

**Decision-based approach to the extraction of coal
pillars in opencast mines by Junior Miners**

by

NATHANIEL CHABANGU

Submitted in accordance with the requirements
for the degree of

MASTER OF ENGINEERING

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: Prof FK MULENGA
CO-SUPERVISOR: Dr VC MADANDA

MAY 2026

DECLARATION

I, the undersigned NATHANIEL CHABANGU, student number 21000603, hereby declare that this thesis is my own original work with the exception of quotations and references, which are attributed to their sources. This thesis has not been previously submitted to any other university and will not be presented at any other university for a similar or other degree award.

Nathaniel Chabangu



Date: 20 May 2026

ABSTRACT

Coal pillar mining has been applied in South Africa since the 1990s. Over the years, coal pillar extraction has become the preferred method for Junior Miners to enter the coal mining sector in South Africa, due to its low capital to operation investment requirement. An abundance of coal pillar resources in excess of 1.1 Gigatons (Gt) of coal still remains from previous underground coal mines. Therefore, developing models that will ensure Junior Miners are able to optimise coal resources is very important. This research proposed models that would ensure Junior Miners maximise and realise maximum economic benefit from their coal pillar resources based on two mines located in the Emalahleni region as a case study.

A mixed-methods approach, combined with primary and secondary sources, was adopted for this study to address the research objectives. The mines were studied by physically observing the operations as well as analysing their mine, production, and schedule plans. This study was also able to design and draw conclusions from numerical modelling of mine plans and scheduling parameters. Approximately 60% of the coal from Mine 1 is sold to the domestic market. Mine 2 is a typical drill and blast operation producing an average of 210 kilotons (kt) per annum. Mine 1 will need to produce 600 kt per annum to achieve a net present value (NPV) of ZAR532 million with an internal rate of return (IRR) of 23.35%, while Mine 2 will need to produce 480 kt per annum to achieve an NPV of ZAR212 million with an IRR of 42.88%.

Both mines have dilution and contamination issues due to poor planning and a lack of appropriate mine designs. This study revealed the importance of accessing historical information, understanding challenges associated with coal pillar mining and addressing all environmental and safety issues that may arise. Critically, this study demonstrated that having a technically competent management team will ensure that appropriate mine plans, designs and schedules are always in place. Lastly, all coal pillar extraction operations need to have a practical financial model that addresses key

components such as NPV and IRR, which are vitally important to the sustainability of mining operations of this nature. Having robust mine designs and plans are essential prior to deploying and establishing machines on-site for sustainable coal pillar mining operations.

Keywords: Coal Pillars, Dilution, Contamination, Junior Miner, Net Present Value, Internal Rate of Return, Optimisation

ACKNOWLEDGEMENTS

I am forever grateful to my supervisors Professor Francois Mulenga and Doctor Carol Madanda for their constant support and constructive feedback throughout this journey. Without the constructive criticism, guidance and patience of my supervisors, this journey would have been much more difficult.

Secondly, I would like to extend my gratitude to every single person and company that assisted me with all that I required to make this project a success. Without your help I would not have been able to complete this research.

Lastly, I want to sincerely thank my family for supporting me throughout this journey, you guys are superstars.

TABLE OF CONTENTS

DECLARATION	I
ABSTRACT	II
ACKNOWLEDGEMENTS	IV
LIST OF FIGURES	X
LIST OF TABLES	XIII
LIST OF ABBREVIATIONS	XV
LIST OF SYMBOLS	XVII
CHAPTER 1: INTRODUCTION	1
1.1. Background of the study	1
1.2. Problem statement.....	2
1.3. Research objectives	3
1.4. Justification and significance of the study	4
1.5. Selected study areas	9
1.6. Outline of the dissertation	12
CHAPTER 2: LITERATURE REVIEW.....	13
2.1. Introduction.....	13
2.2. Mine cycle.....	15
2.3. Coal demand and supply analyses.....	17
2.3.1. World overview	17
2.3.2. South African coal overview.....	19
2.3.3. South African coal mining industry	20
2.3.4. Classification of miners	22
2.4. South African coal mining techniques and methods	24
2.4.1. Underground mining	25
2.4.2. Surface mining.....	27

2.5.	South Africa's Junior Mining Sector value chain.....	32
2.5.1.	Junior Miner business model	32
2.5.2.	Funding and investment for Junior Miners in South Africa	34
2.6.	Value proposition of junior coal miners	35
2.6.1.	Types of coal products	36
2.6.2.	Run of mine	39
2.6.3.	Corporate social responsibility	40
2.6.4.	Objectives and classifications of Junior Miners.....	41
2.6.5.	Development and constraints	44
2.7.	Remnant metal mines and Junior Miners	46
2.8.	Legal framework	48
2.9.	Chapter summary	50
CHAPTER 3: EMPIRICAL DATA COLLECTION AND FIELD OBSERVATIONS		51
3.1.	Introduction.....	51
3.2.	Methodological approach and rationale.....	53
3.3.	Research design.....	53
3.4.	Data collection	55
3.4.1.	Historical data.....	56
3.4.2.	Site observations.....	61
3.5.	Data analysis	65
3.6.	Limitations and challenges	68
CHAPTER 4: RESULTS.....		69
4.1.	Introduction.....	69
4.2.	Results produced from Mine 1	69
4.2.1.	Resources and reserves of Mine 1.....	70

4.2.2.	Present mining activities in Mine 1	72
4.2.3.	Challenges encountered at Mine 1.....	73
4.2.4.	Opportunities identified at Mine 1	75
4.2.5.	Efficiency and optimisation model of Mine 1	75
4.2.6.	Economic benefit and maximisation model of Mine 1 ..	79
4.2.7.	Model of Mine 1 to reduce dilution and contamination during extraction	85
4.3.	Results produced from Mine 2.....	86
4.3.1.	Resources and reserves at Mine 2.....	87
4.3.2.	Planning and design of Mine 2	89
4.3.3.	Challenges encountered at Mine 2.....	90
4.3.4.	Opportunities identified at Mine 2.....	91
4.3.5.	Efficiency and optimisation model of Mine 2	92
4.3.6.	Economic benefit and maximisation model of Mine 2 ..	95
4.3.7.	Model of Mine 2 to reduce dilution and contamination during extraction	101
4.4.	Comparison of the performance of the two mines	103
4.5.	Junior Miner Coal Pillar Mining Matrix	104
4.6.	Summarised findings	107
CHAPTER 5: DISCUSSIONS OF MODELS AND PLANS.....		108
5.1.	Introduction.....	108
5.2.	Modelling and planning of Mine 1	108
5.2.1.	Analysis of dilution and contamination at Mine 1	108
5.2.2.	Mitigation strategies for contamination and dilution at Mine 1	114
5.3.	Modelling and planning of Mine 2	116
5.3.1.	Analysis of dilution and contamination at Mine 2	116

