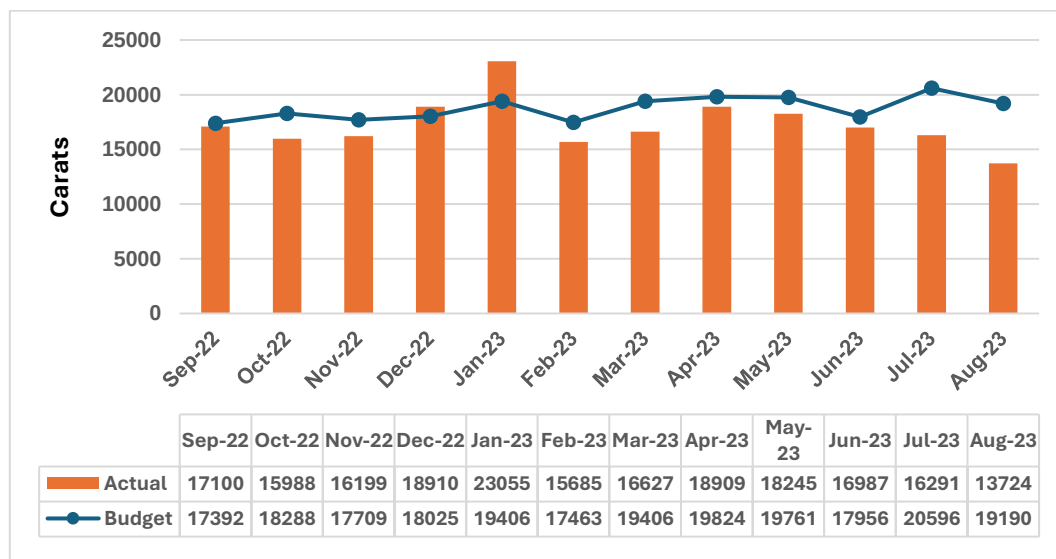


Figure 1-5: Actual carats compared to planned carats for each month

Figure 1-5 shows that there are discrepancies between the budgeted and achieved carats. There have also been issues at the mine, including missed schedules, unmet mineral resource grades, and lower-than-expected mine call factor (MCF) compared to the grade control model

forecasts. These discrepancies can jeopardise the future of mining operations, potentially leading to inaccurate decision making. Incorrect data may result in prematurely halting a profitable operation or investing in a capital project with misguided expectations of extending the mine's lifespan.

1.4. Justification for Research

SMD – Kao Mine faces a critical juncture with only three years remaining in its life of mine (LoM). This stage necessitates crucial decisions regarding the future of the mining operation. Such key decisions involve maintaining the current LoM and preparing for closure or exploring alternatives, such as mineral resource re-evaluation by reassessing the existing orebody data to uncover potential areas to identify additional mineral reserves. All these key decisions depend on the accuracy of the orebody knowledge. Inaccurate orebody knowledge can either lead to a very lucrative mine project being closed prematurely, or capital investment being made for an orebody that is no longer worth pursuing in the long run.

Errors are bound to happen during mineral resource estimation especially when limited information is available. However, errors should be within a certain acceptable range and as small as they may seem, their net effect on the net present value (NPV) of an operation should still be examined (Parker, 2012). It is crucial to continuously monitor and integrate actual mining data into predictive models to improve mining operations. Incorporating new geological information, such as the identification of basalt intrusions in kimberlite and variations in grade distribution, is essential for accurate volume, tonnage, and grade estimations. Utilising this data improves the precision of the mineral resource model, leading to well-informed business decisions and maximising shareholder value. Additionally, integrating geotechnical data obtained during mining improves open pit designs, mitigating potential slope failures. Understanding and avoiding errors is possible, hence the need for this research to reconcile mineral resources estimates and actual mined results at SMD - Kao Mine. Reconciliation allows for the collection and analysis of data to gain more understanding. As more data is collected and analysed through reconciliation, understanding of an orebody is improved. The improved orebody knowledge results in better decision making.

The discrepancies highlighted in Figure 1-5 show the necessity for reconciliation throughout the mine value chain. By implementing a robust reconciliation process, SMD-Kao Mine can improve accuracy and reliability in its operation. It is worth noting that reconciliation in this research project was not regarded as a tool to measure the success of SMD-Kao Mine. It was seen as a tool that can be used to:

- Improve the accuracy of planning based on current valid data;
- Provide a baseline for continuous improvement;
- Increase accuracy of the orebody knowledge to ease the decision-making process; and
- Identify risks, so that mitigation strategies can be implemented on time.

Implementation of reconciliation techniques will enable management at SMD-Kao Mine to maintain consistent and transparent reporting. According to Shaw *et al.* (2013), a robust reconciliation process is key to driving and adding value during the development or expansion of any mining project. It is upon this basis that this research is important for SMD-Kao Mine as it faces closure soon.

To ensure that mining processes occur in a more gradually anticipated manner, many companies are focusing on reconciliation along the mining value chain (Bester *et al.*, 2016). The more predictable the orebody is, the more accurate mine plans become, and ultimately the easier it is to gain investors' confidence. The role of reconciliation is to make it easy to understand complexities associated with the orebody.

1.5. Results Significance

Results from this project can be used by SMD - Kao Mine to:

- Understand the mineral resource and mineral reserve better;
- Understand whether the contractor carrying out loading and hauling activities is being underpaid or overpaid;
- Highlight some of the improvement opportunities to better the mine's operations and enhance efficiency; and
- Validate the mineral resource and mineral reserve estimates to further aid in decision making.

The mine-to-design results can be used to profile potential risks of slope failures. The study will serve as the secondary source of reference for future studies conducted in mine reconciliation.

1.6. Research Aim and Objectives

The research aimed to do a temporal and spatial reconciliation at SMD – Kao Mine. The objectives of the research were to:

- Review the literature on temporal and spatial reconciliation;
- Validate the predictions of the mineral resource model by regular monitoring of the material movement, thereby comparing the actual tonnages, volumes and mineral resource grades with the original mineral resource estimates;
- Determine variations in mineral resource volumes, tonnages and mineral resource grades to improve the mine's planning processes regarding block sequencing, material blending and production scheduling; and
- Provide a baseline for continuous improvement on mineral resource estimates to make them more realistic and practical.

1.7. Research Scope

The focus of this study was temporal and spatial reconciliation at SMD - Kao Mine. Temporal reconciliation ensures that the estimated resources align with the actual achievements. Spatial reconciliation ensures that mining is carried out in the designated areas as per the schedule, thereby securing access to more mineable ore for the future; a crucial need for SMD - Kao Mine.

1.8. Structure of the Research Report

The research report consists of five chapters. Chapter 1 is the introduction and provided the background of the research topic, the problem statement, the justification for the research and the research objectives. Chapter 2 is the literature review and covers the key concepts, theories and previous studies carried out on mining reconciliation. Key debates and controversies existing in the previous studies are also highlighted. Chapter 3 describes the research methodology. It describes how the research was designed and conducted. Data collection and data validation processes are also described in the chapter. Lastly, the data analysis approach is discussed. Chapter 4 presents the data for the study and analyses the research results. Chapter 5 provides a summary of each chapter and presents the research observations, conclusions, and key findings. It also discusses the contributions of the research. Lastly, recommendations for further and future research work are also discussed in the chapter.

2. LITERATURE REVIEW

2.1. Chapter Overview

This chapter provides a literature review on temporal and spatial reconciliation. The chapter discusses the factors that cause reconciliation variances and how they can be avoided or minimised. It also provides the basis from which the reconciliation process is carried out.

2.2. Reconciliation

Reconciliation is a process that involves comparing measurements and estimates throughout the mining value chain to monitor and optimise metal recovery (Macfarlane, 2015). The initial mine planning is based on many assumptions that need to be tested and authenticated from time to time. These plans are critical factors in the success or failure of a mine as they deal with the cash flow of the mine (Dimitrakopoulos & Ramazan, 2004). Therefore, plans must be compared to actuals mined, as continuous reconciliation helps to improve the plans and ultimately makes the mining operation more profitable.

2.2.1 Temporal reconciliation

Temporal reconciliation within the mineral industry entails the comparison of targets such as the volumes, tonnages, and mineral resource grades with actual data obtained from survey measurements, mineral processing plant recovery, mineral processing plant scales/weightometer and truck counts (Schofield, 2001). This process aims to determine variance and avoid future variance between the actual production and the targets projected by the mineral resource model. Regular temporal reconciliation plays a crucial role in updating and validating the quantity of the mineral resource. Richard and Sulemana (2015) indicate that while temporal reconciliation is primarily based on time, it can also be applied spatially, particularly when evaluating the performance of each geological block or open pit bench over time.

The availability of more exploration data results in more accurate mineral resource estimates. Variations in grades and the tonnages produced from the model-based estimates are a result of the extent of exploration data (Benndorf, 2013). The more data is gathered, the more accurate the model becomes. The variations of this nature need to be investigated to determine whether there have been any mineralogical changes. Reconciliation is required to ascertain any change due to the deviations. Temporal compliance investigates the alignment between budget and actual tonnages mined, as well as stockpile movements and deliveries

to the mineral processing plant. This involves comparing budgeted figures with actual performance data. Temporal reconciliation further delves into the analysis of the geological structures within an orebody. This includes understanding the variations and complexities within the orebody that significantly influence the overall ore grade.

Due to the scarcity of mineral resources, the mining industry is constantly looking for better ways to monitor and reconcile mineral resource estimates with the actual production results across the different stages of mineral resource extraction (Morley, 2014b). The integration of new information into the mineral resource model empowers management to make well-informed decisions regarding the future of operations. These decisions may involve production scheduling, stripping ratio strategies, stockpiling options and whether or not to engage in expansion projects.

The precision of short-term production scheduling is based on the accuracy of the mineral reserve model. The model assists in defining the extraction sequence that aligns with the short-term production targets in terms of tonnages and associated block grades (Benndorf & Buxton, 2016). Although the mineral resource model is built using geostatistical modelling techniques, deviations from the in-situ mineral resource characteristics are sometimes evident (Maleki & Emery, 2015). It is important to have a mineral resource model that is accurate and can be used with a reasonable degree of confidence. This can be achieved by continuously reconciling the original mineral resource model as new data becomes available.

Increasingly, more research is being done in the mining industry that introduces specific methods to allow for the integration of data to update the mineral resource model continuously (Benndorf, 2015). Integration of production data into a mine simulation system is used as the basis for short-term optimisation and production control improvement and thus temporal reconciliation (Benndorf & Shishvan, 2014).

A mineral resource estimate is a crucial factor in open pit mine planning and optimisation, and failure to recognise the risk associated with this estimate can lead to a significant loss in investment capital. Hence, it is essential to evaluate project risks related to mineral resource estimation for financing purposes and internal planning processes, making the reconciliation process crucial (Van Bruce & Rossi, 1999). The methodology for modelling and quantifying risk profiles has been published by authors such as Vann *et al.* (2002), Rossi and Camacho (2000), and Rossi and Van Brunt (1997). The models take all the possible sets of grades for each block as an input variable. This is done to quantify the risk using probability intervals to designate the risk profiles or the confidence level attached to each interval.

The reconciliation system implemented at Sishen Mine was found to have various benefits. These included improved efficiency of the mining operation, lowered operating costs, and enhanced accuracy of estimates (Morley & Moller, 2005). The process of pit optimisation and mine planning relies on accurate mineral reserve estimation as the foundational element. Strategic mine planning aims to maximise the value of the mineral resource based on this estimation. Subsequently, the value is realised through operational mine planning decisions, which are periodically updated as new information emerges. A reconciliation system continually enhances the ability to update these decisions by providing feedback into the mineral resource estimation model (Davis & Newman, 2008).

To improve temporal reconciliation by reducing ore losses, dilution, and material misclassification, Eshun and Dzigbordi (2016) recommend the implementation of a blast movement monitoring system. They indicate that this system was introduced at Iduapriem Mine during the second year of operations in response to reconciliation challenges faced in the first year. Despite the associated costs, the results have been favourable.

2.2.2 Spatial reconciliation

Another key performance indicator (KPI) for evaluating the level of compliance against the mine plan is spatial or area-based measurement. The spatial mine to plan reconciliation assesses the level of compliance in three dimensions (3D). This is where emphasis is being put on mining to mine in the right areas, to design and to schedule. When mining activities take place in the right areas and at the scheduled time, that ensures that access to future sustainable ore is always maintained. The inability to execute plans spatially can also affect mining flexibility where other mining areas can be rendered inaccessible due to mining in wrong areas.

Spatial reconciliation involves comparing specific areas over a designated period, typically 12 months. It is critical to verify that mining operations are conducted in planned areas, at correct times, and in a proper sequence to ensure timely access to future ore. Spatial compliance with mine design is one commonly overlooked KPI. This KPI monitors and measures how well mine plans have been executed geospatially (Otto & Musingwini, 2019). Spatial reconciliation assesses the geographical locations of planned mining areas versus the actual mined areas. This helps in evaluating compliance with mining plans and identifying deviations that need to be addressed.

At the end of each month, a compilation is conducted to assess the amount of planned area that has been mined. Following this, a root cause analysis is conducted to understand why

the plan was not followed and how similar situations in the future can be avoided. Any reasons for falling short of following the plan are also identified. The findings from the root cause analysis would assist in preventing deviations from the plans and enhance the execution of mine plans.

Open pit mine reconciliation is usually based on comparing plans with execution of the actual activities for spatial KPIs with an aim of operational improvement (Otto & Musingwini, 2019). Clearly defining the movement of mined material from one area to another is crucial to ensure adequate progress in mine development, aligning with a company's long-term strategic goals (Hall & Hall, 2015). Operational performance that only considers temporal KPIs such as ore and waste tonnages mined over a certain period can provide a false sense of security to management as performance against these KPIs can be positive while mining activities are occurring in wrong geospatial areas in the pit (Otto & Musingwini, 2019). This means that the long-term future strategic targets of the company can be compromised significantly as the timely access to future ore is not being realised.

Mine to design compliance

Mine to design compliance involves addressing key geotechnical areas such as slope failures and rockfall hazards by ensuring the final wall pit limit is achieved as planned (Bester *et al.*, 2016). The need for mine to design compliance is governed by social (safety) factors, economic factors and regulatory factors. For the sustainability of mining operations, safety is of prime importance and must be emphasised at all levels from design to execution. It is a legal requirement that personnel's working conditions be conducive in such a manner that they are protected against any danger that may cause fatality or injury of any sort (Lesotho Government, 2024). Too steep and shallow slope angles can have positive and negative impacts respectively, on the economic performance of open pit mines. While a too steep slope angle results in a higher economic value to the mine, it can also lead to slope failures which ultimately lead to economic losses due to fatalities and damage to equipment. Shallow slope angles mean more waste must be mined thus increasing the stripping ratio. Mining more waste than is required lowers cash flow. Therefore, an optimum slope angle must be achieved with a certain acceptable level of stability.

The successful mitigation strategies for rockfall hazards and slope failure in open pit mines require that final pit slopes be mined to design as per berm width and the overall design angle (Bester *et al.*, 2016). Figure 2-1 shows an open pit mine's slope design elements.

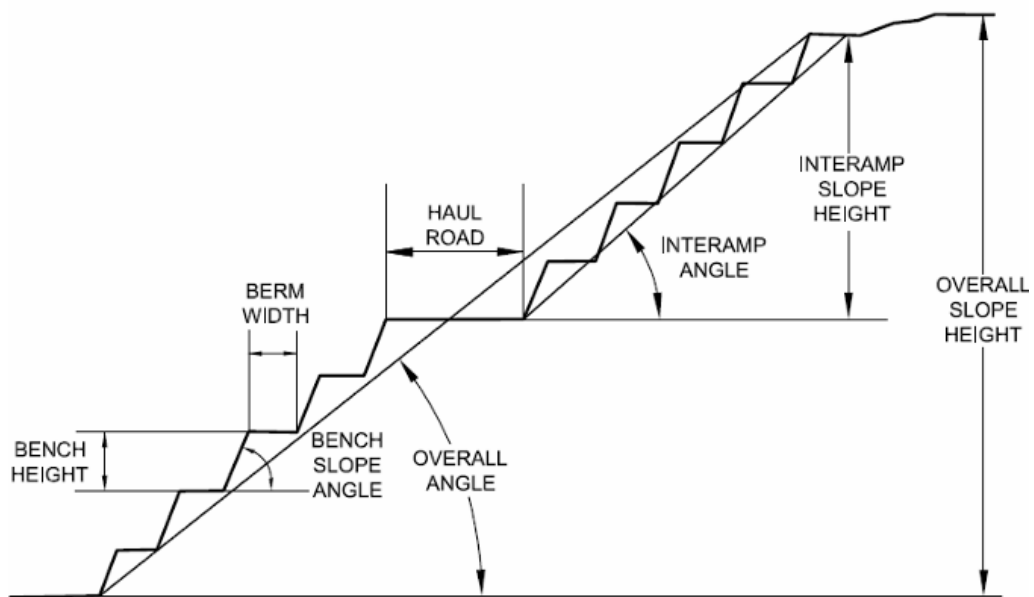


Figure 2-1: Open pit slope design elements

(Source: Sullivan, 2006)

Inadequate bench width offers little protection against falling rocks. The efficient design and operational management of an open pit mine should ensure that mine design reconciliation becomes an ongoing geotechnical assessment process. This is vital to ensure that the risk of slope instability is balanced with the optimal economic outcome. The level of effort and thoroughness in mine-to-design reconciliation is determined by the specific requirements of each open pit mine. These requirements typically consider safety, economic factors, and best practices (Dixon *et al.*, 2011).

The effectiveness of ultimate pit boundaries can be assessed by considering the resulting geometry and evaluating the blast performance of the face conditions (Read & Stacey, 2009). Bench face angle, bench width, and toe position are among the components assessed against the slope design to achieve the deserved value, particularly in terms of geometry and catchment berm capacity.

Bench face angle is a function of several factors which include among others the rock mass competency, the condition of discontinuities and the intensity of scaling. Due to the complexity of the factors, the most direct method to assess the performance of the bench face angle is to compare the actual angle with the design angle (Read & Stacey, 2009). Figure 2-2 shows the representation of cumulative frequency analysis of the backbreak angle for both steeper and shallow angles.