A4. Mine 2 – Coal calorific value and coal thicknesses	184
Appendix B. Mine 1 and Mine 2 – Monthly projections and forecasts based on ROM and finished product sales	185
B1. Mine 1 – First Year Monthly Projections and Forecast (ROM)	185
B2. Mine 1 – First Year Monthly Projections and Forecast (Finished Product).....	186
B3. Mine 2 – First Year Monthly Projections and Forecast (ROM)	187
B4. Mine 2 – First Year Monthly Projections and Forecast (Finished Product).....	188
Appendix C. Mine 1 – Discount Rates from 0% through to 30% over four years.....	189
Appendix D. Mine 1 – Production Information for the Life of Mine	190
Appendix E. Mine 2 – Discount Rates from 0% through to 30% over eight years	191
Appendix F. Mine 2 – Production Information for the Life of Mine	192
Appendix G. Participants’ Questionnaire	193
Appendix H. Decision-Based Framework	197

LIST OF FIGURES

Figure 1.1: Commodity Dollar prices (Source: Minerals Council South Africa, 2021a).....	6
Figure 1.2: Commodity Rand prices (Source: Minerals Council South Africa, 2021a).....	6
Figure 1.3: South African coal production in 2019 (Source: Statistics South Africa, 2019).....	7
Figure 1.4: South African coalfields (Source: Vorster, 2003)	10
Figure 1.5: Locality map of Mine 1	11
Figure 1.6: Locality map of Mine 2	11
Figure 2.1: Life cycle of a mine project (Source: Harraz, 2010)	15
Figure 2.2: Global coal consumption between 2021 and 2023 (source: International Energy Agency, 2023).....	19
Figure 2.3: Junior Miner licences in South Africa, 2017 (Source: (Minerals Council South Africa, 2019a)	22
Figure 2.4: Different types of mining methods (Source: Iwuji et al., 2016).....	24
Figure 2.5: Bord and pillar mining (Source: Harraz, 2014).....	26
Figure 2.6: Longwall Mining Illustration (Source: Kohler, 2020).....	27
Figure 2.7: Illustration of box cut, strip cuts, and spoil piles in opencast mining (Source: Mitra and Saydam, 2012).....	28
Figure 2.8: How strip-mining works (Source: Hamer, 1973)	29
Figure 2.9: Main mine elements and parameters (Source: Mining Engineering, 2016).....	30
Figure 2.10: Detailed mining operation in an open pit (Source: Altit et al., 2021).....	30
Figure 2.11: Coal prices between 2019 and 2023 (Source: Agnolucci et al., 2023).....	38
Figure 2.12: South African coal exports in 2023 (Source: Coal Hub, 2023)	39
Figure 3.2: Typical borehole log at Mine 1	60
Figure 3.3: Inputs and outputs for the life of mine and pit optimisations ..	61
Figure 3.4: Loading time study under soft ground conditions at Mine 1 ...	62

Figure 3.5: Loading time study of the bottom seam at Mine 2	62
Figure 3.6: Cycle time study of Mine 1	63
Figure 3.7: Cycle time study of Mine 2.....	63
Figure 3.8: Coal pillar cleaning at Mine 1	64
Figure 3.9: Error checks using the built-in verification and validation checks in Leapfrog Geo	66
Figure 3.10: Simulation of the Seam 4 and inter-burden below the seam	67
Figure 4.1: Historical layout of Mine 1 superimposed on underground coal pillars	72
Figure 4.2: Pilot blast of overburden to approximately 0.50 m top of coal	76
Figure 4.3: Full layout of Mine 1	77
Figure 4.4: Optimised layout of Mine 1	78
Figure 4.5: Plan view of the geological model of Mine 1 generated using Leapfrog.....	79
Figure 4.6: Sales, cost, and profits of ROM material over four years for Mine 1	84
Figure 4.7: Sales, costs, and profits of crushed and screened products over four years for Mine 1	85
Figure 4.8: Block model of Mine 1 generated in Leapfrog.....	86
Figure 4.9: Full layout plan of Mine 2	93
Figure 4.10: Optimised layout of Mine 2	94
Figure 4.11: Plan view of the geological model of Mine 2 generated using Leapfrog.....	95
Figure 4.12: Distribution of expected IRRs in feasibility studies for projects developed by select Junior Miners listed on the Toronto Stock Exchange TSX (Source: McKeown et al., 2024).....	98
Figure 4.13: Sales, cost, and profit of the ROM material from Mine 2 over a period of five years.....	99
Figure 4.14: Sales, cost and profit of crushed and screened products from Mine 2 over a period of five years	100
Figure 4.15: Seam 2 split into Seam 2 Upper and Seam 2 Lower by a sandstone band	101
Figure 4.16: Contaminated coal at the stockpiling area of Mine 2.....	102

Figure 4.17: Block model of the coal seam of Mine 2 generated in Leapfrog.....	103
Figure 5.1: Relationship between bench height and diameter for drilling and blasting (Source: Adhikari, 1999)	109
Figure 5.2: Example of blast design as piloted in one of the blocks of Mine 1	111
Figure 5.3: Dilution localised to the southeastern portion of the mine....	114
Figure 5.4: Coal distribution without the inherent sandstone/siltstone dilution at Mine 2.....	118
Figure 5.5: CV and TS grade control samples from Seam 2 at Mine 2 between February and April 2024	120
Figure 5.6: CV and TS grade control samples from Seam 2 Upper at Mine 2 between February and April 2024	121
Figure 5.7: CV and TS grade control samples from Seam 2 Lower at Mine 2 between February and April 2024	122
Figure 5.8: Price of coal at different qualities and associated mining cost	124
Figure 5.9: Cost of mining ROM vs cost of mining and sizing the same ROM material.....	125
Figure 5.10: NE-SW borehole correlation at Mine 1.....	127
Figure 5.11: Simplistic pit design for Mine 1	128
Figure 5.12: Spontaneous combustion of coal pillars at Mine 1	129
Figure 5.13: Pit design of Mine 2 for the optimisation of pillar extraction optimisation.....	133
Figure 5.14: Block flooding after Seam 4 extraction in Mine 2	135
Figure 5.15: Grade tonnage curve for Seams 1 and 2 at Mine 1	140
Figure 5.16: Grade tonnage curve for Seams 4 and 2 at Mine 2	142