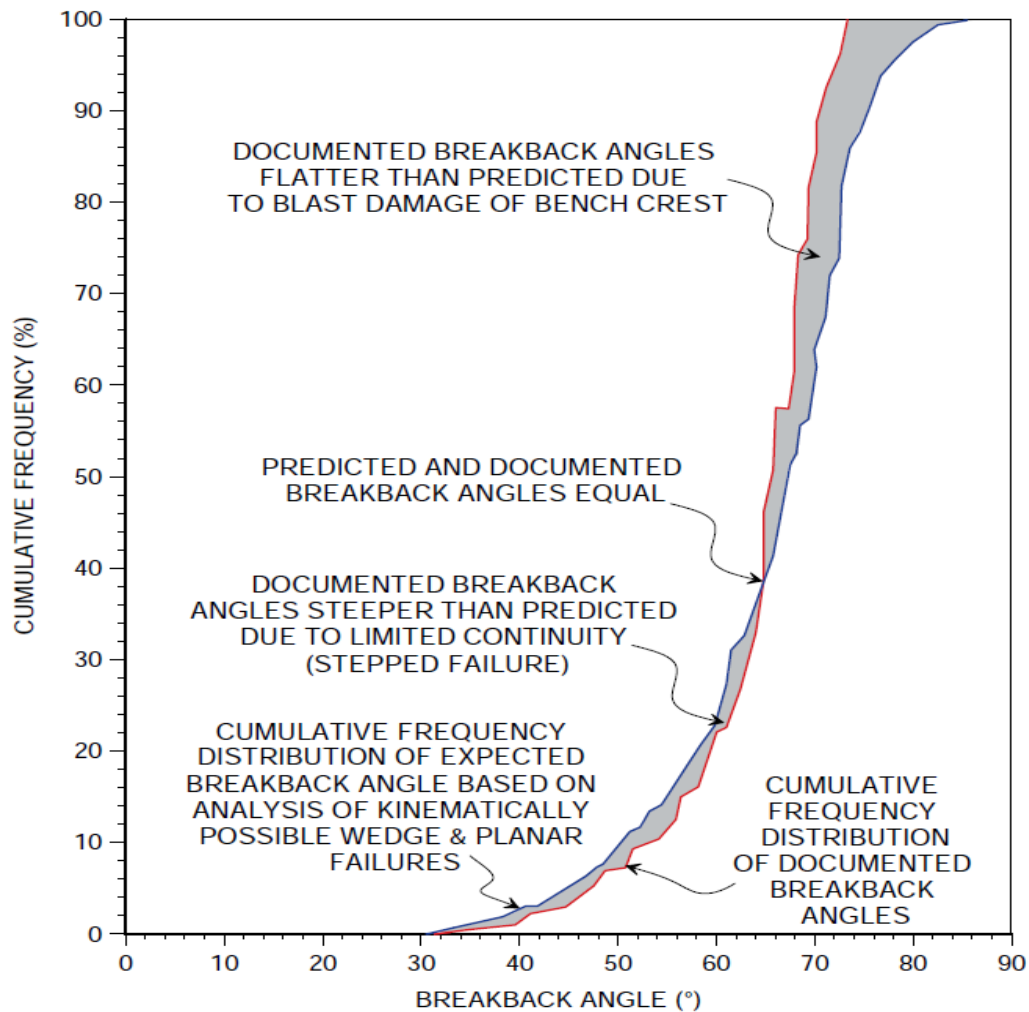


Figure 2-2: Expected back break versus the as-mined back break using the cumulative-frequency analysis

(Source: Read & Stacey, 2009)

The process of comparing the actual bench face angles with the designed angles requires the collection of the as-mined data. The most basic method is using surveyed profiles to back-calculate the bench face angle by depicting the crest and the toe. According to Read and Stacey (2009), this method has flaws as it normally results in accuracy levels ranging between 2° and 10° compared to the actual angles. This is because sometimes mine surveyors may not be permitted to get as close to high walls as possible due to safety procedures as dictated by the mine. An alternative approach is to use a Brunton compass or a clinometer, as depicted in Figure 2-2, to indirectly measure the bench face angle.

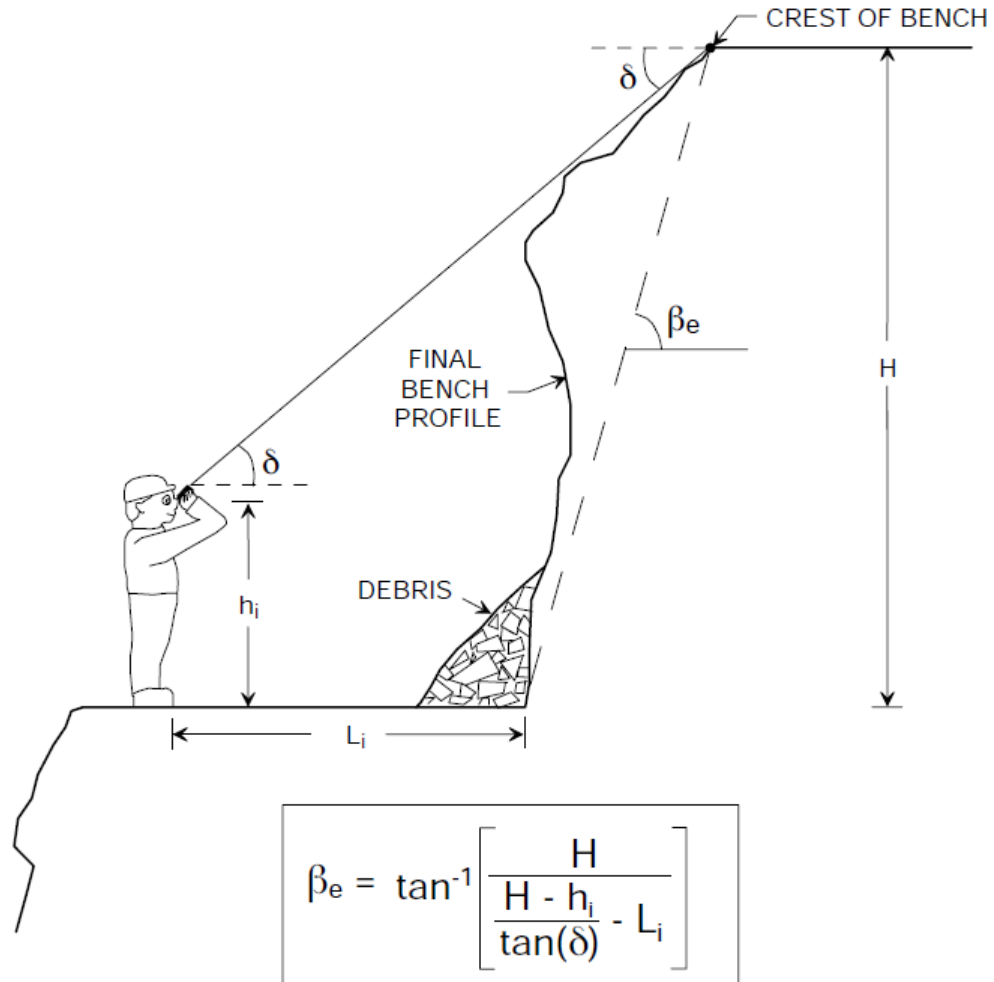


Figure 2-2: Measuring bench face angle using a clinometer

(Source: Read & Stacey, 2009)

Other latest technologies being utilised in the mining industry include drone surveys shown in Figure 2-3. The accuracy of the drone survey method is enhanced by the fact that it can gather more data points compared to any other method used (Civil Tracker, 2024).



Figure 2-3: Drone survey in an open pit mine

(Source: Ball, 2020)

Figure 2-4 shows data profiles collected by three different survey systems. A drone survey point cloud is denoted by grey dots. The red line connects two points of data collected by the global navigation satellite system (GNSS). The black line connects two data points collected using an unmanned aerial vehicle.

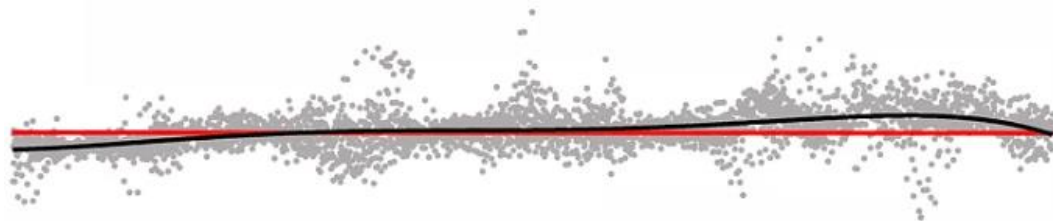


Figure 2-4: A comparison of results from drone survey, GPS and unmanned aerial vehicle

Survey Methods

(Source; Civil Tracker, 2024)

The data presented in Figure 2-4 reveals that the drone survey method results in a more accurate digital terrain map compared to other methods. This can be attributed to the higher volume of data points collected through drone surveys in comparison to other methods.

It is important to conduct scaling and bench cleanup after each blast, particularly against high walls, to ensure that the remaining materials on the benches are secure and do not pose a safety hazard to people and equipment. After the bench scaling and cleanup, a certain catchment bench width remains. This catchment bench width is termed the effective bench

width (Read & Stacey, 2009). As a safety precaution, the effective catchment bench width must be wide enough to contain any potentially dangerous spillages from benches above.

The minimum bench width varies from mine to mine based on a combination of operating experiences and each mine's operating policy. It is not economically practical to design a bench width that would retain all the failed material. However, a limit is set to 70% – 85% of the potentially failed volumes (Read & Stacey, 2009). To assess the performance of the bench width, normally the as-mined data is required. This data helps to compare what was mined with the design. With the latest technological advancements, drone surveys are now used for data collection, leveraging laser scanning and photogrammetric methods, with the former being the preferred approach due to its accuracy. There are several systems used in the mining industry for evaluating bench width achievement. One such system involves a matrix that evaluates the actual bench width relative to design in terms of distance from the final wall.

Poor blasting practices affect mine design and overall slope angle. Both under-break and overbreak result in designed mine limits not being achieved. The performance of a blast is evaluated based on factors such as visible drill barrels, open joints, intact rock breakage, loose material on the face, bench face profile, and crest conditions. Open pit slope angle optimisation involves a detailed consideration of the economic and operational risks associated with mining activities (Epiga & Rupprecht, 2017). This is because shallow slope angles can result in increased stripping ratios, while steep slope angles can introduce operational risks such as slope failures, leading to fatalities and equipment damage.

Slope Monitoring

Slope monitoring is prompted by the need to protect personnel and equipment as slope failures can result in fatalities and economic losses. Therefore, design performance must be continuously assessed using slope monitoring techniques. The primary objectives for slope monitoring are to (Read & Stacey, 2009):

- Provide safe working conditions to protect employees and equipment;
- Provide early warning signs of potentially unstable high walls so that mine plans can be modified to reduce the impact of slope displacements;
- Assess the slope design performance; and
- Provide geotechnical data that will help in slope stability analysis so that remedial actions can be carried out accordingly.

Ministry of Mining of Lesotho (2015) as well as the Lesotho Government (1981) require that the safety of personnel and equipment be enforced. Slope monitoring ensures that safe working conditions are ensured at all times.

Risk Management

The valuation of mining projects requires that open pit design and long-term production scheduling be done in line with evaluating and managing the ore-body risk (Godoy & Dimitrakopoulos, 2004). This is because the impact of ore-body risk on performance such as stripping ratio over the life of the mine is critical (Rendu, 2002). It is therefore important that the optimal production schedule is the one that maximises the NPV of the mining project. Management of waste over the entire life of the mining project in open pit mining forms an integral part of risk modelling in dealing with all aspects of ore-body uncertainty. According to Godoy and Dimitrakopoulos (2004), uncertainties in the orebody have a greater influence on the NPV of mining projects.

The use of a risk-based approach to open pit slope design has numerous long-term advantages. Depending on company policies, the geotechnical slope risk-based approach assists mine management in defining acceptable levels of safety and economic risk (Tapia *et al.*, 2007). The idea is to quantify economic value in conjunction with the level of risk associated with each slope configuration. The quantification of economic value together with the associated level of risk provides a basis from which risk response plans are triggered.

The inability to mine up to the designed or final wall limit poses a risk (Robert & Whitman, 1984). This is because the final wall limit is often pre-split, and by not mining to the limit, a plane of weakness is created, waiting for anything to trigger its collapse. Depending on the anticipated risk level, reconciling the as-mined with the design may become challenging. This can happen due to various factors, such as the loss of access to benches. In such cases, it may be necessary to make changes to the design of the next benches.

Geotechnical-induced slope failures can lead to fatalities and equipment loss. When these failures occur, they reflect poorly on the company's integrity and can even result in mine closures. Therefore, it is crucial to incorporate risk assessment into every design process (De Graaf *et al.*, 2019). Comparing the actual geotechnical slope with the design is essential for the reconciliation process. Slopes that deviate from the planned design pose inherent risks of failure. Based on the extent of the deviation, the actual geotechnical slope must be reconciled with the design.

Mining operations are associated with significant risks that demand a meticulous assessment of economic factors and potential instability risks stemming from mining activities. To optimise the worth of mineral resources, it is crucial to promptly evaluate and adjust slope design to mitigate any potential issues. Consistent geotechnical slope reconciliation can effectively tackle concerns related to slope failures, which may lead to restricted access to the mining site, elevated stripping ratios, and extra remediation expenses (Dixon *et al.*, 2011).

The reconciliation process is driven by the outcome of risk assessment, which forms the central part of it (Dixon *et al.*, 2011). Figure 2-5 demonstrates the role that slope design reconciliation plays in the design feedback loop.

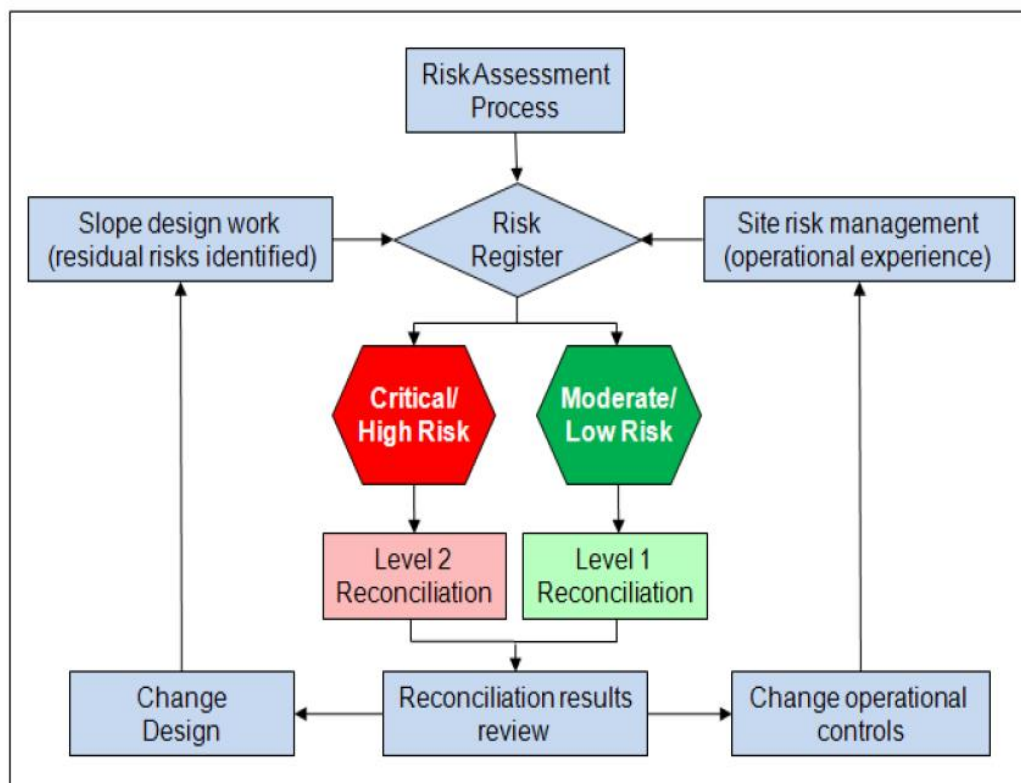


Figure 2-5: The role of reconciliation in the geotechnical design and risk management process
(Source: Dixon *et al.*, 2011)

The risk assessment of slopes considers various factors such as the highwall orientation, geotechnical domain, potential failure mechanisms, and slope design geometry. It is a qualitative assessment that uses a probability of failure versus consequence risk matrix, in case of a failure. SMD - Kao Mine employs a collaborative approach to conduct risk assessment, with a team consisting of members from production, mine planning, geotechnical, and health and safety. Conclusions drawn from the assessment can greatly influence the

mine's NPV, either enhancing or diminishing it. The following three aspects drive the need for reconciliation (Dixon *et al.*, 2011).

- Standards and legislative requirements;
- Safety and economic aspects; and
- Duty of care.

Standards and legislative requirements

The primary goal of regulations and operating standards is to ensure a safe working environment. This is achieved by ensuring that a slope design has considered the in-situ rock properties, the mining strategy, and other geotechnical assessments. This entails following a specific process to reconcile the design assumptions and parameters with actual mining. Table 2-1 shows the bench sign-off printable form used by SMD-Kao Mine after each blast, particularly against high walls.

Table 2-1: The bench sign-off printable form used at SMD - Kao Mine

Limit Blasting and Cleaning Quality Assessment				
Blasthole barrel exposure quality	Barrels fully exposed on the face (15 – 20)	Up to 10% of barrels are not visible (10-15)	Up to 10 to 50% of barrels not visible (5-10)	Barrels are poorly exposed on the face >50% (0-5)
Bedding/ Joint condition	Joints/bedding is tight (15-20)	Occasional joints/bedding have opened (10-15)	Frequent joints/bedding is open and blocks are loose (5-10)	Dislocated blocks/shattered (0-5)
Cracking	No cracking behind crest line (15-20)	Hairline cracking behind crest line (10-15)	Open cracks behind crest line (5-10)	Large cracks open behind crest line (0-5)
Crest condition – back break	Minimal back-break (0 to 10%) (15-20)	Minor back-break (10 to 20%) (10-15)	Major back-break (20 to 50%) (5-10)	Severe back-break (>50%) (0-5)
Toe Condition – Under break	Minimal toes (0 to 10%) (15-20)	Minor toes (10 to 20%) (10-15)	Major toes (20 to 50%) (5-10)	Severe toes (>50%) (0-5)

The purpose of the form is to evaluate blast performance by examining benches' face conditions, such as the exposure of pre-split barrels, crest and toe conditions, high wall bedding/jointing conditions, and cracks beyond the pit design limit. If a favourable outcome is not achieved, remedial actions such as implementing operational controls like high wall scaling and radar monitoring may be necessary. The radar monitors the slope movements and triggers an alarm if the movement is of a magnitude that poses a risk. In some cases, changes to the slope design may also be required.

In the early stages of mining operations, the mine design is based on a limited geotechnical database. However, as mining activities progress, a ground control management plan is implemented to gather more data. This data is then used to provide feedback on the initial geotechnical model, to improve the geotechnical database and to continuously assess the stability and suitability of the current mine design. This is done to improve the geotechnical database and also to continuously assess the suitability and stability of the current mine design (Department of Minerals and Energy, 1999).

Safety and economic aspects

The initial geotechnical model on which the initial slope design is based has many uncertainties which results in very low confidence regarding the understanding of the expected slope behaviour. The lack of data, knowledge and understanding of the geological and structural model is cited as one of the contributing factors that lead to unexpected slope failures (Sullivan, 2006).

As the mining project moves into the operational phase, more knowledge is gained about the properties and behaviour of rock. This information is then incorporated into the geotechnical model. The data gathered during the operational stage is compared to the initial assumptions made. If necessary, adjustments to the slope angles might be required, which could lead to a decrease in ore recovery and a reduction in the NPV of the mineral asset. However, if the data shows that the rock is competent, steeper slopes can be used, resulting in higher ore recoveries, improved NPV of the mineral asset, and overall success of the project.

Duty of Care

According to the Professional Code of Ethics, engineers are expected to appropriately execute high standards and best conduct in carrying out their duties to the general public, their clients, their employers, their colleagues and their profession (Marston, 1996). Engineers are bound by their profession and legal duty to provide safe designs that will serve their intended purpose. Incorporating safety in the design helps to eliminate hazards at an early stage as it may be very costly to rectify design flaws at a later stage (Dixon *et al.*, 2011). Slope reconciliation is crucial to completing the design feedback loop and ensuring safety in the operational mining environment.

2.2.3 Factors affecting reconciliation

This section discusses factors that significantly influence the accuracy and reliability of reconciliation outcomes. It provides an examination of the truck factor, density, dilution, and

stockpile management, all of which are integral to ensuring that production data aligns with mineral resource models and estimates.

Truck Factor

During mining, the two most important aspects that affect reconciliation results are the truck factor and stockpiles (Fouet *et al.*, 2009). Truck factor is a term used to define the ratio applied to a truck to convert a single truckload to payload in tonnes. Generally, every truck has a certain truck factor attached to it depending on the size of the truck. Similarly, every type of material (ore and waste) in the mining operation has a certain factor applied to it depending on material properties such as moisture content and specific gravity. Truck factor can also be affected by operators' loading habits (such as over-loading or under-loading of trucks), and blast fragmentation size (Fouet *et al.*, 2009). As a result, the truck factor should be reviewed regularly upon realising changes in any of the mentioned variables that affect it. It is therefore not good practice to assume that the factor will remain the same over the LoM (Glacken, 2019). Overloading or underloading of trucks coupled with fragmentation size can result in reports showing that there is no material available in the pit while there is still material. This is where continuous adjustments and reconciliation are necessary. This exercise is normally performed by mine surveyors, mining engineers and geologists who are normally on site and know exactly what is happening on the ground. According to Campelo and Marin (2018) and Morley and Arvidson (2017), among various methods of calculating truck factor, using the manufacturer's specifications for tray volumes multiplied by density is considered the least accurate. This approach fails to take individual site conditions into account.