LIST OF TABLES

Table 2.1: Miner classification according to various parameters (adapted from Chukwudumebi, 2018).....	23
Table 2.2: Coal qualities, specifications, and definitions (Source: GlobalCoal, 2019).....	36
Table 2.3: Classification of large-scale, small-scale or artisanal and junior mining companies (Adapted from Chukwudumebi, 2018).....	43
Table 3.1: Data evaluation methods for the two studied mines in this research.....	52
Table 3.2: Discount rates by country for 100 System for Electronic Document Analysis and Retrieval (SEDAR)-filed projects, 2010-2020, and January 2020 values of country risk premiums (Source: Ovalle, 2020) ...	58
Table 4.1: Coal resources and reserves of Mine 1.....	71
Table 4.2: Qualities of raw coal at Mine 1	71
Table 4.3: Production data over four years – Mine 1	80
Table 4.4: ROM present values at different discount rates over a period of four years for Mine 1	81
Table 4.5: ROM NPV and profit incremental increase of 10% for Mine 1 over a period of four years at hurdle rate of 12% based on projections in Appendix B	81
Table 4.6: NPV of crushed and screened products from Mine 1 at a discount rate of 15% based on projections in Appendix B over a period of four years.....	82
Table 4.7: Resources of Mine 2 over the entire mining permit and prospecting right area	88
Table 4.8: Qualities of raw coal at Mine 2	88
Table 4.9: Mining sequence including prospecting the right resources of Mine 2	96
Table 4.10: NPV of the ROM material from Mine 2 over a period of 8 years at a discount rate of 15%	96
Table 4.11: NPV of crushed and screened products from Mine 2 over a period of 8 years based on a discount rate of 15%	97

Table 4.12: IRR for crushed and screened products from Mine 2 over a period of eight years	98
Table 4.13: IRR for the ROM material from Mine 2 over a period of eight years	99
Table 4.14: Mining Projects Analytic Hierarchy Process Values	104
Table 4.15: Normalised Pairwise Comparison Matrix	105
Table 4.16: Junior Miner's checklist prior to starting a new mining project	106
Table 5.1: Dilutions for a mining block that is 50 m x 50 m in dimension, with an average coal thickness of 2.24 m at a 60% yield	117
Table 5.2: Typical blending parameters for the different types of coal using raw qualities for Mine 2	119
Table 5.3: Parameters used in the mine design for Mine 1	127
Table 5.4: Pit slope design parameters and critical areas of operation (modified after Sullivan, 2006)	133

LIST OF ABBREVIATIONS

Abbreviation	Description
AR	As Received
ARB	As Received Basis
BA	Biodiversity Act
BBBEE	Broad Based Black Economic Empowerment
BCEA	Basic Conditions of Employment Act
BCM	Bank Cubic Meter
BEE	Black Economic Empowerment
Bt	Billion Tonnes
CAAGR	Compound Average Annual Growth Rate
CM	Continuous Miner
CSMI	Centre for Sustainability in Mining and Industry
CSR	Corporate Social Responsibility
Disc	Discount
EU	European Union
GDP	Gross Domestic Product
Geo	Geological
Gt	Gigatons
GTIS	Gross Tons In-Situ
Ha	Hectares
IEA	International Energy Agency
JMS	Junior Mining Sector
JSE	Johannesburg Stock Exchange
LOMP	Life of Mine Plan
LOW	Limit of Weathering
M	Metre
MHSA	Mine Health and Safety Act
MKB	Main Karoo Basin
MPRDA	Mineral and Petroleum Resources Development Act
MQA	Mining Qualifications Authority

Mt	Million Tons
MW	Mega Watt
NAR	Net As Received
NEM	National Environmental Management
NEMA	National Environmental Management Act
NWA	National Water Act
OECD	Organisation for Economic Cooperation and Development
PAA	Protected Areas Act
PoF	Probability of Failure
RD	Relative Density
ROM	Run of Mine
SADC	Southern Africa Development Community
SAMREC	South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves
SR	Strip Ratio
TTIS	Total Tons In-Situ
WA	Waste Act

LIST OF SYMBOLS

Symbol	Description	Unit
°	Degree	Celsius
%	Percent	
B	Burden, which is the distance between adjacent rows	
D	Market value of the company's debt	
D/V	Percentage of financing that is debt	
dmin	Diameter minimum	
dmax	Diameter maximum	
E	Market value of the company's equity	
E/V	Percentage of financing that is equity	
g/cm ³	Grams per cubic centimetre	
Ha	Hectare	
Kcal/kg	Kilocalories per kilogram	
L	Full length of blast block	Length
m ³	Cubic metres	
MCS	Monte Carlo Simulation	
MJ/kg	Megajoules per kilograms	
n	number of time periods (from initial year of investment to final year of production closedown)	
r	Discount rate	
Rd	Cost of debt	
Re	Cost of equity	
R _t	Net cash inflows – net cash outflows during a single period (Cashflow)	

S	Spacing, which is distance between blastholes in the same row	Spacing
t	Number of time periods (from initial year of investment to final year of production closedown)	
T _c	Corporate tax	\$
US\$	United States of America Dollar	\$
V = E+D	The total market value of the firm's financing	
W	Full width of a blast block	m
ZAR	South African Rands	

CHAPTER 1: INTRODUCTION

1.1. Background of the study

Coal was discovered in South Africa between 1838 and 1859 in areas such as KwaZulu-Natal, Mpumalanga, and the Eastern Cape Provinces. Since then, it has played an important role in the economy and energy supply (Hancox and Gotz, 2014). Coal is the most abundant and inexpensive source of electricity in South Africa. Although this coal has a low to moderate heat value and a high ash content, mining it is relatively economical in comparison to the international industry. Coal presently accounts for around 70% of South Africa's main energy. Coal-fired thermal generating generates 90% of the country's power while the coal conversion technology from Sasol, in operation since 1955, meets around half of the liquid fuel needs of South Africa (Jeffrey et al., 2015).

Consequently, while considering the coal mining industry, bord and pillar mining has been a crucial technique for extracting coal from underground coal mines in South Africa (Wagner, 1980). For many years to come, coal is expected to continue playing a significant role in the global economy. The demand for coal is predicted to rise at least until the 2040s, particularly in what were once emerging economies like China and India (Schernikau, 2010; U.S. Energy Information Administration, 2016). According to Mohutsiwa and Musingwini (2015), during the early years of coal mining, over 90% of the South African coal was produced by underground bord and pillar mining. However, in bord and pillar mining, a significant amount of coal is left behind in standing pillars as primary support. It has been estimated that a total of 9.55 Gigatons (Gt) of coal has been mined in South Africa, of which approximately 53% came from bord and pillar mines (Van der Merwe and Mathey, 2013).

In recent years, the mining landscape in South Africa, particularly in the Emalahleni area of Mpumalanga province, has seen an influx of junior coal miners seeking economic opportunities. Many of these Junior Miners focus

on exploiting old mine workings, where they extract coal from these abandoned sites. Junior Miners use opencast methods to exploit the pillars left from previous operations. However, these practices present serious challenges. A major issue is the lack of plans and designs to optimise operations and unlock the full value of these pillar-mining activities. Currently, Junior Miners are primarily focused on extracting these pillars for immediate economic benefit without developing a clear long-term strategy.