Stockpiling Strategy

Effective stockpile management is a crucial aspect of any mining operation. Stockpiles serve as a buffer between open pit loading and mineral processing, to ensure a steady mill feed and consistent ore blending at the processing plant. A key step in reconciling mined material involves accurately tracking material flows throughout the entire mining value chain (Cawood & Tetteh, 2017). This includes capturing detailed data on material movements, such as the origin and destination areas and the quantity transported. Drone surveys have streamlined this process, allowing for more frequent and thorough assessments compared to traditional methods like tacheometry.

The presence of stockpiles means that although material has been mined in the open pit, it might take longer to go through the processing plant (Newman & Rezakhan, 2020). The material residence time on stockpiles might affect the accuracy of reconciliation results. This means that in carrying out reconciliation, material residence time on stockpiles should also be

considered to ensure reconciliation accuracy. Inherent errors coupled with human error can result in reports showing inventory when stockpiles are visibly empty or reports showing no inventory when in reality there is inventory. This means that from time to time stockpiles must be adjusted to reflect the material movement to and from the stockpiles.

Density of rock

Accurate determination of the matrix density of the material under evaluation is crucial for obtaining reliable values for mineral resources and reserves. Applying incorrect density values to the tonnage calculation can result in losses/gains ranging from 15% to 20% (Roux, 2021). SMD - Kao Mine comprises four distinct types of kimberlite within a single kimberlite pipe, each identified by specific contacts. Occasionally, during blasting, kimberlite from one type may fall beyond its designated contact. As a result, if the material is not accurately traced back to its source, incorrect density may be attributed during mining and tonnage calculations.

Dilution

Dilution is a critical design parameter that significantly impacts the economics of a mining project. Revenue from mining operations is determined using financial models that take into account the estimated tonnage and grade of the orebody (Camara & Peroni, 2016). These estimates are derived from the mineral reserve model, which considers dilution and mine recovery factors. Failure to control dilution can lead to discrepancies in grade reconciliation. Due to the assumed dilution factor, the difference between the planned and actual mined grades can have negative consequences on the mining project (Ebrahimi, 2013). The assumed dilution factor may stem from insufficient data to accurately estimate dilution for use in mineral reserve estimation.

When developing cash flows for a mining operation, it is crucial to consider dilution as a key factor. Dilution occurs when waste material is mined alongside ore during the operation (Ebrahimi, 2013). Failing to consider dilution can significantly impact the assessment of the mining venture. This is because dilution lowers the average ore grade while increasing mineral processing expenses. The revenue estimates in mine financial models depend on tonnages and ore grades determined by the mine design, which are based on the mineral resource model.

It is a good idea to benchmark with similar operations during preliminary economic assessment of mining projects. However, the reality is that every mining operation is unique. This is especially true when it comes to design parameters such as the dilution factor. There are two types of dilution namely internal dilution and external dilution (Ebrahimi, 2013). Figure 2-6 shows a mining block bench in an open pit depicting both internal and external dilution.

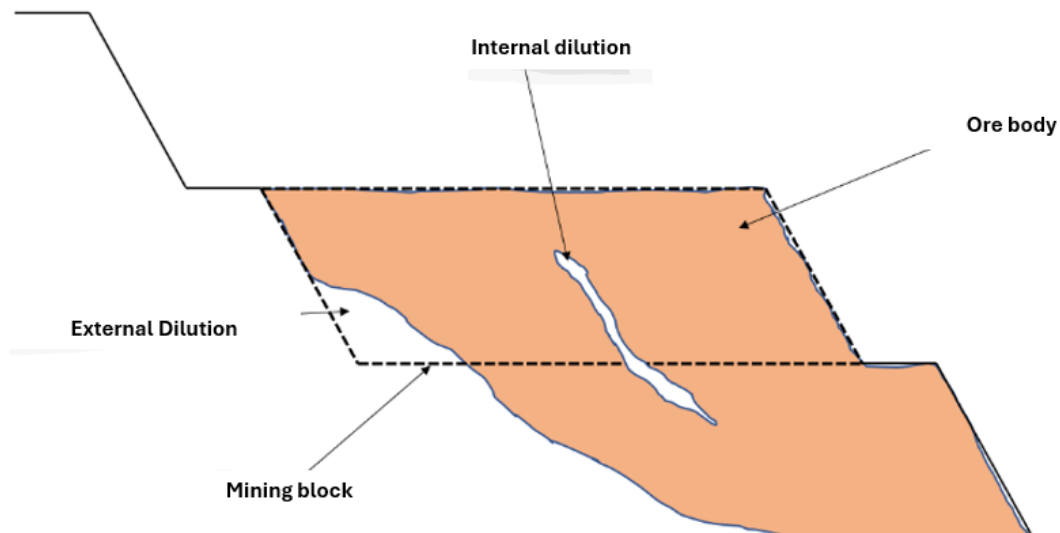


Figure 2-6: Mining block bench in an open pit mine and different types of dilution

(Source: Ebrahim,2013)

Internal dilution is the waste inclusions or low-grade pockets within a mining block, that cannot be separated from the mining block. This dilution is affected by the features inherent to the mineral resource, such as the lithology, structural geology, grade distribution and the orebody thickness. This type of dilution cannot be controlled as it happens within the ore block.

External dilution is also referred to as contact dilution. It is the waste around the orebody that is mined with a mining block. Contact dilution varies with the shape of an orebody, geology, drilling and blasting techniques, equipment size and the scale of operation. This type of dilution can be controlled.

External dilution is mine operation-related. This is the dilution that occurs because of the mining method, mine geometry, equipment size and also mining practices. Due to operational challenges, a 2 m contact waste is normally added to mining blocks (Ebrahimi, 2013). This is to cater for back breaks when mining at contacts and forms a basis from which external dilution is quantified.

Tracking actual dilution during mining is crucial for identifying its sources. This information is essential for making necessary adjustments, such as changing mine layouts, to control dilution. Dilution reconciliation is needed because, in the early stages of a project, there is often insufficient data to draw accurate conclusions. Typically, at the beginning of a project, a 5% dilution factor is assumed for massive ore deposits and 10% for narrow or tabular deposits (Ebrahimi, 2013). Although this is a good starting point, these assumptions overlook the fact

that dilution factor varies from mine to mine and even within the same mine from bench to bench and ore zone due to the orebody's geometry.

The inability to quantify, identify sources of dilution and control it, can affect the economic value of a mining operation in a manner outlined below (Ebrahimi, 2013). The presence of dilution in a mining block reduces the mill feed grade. The lower the mill feed grade the lower the income. In some instances, a mining block can become uneconomically viable to process due to the presence of dilution. The feed grade that goes into the mill after the application of the dilution factor is calculated using Equation 1 (Ebrahimi, 2013):

$$Feed_g = \frac{Ore\ grade + Waste\ grade * Dilution}{1 + Dilution} \quad \text{Equation 1}$$

Where:

Feed_g is mill feed grade

Dilution is a value between 0 and 1

Ebrahim (2013) further states that for a gold mine with a milling cut-off grade of 0.30 g/t, a 10% dilution factor reduces the grade of ore from 0.30 g/t to 0.28 g/t. This means that with the presence of a certain dilution percentage and depending on the mine cut-off grade, an ore block can be rendered uneconomically viable for mining. Incorrect estimation of dilution factor may render a mining project uneconomically viable as it affects the grade of the orebody. According to Parker (2012), a 10% error in copper grade can lead to a 60% change in NPV. Therefore, it is essential to always control dilution to ensure alignment between the initial design and actual results.

The presence of dilution in a mineral reserve raises the unit operating cost of milling, as energy and materials are wasted in processing the waste portion of the feed. Therefore, to effectively minimise operating costs, it is crucial to monitor dilution and control it daily. This practice facilitates the identification of deviations from the original plan and allows for improved control over the milling process by pinpointing the sources of dilution.

A mineral reserve model has an inbuilt dilution factor developed from drilling data. However, during mining operations, dilution information is derived from samples from the belt conveyor after crushing (Ebrahimi, 2013). This means that during mining dilution as obtained from samples on the belt conveyor needs to be reconciled with dilution from drilling data to

continuously update the mineral reserve model. If actual dilution is constantly higher than the dilution factor used in the mineral reserve models, mine plans may need to be changed.

Several computer software packages are available in the industry to quantify the amount of dilution for open pit mines. Although every operation is unique and should be dealt with differently in quantifying dilution, the methodology as outlined by Ebrahimi (2013) in Equation 2 is generally followed.

$$\text{Dilution} = \frac{\text{Waste tonnes}}{(\text{Ore tonnes} + \text{Waste tonnes})} \times 100 \quad \text{Equation 2}$$

Equation 2 defines dilution as the ratio of waste tonnage mined and sent to the mineral processing plant to the total tonnage of both waste and ore processed. Additionally, McCarthy (2001), outlines several methods for calculating dilution, with the second method represented by Equation 3.

$$\text{Dilution} = \frac{\text{Waste tonnes}}{\text{Ore tonnes}} \times 100 \quad \text{Equation 3}$$

Equation 3 expresses dilution as a percentage, emphasising the proportion of waste material relative to ore extracted. While Equations 2 and 3 yield different results, they both highlight that high levels of dilution can negatively affect the efficiency of a mineral processing plant by increasing unnecessary material handling and ore processing costs. Both equations are acceptable to be applied in dilution calculations, provided they are clearly defined beforehand (McCarthy, 2001).

To enhance efficiency of the mineral processing plant, dilution must be minimised as much as possible. Although some level of dilution is inevitable due to geological, mining and operational constraints, effective blasting techniques, selective mining, and implementation of grade control measures can significantly reduce dilution.

2.3. Chapter Summary

It is crucial to conduct temporal and spatial reconciliation in the mining industry. Temporal reconciliation involves comparing projected targets such as volumes, tonnages, and grades with actual production data. This process is essential for accurate production scheduling, mineral resource management, and decision-making, especially when dealing with geological complexities that impact ore grades.

Spatial reconciliation focuses on ensuring that mining activities occur in the correct locations and sequences to aid long-term planning. The chapter emphasises spatial compliance as a significant performance indicator to avoid future operational disruptions. Mine-to-design compliance ensures that open pit mining follows planned pit wall limits while managing geotechnical risks, such as slope failures. This involves continuous geotechnical assessments and advanced technologies like drone surveys for accurate data collection.

Several key factors impact reconciliation outcomes, including accurate payload conversion for trucks (Truck Factor), effective tracking of material movements (Stockpile Management), precision in material density tracking (Density), and controlling internal and external dilution to maintain ore grades and minimise costs (Dilution).

3. RESEARCH APPROACH

3.1 Chapter Overview

The chapter presents an outline of the methodological framework and approach employed for the temporal and spatial reconciliation research at SMD-Kao Mine. It encompasses a systematic methodology tailored to meet the study's objectives, encompassing research design, data acquisition, validation, and the analysis process. The methods used to measure mined tonnes are justified in this chapter. A combination of manual, digital, and geospatial tools used ensured that the strengths of each method complemented the weaknesses of others, creating a reliable system for tracking mining progress.

3.2 Research Design

Scientific research relies on qualitative and quantitative methods to model and analyse phenomena. Qualitative research aims to understand complex reality by providing meaning behind actions in a given scenario, while quantitative research aims to obtain accurate and reliable data for statistical analysis (Queiros *et al.*, 2017). The main difference between qualitative and quantitative research is the type of data each method deals with. Both methods can also be used to evaluate risks in companies. A quantitative approach to risk analysis involves quantifying numeric values associated with each element for post-risk analysis. Smaller companies typically use the qualitative research method, using relative descriptions such as rare/often, low/high, vital and critical, instead of numeric values to evaluate risks in an organisation (Wadawi *et al.*, 2011). Only the quantitative research method was used for this research because the study aimed to employ numerical illustrations of facts to reach conclusions.

3.3 Data Collection Process

3.3.1 Temporal and spatial mine to plan data acquisition processes

A plan outlines the necessary amount of mined tonnes required to sustain a mine each month. To monitor the progress of tonnes mined in comparison to the plan, various measurement methods were utilised for this research. The initial method involved manually counting truck loads. Spotters were positioned at strategic locations, often inside cabins, to manually count the number of truck loads as they passed different locations with full loads. At the end of the shift, a specific truck factor was applied based on the truck's size to obtain the total tonnes for the day. However, this method is susceptible to errors as it assumes that all trucks are loaded

to full capacity, which may not always be the case. This method of manually counting truck loads offered a straightforward and low-cost approach to estimating tonnes mined. While it provided a basic measure of activity, the inherent assumption that all trucks are loaded to full capacity introduced potential errors. However, this limitation was mitigated by integrating AVAFMS, an advanced technology, into the process.

The research utilised total stations as the second method for acquiring temporal and spatial data. A total station is an advanced device that integrates the functions of a theodolite for measuring angles and an electronic distance measurement (EDM) device into a single instrument. This integration enables the instrument to calculate horizontal and vertical angles, as well as the slope distance of a specific data point (Chekole, 2014). Figure 3-1 shows a total station set up in the field during the data collection process.



Figure 3-1: Total Station

Once the data was collected, it was imported into Datamine Studio OP software. This data was then used to generate topographic maps of the entire pit or a specific area of interest.

Using total station as the second method provided a precise and reliable means of collecting temporal and spatial data. The ability to measure horizontal and vertical angles, as well as slope distances, made the total station particularly suitable for generating accurate topographic maps of the pit or specific areas of interest when integrated with Datamine Studio OP software. This supported accurate volumetric calculations and progress tracking.

An additional tool utilised for data collection was the GNSS. This system utilises a network of satellites orbiting the earth, continuously transmitting signals containing their location and timestamp information. Upon receiving these signals, ground-based GNSS receivers use them to compute their exact position in 3D space (Chekole, 2014). Figure 3-2 shows the GNSS that was used for data acquisition for this research project.



Figure 3-2: Global Navigation Satellite System

The GNSS was utilised to gather data in all areas where mining operations took place. The data collected using GNSS was saved in a drawing exchange format (DXF) file, ensuring

compatibility with various software packages, such as Datamine and Model Maker, both of which were used in this research project. The incorporation of GNSS further enhanced the data collection process by enabling 3D positioning with high accuracy. GNSS allowed for efficient surveying of areas to calculate cut and fill volumes, providing critical input for reconciliation against planned tonnes. The compatibility of GNSS data with software such as Datamine and Model Maker ensured seamless integration into the broader analytical framework.

At the end of each month, a compilation was conducted to assess the amount of planned area that has been mined. Following this, a root cause analysis was conducted to understand why the plan was not followed and how to prevent similar situations in the future. The findings from the root cause analysis would assist in preventing deviations from the plans and enhance the execution of mine plans.

The research also used an unmanned aerial vehicle (UAV) to collect data. The UAV survey was typically conducted at the end of each month for 12 months by an external contractor. A UAV was fitted with high-resolution cameras and/or light detection and ranging (LiDAR) sensors and was flown over the entire mining lease area. Figure 3-3 shows the UAV equipped with high-resolution cameras for data collection.



Figure 3-3: UAV equipped with sensors and high-resolution cameras for aerial survey

(Source: Survey Drones Ireland, 2023)

Equipped with advanced sensors, the UAV captured a wide range of geospatial data, such as high-resolution images and point clouds. This survey technique was particularly valuable in locations where GNSS and total station access were challenging. By comparing the latest pit scans with the previous month's end scans, it became possible to calculate cut and fill volumes, ultimately leading to a precise determination of the mined-out tonnes for that specific

3.3.2 Dilution reconciliation data acquisition process

Belt-cut samples were taken for this research to reconcile dilution data. This involved strategically selecting sampling points along the belt conveyor to ensure a representative sample of ore was obtained. A sample cutter was then placed at these points, and as the ore moved past the cutter, a sample was scooped and collected in a container. The collected sample was then sent to the laboratory for analysis and interpretation.

The use of belt-cut sampling for reconciling dilution data was justified by the need for accurate and representative sampling of ore during its movement to the processing plant. Strategically selecting sampling points along the belt conveyor ensured that the samples reflected the actual material being processed, minimising the risk of bias and improving reliability of the data. The placement of a sample cutter at these points allowed for consistent and precise sample collection as the ore moved along the belt conveyor. This method provided a practical and efficient way of capturing the variability of the ore stream, which was critical for assessing dilution. By analysing the collected samples in a laboratory, detailed insights into the characteristics of ore were obtained. This enabled an accurate reconciliation of dilution data and better decision making in grade control and process optimisation.

3.3.3 Stockpile reconciliation data acquisition process

Ore is extracted from the mine and transported to stockpiles using excavators and articulated dump trucks. The stockpile volume was acquired using a total station and GNSS. The survey data acquired was transferred to a computer using a USB which was then used for further processing. Once transferred this data was stored in mostly comma-separated values (CSV) or DXF format. The data include coordinates and elevations from which volume calculations were made. The data was then imported into AutoCAD 3D whereby surface models were created that represent the existing stockpile terrain. To calculate stockpile volumes, the previous stockpile surface model was compared with the current stockpile surface model. The approach employed for stockpile measurement combined precision, efficiency, and compatibility with modern geospatial and CAD tools. Acquiring stockpile volumes with a total station and GNSS ensured high accuracy in capturing spatial data, as these instruments are reliable for measuring coordinates and elevations.

The transfer of survey data to a computer through a universal serial bus (USB) for processing and storage in formats like CSV and DXF is both practical and efficient, as these formats are widely supported and facilitate seamless integration with analysis software. The inclusion of

coordinates and elevation data provided the necessary inputs for accurate volume calculations.

Importing data into AutoCAD 3D to create surface models of the stockpiles allowed for precise visualisation and manipulation of 3D terrain. Comparing the previous and current surface models enabled accurate calculation of stockpile volume changes, making this method effective in monitoring stockpile dynamics and ensuring reliable stockpile management.

3.3.4 Mine to design reconciliation data acquisition process

Data collection for mine to design reconciliation process involved the identification of areas that have been mined to the final pushback limit. Figure 3-5 shows exposed pre-split barrels confirming that pit final wall limit has been reached.



Figure 3-5: Highwall mined to the limit

The mine-to-design data was collected using total station, GNSS, and UAV. The data was then imported into Model Maker Software for further processing. The data collection for mine to design reconciliation was in line with a geotechnical assessment so that the amount of crest loss, the catchment berm capacity, and frozen toes could all be established.

Bedding or jointing conditions were also evaluated based on the bedding/jointing tightness, open joints with loose blocks and shattered or dislocated blocks. Crest conditions were also evaluated and depending on the extent of back breaks a certain score or rating was awarded. The toe condition evaluation looked at the under-breaks at the foot of the highwalls. It was from the outcome of this evaluation that the necessary actions were recommended. Figure 3-6 shows typical crest loss and frozen toes.

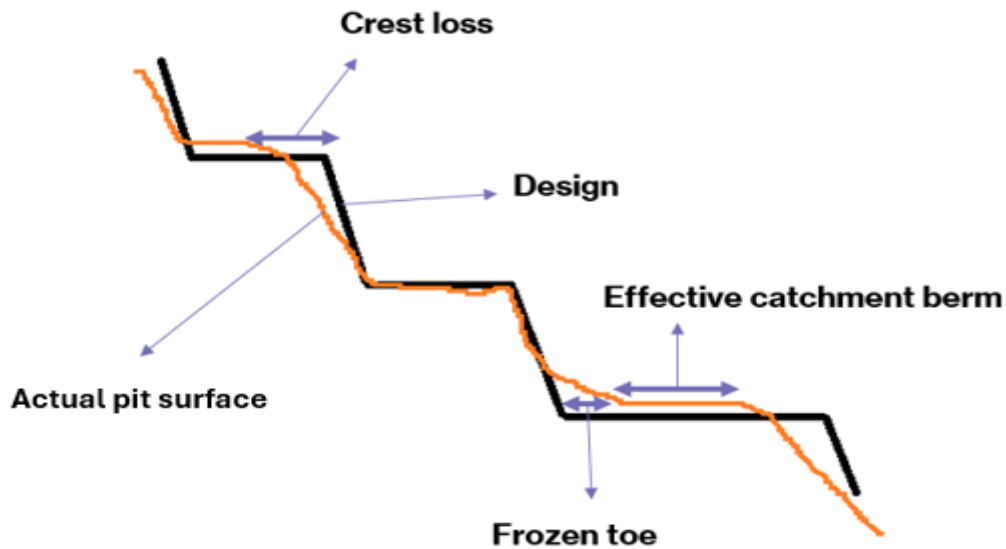


Figure 3-6: Schematic cross-section defining crest loss and toe flare/frozen toe

(Source: Basson & Jack, n.d)

The methodology for data collection in the mine-to-design reconciliation process was justified as it ensured comprehensive and precise analysis of mined areas relative to design specifications. Identifying areas mined to the final pushback limit was essential for evaluating compliance with the design and assessing deviations that impact operational efficiency and safety.