Many junior mining operations involved in opencast coal pillar extraction often operate with limited long-term planning and optimisation frameworks. This situation is frequently influenced by constraints such as restricted technical capacity, incomplete historical mine data, and a focus on short-term economic viability. As a result, coal pillar extraction is often carried out without a thorough evaluation of alternative extraction strategies, long-term economic outcomes, or integrated risk considerations.

While previous studies have explored the geotechnical challenges and risks associated with underground coal pillar extraction using opencast mining methods (Ngwenyama et al., 2017; Ngwenyama and de Graaf, 2021), there has been little attention given to structured decision-support frameworks that balance safety, technical feasibility, and economic performance, especially regarding junior mining operations. This gap highlights the need for a systematic, defensible approach to support informed decision-making in opencast coal pillar extraction, which serves as the foundation for the problem addressed in this study.

1.2. Problem statement

The mining of coal pillars from previous underground operations poses various risks and challenges. These risks and challenges include collapse of pillars, spontaneous combustion, sinkholes and subsidence, excessive dilution, pit flooding and water retention from underground water, and highly undulating coal seams (Ngwenyama and de Graaf, 2021). Thus, there are two risk components that need to be studied and mitigated accordingly: the

safety of the operation and the economic benefit associated with the efficient extraction of the coal.

Resource optimisation is a critical factor underpinning coal pillar mining operations (Pasch and Uludag, 2018). However, in practice, many junior mining operations lack structured approaches to optimise coal pillar extraction. This leads to inefficient mining practices, high levels of dilution and coal losses, and, in some cases, the sterilisation of potentially recoverable coal resources.

The complexity of coal pillar mining often leads Junior Miners to prioritise short-term production to cover operational costs rather than comprehensive planning and optimisation of coal resources. As a result, thoroughly researched mine plans are frequently abandoned, leading to coal contamination, reduced product quality, and losses in recoverable reserves. The Junior Miners considered in this study are based in the Emalahleni region, where these challenges have constrained their ability to improve efficiency and transition into sustainable, medium-sized mining companies.

1.3. Research objectives

Opencast coal pillar mining has become a cheaper option for miners, particularly junior miners, because limited or no exploration is conducted to assess the potential of coal deposits. Junior coal miners are simply relying on historical underground operations that have since stopped operating. Therefore, the objectives of this study are as follows:

- To develop an efficiency and optimisation model that will enable junior miners to maximise and realise the economic benefit of their operations with suitable mine designs and plans.
- To develop/ assess methods for optimising coal pillar extraction with the view to reducing dilution and loss of coal.
- To develop/assess techniques that may lead to reduced contamination of the mined product.

1.4. Justification and significance of the study

The significance of this study is its ability to ensure junior miners are efficiently capacitated to participate in the supply of coal, that will be driven by increased demand. This study focused on improving efficiency, optimisation of coal resources, and adding value to ensure supply sustainability. In the period 2023-2027, coal production in South Africa was expected to grow at a compound annual growth rate (CAGR) of 1% (Mining Technology, 2024). Global coal use reached a record 8.77 Bt in 2024 (Kazanci, 2024). Therefore, making it critically important for miners to have capacity to meet the coal demand.

The South African government has been expanding its coal-based power supply by building two power stations that were supposed to add sufficient capacity to the energy needs of the country, albeit with some delays. According to Blignaut (2012), Medupi and Kusile power stations each have a gross capacity of 4 800 MW. It is anticipated that each of these stations will consume about 17 million tonnes of coal annually. Making it important for coal supplies to be ready and capacitated enough to meet this anticipated demand.

It is therefore important to note that during times of energy crises and uncertainty, most nations, especially developed nations, will resort to coal. As it provides a tried-and-tested source that has been utilised to generate energy for centuries. In 2025, the South African coal industry exported 57.66 Mt of coal as reported by Banya (2026), which is 26% of its production, from its average of 224 Mt of marketable coal (Eskom, 2021). The tendency for nations to revert to coal during times of crisis underscores its importance as an energy source. Due to this demand coal miners have been given the opportunity to maximise their resources.

Historically, coal miners who have enjoyed the full benefit of this opportunity were the major players in the industry. While Junior Miners had to settle for what was left behind by the major players. However, with rising demand for coal, junior miners and new entrants into the coal mining sector have seen

their status elevated. The elevation is also due to lack of capacity of major role players to deliver more than what they have already committed, which then means Junior Miners have an opportunity to fill that gap. The current trend of junior coal miners is that they tend to struggle to maintain consistent quality supply. This is due to the lack of sound decision making prior to commencing operations.

Most Junior Miners appear to be more concerned with generating profits, which is often at the expense of operational readiness. Coal consumers are always looking for premium products, meaning that miners need to mine and supply high-quality coal. Thus, since the advent of the energy crisis, the market's demand for coal has led consumers to focus on coal quality ranging from 4 800 kcal/kg to the highest-quality coal (RB1). The rise in demand has seen a number of Junior Miners participating in this coal demand frenzy. However, due to the limited quality coal availability, most miners, including Junior Miners, have resorted to mining pillars.

In Emalahleni, these pillars were left behind by previous underground mining operations. The coal from these pillars meets the quality standards desired by the markets. In addition to coal demand, commodity prices and exchange rates tend to experience volatility, in response to global affairs. This commodity prices cyclicity in dollar and rand is illustrated by Figure 1.1 and Figure 1.2 respectively.

Dollar prices					
	Coal US\$/t	Iron ore US\$/t	Gold US\$/t	Platinum US\$/t	Dollar Index
Year to Dec 21	119.0	161.1	1,797.4	1,086.7	237.6
Year to Dec 20	65.7	108.9	1,770.3	883.4	173.7
Change year to date %	81.3	47.9	1.5	23.0	36.8
12 months to Dec 21	119.0	161.1	1,797.4	1,086.7	237.6
Change 12 months %	81.3	47.9	1.5	23.0	36.8
Change 1 month %	(13.3)	15.3	(0.1)	(2.0)	(2.7)
Dec on 12 Months	1.7	(31.7)	(0.3)	(12.1)	2.0
Change year-on-year %	42.1	(29.2)	(3.6)	(7.1)	21.0
Dec before lockdown	98.95	(0.92)	22.56	9.95	56.47
12 months average before lockdown	70.12	96.29	1,462.94	885.84	159.10

Figure 1.1: Commodity Dollar prices (Source: Minerals Council South Africa, 2021a)

For instance, after soaring to a record high during the recent energy crisis in 2022, the International Energy Agency (2025) notes that thermal coal prices have pulled back over the past two years.