The use of total stations, GNSS, and UAVs to collect the mine-to-design data was appropriate, as these technologies provide accurate spatial data, enabling detailed mapping of mined surfaces. Importing this data into Model Maker Software for further processing allowed effective visualisation and analysis, ensuring consistency and accuracy in the reconciliation process.

Incorporating a geotechnical assessment into the reconciliation process added significant value by evaluating critical structural and stability factors, such as crest loss, catchment berm capacity, and frozen toes. This ensured that safety and operational standards were maintained. Assessing bedding and jointing conditions, as well as crest and toe conditions, provided a detailed understanding of slope stability and potential risks.

By plotting the design against the actual pit surface, areas of compliance and non-compliance were identified, as demonstrated in Figure 3-6. This approach facilitated targeted corrective actions to reconcile discrepancies, enhancing the overall alignment of mining operations with the design plan. This integrated process ensures that mining activities remain safe, efficient, and aligned with the intended design objectives.

3.4 Data Validation Process

Data validation is a methodology that is followed to ensure that the integrity, accuracy, and structure of the data are checked before it can be used for any decision-making purposes (Kerner, 2023). The data used in this research was collected from various sources and it was presented in different formats. These formats include CSV, DXF, and Datamine (DM) file formats. Data collected from multiple sources and presented in various formats inherently requires validation to ensure consistency and usability. By adhering to a structured methodology, these processes minimised errors, improved data quality, and enhanced the reliability of subsequent analyses.

The Datamine file format validation process involved importing the data into the Datamine software package. The data was then profiled for its characteristics such as structure, size, content and other attributes through the Datamine table editor. The next step of the process was data cleaning, where missing values, outliers and inconsistencies were identified. The corrective measures involved the removal of duplicates, interpolation of missing values and removal of any outliers or anomalies that could result in skewed data. Addressing issues like missing values, outliers, and duplicates through interpolation, anomaly removal, and other corrective measures further enhanced the data's accuracy and reliability.

A data consistency check was also carried out as a subsequent step. This was where consistencies such as geological codes and unit names were checked across different data sources. The software package visualisation tools were then used to create charts, plots and digital terrain maps. Viewing the data on plan and also on cross sections made it easier to assess and identify anomalies or data points that warranted further analysis. Sometimes the data, such as stockpiles and blasted material data required manual inspections and judgment. Consultations with mining engineers, mine surveyors and geologists on-site with domain knowledge were made to ensure data made geological and logical sense. The manual inspections and consultations with mining engineers, surveyors, and geologists provided an additional layer of validation. This leveraged domain expertise, ensuring the data aligned with geological and operational expectations.

Validation rules were set depending on the data being validated. Some of these rules included verifying consistency in lithological descriptions of the known geological formations, for example, ensuring that the grades fall within the expected grade ranges. The data consistency check, which examined geological codes, unit names, and other attributes across sources, was critical for ensuring uniformity and reducing discrepancies. The use of visualisation tools,

such as charts, plots, and digital terrain maps, allowed for detailed inspection of the data in both plan view and cross-section, making it easier to identify and address anomalies. This visual approach enhanced the understanding of spatial relationships and data trends. Setting validation rules, such as verifying lithological descriptions and ensuring grades fall within expected ranges, established clear benchmarks for data accuracy. This comprehensive and iterative validation process not only ensured the reliability of the data but also built confidence in its use for informed decision-making.

3.5 Data Analysis

3.5.1 Temporal reconciliation

One of the KPIs used to evaluate the level of compliance against the mine plan is the temporal or time-based measurement. Temporal mine to plan compliance involves comparing the budgeted tonnes for a specific period with the actual tonnes mined during that period. It also includes comparing the expected mineral reserve grades with the actual mineral achieved. There is a possibility of either ore gain or loss when the comparison is being carried out. According to Morely and Moller (2005), ore gain or ore loss refers to variations that exist between the estimated ore tonnes and the actual tonnes mined out from the same polygon.

Ore gain or ore loss has either positive or negative implications on a mine. Ore loss implies reduced profits and is a key indicator of mining efficiency (Eshun & Dzigbordi, 2016). Therefore, reconciliation along the mine value chain must be established to identify areas where ore is being lost. Several methods of measurement were employed in this research study as part of the temporal reconciliation process. The UAV survey was used to scan the open pit and the results compared with the previous month's scan. The other reconciliation method that was used was a daily counting of loaded trucks which gave a daily total of tonnes mined after applying a truck factor to each load and progressively to month-end figures. When material was being fed into the plant, a plant weightometer was also used to measure the weight of the ore fed into the plant. At the end of the month, reconciliation was done between the plant weightometer and the survey figures to find the amount of tonnes that were fed into the plant.

Temporal KPI compares the actual tonnage moved to the budgeted tonnage. After gathering historical data on tonnage moved and processed, a time series analysis was conducted to identify production and reconciliation performance trends and patterns over time. The actual

production data was compared with the mine's planned production, and the variances between planned and actual production for each month were calculated.

Charts and graphs were utilised to present temporal mine reconciliation, making it easier to illustrate trends and anomalies. A root cause analysis was carried out to identify any discrepancies between actual production tonnes and budgeted tonnes.

3.5.2 Spatial mine to plan reconciliation

The spatial reconciliation data analysis process involved establishing a categorised database. The database encompassed details on various aspects, including the total planned area of polygons for the month, the percentage of the planned areas that were mined, the percentage of the mined area that was unplanned, and the areas that were planned for mining but not mined. Planned polygon areas were measured using the Datamine software package after the survey department had updated the open pit mine both before and after mining.

3.5.3 Stockpile reconciliation

Once the data was collected, imported into a computer, and cleaned, wireframes of the stockpile were created. These wireframes were then overlaid onto the previous day's stockpile wireframe as shown in Figure 3-7, to calculate cut and fill volumes. The volumes were then converted into tonnes by applying a density factor based on the type of material in the stockpile.

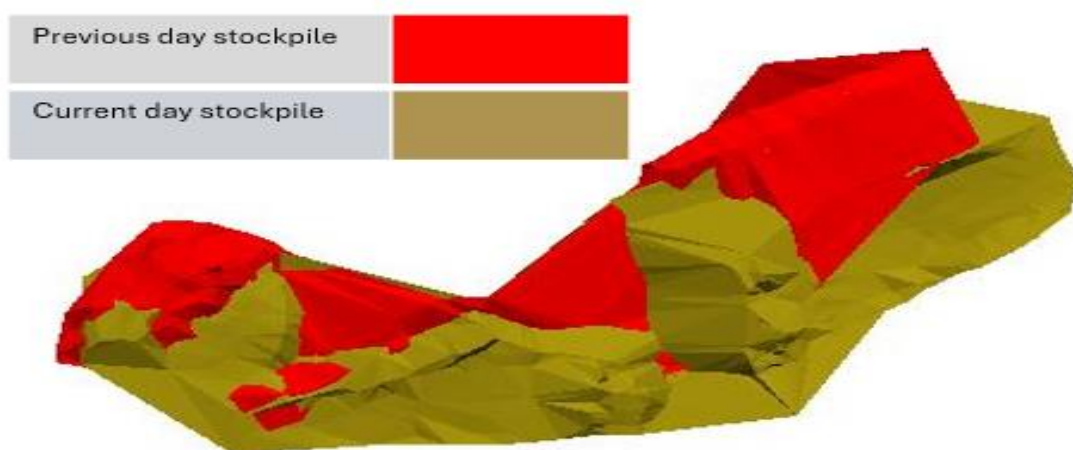


Figure 3-7: Stockpile comparisons

3.5.4 Mine to design reconciliation

The raw scan data was gathered and imported into Model Maker and AutoCAD 3D software packages to carry out mine-to-design reconciliation for the research. Subsequently, a digital terrain map (DTM) of the highwall was generated from the scanned data, with a focus on marking the toe and crest lines on the DTM or contour lines. The design layout was imported from the mine planning database to compare the actual toe and crest lines with the design layout. The result of the comparison is shown in Figure 3-8 where red denotes the design and yellow denotes the latest pit update.

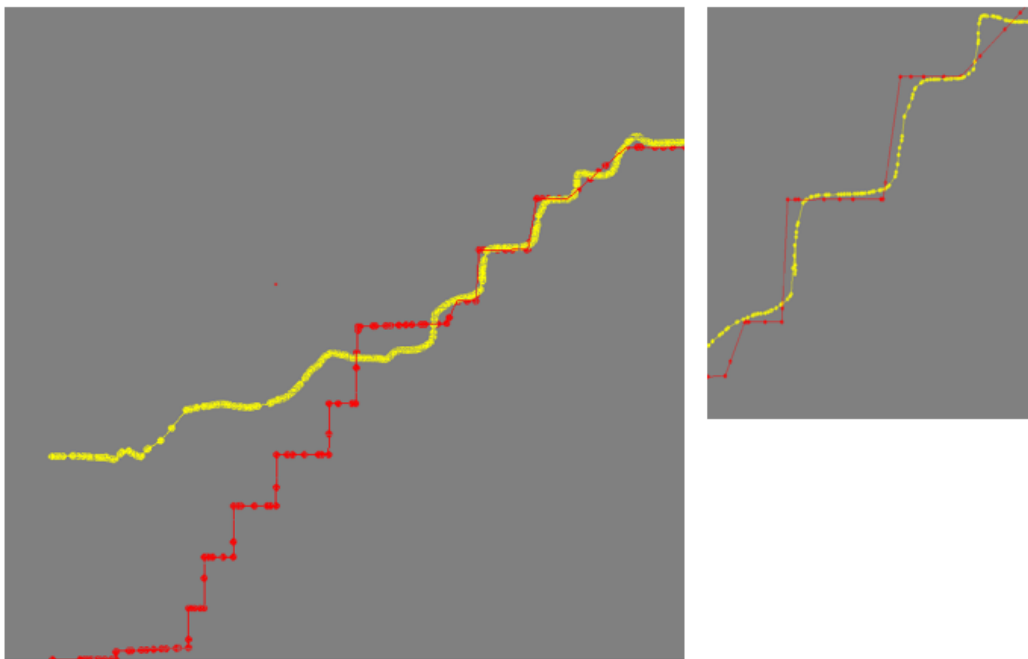


Figure 3-8: Mine design is overlain by the latest pit update

The target outcome was to calculate the statistical distribution of the crest loss, toe flair (frozen toes) and the effective catchment berm as shown in Figure 3-6. Distance measurements were utilised to create a histogram showing distances from the design. Any discrepancies and anomalies resulting from the comparisons were examined to understand their occurrences and to find potential solutions.

3.5.5 Dilution reconciliation

Samples collected from the belt cut were taken to the laboratory for testing. Various properties such as composition were tested to determine the dilution content in the sample. The total mass of the sample in the sealed container was measured. Then, the sample was physically separated to separate ore from basalt. After this separation, both the ore and basalt samples

were weighed separately to determine their mass, and the percentage dilution content was calculated.

3.6 Chapter Summary

This chapter discussed the research design, data collection processes, data validation and data analysis approach for the reconciliation research report. The research design discussed the objectives of the research report, the data sources and the equipment used during data collection. Data sources are also highlighted for each research reconciliation area.

The temporal reconciliation process compares budget tonnes to actual mined-out tonnes over a certain period. Spatial reconciliation is an area-based reconciliation and compares the actual mined-out areas with the planned and unplanned areas. The chapter also touched on dilution reconciliation, where dilution content in the ore is continuously being monitored against dilution catered for in the budget.

4. RESEARCH FINDINGS AND ANALYSIS

4.1 Chapter Overview

This chapter delves into the analysis of the research results. Firstly, the chapter presents temporal reconciliation results, which involve comparing planned tonnes with actual mined tonnes. Temporal reconciliation further looks at mineral grades expected versus mineral grades achieved. Additionally, the chapter presents spatial reconciliation results. Spatial reconciliation ensures that mining activities occur in the right planned areas to ensure future access to more ore. Furthermore, under spatial reconciliation, mining to design limits results are presented.

4.2 Temporal mine to plan compliance results

Table 4-1 compares the survey figures and the tally system for the period of September 2022 to August 2023. The area of this reconciliation was in the pit

Table 4-1: Survey measurements versus tally measurements ('000)

Date	22-Sep	22-Oct	22-Nov	22-Dec	23-Jan	23-Feb	23-Mar	23-Apr	23-May	23-Jun	23-Jul	23-Aug
Survey	389	422	390	419	422	387	387	364	424	419	426	419
Tally	413	457	437	456	451	433	422	395	460	439	477	467
% difference	6%	8%	11%	8%	6%	11%	8%	8%	8%	5%	11%	10%

The planned tonnages were according to the number of days in each month, leading to fluctuations every month. These planned tonnages also considered scheduled plant maintenance days and historic downtimes, such as the impact of weather on plant throughput. Figure 4-1 shows the bar chart generated using data in Table 4-1.

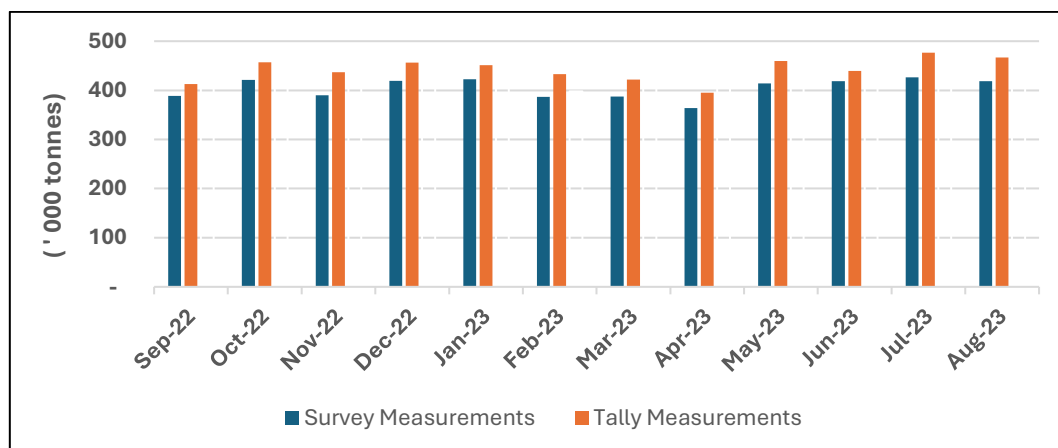


Figure 4-1: Survey measurements versus tally

Figure 4-1 reveals that the tally tonnes exceed the survey tonnes by 5% to 11%. This discrepancy was due to the following reasons: Loading pecker material from the open pit onto stockpiles impacts the bucket fill factor due to voids between boulders, causing the tally measurement to count a truck as fully loaded when it may not be. Additionally, loading zones are dressed with tailings material to protect tyres. The tailings material loaded with ore is counted as part of the load by the tally measurement but not by the survey.

According to (Tetteh & Cawood, 2014) and (Berman, 2016), a strong linear relationship between survey measurements and tally measurements results in a correlation coefficient closer to one. This strong positive relationship in this regard means that when tally figures increase, survey figures also increase and vice versa. This relationship implies that survey data can reliably predict tally measurement and highlight the accuracy and consistency of the measurement process. Conversely, if the correlation is weak or significantly lower than one, it would suggest inconsistencies or possible errors in the data collection methods. To test if there was any relationship between survey measurements and the tally figures, Pearson correlation coefficient (r) was used which is calculated using Equation 4 (Berman, 2016):

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \cdot \sum(Y_i - \bar{Y})^2}} \quad \text{Equation 4}$$

Where: X_i = Individual survey measurement

Y_i = Corresponding tally measurement

$\bar{X}$ = Mean of survey measurements

$\bar{Y}$ = Mean of tally measurements

The application of Equation 4 with survey and tally measurements at SMD-Kao mine resulted in a strong positive linear correlation as shown in Figure 4-2.

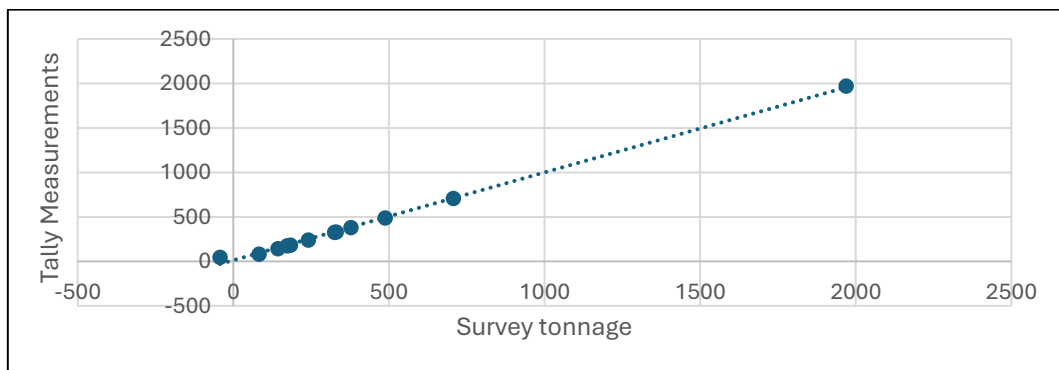


Figure 4-2: Correlation between survey measurements and tally measurements

Material overspill between ore zones during blasting, along with the incorrect application of density, contributes to measurement discrepancies. LQ has a density of 2.71 kg/m^3 , FK has a density of 2.63 kg/m^3 , and GK has a density of 2.64 kg/m^3 . As a result, when FK is blasted, it sometimes spills into the LQ zone. At the end of the month, during survey measurements, if material in the LQ zone is surveyed, the LQ density is applied, even though the material may actually belong to the FK zone and vice versa. Temporary ramps constructed with blasted ore are sometimes mined and backfilled with tailings, which the survey may miss when measuring the material at the end of the week or month, only considering the void created. Furthermore, heavy rainfall in December 2022 led to tailings material being loaded from the plant discharge and tipped back into the pit to create a haul road to retrieve drilling machines from the other side of the pit. Figure 4-3 shows the pit flooded due to heavy rains.



Figure 4-3: Pit flooding due to heavy rainfall

The consequences were still being felt during 2023 because tailings were mixed with blasted material that spilt from the top benches during blasting. As blasted material was being loaded, the tally measurement system counted that as blasted material while the mine survey department could separate that from the original in-situ material. Generally, the mine survey measurements are believed to be more accurate than the tally measurements, and only survey figures are used when payments are made at the end of the month at SMD - Kao Mine.

Another area where reconciliation was carried out was at the plant head feed. The tally method and the weightometer methods were used to record the weight of ore at the plant and together

these were compared to the planned weights. Table 4-2 shows the information obtained from loader bucket counts as well as the plant weightometer.

Table 4-2: The tally versus plant weightometer measurements ('000)

Date	22-Sep	22-Oct	22-Nov	22-Dec	23-Jan	23-Feb	23-Mar	23-Apr	23-May	23-Jun	23-Jul	23-Aug
Tally	411	382	387	433	432	380	399	380	410	380	437	414
Weightometer	409	385	395	425	425	394	397	374	406	412	428	412
% difference	0.60%	-0.70%	-2.00%	1.80%	1.70%	-3.60%	0.50%	1.30%	0.90%	-8.30%	1.90%	0.40%

The variations in the plant feed budget are due to the number of available days for each month. The planned figures also took into account the plant planned maintenance days for each month. The historic downtimes, such as weather, power failure and crusher chokes were also incorporated into the budget. The budget was frequently not met between September 2022 and August 2023. This can be attributed to poor fragmentation which affected loading rates from the open pit. During this period, new geological features were intersected. The limited information on these geological features negatively affected the blasting outcome. Lack of explosives which delayed blasts also affected the ability to avail loadable ore to feed the plant and as a result, the plant had to run on reduced hourly rates. Furthermore, with poor fragmentation, there were frequent crusher chokes due to boulders thus leading to 84.5% achieved plant availability compared to a target of 92.3%. Mining equipment availability also played a role in not achieving the planned plant throughput. Figure 4-4 shows the comparison between the tally, plant weightometer as well planned tonnes.

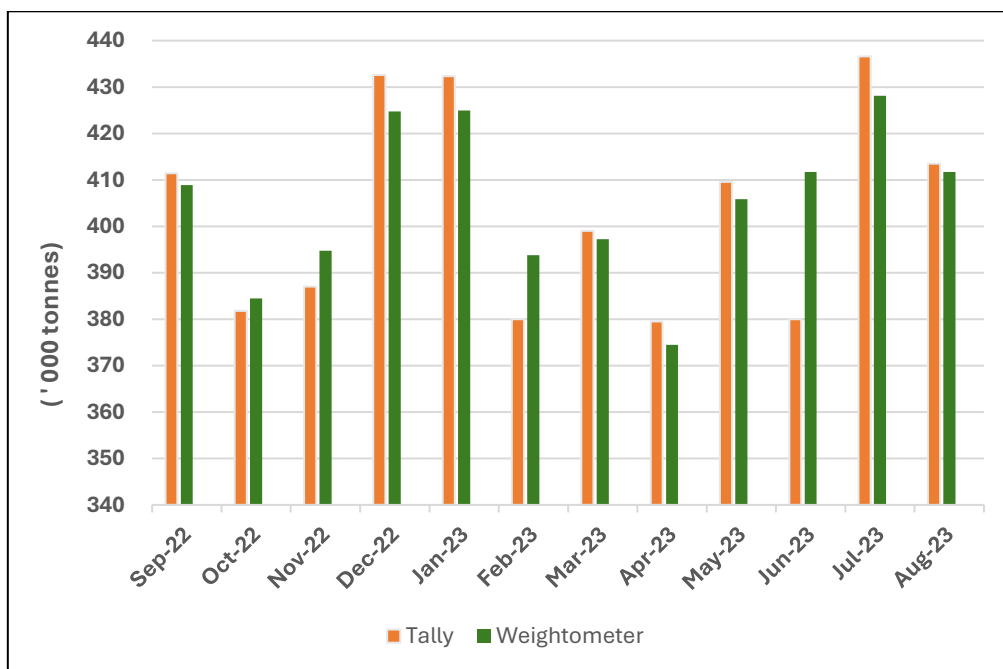


Figure 4-4: The tally versus the plant weightometer

Table 4-2 and Figure 4-4 present the measurements and variance between the plant weightometer and the tally measurements. These variations range from -8.3% (where the tally measurements are lower than the weightometer measurement) to 1.9% (where the tally measurements exceed the weightometer measurement). Although human error is possible in both under and over-tallying, it was observed more during the months of under-tallying. During those instances, changes in the spotters' location occurred. Typically, spotters are stationed at stockpiles, but during this instance, they were positioned in the control room and had to count the loader buckets from the control room's camera. While the camera is visible during the day, visibility was diminished at night, leading to some loader buckets being overlooked. SMD - Kao Mine's mineral processing plant is fed by 988CAT and 986CAT loaders at feeding ends. Tally records are taken as the loader tips into the crusher. The ore is then transported into the plant using a belt conveyor, and a distance from the crusher the weightometer is located to measure the ore that is being fed into the plant. Occasionally, oversized material is ejected just before it reaches the plant weightometer after passing through the crusher. At this point, the ore would have already been recorded by the tally clerks but the weightometer would not capture it, as it had not yet reached that stage.

An alternative method for measuring compliance involved conducting survey measurements. Each morning, stockpile movements were measured to determine the plant feed. Table 4-3 shows the plant weightometer compared to the survey measurement.

Table 4-3: Survey versus plant weightometer measurements ('000)

Date	22-Sep	22-Oct	22-Nov	22-Dec	23-Jan	23-Feb	23-Mar	23-Apr	23-May	23-Jun	23-Jul	23-Aug
Survey	417	392	393	434	432	389	398	371	407	410	431	410
Weightometer	409	385	395	425	425	394	397	374	406	412	428	412
% Variance	1.90%	1.80%	-0.50%	2.10%	1.70%	-1.30%	0.30%	-0.90%	0.20%	-0.30%	0.70%	-0.30%

The budget for the plant, as presented in Table 4-3, fluctuates monthly primarily due to the number of available days each month. These budget figures also include the scheduled plant maintenance days, typically lasting 12 hours every Wednesday. Additionally, the budget figures account for unplanned downtime related to process, mechanical, electrical, mining, and weather-related issues. These unplanned hours are based on historical data from previous years. Figure 4-5 shows the comparison between survey measurements and plant weightometer as well as planned tonnes.

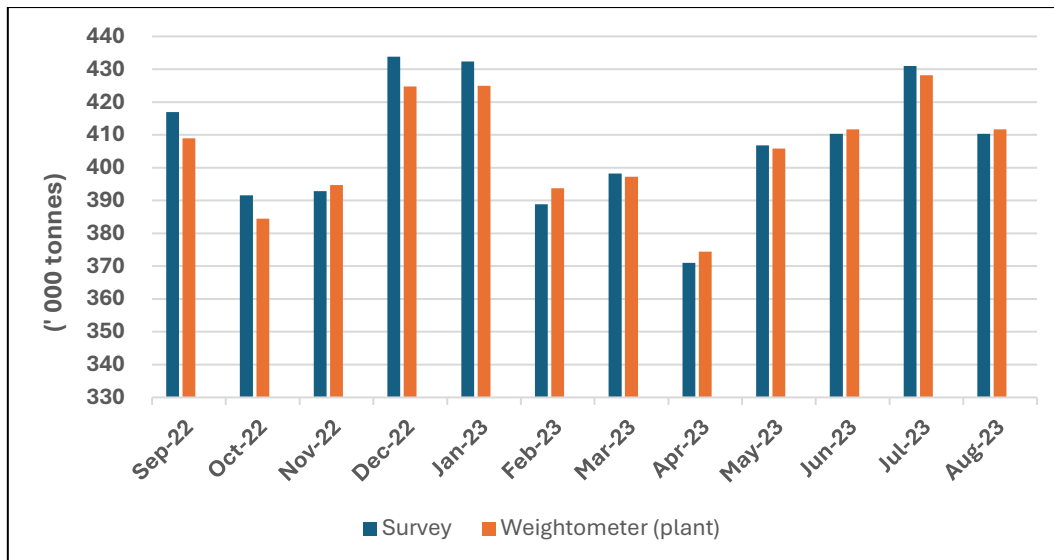


Figure 4-5: The survey measurements versus the plant weightometer

The variance between survey and plant weightometer measurements ranges from -1.3% to 2.1%. A negative percentage variance indicates that survey measurements were below the mineral processing plant weightometer, while a positive percentage indicates that survey measurements were above the weightometer measurements. Survey measurements were taken at stockpiles, while the weightometer measurements were taken at a position beyond the crushers and into the plant. From the stockpiles, the ore is fed into the jaw crusher or mobile crushers using the loaders and discharged into bins. The ore was transferred from the bins using the belt conveyor to the head pulley, where the weightometer was situated just before the plant screens. In between the stockpile and the weightometer, some spillages were encountered. This meant that although the survey measurements were captured on the stockpile, not all of them reached the weightometer due to spillages along the belt conveyor. Since the measurements were taken at two different locations, the survey figures included the oversized ore on the stockpile, which normally got ejected before reaching the weightometer when fed. Consequently, the survey measurements captured any material movement into and from the stockpile, while the weightometer only captured ore that had reached it.

4.2.1 Stockpile and its effect on reconciliation

Mining operations are subjected to many constraints that at times hinder the accessibility of ore at the right time. The constraints are further reinforced when geo-metallurgical characteristics of the ore, along with appropriate ore blending practices, become essential in optimising the performance of the mineral processing plant. This is where stockpiling plays an important role (Rezakhah, *et al.*, 2020).

The following outlines several purposes for stockpiling (Rezakhah, *et al.*, 2020):

- Creating buffer stocks to cater for periods of poor mine production;
- Storing marginal ore that would otherwise be handled as waste;
- Stockpiling of different ore grades to manage head grade; and
- Stockpiling ore with different geo-metallurgical characteristics to achieve a consistent blend feed into the plant.

Numerous reasons have been cited to underscore the significance of maintaining stockpiles, and SMD-Kao Mine has its specific rationale for doing so. The mine is located in the elevated terrain of Lesotho, where heavy summer rainfalls can render the kimberlite rock extremely slippery, hampering access to the open pit and disrupting plant operations. Moreover, winter brings snow, further complicating pit access. These conditions can potentially jeopardise the quality of mineral processing plant feed. To mitigate this risk, SMD-Kao Mine maintains buffer stocks to sustain operations during these challenging periods.

SMD - Kao Mines extracts three distinct kimberlite facies, each with varying grades and geo-metallurgical properties. Through trial mining, it was discovered that the plant operates more effectively when ore is fed in specific ratios. Therefore, one purpose of maintaining stockpiles at SMD-Kao Mine is to manage blending ratios and the geo-metallurgical properties of ore processed in the plant.

SMD - Kao Mine operates a 730 tph plant with three feeding ends: run of mine (ROM), JAW, and new front end (NFE). The plant is consistently fed with a blend of three ore types in specific ratios. The ROM receives pre-crushed ore (LQ, FK, and GK), the JAW processes uncrushed ore (LQ, FK, and GK), and the NFE exclusively handles pre-crushed FK ore.

The company has set specific standards for the minimum and maximum stockpile strategic levels. Each ore facie stockpile should be able to sustain operations for a minimum of 72 hours (equivalent to three days) and a maximum of 120 hours (equivalent to five days). Additionally, the stockpile height should not exceed eight meters per mine standards.

The approach to managing stockpiles should involve turning them over frequently to ensure accuracy of the data. This helps prevent loss of ore blocks and ensures that the data used to create stockpile bar charts is reliable.

Table 4-4 contains the stockpile reconciliation data, which includes information about mined ore, materials fed into the plant, and the stockpile balance at the end of the month. This means

that the closing stockpile balance for one month serves as the opening stockpile balance for the next month.

Table 4-4: Stockpile reconciliation data ('000)

Date	22-Sep	22-Oct	22-Nov	22-Dec	23-Jan	23-Feb	23-Mar	23-Apr	23-May	23-Jun	23-Jul	23-Aug
Mined tonnes (Survey)	389	422	390	419	422	387	387	364	414	419	426	419
Plant Feed (weightometer)	409	385	395	425	425	394	397	374	406	412	428	412
Stockpile balance: end of the month (Surveyed)	20	51	386	24	14	12	5	4	11	21	16	23
Stockpile balance: end of the month (Theoretical)	16	53	48	43	40	33	23	13	20	27	25	32
Stockpile balance (Theoretical)	16	53	48	43	40	33	23	13	20	27	25	32
Difference between Surveyed and theoretical stockpile	-5	1	9	18	26	21	18	9	10	7	9	9
% Discrepancy	-30%	2%	19%	43%	64%	63%	77%	69%	47%	24%	37%	28%

Figure 4-6 shows amount of ore mined from the pit, amount of ore fed into the plant as well as the stockpile at the end of every month. Ideally, adding the amount of ore on the stockpile at the beginning of the month to the amount of mined ore during the month and then subtracting the processed amount of ore should give the closing stockpile balance at the end of the month. However, on average, there were around 10,000 tonnes of ore that could not be accounted for at the end of each month during the period under review.

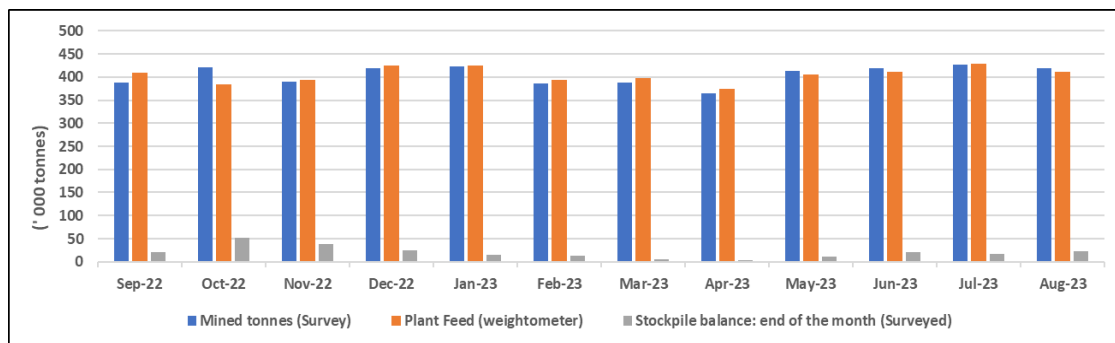


Figure 4-6: Mined tonnes, plant feed and stockpile balance

The major sources of these discrepancies can be attributed to the following:

- There were instances whereby a material mix-up on the stockpiles occurred, resulting in the application of an incorrect density to a specific ore.
- The accuracy of measuring equipment degrades over time. Therefore to improve this accuracy, equipment should be calibrated more often. At SMD-Kao Mine, survey equipment is calibrated once a year during servicing, which an external company typically conducts. This can affect the accuracy of the equipment based on the fact that that equipment is utilised every day, 365 days a year.

- Normally a bulking factor of 30% is applied to every blast when calculating blasted tonnes at SMD - Kao Mine. Ore on stockpiles gets compacted as trucks tram over when they tip. This could significantly impact changes in volume from blasted ore in the pit and the ore on stockpiles. According to Ofoegbu et al. (2008), the stockpile might have a lesser bulking factor due to fewer voids and having been worked on by mining machinery.
- Stockpiles are measured using GNSS which is used by the mine surveyor. Sometimes the whole stockpile area might not be covered especially at stockpile edges due to fear of slipping and falling thus resulting in incorrect stockpile figures.
- SMD kimberlite has internal dilution whereby when such areas are blasted a grade control has to be deployed full-time to direct trucks either to stockpiles or waste dumps physically. During this process, some trucks carrying waste material may be directed onto the dump while the mine survey recorded that as ore tonnes.

Table 4-5 presents the database used for reconciling the stripping ratio, showing the monthly percentage adherence to budget from September 2022 to August 2023. The budget stripping ratio fluctuates between 0.14 and 0.15. This was dictated by the amount of ore tonnes budgeted for each month. For every tonne of ore mined in September 2022, 0.15 tonnes of waste needed to be mined. Percentage compliance shows how much the budget was adhered to.

Table 4-5: The actual stripping ratio and % compliance compared to the planned monthly stripping ratio

Date	22-Sep	22-Oct	22-Nov	22-Dec	23-Jan	23-Feb	23-Mar	23-Apr	23-May	23-Jun	23-Jul	23-Aug
Actual	0.15	0.13	0.02	0.04	0.04	0.09	0.22	0.08	0.21	0.23	0.24	0.27
Planned	0.15	0.14	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14
Percentage compliance	98%	90%	12%	28%	28%	60%	142%	59%	151%	166%	175%	194%

Table 4-5 shows that during the first six months of the period spanning from September 2022 to August 2023, waste mining fell behind. During temporal reconciliation of waste, it was identified that a waste catch-up plan had to be developed for waste mining to be adhered to at the end of the period. This is why from March 2023 to August 2023, compliance with the plan exceeded 100% except in April. While this was a good thing to ensure that the overall plan was adhered to at the end of the period, this strains the monthly cash flow as more money has to be spent in some months than what is budgeted. The waste loading for the financial year was affected by equipment availability (excavators' average availability was 81.9% and articulated dump trucks (ADTs) availability was 64.4% against a target of 85% from November 2022 to February 2023) and delay in procuring explosives leading to blasts being postponed.

At SMD-Kao Mine, three ore facies are loaded and fed into the plant at any time. This means that including waste mining, there are four loaders at any given time. Each time, one of the loaders loading ore was on break-down, the waste loading was suspended because ore was prioritised to keep constant feed going into the plant. The waste catch-up plan meant that for the subsequent months, more waste had to be mined to catch up on budget hence the higher percentage of compliance to budget. The plan included capital re-investment of having to buy more equipment (4 extra ADTs added to run with 25 ADTs from 21 ADTs) which was originally not planned, thus implying a negative effect on the company's cash flow. The contractor also had to ensure that on any given day, the level of explosives stock should not be below a certain level, otherwise, monthly penalties on the contractor would be triggered.

Inability to mine waste as per schedule means that the mine fails to provide future access to mineable ore. The nature of open pit mining is such that as waste stripping is deferred, the whole mining project becomes uneconomically viable. The amount of waste that has to be mined at a later stage, the stripping ratio becomes unnecessarily high as seen in Table 4-5. The production schedule must be adhered to as it deals with the most profitable mining sequence over the entire life of the mine. Anything that compromises the production schedule such as the persistent poor equipment availability should be addressed immediately or as soon as possible.

4.2.2 Dilution and grade – mineral reserve reconciliation

Figure 4-7 shows the expected grade compared to the actual grade from September 2022 to August 2023. Dilution that was achieved each month is also shown.

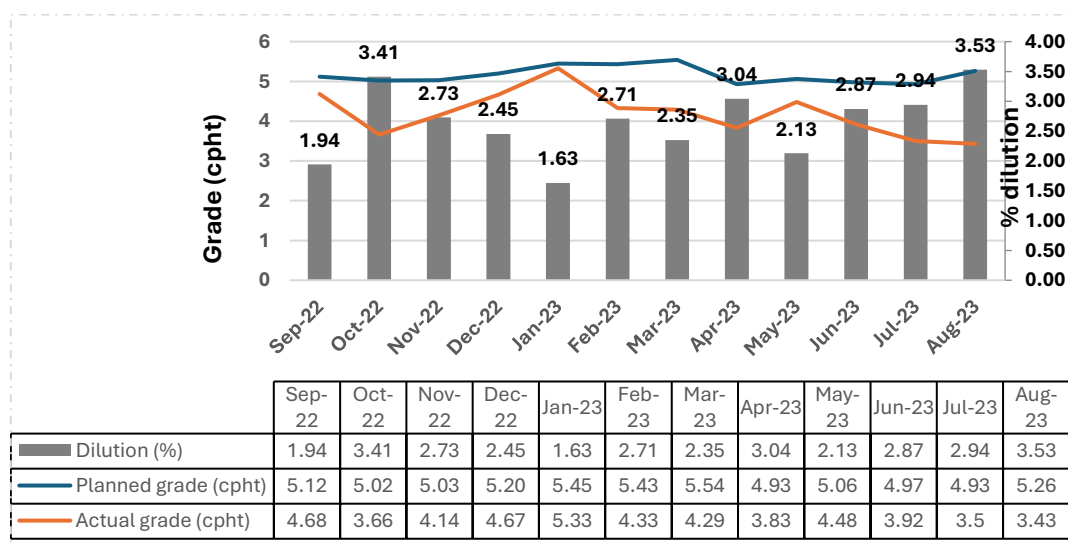


Figure 4-7: Impact of dilution of mineral reserve grade

Figure 4-7 shows that actual ore grades always lag behind expected ore grades during the review period. This indicates that the ore quality did not align with projections. Figure 4-7 It also shows that during periods of high dilution, actual ore grades decreased even further. Dilution reduces the average ore grade and increases mineral processing costs. Although planned grades account for a maximum of 1.5% dilution, actual dilution consistently exceeds 1.5%. Due to limited exploration data, dilution estimates are primarily based on historical experience. Consequently, the potential impact of dilution may be underestimated, potentially leading to inaccuracies in future projections. During the review period, it became evident that dilution at SMD is unavoidable, primarily due to it being internal dilution. Throughout this period, there was no instance in which dilution fell below the planned levels. The closest alignment with the planned dilution occurred in January 2023, when an actual dilution of 1.63% was recorded, compared to the planned dilution of 1.5%. Table 4-6 shows the impact of dilution on revenue, where the planned grade and planned tonnages were used to calculate the expected revenue. This planned revenue was then compared to the actual revenue, which was determined using the actual grade, accounting for the effects of dilution.