Rand prices						
	Coal US\$/t	Iron ore US\$/t	Gold US\$/t	Platinum US\$/t	Rand Index	Exchange rate (ZAR cents:US\$)
Year to Dec 21	1,762.3	2,365.0	26,570.8	16,037.8	350.0	1,479
Year to Dec 20	1,071.3	1,788.0	29,231.0	14,484.7	295.2	1,650
Change year to date %	64.5	32.3	(9.1)	10.7	18.5	11.6
12 months to Dec 21	1,762.3	2,365.0	26,570.8	16,037.8	350.0	1,479
12 months to Dec 20	1,071.3	1,788.0	29,231.0	14,484.7	295.2	1,650
Percentage change (%)						
Change 12 months %	64.5	32.2	(9.1)	10.7	18.5	11.6
Change 1 month %	(11.4)	17.8	2.1	0.2	(3.3)	(2.1)
Dec on 12 Months	9.0	(26.2)	71	(5.5)	2.5	(6.9)
Change year-on-year %	51.4	(24.6)	2.7	(1.0)	14.2	(6.2)
Dec before lockdown	109.21	4.33	28.55	15.69	50.56	(6.84)
12 month average before lockdown	1,036.10	1,420.85	21,673.69	13,082.13	246.47	1,478.78

Figure 1.2: Commodity Rand prices (Source: Minerals Council South Africa, 2021a)

According to XMP Consulting (2013), about 64% of South Africa's coal is mined by opencast methods and 36% by underground methods, i.e., bord and pillar, 33.6% almost entirely mechanised, some 0.5% by longwalling and 1.9% by pillar recovery (stooping). South African coal production

reached a high of 306 million metric tons in 2019 (see Figure 1.3), accounting for 75% of the total mass of minerals produced in that year (Statistics South Africa, 2019). However, production has seen a steady decline over the past four years, with South Africa in 2022 the seventh-largest coal producer in the world, accounting for 3.2% of global production and exporting about 20% (Cole et al., 2023).

The recent rise in demand for South African coal has led to an upsurge in miners seeking to fill that gap which in turn has given rise to many new coal operations. However, due to various factors, most new miners are “scavenging” pillars from old underground workings. The price of coal offsets the cost of mining these pillars thereby making the business case for mining them very attractive to miners, especially new entrants into the sector. The rise in demand for coal and miners seeking to fill that gap has prompted the proposal to identify efficient ways to optimise and maximise the extraction of coal pillars with specific attention to previously mined underground operations.

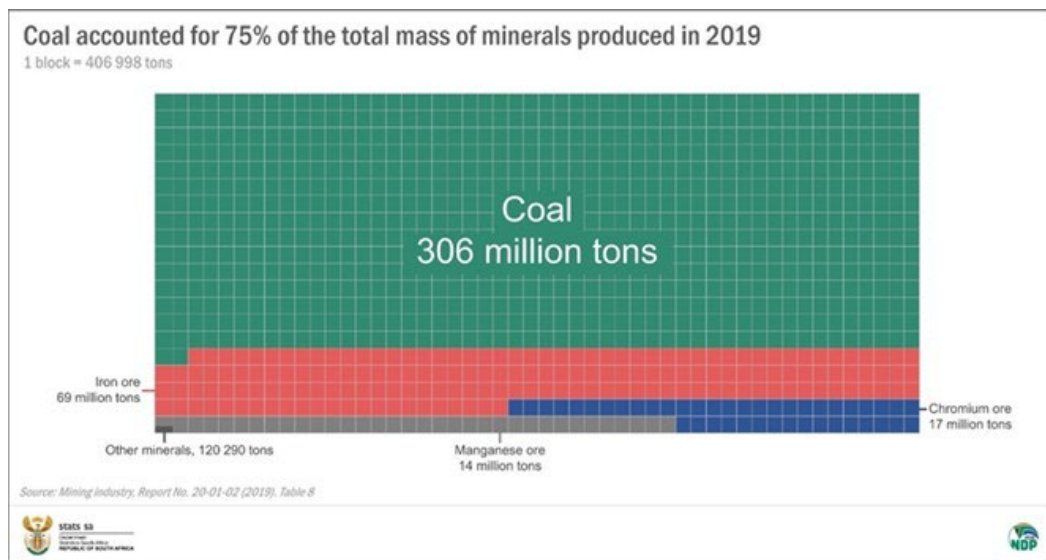


Figure 1.3: South African coal production in 2019 (Source: Statistics South Africa, 2019)

As stated by Chavalala (2016), while it is understood that climate change will affect all areas of the coal mining value chain. It is also important to

understand how miners can efficiently mine pillars with less contamination, dilution and loss of volumes on mined product. As well as avoid the potential of pillar failure while mining. This study provides a model that junior coal miners can adapt to better design and plan the extraction of underground coal pillars using opencast mining methods. Unlocking and optimising economic benefits while enhancing the efficiency of coal extraction without compromising quality or volume.

At present, junior coal miners do not seem to have the budget and/or patience to actually undertake the work of efficiently planning their operations. Therefore, emphasis is on extracting coal to generate revenue, which in turn pays for labour and service providers, with the balance being profits. The Emalahleni area is experiencing the effects of this trend, where miners are simply mining to generate revenue without necessarily having adequate mine plans, including plans to rehabilitate the area once mining of certain sections of the pillars is complete.

The significance of this study is that it also explores ways to ensure that rehabilitation is not left solely to the authorities but becomes a collective effort among all stakeholders. This study aims to identify methods and approaches for designing and planning safe mining of underground coal pillars using opencast methods. It also suggests methods to optimise resources during mining to unlock economic value. The current data is highly focused on risks and challenges associated with mining underground coal pillars using opencast methods. It does not necessarily propose methods to assist Junior Miners in planning and executing mining of these pillars.

This study adds new information to the already existing body of knowledge, with particular focus on Junior Miners and their bid to access underground coal pillars for economic benefit. This study also offers a model that will assist Junior Miners to not only efficiently extract coal pillars, but it will also detail methods to unlock value and ensure the sustainability of such

operations to keep up with the coal demand envisaged by Schernikau (2010) and U.S. Energy Information Administration (2016).

1.5. Selected study areas

South African coal fields are situated in rocks of the Main Karoo Basin (MKB) and its associated sub-basins as shown in Figure 1.4 (Hancox and Gotz, 2014). The sedimentary part of the Karoo Supergroup is subdivided into four main lithostratigraphic units, which, from the base up, are the Dwyka, Ecca, Beaufort and Stormberg (Molteno, Elliot and Clarens formations) groups (Hancox and Gotz, 2014). Although rocks of the Ecca Subgroup are widespread across the country, conditions suitable for coal formation did not occur everywhere (Chavalala, 2016). The coal deposits are fairly restricted, occurring in the main Karoo basin in an arc from Welkom in Free State Province to Nongoma in KwaZulu-Natal, and in several smaller outlying remnants of the Karoo Supergroup (McCarthy and Pretorius, 2009).