Table 4-6: Planned revenue versus actual revenue

	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23
Planned Tonnes ('000)	419	434	412	433	433	389	398	420	427	418	433	427
Planned grade (cpht)	5.12	5.02	5.03	5.2	5.45	5.43	5.54	4.93	5.06	4.97	4.93	5.26
Total Carats	21.45	21.79	20.72	22.52	23.60	21.12	22.05	20.71	21.61	20.77	21.35	22.46
\$ /carat	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00
Revenue (millions)	7,808.82	7,930.40	7,543.39	8,195.82	8,589.85	7,688.66	8,025.91	7,536.98	7,864.66	7,561.95	7,770.27	8,175.51
Actual Grade (cpht)	4.68	3.66	4.14	4.67	5.33	4.33	4.29	3.83	4.48	3.92	3.5	3.43
Total Carats	19.61	15.88	17.06	20.22	23.08	16.84	17.07	16.09	19.13	16.39	15.16	14.65
\$ / carat	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00	364.00
Revenue (millions)	7137.75	5781.92	6208.68	7360.48	8400.72	6131.11	6215.01	5855.30	6963.17	5964.36	5516.42	5331.18
% difference in Rev	9%	27%	18%	10%	2%	20%	23%	22%	11%	21%	29%	35%

The data presented in Table 4-6 quantifies the impact of dilution, demonstrating that, on average, dilution resulted in a 19% reduction in planned revenue over the review period. The smallest discrepancy between planned and actual revenue was recorded in January 2023, coinciding with the lowest dilution levels, as shown in Figure 4-7. Conversely, the highest percentage difference in revenue was 35%, which occurred during the period of highest recorded dilution.

4.3 Spatial mine to plan compliance results

Spatial mine-to-plan reconciliation has been analysed from two key perspectives: area reconciliation and design reconciliation.

4.3.1 Spatial mine to plan – area reconciliation

This spatial mine to plan compliance was done monthly where the planned area was compared with the actual mined-out area. Strings which define boundaries of polygons were drawn to determine areas mined as per the following legends:

- Area mined on plan: This is the area that was planned and was mined according to the plan;
- Area mined out of plan: This represents an area that was mined even though it was not on the plan for that month; and
- Area planned not mined: This represents all the areas that were scheduled to be mined in that month but were not mined.

Table 4-7 shows the spatial reconciliation results, which served as the basis for creating the monthly reconciliation report. This database shows the total planned area for the months, the mined area matching the plan, the area mined beyond the plan, and the area that was planned for mining but not yet mined. Similarly, in this research, the target-setting approach ensured that at least 85% of mining occurred within planned areas. This approach is designed to maintain a correct mining sequence and ensure timely access to mineable ore.

Table 4-7: Spatial reconciliation results

Date	Area Planned	Area Mined on Plan	Area Mined out of Plan	Area Planned Not mined
Sep-22	27 838	12 337	7 966	15 500
Oct-22	46 681	30 874	10 206	15 808
Nov-22	29 602	20 212	10 727	9 389
Dec-22	33 312	20 332	13 523	12 980
Jan-23	24 248	18 576	1 239	5 672
Feb-23	21 079	16 917	524	4 162
Mar-23	31 315	25 783	5 971	5 532
Apr-23	32 438	28 630	6 547	3 808
May-23	28 674	22 140	1 554	6 535
Jun-23	43 977	41 693	5 341	2 284
Jul-23	15 558	13 020	6 451	2 538
Aug-23	22 323	17 853	2 593	4 470
AVG	29 754	22 364	6 053	7 390

Figure 4-8 depicts the monthly spatial reconciliation results. The figure was drawn using data in Table 4-7.

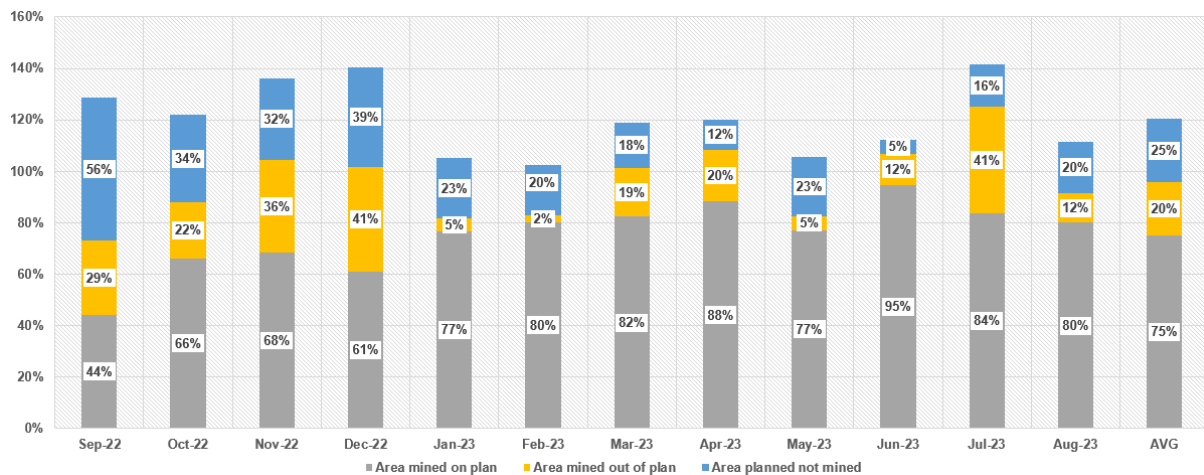


Figure 4-8: Monthly spatial reconciliation results

Figure 4-8 shows that on average, during the period under review; the following results were achieved:

- 75% of mining happened within the planned area;
- 20% represents the area mined out of the plan; and
- 25% of the planned area was not mined. This means there was a shortfall in adhering to the schedule, which could lead to the inability to open access for future ore extraction.

In September 2022, there was a low adherence to the plan, with only 44% of the area being mined according to the plan, while 56% was planned but not mined as shown in Figure 4-8. The main challenge during that month was equipment availability, which averaged 75% for the month, which is 10% below the target (Storm Mountain Diamonds, 2022a). The scheduled blocks could not all be mined as per the plan, as overall drilling was 4% below the target for the month. However, there were days when drilling had to be suspended. This was due to work being done on trenches above the open pit. Rocks rolled down the slope into the open pit, creating a safety concern. Additionally, drilled polygons could not be blasted as scheduled due to the unavailability of explosives on site. Delayed blasts led to the historic stockpile being loaded to keep the plant running, representing 29% of the area mined outside the plan.

Adherence to plan improved during the first quarter of the period under review. In September 2022, the adherence rate was 44%, but it increased to 66% and 68% in October and November respectively, as shown in Figure 4-8. During these two months, equipment availability rose to 81.9%, a 6.9% increase from September 2022 (Storm Mountain Diamonds, 2022b). Despite this improvement, equipment availability remained 3.1% below the target. The percentage of planned but unmined areas was 34% in October 2022 and 32% in

November 2022. These numbers reflect an improvement from the 56% of unmined areas in September 2022.

In October 2022, the percentage of area mined outside the plan decreased from 29% in September to 22%, resulting from a slight improvement in drilling, loading and hauling equipment and explosives availability. This improvement allowed operations to continue without the need to mine from the historic stockpile. However, in November 2022, there was a slight increase in the percentage of area mined outside the plan, rising to 36% from 29% in September 2022. This increase was attributed to the availability of support equipment, which negatively impacted the preparation for scheduled polygons. As a result, these polygons were delayed, leading to mining from the historic stockpile, despite not being part of the original plan.

In December 2022, the mining team successfully mined 61% of the planned area, with 41% of the total area being mined outside of the initial plan and 39% remaining unmined. This represented a decrease from November 2022, when 68% of the total area was successfully mined according to plan. The mining schedule was impacted by heavy rainfall in December 2022 as shown in Figure 4-9.



Figure 4-9: Flooded open pit bottom

Due to flooding of the bottom of the open pit, 41% of the total area planned was mined outside the original plan. The top benches on the northern side of the open pit as shown in Figure 4-10 are composed of mostly weathered kimberlite that allowed for free dig with no blasting. It is worth noting that 41% of the total area planned that was mined outside plan was from these benches.

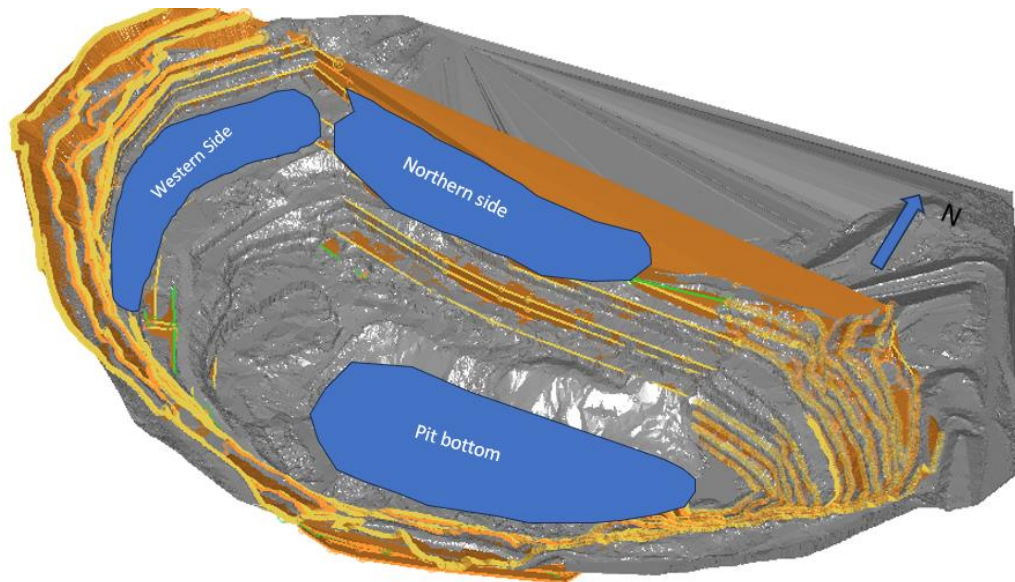


Figure 4-10: Spatial mine-to-plan compliance at SMD

During the period between January 2023 and August 2023, there was a notable increase in adherence to the plan, as demonstrated in Figure 4-8. The adherence to plan was influenced by two main factors. Firstly, the activation of contractual penalties played a role. At SMD-Kao Mine, the load and haul contractor is responsible for procuring explosives, and there is a predetermined minimum target for explosives, below which penalties are enforced. Secondly, the construction of a dam, shown in Figure 4-11, facilitated easy dewatering of the open pit. Water was pumped into this facility whereby flocculant was applied to clear turbidity, before being released into the river.



Figure 4-11: Flocculant dam

The Department of Water Affairs and Environment has set legal limits for both turbidity and nitrates in the water that the mine pumps and releases. The mine uses flocculant to improve the clarity of the water and reduce turbidity before releasing it into a river. The water is released into the river downstream once the turbidity is below the legal limit. To ensure that the nitrates level is below the legal limit, SMD - Kao Mine has installed a clean water pipeline connecting to the flocculant dam discharge. This pipeline dilutes water from the flocculant dam before releasing it into the river.

4.3.2 Mine to design reconciliation

The recommended slope design for kimberlite rock at SMD - Kao Mine is as follows:

- Bench stack height of 72 m, with 6 x 12 m benches per stack; and
- A bench width of 12 m.

Figure 4-12 shows the design configuration.

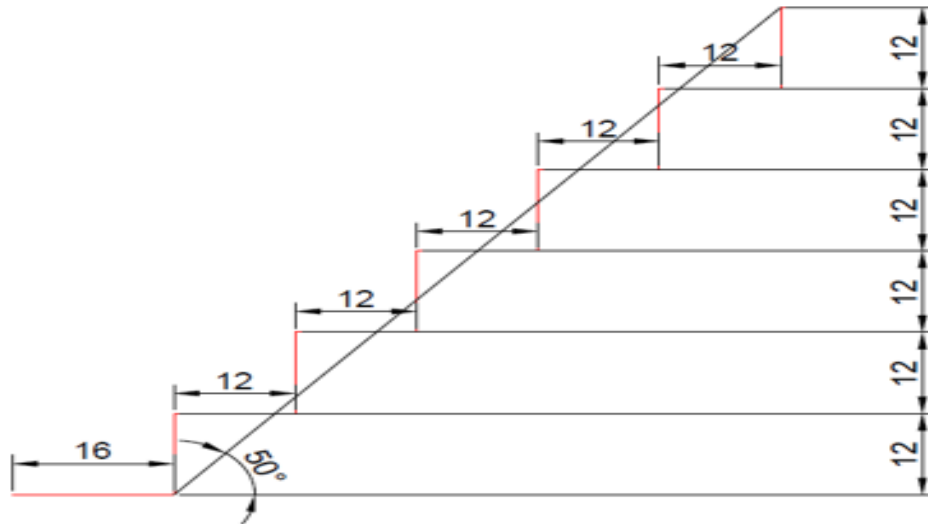


Figure 4-12: SMD recommended interim slope geometry for the kimberlite rock

The design configuration that is shown in Figure 4-12 results in a 50° toe to crest (TTC) inter-ramp angle. The recommended inter-ramp design for basalt rock at SMD - Kao Mine is as follows:

- Bench stack height of 72 m with 3 x 24 m benches per stack; and
- A berm width of 12 m.

Figure 4-13 shows the design configuration for basalt rock final wall.

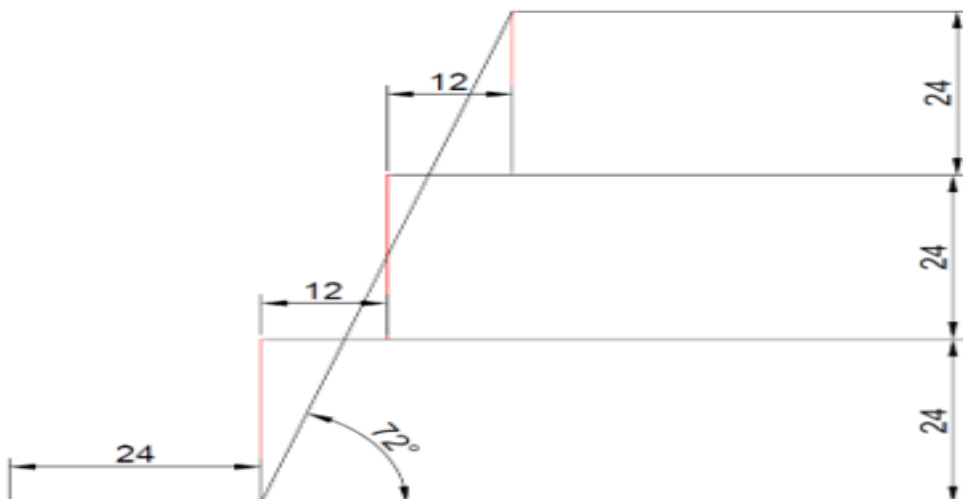


Figure 4-13: SMD recommended interim slope geometry for the basalt rock

The design represented in Figure 4-13 results in a 72° toe to crest (TTC) inter-ramp angle. As part of the mine's slope failure management, various cross sections of the pit are taken and compared to the actual design. Best practice is to do this immediately after a bench has been mined out. This makes it easier to correct any areas that were not mined properly while still on the same level. Climbing back and correcting multiple highwalls and benches once they're mined out is very difficult and expensive. To do so, an abseiling exercise is usually required. At the end of each week, a survey is conducted to update the status of the pit. This update reflects areas that were mined out and those that are still to be mined. The data collected using GNSS or drones is processed using Model Maker software to generate the latest pit faces. This update is then integrated into Studio OP, along with the pit design, to produce the final results. The results are shown in Figure 4-14. Figure 4-14 shows the southwest pit cross-section. The red line indicates the design faces while the yellow line indicates the actual faces.

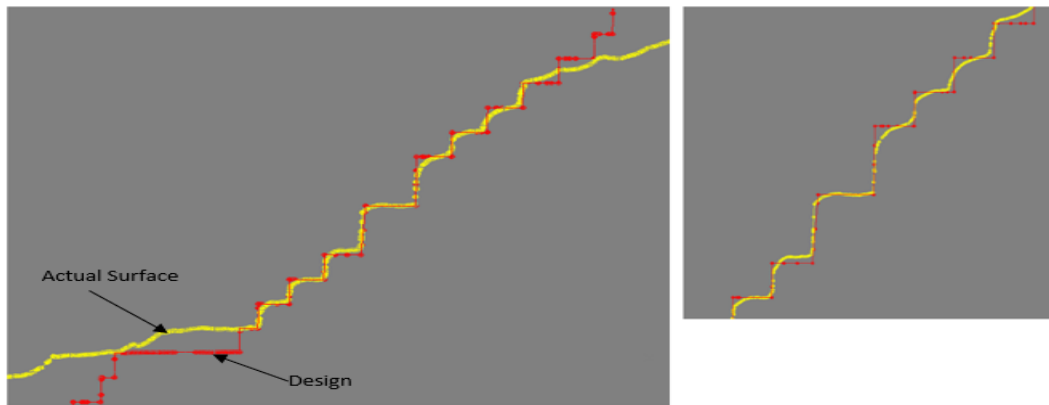


Figure 4-14: Southwest pit cross-section

Figure 4-14 shows that the bench was excessively mined due to the presence of weathered material. Whenever there was a delay in blasting, the production team would resort to free-digging this area to maintain the plant feed. As mining progressed, many bench crests were lost from one bench to another. The loss in crests is due to the presence of geological planes. As the blasting process continues towards the final wall, high wall failures occur along these planes. Moreover, the excessive vibration during blasting weakens these planes, making them fall on their own with time (Adiyansyah *et al.*, 2023). Figure 4-15 shows an example of highwall crest failure. The red line shows the original boundary of failed material.



Figure 4-15: An example of high wall crest failure

Mine-to-design reconciliation in this report was done to ensure that mining follows safety standards. This is normally achieved by controlled drilling and blasting of final walls. At SMD - Kao Mine this process involves pre-split blasting on the final pit limit. Blocks are divided into production blocks and trim blocks. Trim blocks are blast polygons found between the high wall and production blocks. To minimise explosive energy to the high wall, the trim blocks are limited to a width of only 20 metres. The sequence of blasting begins with pre-splits, followed by the production holes and finally the trim holes. While production blocks can be at least 20 m in width, the width of trim blocks is limited to 20 m. Figure 4-16 shows the cross-section of the pit and the design in the south. The red line indicates the design faces while the yellow line indicates the actual faces.

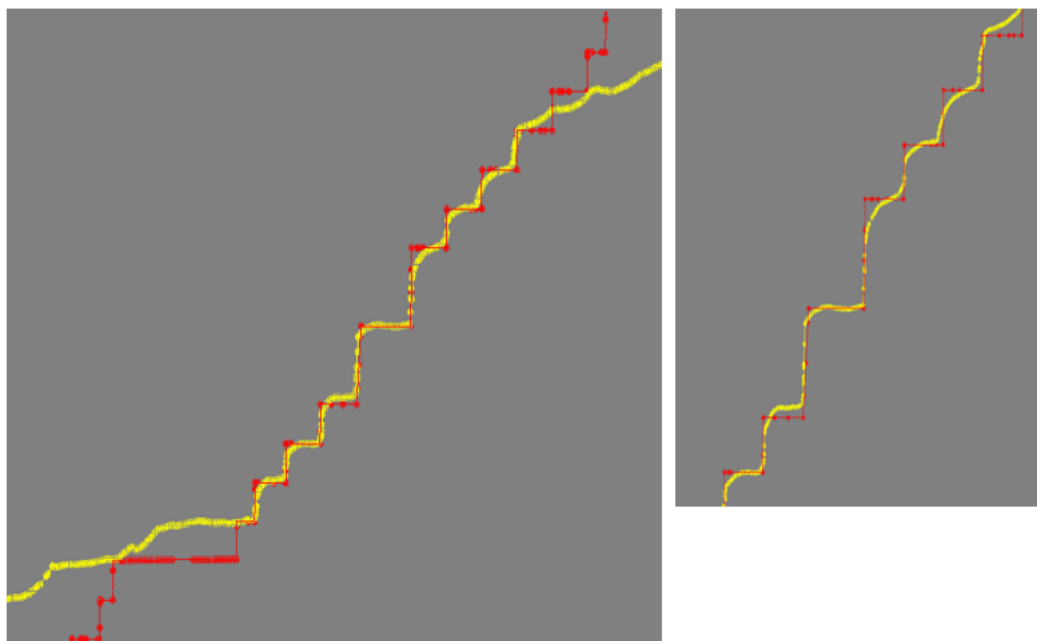


Figure 4-16: South pit cross-section

It can be seen from Figure 4-16, that the first four benches did not adhere to design. After evaluating the bench faces, it was concluded that there were back breaks on crests. A thorough analysis was carried out and it was found that the back breaks were caused by the charging and blasting of pre-split holes using emulsion instead of megamite cartridges.