According to Hancox and Gotz (2014), over a century and a quarter later, the Witbank coalfield is still one of the most important in South Africa, supplying more than 50% of South Africa's saleable coal. It produces both metallurgical coal and thermal coal for the export and local markets. The Witbank coalfield is situated on the northern margin of the Karoo Basin, south of the township of Emalahleni, and about 20 km due east of the city of Johannesburg.

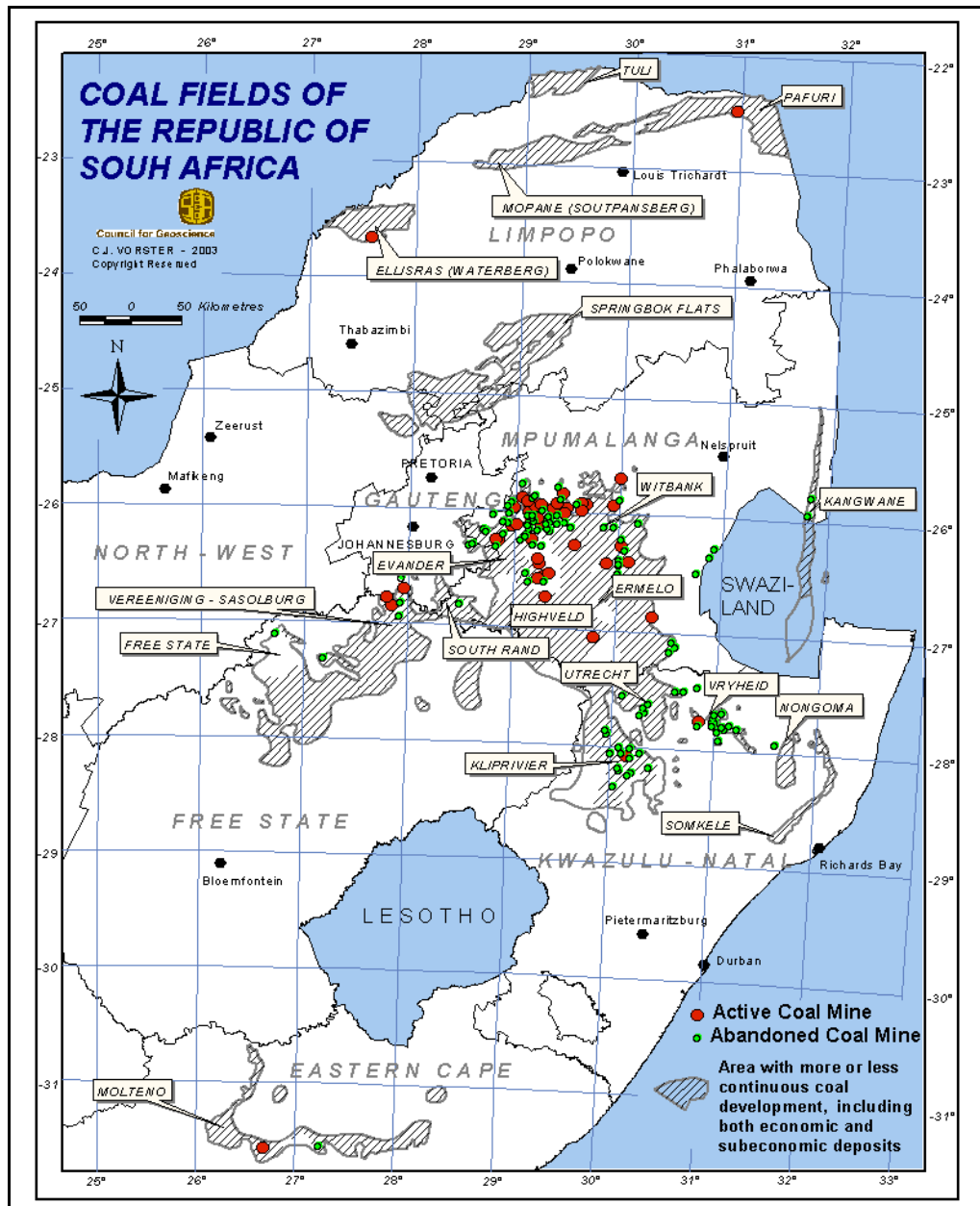


Figure 1.4: South African coalfields (Source: Vorster, 2003)

The selected area for this study is Emalahleni, Mpumalanga province, which hosts the Witbank coalfield. Mine 1 (Figure 1.5) is located approximately 10 km North-West of Emalahleni and 33 km South-West of Mine 2. Mine 2 is located in the Balmoral area (Figure 1.6). It is approximately 36 km North of the Emalahleni municipality and 25 km from the town of Bronkhorstspuit, while Mine 1 is a further 28 km away.



Figure 1.5: Locality map of Mine 1



Figure 1.6: Locality map of Mine 2

For the purposes of this study, all the junior coal miners chosen were level 1 BEE contributors as per the classification used by the BBEE Act, that is, the Broad-Based Black Economic Empowerment Act. They were selected based on the parameters outlined later in Table 2.1 of Chapter 2 for Junior Mines. The Mining Charter and the BBEE Act have enabled many Junior Miners to participate in the country's mining industry.

1.6. Outline of the dissertation

This dissertation is structured into six chapters.

Chapter 1 provides a general overview of the study, including the background, problem statement, objectives, justification, and selected study location.

Chapter 2 focuses on literature review detailing the origin, formation, distribution, and exploitation of the South African coalfields, with particular focus on the Witbank Coalfield. It also provides an overview of the coal markets, coal mining, and analysis of the country's coal mining at present.

Chapter 3 focuses on the research methodology, including definitions of the junior coal mining entities studied. It also outlines the research design, specifying the data type and sources, the data-gathering approach, and the data-analysis approach used in the study.

The results of the study are presented in Chapter 4.

Chapter 5 discusses the results of junior coal pillar mining in the Witbank coalfield. Special attention is paid to planning and designing coal operations. This is done in view to optimise coal pillar extraction while limiting contamination, pillar failure, and dilution, and maximising the economic benefit from these operations.

Chapter 6 concludes by discussing recommendations, along with any future work that could be undertaken to ensure maximum economic benefit from coal pillar mining. Future work is identified especially from bord-and-pillar coal operations that may be reaching the end of their life.

CHAPTER 2: LITERATURE REVIEW

This chapter focuses on comprehensive review of existing data that is relevant to this study. Current coal mining trends, prices and efficiency theories are explored, where findings and gaps are highlighted. This chapter forms the basis of this study as it analyses contributions made by different scholars while identifying areas that need further investigations.

2.1. Introduction

The secondary extraction of pillars from previously mined underground bord and pillar operations dates back to the early 1990s in South Africa and earlier than this in other countries, such as Scotland (Ngwenyama and de Graaf, 2021). In South Africa, this coal mining method has become prevalent in the past couple of years due to its lower cost as there is no need to conduct exploration to determine the presence of coal deposits.

In recent years, the mining of old coal pillars has been the preferred method for Junior Miners. Moodley (2021) has divided Junior Miners into three categories: the first group is exploration companies, the second group is developers who take a known deposit and build the mine with a view to moving on into production and the third group consists of smaller and mid-tier producers who typically buy a small operation with the intention of mining. The Minerals Council South Africa (2020) defines these producers as having an annual turnover below ZAR500 million (or R500m). Junior Miners are naturally drawn to old underground mines where substantial coal remains in the form of remnant pillars, seeking low-cost opportunities.

Moolman and Canbulat (2003) posit that approximately 1.1 Gt of potentially mineable pillar coal remains in the ground as remnant pillars, mostly from mining operations dating back to 1970-1997. This number is growing by approximately 110 million tons per annum due to current bord and pillar mining practices (Van Eck, 2016). However, mining remnant pillars

underground can be difficult and constrained by geotechnical, geological, environmental, and economic factors. Because underground mining of coal pillars poses serious challenges, companies have opted to mine them using opencast methods. Ngwenyama and de Graaf (2021) suggest that opencast pillar mining operations can compete with virgin coal operations.

In the Mpumalanga region, particularly in the Emalahleni region, opencast coal pillar mining has been preferred over underground pillar extraction. This is due to factors such as safer working environments, higher extraction and recovery rates, flexibility, reduced coal losses, and increased productivity of surface methods, as well as better control of spontaneous combustion of the coal.

As South Africa's virgin coal resources continue to deplete several studies have shown that vast potential exists through the application of pillar extraction mining methods for the increased utilisation of the coal resource (Moolman and Canbulat, 2003; Van Eck, 2016). Currently, in Mpumalanga, a large contingent of Junior Miners has entered the coal mining industry to provide jobs for communities and create business opportunities for themselves. However, some opencast pillar mining operations operated by Junior Miners are not designed or planned for optimisation. They are simply for the extraction of coal to generate income and in most cases, results in major tonnage losses and compromises and even contaminates the coal quality.

Ngwenyama and de Graaf (2021) found that information about old workings is either unavailable or only partially understood. The partially available information is extrapolated from old mine plans, which are less accurate than modern plans. This is because the old mine plans were constructed manually due to the lack of advanced survey technology at the time. The unavailable or partially known information includes the exact positions of the pillars, their centres, pillar dimensions, bord width, and roof undulation and thickness. The lack of sufficient information about the condition of some of these old operations also makes it difficult to understand the general

conditions of the areas, posing a serious planning challenge. Thus, it is critical to adopt an appropriate decision-based approach in the design and planning of such operations to ensure a balance between revenue generation (economic benefit) and the optimisation of coal pillar extraction.

2.2. Mine cycle

The mining cycle is comprised mainly of 5 stages (Figure 2.1), exploration and prospecting, mine-site design and planning, development, production and processing and lastly reclamation (closure). The beginning of any mining project is the prospecting stage, which, according to Chavalala (2016), is the search for financially viable and exploitable mineral reserves. It is the search for ores or other valuable minerals (coal or non-metallic). Mineral deposits may be located either at or below the surface of the earth, where both direct and indirect prospecting techniques are employed (Alzahrani, 2018).

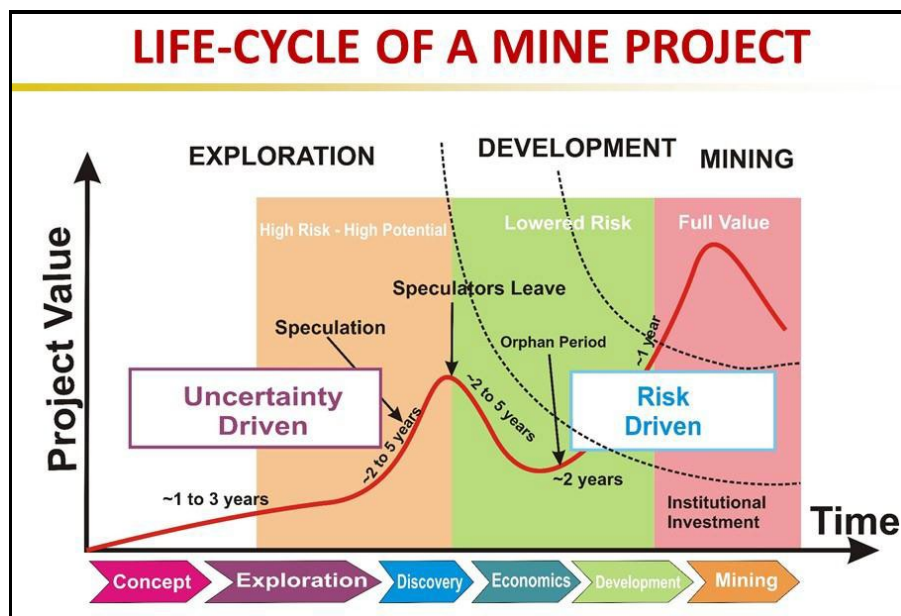


Figure 2.7: Life cycle of a mine project (Source: Harraz, 2010)

The exploration stage determines as accurately as possible the size and value of a mineral deposit, utilising techniques similar to but more refined than those used in prospecting (Alzahrani, 2018). The stage following the

exploration stage is the mine design stage, which analyses data gathered during the exploration phase. When the gathered data indicates that the mineral deposits are economically viable and that sufficient mineral resources are available to sustain the mining project, the mine design will commence.

The mine design will include the mining activities to be undertaken, then proceed to the development phase. During the design and development phase, the safety of the project needs to be determined and established in relation to environmental and social practices. Therefore, during this stage, it is critically important to unequivocally determine and illustrate the project's economic viability, as well as its ability to meet social responsibility and regulatory requirements. The main stage during the life cycle of a mine is the production and processing stage. According to Alzahrani (2018), it is associated with the actual recovery of minerals from the earth.

Although development may continue, the emphasis in the production stage is on mineral production. Usually, only enough development is done prior to exploitation to ensure that production, once started, can continue uninterrupted throughout the life of the mine. In a coal environment, coal is extracted along with associated products, such as methane gas, from the ground. Coal is then processed into various products that include lignite, sub-bituminous and bituminous and anthracite (Chavalala, 2016). The mining method selected for exploitation is primarily determined by the characteristics of the mineral deposit and the constraints imposed by safety, technology, environmental concerns, and economics.

Geologic conditions, such as the dip, shape, and strength of the ore and the surrounding rock, also play a key role in selecting the mining method (Alzahrani, 2018). The final stage in the mine cycle is reclamation, also known as the closure stage. This is the process of closing a mine and recontouring, revegetating, and restoring/rehabilitating the land and water (Harraz, 2010). Therefore, it is standard practice that, during the planning, design, and development stage of the mine, closure plans and processes

are considered together with their associated costs. Chavalala (2016) also suggests that such plans are developed and agreed upon by the mining companies, the government, and the community before mining commences. This is meant to ensure that the land in and around mining sites is restored and/or remains fairly productive.