It was only when the fifth bench was being mined that megamite cartridges were used instead of emulsion. As illustrated in Figure 4-16 there were still some overbreaks on crests but they were significantly lower than those on the first few benches. Additionally, the overbreak on the crests was also found to be influenced by the presence of joints in the rock. Factors such as joint orientation, joint spacing, clay fillings and alterations, rock strength, and ground stress effects all play a significant role in determining the extent of overbreaks and underbreaks during blasting (Ibarra *et al.*, 1996). In the case of geometry and catchment capacity evaluation, it is not practical and not economically viable to design benches that can retain spillages from all potential failures from benches above. However, a target set for the failed volume is usually between 75% to 85% of the potential volume that is anticipated to fail (Read & Stacey, 2010). The toes can be attributed to various factors such as the inability to drill blast holes to the correct depth as staked by surveyors. However, the implementation of improved quality controls, such as measuring holes immediately after drilling, can help minimize the toes.

Despite the implementation of final wall control blasting practices, the intended outcome is not always achieved, resulting in potentially hazardous high walls. The pre-split creates a plane of weakness, and if the trim block is not blasted to its final limit, the remaining material on the high wall may fall unexpectedly with a trigger of any kind. Figure 4-17 shows the eastern pit cross-section. The red line indicates the design faces while the yellow line indicates the actual faces.

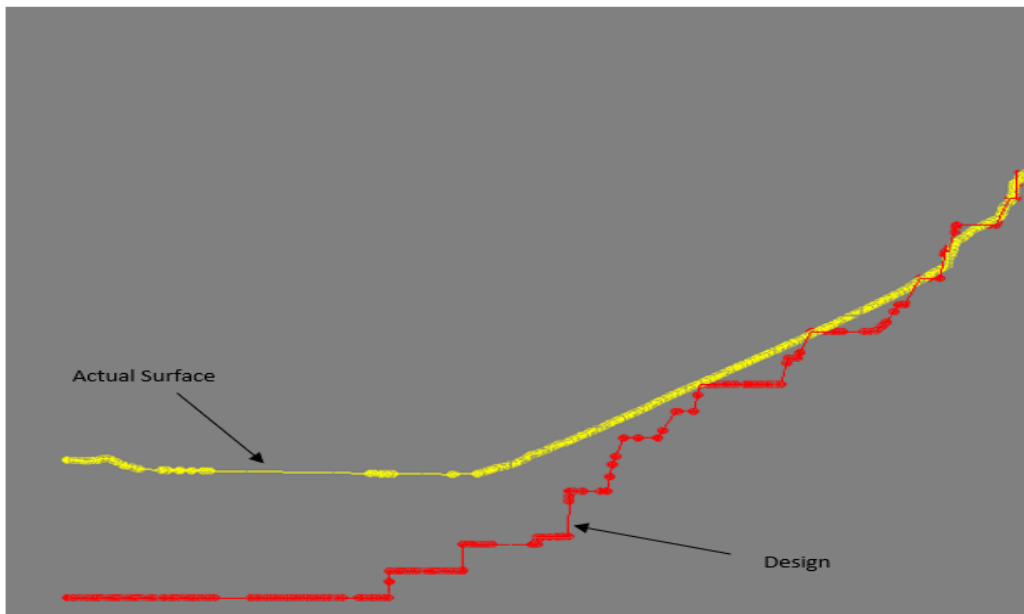


Figure 4-17: The eastern pit cross section

Although this eastern pit cross-section appears not to have been mined to the final design limit, this is due to the overspill of material resulting from mining the upper benches of Cut 5. Figure 4-18 shows the cross-section of the northern side of the open pit.

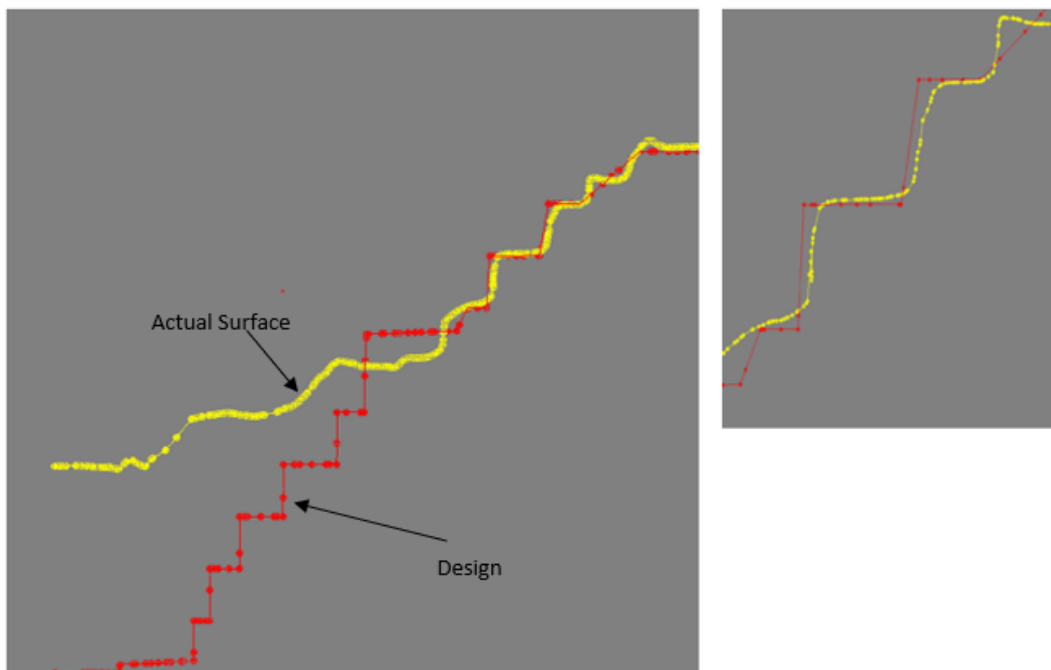


Figure 4-18: The north cross-section

Despite the northern area being previously mined, the design of Cut 4 had to be adjusted as a temporary ramp was added on this side. This was necessary because the permanent ramp was obstructed by spillages that occurred during the mining of Cut 5. As a result, an alternative entry point to the pit was required.

The bench face condition shown in Figure 4-18 reveal that most of the benches were mined beyond the design limit. This area of the open pit is composed of mostly weathered rocks of which achieving final control is a challenge. The face conditions and blast performance evaluation focus on the percentage of half barrels exposed to those that are not exposed as shown in Figure 4-19.



Figure 4-19: Exposed pre-split barrels from the high wall

(Source: Storm Mountain Diamonds, 2023a)

Figure 4-19 shows exposed pre-split barrels from the high wall. The percentage of pre-split accuracy at SMD Mine is expected to be at least 75%. Using the half-cast factor method, the lengths of all exposed barrels were measured and compared to the total length of pre-split holes that were designed. The half-cast factor is expressed as the ratio of planned pre-split lengths to the achieved pre-split lengths. Figure 4-20 shows the plan view of the pit, with all the benches across the different sections of the pit.

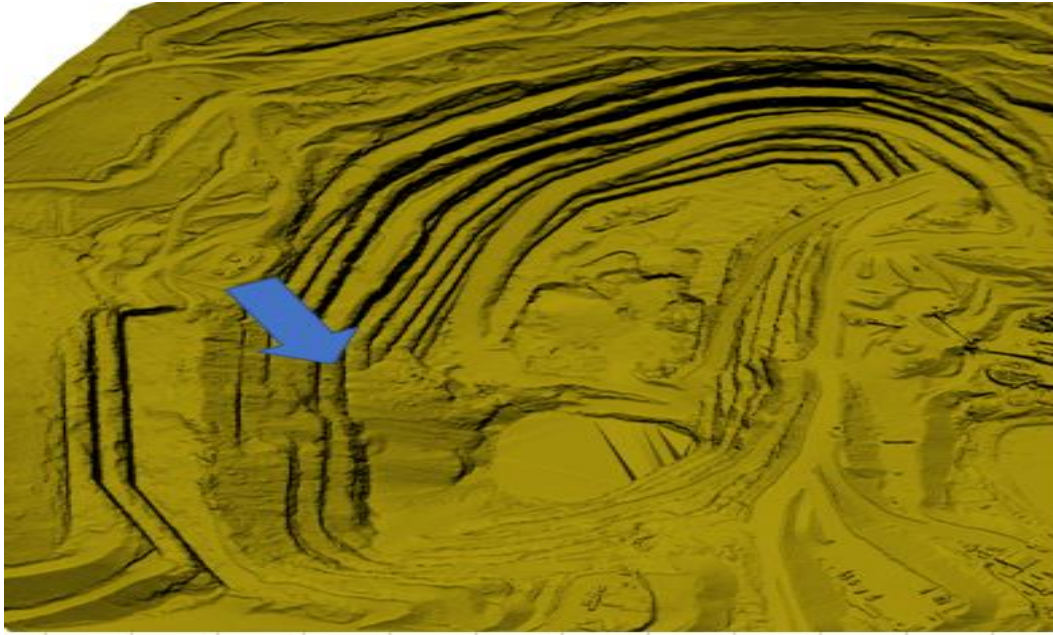


Figure 4-20: A plan view of actual mined-out areas for the whole pit

(Source: Storm Mountain Diamonds, 2023a)

Due to mining of Cut 5, some spillage from the blast could not be trapped by the catchment bench width. The risk assessment was carried out in that area, and it was decided that the work areas below should be halted, and this was included in the mine open pit hazard plan. Depending on the rock mass classification and the geotechnical model, it may be possible to make some areas steeper with a minimal catchment bench width, while other areas may need to be made shallower with a bigger catchment bench width. The minimal catchment berm width is defined in Equation 5 (Ryan & Pryor, 2000):

$$\text{Bench width(m)} = 0.2 * \text{Bench height} + 4.5 \text{ m} \quad \text{Equation 5}$$

This means that at SMD - Kao Mine the catchment bench width, for 12 m, and high benches should not under any circumstance be below 7 m. To carry out the reconciliation process in this research, monthly survey data was imported into GEM4D software along with Cut 4 design to compare the design with actuals that are achieved. Figure 4-21 shows the state of the open pit with each colour scale representing up to a 2.5 m distance between the actual open pit as mined and the Cut 4 design. The scale used ranged from -5.00 m to 5.00 m, with -5.00 m (red) representing the under-breaks while the 5.00 m (dark blue) represent the over-breaks.

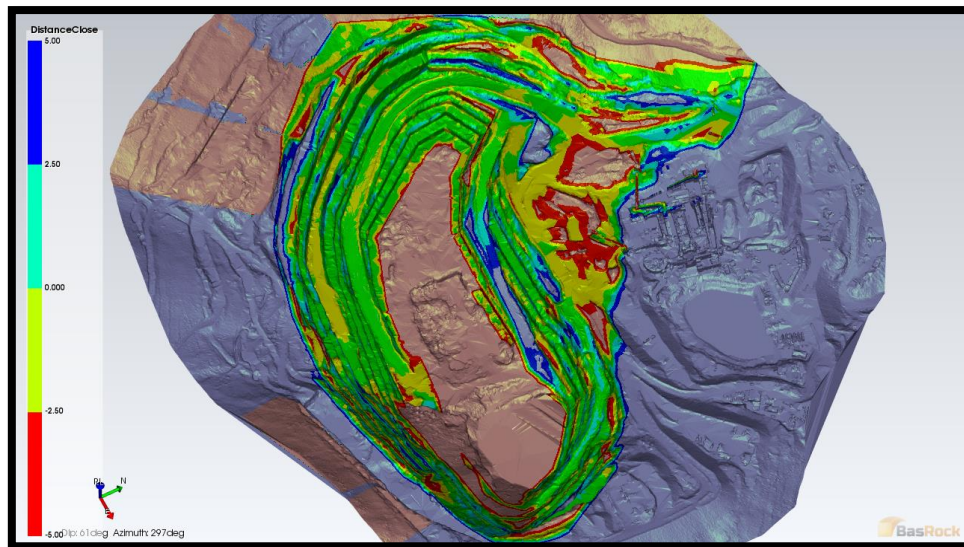


Figure 4-21: SMD pit update indicating mine to design compliance
(Source: Storm Mountain Diamonds, 2023b)

The purpose of comparing the actual pit-as-mined with the design as mining progresses is to analyse visually where adherence to design has been compromised. This helps identify areas where improvements can be made. Mining is inherently risky, and some risks can be eliminated immediately after being identified, while others require more time. Frequent mine design compliance checks also help identify these risk areas.

Figure 4-22 highlights certain areas of concern found during the analysis. These areas have been mined beyond their intended limit or design.

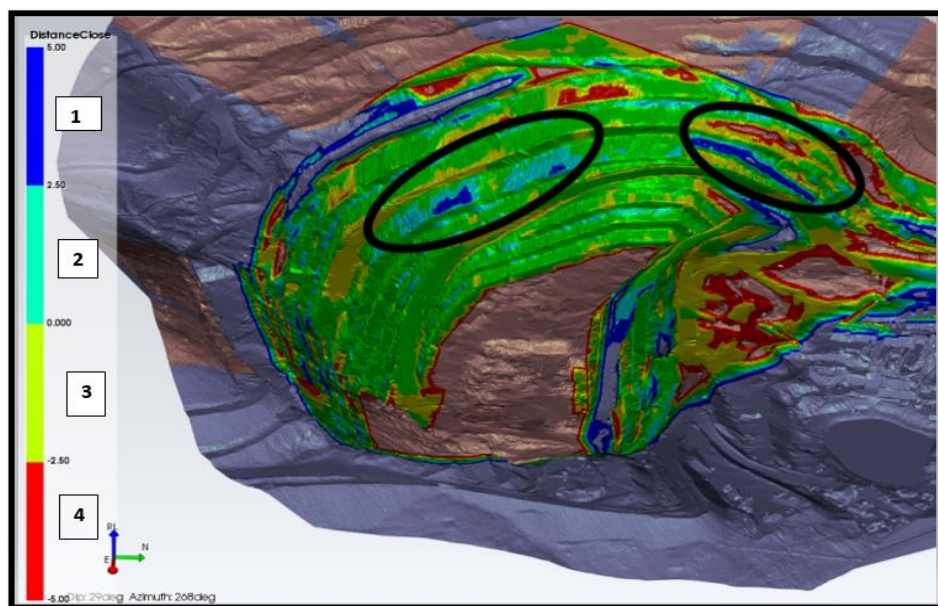


Figure 4-22: Overbreak on the highwalls beyond the pit limit
(Source: Storm Mountain Diamonds, 2023b)

Over-breaks as highlighted in Figure 4-22 are classified into two categories. The first category represented by colour 1 (blue) is overbreaks measuring up to 5 m. The second category represented by colour 2 is overbreaks measuring up to 2.5 m from the highwall. Due to the over-break, this means that in some areas up to 2.5 m of bench catchment capacity has been lost while in other areas, up to 5.0 m of bench catchment capacity has been lost. The idea is to design each bench capable of retaining 85% of falling rocks while the rest of the remaining 15% is retained by the subsequent benches below. The consequence of overbreaks is that if up to 2.5 m and 5.0 m bench catchment capacity has been lost means that the immediate benches would no longer be able to retain 85% of the material should there be any failure. These areas are constantly monitored by movement and surveying radar and highlighted in the monthly hazard plan to warn people of the compromised design and associated risks. Despite efforts to control the final wall, geological structures such as joint sets that dip into the face of the highwall cause slabbing and over-break beyond the pit design.

On the other hand, under-breaking occurs in some areas. Likewise, under-breaks are categorised into two. The first category represented by colour 3 is under-breaks measuring up to 2.5 m. The second category represented by colour 4 is under-breaks measuring up to 5 m from the highwall. Figure 4-23 shows colours three and four, which represent under-break of up to 2.5 m and 5.0 m respectively.

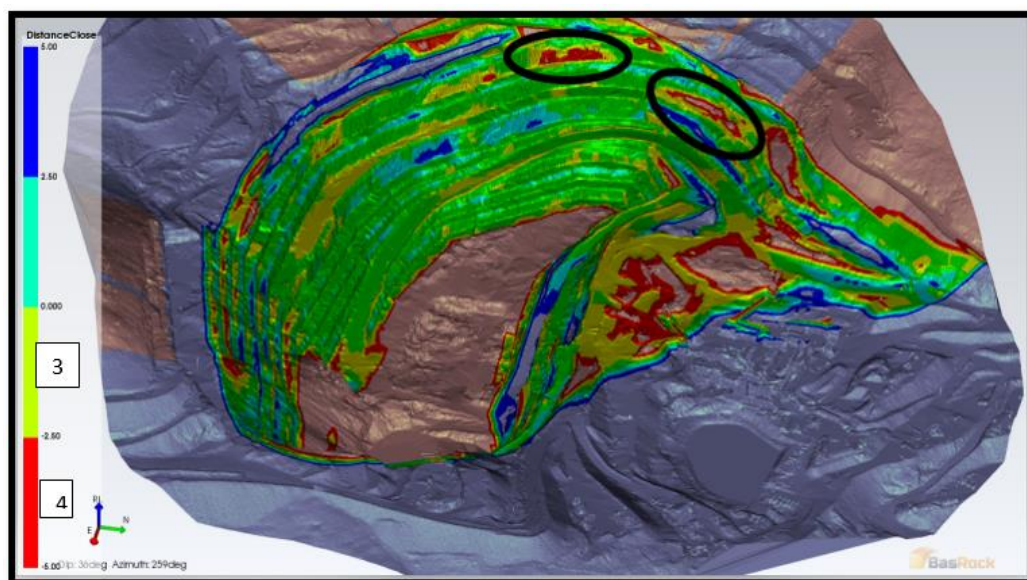


Figure 4-23: Under-break on the highwalls

(Source: Storm Mountain Diamonds, 2023b)

Under-break represents frozen toes and areas which resulted from incorrect blasting practices. This can be a result of drilling shorter holes compared to the planned drill depth. Also, under-breaking happens if the burden and spacing are too wide such that there is

minimal or no interaction between holes during blasting. The idea of carrying out the mine to design compliance is to be able to identify these areas. Frozen toes should be removed either by blasting or through mechanical braking. The inability to identify and correct under-breaks restricts the effective bench catchment capacity. This is because the frozen toes act as the plane on which falling rocks fall and propel off. The falling rocks as they propel off the frozen toes, are provided with an added momentum to potentially cause further harm.

Figure 4-24 shows the damaged crests throughout the pit. Pre-split holes are drilled at 90°, vertical to the horizontal floor.

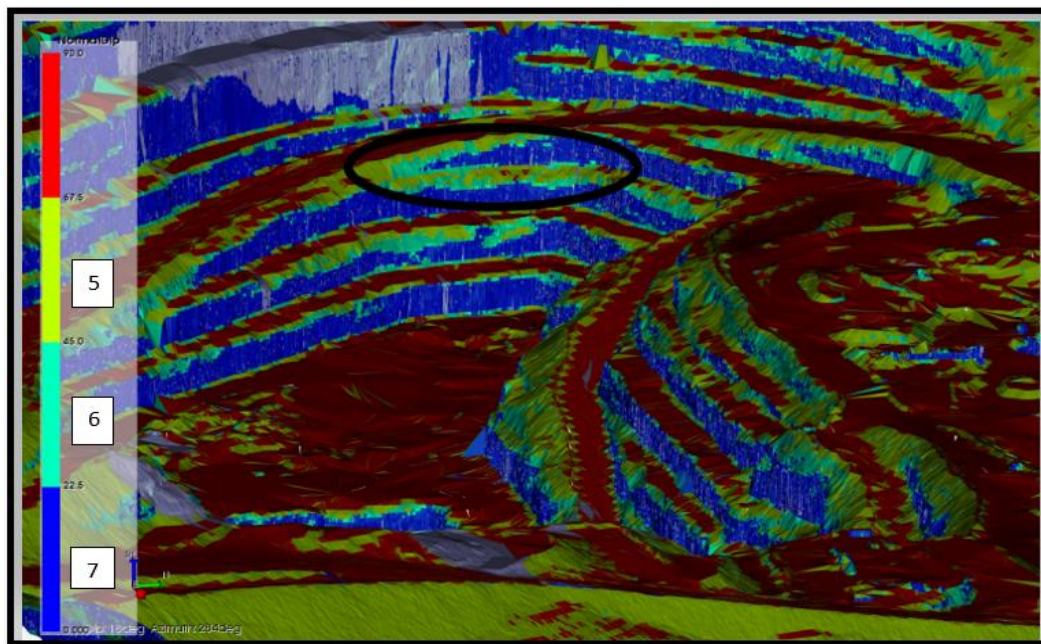


Figure 4-24: Damaged crests

(Source: Storm Mountain Diamonds, 2023b)

From Figure 4-24, there is a notable presence of colours five and six, indicating areas where crests have been lost. Colour seven delineates the vertical highwalls from which pre-split holes were drilled. The loss of crests means that the effective bench catchment capacity has been compromised. The continued loss of crests on all subsequent benches poses economic and safety risks. As more and more crests are being lost especially on all subsequent benches, the design of bottom benches must be changed. The bench catchment must be made larger to accommodate all rocks that are likely to fall from upper benches. Due to these design changes, the inter-ramp angle will become too shallow. This reduction in slope angle often has negative economic consequences (Pothitos & Li, 2007).

4.4 Chapter Summary

This chapter presented the results, analysis, and findings from both the temporal and spatial reconciliation processes. Temporal reconciliation examined the variance between expected and actual tonnages over 12 months. The analysis highlighted discrepancies among different data sources, which included survey, tally records, and the fleet management system. Spatial reconciliation encompassed both area reconciliation and mine-to-design reconciliation, evaluating deviations from planned mining activities. Additionally, the chapter explored the extent and causes of these deviations, offering insights into their impact on overall mining efficiency.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

Reconciliation along the mine value chain is an important process in mining operations. Several reconciliation performance indicators are employed in the mining industry. Two such compliance measure methods are temporal reconciliation and spatial reconciliation. Temporal reconciliation is a time-based compliance metric that measures tonnes moved over a certain period. The primary objective is to monitor a mining operation's performance and correct any deviations. Spatial mine to plan reconciliation attaches location and time to the plan. It ensures that mining activities happen at scheduled places and at the right time. This is to ensure future access to sustainable ore. This form of reconciliation is still new at SMD-Kao Mine. However, for the period under review, there has been a gradual improvement in terms of adherence to plans as the percentage execution of plans rose from 44% to 75% at the beginning and ending of 2022/2023 financial year, respectively. Also, there has been a 56% to 25% gradual decrease in areas planned and not mined noncompliance. The area mined out of planned noncompliance also decreased from 29% to 20% over the review period.

There are numerous reasons why stockpiles are kept by mining operations. One of the reasons SMD-Kao Mine keeps stockpiles is to ensure that there is a correct blend of material sent to the processing plant. Furthermore, material-to-material interaction is also needed for liberation purposes. To ensure that the purpose of stockpiling is adhered to, SMD-Kao Mine has a certain strategic stockpile level that should always be maintained. Hence the need to constantly reconcile the actual levels with the required level.

Mine to design reconciliation in this research focused on mining to the pit limit or the final wall. This reconciliation method was achieved by evaluating bench face conditions and the geometry of catchment berms. The inability to track and reconcile the actual mining to the design can result in the inherent introduction of risk due to mining activities. This type of reconciliation is important because it is used to continuously evaluate the status of the catchment berms should there be failure. It is also an important tool to inform if the design of subsequent benches should change or not be based on what has been achieved on upper benches.

5.2. Summary of Chapters

This report consists of five chapters. Chapter 1 covers the research background. The Government of Lesotho together with Namakwa Diamonds formed SMD, with 25% and 75% share splitting, respectively. SMD - Kao Mine is located in northern Lesotho in the Upper Karoo Super Group. The mine was operated for 60 years by artisanal miners before the official discovery of the main diamond pipe in 1955. SMD - Kao Mine's main pipe is a primary diamond deposit with a near-vertical cylindrical-shaped pipe. The mine also has a satellite pipe which has not been mined to date. Furthermore, Chapter 1 also outlined the problem statement, justification of the research and the significance of the research. The chapter also provided the aim and objectives of the research. The objectives include among others the identification of key opportunities with the view of improving SMD - Kao Mine. The continuous integration of variations into the mineral resource model and mine plans makes them more realistic and practical.

Chapter 2 is the literature review. This chapter introduced the need for reconciliation and benefits as discussed by several authors. The bottom line is that reconciliation seeks to bridge the gap that exists between two like measures that are taken at different times along the mine value chain. Further, the chapter discusses different reconciliation models which are spatial, and temporal. The benefits of these reconciliation models are also highlighted. Chapter 2 also highlighted the type of data required for each reconciliation model to be done in practice.

Chapter 3 describes the research methods used in the research. This chapter discussed the research design, data collection processes, data validation as well as data analysis approaches used in the research report. The research design discussed the objectives of the research report, the data sources as well as the equipment used during data collection. Data sources are also highlighted for each research reconciliation area.

The temporal reconciliation process compares budget tonnes to actual mined-out tonnes over a certain period. It is a time-based reconciliation. Spatial reconciliation is an area-based reconciliation. It compares the actual mined-out areas with the planned and unplanned areas. The chapter also discussed dilution reconciliation, where dilution content in ore is continuously monitored against dilution catered for in the budget.

Chapter 3 also covers the data for the study. Most of the data was collected over 12 months from September 2022 to August 2023. This is normally data that is made available every day or at the end of every month. However, some data is only made available once in a while such as mine to design limit data. This kind of data is only made available when mining takes place towards the pit limit, which may sometimes be after a few months. That type of data was only

collected when it became available as mining activities progressed. SMD experiences four seasons of the year. Winter is extremely cold with snowfall and heavy rainfalls are normally experienced in summer.

Chapter 4 analyses findings from the temporal and spatial reconciliation models discussed. Temporal reconciliation is a time-based reconciliation model whereby planned tonnes are reconciled with actual tonnes over 12 months. The second reconciliation model discussed in this chapter is spatial reconciliation. This is an area-based reconciliation. This is whereby an area planned to be mined over a certain period gets compared with the actual area mined at the end of that period. Mine-to-design is another reconciliation model that is covered in Chapter 4. This is driven by the company's duty of care to ensure that the extraction of mineral resources is done responsibly and safely. This is where mining is done to the pit limit whereby competent solid rock is exposed to prevent future possible highwall failures.

Chapter 5 presents conclusions and recommendations of the study. It starts by summarising preceding chapters and combining key insights and findings. The chapter also includes a discussion of research observations, encompassing the initial and complementary studies and their significant outcomes. Furthermore, the contributions of this research to the mining industry are outlined. Lastly, recommendations are provided.

5.3. Research Observations

This section of the research project covers what has been observed throughout the research project. This includes the initial and complementary studies to the research and the key findings thereof.

5.3.1 Initial and complimentary studies

Every mining company's objective is to maximise shareholders' value. To achieve this, KPIs are put in place to ensure that every daily activity of the company is driven towards achieving that objective. Reconciliation plays a huge role in setting and refining these KPIs. One such KPI is spatial mine-to-plan reconciliation. Spatial mine-to-plan reconciliation ensures that mining activities take place at the right scheduled places at the right time. This ensures that future access to sustainable ore is maintained throughout the LoM. In a case study carried out by Musingwini and Otto (2019), the implementation of spatial mine-to-plan reconciliation resulted in improved compliance from 69% to 94% over three years. This shows that when metrics are put in place for the team to be measured against, the teams' focus, approach and discipline change for the better. Again, the creation of optimal plans aided by advances in

mine planning software also seems to have added value to production schedules (Dimitrakopoulos, 2011).

The implementation of the reconciliation system at Diavik Mine pin-pointed the lack of communication among different departments within the company (Morley & Thompson, 2006). To optimise ore utilisation and improve profitability of a mining company, communication among key stakeholders is of paramount importance. This is a fundamental approach by mineral resource management of business improvement along the mining value chain.

Reconciliation is viewed as a quality test approach to detect and correct errors along the mining value chain (Chierigati *et al.*, 2019). The ability to detect and correct errors proactively can assist in producing reliable production schedules and LoM plans. Reliable mine plans result in high performance, create value and can also present opportunities for both existing and new projects. The value created out of high performance is a result of an optimised and reliable mine plan, and normally one that aligns with the strategic intent of the operation.

The implementation of a reconciliation system in the mining industry assists in tracking down variance to understand opportunities. This is because whether the outcome of reconciliation is negative or positive it allows management to make informed and timely decisions (Hargreaves & Morley, 2014). During the reconciliation process, an increase in variation normally highlights a problem while a decrease shows an improvement. However, the data and variables that are used in reconciliation whether bad or good form a basis for ongoing monitoring.

5.3.2 `Conclusions and key findings

It can be concluded that the spatial performance of SMD-Kao Mine during the review period was suboptimal, with only 75% of mining occurring within planned areas. Furthermore, mine-to-design reconciliation indicates deviations from the intended design, as demonstrated by over- and under-breakages along the final wall, reaching up to 5 meters beyond the design limit. Additionally, a discrepancy of approximately 8% between tally and survey measurements suggests inefficiencies in temporal performance. However, the comparison between survey measurements and plant weightometer readings demonstrated better alignment, with a discrepancy of only around 1%. The temporal and spatial underperformance can be attributed to the findings discussed in the next subsections, respectively.

Temporal reconciliation

It was observed that sometimes with delays from blasting and demand from the mineral processing plant, temporary ramps built with blasted ore were mined out and backfilled with tailings. This presented a challenge for a month-end survey to confirm all mined areas as the comparison between the beginning of the month scan and the end of the month scan reflected minimal to no changes in mining, in those areas. Missing out on backfilled areas became more noticeable especially when multiple benches were mined concurrently. Before any temporary ramps were mined out and backfilled, the survey team and production team had to meet to review and agree on the mining process. At the end of each month, the mined-out and backfilled areas are then identified to ensure accurate documentation. This process is implemented to prevent any mined areas from being overlooked during the month-end survey.

It was also observed that during the period under review, the discrepancy between dispatch and survey from the pit to stockpiles was around 8%, whereas the difference between survey and dispatch from the stockpiles to the plant was significantly lower at approximately 0.8%. This variation was influenced by material fragmentation, which improves as ore is trucked from the pit and tipped onto the stockpiles due to material-to-material attrition within the truck bucket and during tipping. Enhanced fragmentation, in turn, increases the bucket fill factor, contributing to better loading efficiency. To minimise discrepancies between survey data and dispatch records, efforts were directed towards improving blast fragmentation, while operators received coaching on optimising truck loading to ensure optimal capacity utilisation.

Additionally, it was found that moisture content of ore varied between seasons, impacting both tonnage reconciliation and operational efficiency. At SMD—Kao Mine, a fixed 6% moisture factor is applied year-round to account for these fluctuations. While the weightometer adapts for 6% moisture content, retention time differs across seasons, leading to significant changes in actual tonnage being accounted for. Ignoring seasonal moisture variations can lead to significant operational inefficiencies and financial miscalculations. Moisture content does not only affect tonnage reconciliations but also has a direct effect on loading and hauling costs as more water is moved along with ore.

It was also found that inadequate tracking of material movement resulted in misclassification, ultimately leading to incorrect application of density. To mitigate these issues, grade controllers were strategically placed at loading zones, and mining in high-dilution areas had to be restricted to daytime operations to enhance oversight and quality control. Regular density updates across different mineralisation styles and weathering domains are essential to

maintaining accuracy. However, blasting-induced ore displacement often results in misclassification and incorrect density application, further worsened by unupdated orebody contacts and poorly defined ore boundaries. Additionally, historical data gaps and blast effects, such as heave and throw, introduce further complexities in the accurate application of density measurements.

Furthermore, during the review period, it was found that grade controllers were positioned at loading zones to physically direct trucks to either waste dumps or stockpiles. This approach is prone to errors such as misclassification of waste as ore or vice versa. At the end of every month, surveyors also use discretion to determine the amount of internal dilution in a block and apply densities accordingly. Internal dilution may sometimes be more than originally modelled. The mining of areas requiring selective loading may occasionally coincide with periods when grade controllers are absent. Their absence during lunch breaks and the lack of grade controllers during night shifts increase the risk of dilution and material misclassification. This means there might also be material misclassification. Inaccurate assessment of internal dilution can lead to an overestimation of recoverable ore, which may result in processing inefficiencies downstream. Conversely, an excessive estimation of internal dilution might classify too much material as waste, ultimately reducing overall recovery rates.

Poor geological and structural knowledge of the orebody is also one of the research findings. Sometimes geological structures are first identified during mining. In such instances, structures are normally mapped and re-modelled back into the mineral resource model. However, the size and shape of these structures can only be estimated. Sometimes these structures are exposed after they have already been mined out with nothing to re-model back into the resource model. Limited knowledge of the orebody is a challenge experienced across the mining industry. It decreases confidence in mineral resources, increases operational risks, and can result in higher production costs.

The research also found that stockpiles that are not emptied regularly result in accounting errors that affect reconciliation. The errors are a result of ore accumulating and mixing up with new material being tipped. Over time, inaccuracies in stockpile records accumulate as additional ore is added or removed without regular equipment recalibration. Emptying them regularly minimises these errors.

Spatial reconciliation

It was found that during September 2022, adherence to the mine plan was notably lowest, with compliance at 44%. This deviation was primarily attributed to low equipment availability,

which averaged 75%, well below the required contractual target of 85%. As a result, drilling delays occurred, leading to a subsequent delay in the blasting of planned mining blocks. These delays had a cascading effect on the overall mine schedule, further disrupting operational targets and efficiency.

It was also found that weather conditions contributed to the mine's inability to spatially comply with mine plans. The mine experienced heavy rainfall, which often led to flooding in mining areas, rendering them inaccessible for several days. This caused additional setbacks, as access to key mining areas was temporarily obstructed, further worsening the delays and hindrances to production. Consequently, mining had to be redirected to unscheduled areas.

Additionally, the research found that the ore body at SMD also presented considerable geotechnical challenges, as it is heavily jointed. The extensive jointing compromises the integrity of the final pit wall, leading to overbreaks during mining operations. Additionally, the incorrect use of explosives, particularly the application of emulsion to blast pre-splits rather than the more appropriate megamite cartridges, was another contributing factor to the deviations from the design of top benches.

Furthermore, it was observed that most of catchment benches showed frozen toes, which significantly undermined their ability to effectively contain and retain failed material. This issue was caused by poor drilling and blasting practices, which led to suboptimal wall conditions. As a result, the integrity of the catchment benches was compromised, posing safety risks and weakening the overall stability of the pit structure.

5.4. Research Contributions

The research project contributes to knowledge as a future reference based on practical applications at SMD. The research project represents applied knowledge that can potentially be applied in other open-pit mining operations to create value. The key areas of the research report that contribute to knowledge are:

- Temporal reconciliation: If applied, this ensures that the quality and content budgeted for, by mines are always achieved. Temporal reconciliation ensures that there are minimal ore losses along the mine value chain.
- Spatial reconciliation: If applied and followed can significantly improve the NPV of mining operations and prevent pre-mature closure of mines. Its primary objective is to ensure future access to mineable ore.

- Mine-to-design reconciliation: Applying mine-to-design in other mines will ensure that mineral resources are mined not only profitably but also safely.

5.5. Recommendations

This research recommends SMD-Kao Mine to:

1. Implement visual controls, such as survey polygons to demarcate ore or waste limits after blasting, to improve reconciliation in cases where ore during blasting has fallen outside of its ore boundary. Blast movement should be monitored using high-speed resolution cameras and adjust ore boundaries accordingly before any loading and hauling can commence. This will prevent misclassification of material and ultimately the application of incorrect density to calculate tonnages. However, the use of high-speed cameras and real-time adjustments require a high initial set-up cost. Additionally, blast configuration such as using alternative free faces to direct blast movement should be considered.
2. Regularly update moisture content based on real-time sampling. Utilising moisture sensors on conveyors to dynamically adjust weight calculations can help prevent discrepancies in tonnage calculations. Actual moisture content should be used in tonnage calculations instead of an average moisture factor of 6% used by the mine. The application of an average moisture content for every month has a negative impact on the weighing of tonnages. Actual moisture levels must be measured and taken into account, especially across different seasons of the year. Some dry seasons can record moisture content as low as zero and some heavy rainy seasons do record moisture content as high as 12%. This means that applying 6% throughout affect the accuracy of the tonnages being recorded. Furthermore, the mine can consider implementing an optimised strategy for blending dry and wet ore can effectively balance moisture levels before processing.
3. Implement real-time GPS tracking and, an automated truck dispatch system, to enhance accuracy and reduce human error in material misclassification. The use of a dispatch system with scales attached to trucks will ensure that actual tonnages are recorded, avoiding the inaccuracies of truck counts and bucket factors. While automation minimises human intervention, oversight remains essential to prevent malfunctions. Also, the effectiveness of these systems depends on precise sensors and software, requiring substantial initial investment and ongoing maintenance.
4. Gather and stockpile spillages along the belt conveyor. The survey department should survey this before being taken back to stockpiles and fed again. However, collection and stockpiling of spillage might require dedicated equipment and, in some areas,

might be labour-intensive due to confined space. If not streamlined, it might slow down operations. Poor fragmentation also affects the bucket fill factor. More emphasis should also be put towards improving blast fragmentation.

5. Survey platforms where excavators stand while feeding offloading ore at the processing plant. In situations where stockpile levels are very low, those platforms are normally fed into the plant without being surveyed. In future, surveys must include that in stockpile figures as well.
6. Calibrate the plant weightometer more regularly. Not regularly calibrating weighing equipment results in errors accumulating. The accumulation of errors results in discrepancies also increasing.
7. Keep stockpile levels as low as possible. This should make it easier for stockpiles to be depleted frequently and zeroed more often.
8. Keep short-term plans as short as possible. At SMD-Kao Mine, short-term plans are done in a six-week rolling plan horizon. It is recommended that emphasis should be placed on daily activities. This is because it becomes easier to get side-tracked when there is so much to look at in the future.
9. Further core drilling is necessary to identify geological structures, enhancing the understanding of the orebody. This improved geological knowledge will facilitate more accurate quantification and planning of internal dilution, leading to better mineral resource management and operational efficiency. Additionally, conducting detailed mapping of exposed faces is essential to ensure that geological models are continuously updated before mining advances significantly.
10. Formulate a contingency plan to address adverse weather conditions, incorporating alternative schedules and modifications to mining priorities during times when weather factors hinder the implementation of the primary plan. Furthermore, the mine should establish advanced weather forecasting and real-time monitoring systems to improve the capacity for predicting rainfall and flooding, enabling more proactive adjustments and enhanced management of mining operations during challenging weather conditions.
11. Optimise blast designs based on geotechnical data to help minimise potential final wall damages, reducing the risk of future failures. Additionally, the mine must consider implementing controls to ensure drilling accuracy to prevent issues such as frozen toes, to improve overall operational efficiency and safety.

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