Another reason is to ensure that the ecosystems in those lands are minimally disrupted during and after mining has ceased. Alzahrani (2018) further summarises the closure stage as concerned mainly with three fundamental processes. The first process is the safety of the mine site particularly if the area is open to the public. Restoration is the second major issue, which has to deal with physical environment where the mine was operating. The final concern of the mine planning engineer may be the subsequent use of the land after mining is completed.

2.3. Coal demand and supply analyses

2.3.1. *World overview*

Banks et al. (2015) note that according to the International Energy Agency's (IEA) World Energy Outlook 2014 report, coal played an important role in the global energy mix, accounting for 29% of total primary energy demand in 2012. Banks et al. (2015) therefore posit that coal demand has declined across all OECD regions, particularly in the United States, where the IEA forecasts a nearly one-third reduction in coal-fired electricity generation. It is further mentioned that the decline is due to increased regulation and competition from other fuels, especially unconventional gas and renewables.

Coal demand in developing countries, on the other hand, is expected to increase by one-third by 2040, with significant growth in Southeast Asia, India, Africa, and Brazil. Furthermore, Banks et al. (2015) suggest that coal remains the primary source of electricity generation in Europe and the United States and is expected to continue to account for a major share over the next several decades.

According to Banks et al. (2015), global coal production and pricing trends over the next 25 years will be led by Asia, where coal will remain more competitive than gas for some time. The IEA highlights that China, India, Indonesia, and Australia will account for 70% of global coal production by 2040. Coal competitiveness can be seen in Malaysia. This is a gas-rich country with no coal resources, and yet most incremental demand will be met by coal, reflecting that it is more profitable to export its gas and import coal.

It was widely reported that, over the next 5 to 10 years, coal and lignite capacity in Germany will decline. However, as per the publication by Eckert and Sims (2022), coal has made a comeback in Germany, as Europe's largest economy turns to it for power through the energy crisis. According to ICN Bureau (2026) as well as Palit and Khurana (2025), coal has been and will remain vital to India's energy infrastructure and economic development. It is the world's third-largest coal producer, and coal accounts for roughly 68 per cent of electricity generation. India's Planning Commission projects that coal's use in power generation will have to expand to 2 billion tonnes by 2031-2032 to meet the growing electricity needs of the country. Coal prices have also hit record levels (International Energy Agency, 2022a), which has given rise to an increase in the production of coal from coal producing nations in an attempt to participate in these record high coal prices.

Global coal supply increased by over 5% in 2021, even though production was hampered for a number of producers by supply chain disruptions. Therefore, coal use is anticipated to increase by 3% to 2030 in emerging markets and developing economies, but it will then enter a long-term decline (International Energy Agency, 2022b). China remains the largest consumer of coal, as shown in Figure 2.2, and this trajectory is envisaged to continue into 2024 with India also playing a significant role.

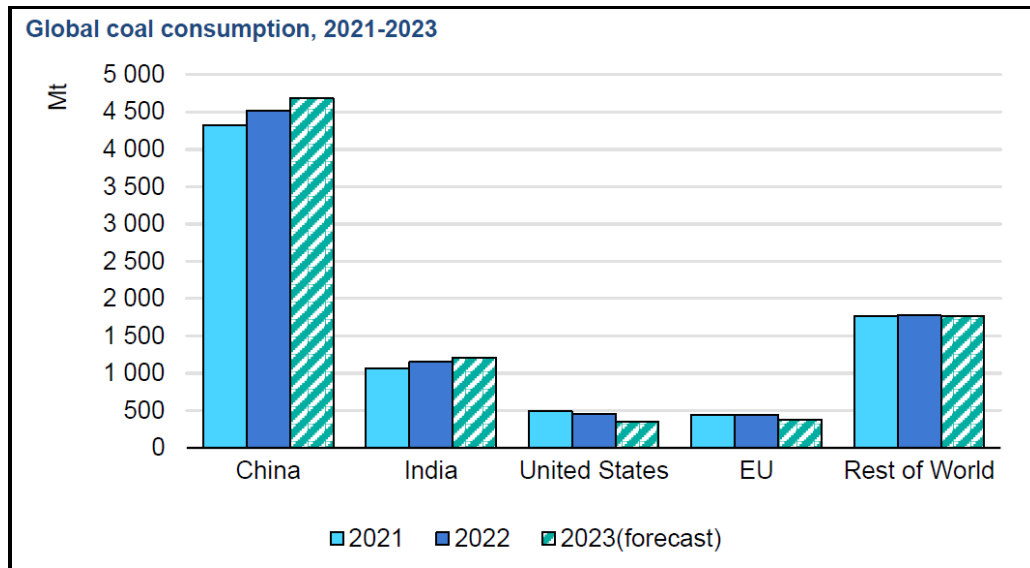


Figure 2.8: Global coal consumption between 2021 and 2023 (source: International Energy Agency, 2023)

2.3.2. South African coal overview

In South Africa, the three main coalfields that produce the majority of the mined coal are the Witbank, Highveld, and Ermelo Coalfields (Chukwudumebi, 2018). The South African energy supply is dominated by coal, which accounted for 65% of the primary energy supply in 2018 (Ratshomo, 2021). South Africa's indigenous energy resource base remains dominated by coal, and the country's reliance on coal-based energy is unlikely to change significantly over the next two decades. Domestic coal consumption in South Africa accounts for more than 75% of the total coal produced annually with the remaining exported.

More than 90% of the country's electricity and approximately 30% of the liquid fuel are produced from coal. It is further suggested by Ratshomo and Nembahe (2018) that coal is expected to play a major role in the foreseeable future, as it is the leading mining commodity revenue generator in South Africa. The major domestic markets for South African coals are Eskom and Sasol, while the remaining users include metallurgical plants, cement, brick

and tile, paper and pulp, and the sugar industries, as well as a host of other manufacturing and service industries (Chukwudumebi, 2018).

South Africa produces an average of 224 million tonnes of marketable coal annually, making it the fifth largest coal-producing country in the world. Coal production and sales in domestic and export markets are dependent on several economic factors, such as demand and supply, quality, pricing, and transportation costs, as reported by Chukwudumebi (2018).

Historically, South Africa exports approximately 70 million tonnes of coal annually. Since 2015, approximately 54% of South Africa's coal has been exported to the Pacific Basin (Asia), according to Chukwudumebi (2018).

In addition to extensive coal use in the domestic economy, South Africa exported 24% of its coal in 2018, with relatively low imports (Ratshomo, 2021). According to Ratshomo and Nembahe (2018), South Africa contributes about 3.5% of the world's coal resources. The country's production is around 3.3% of the world's annual total, and exports approximately 6% of global exports. Eskom (2021) has suggested that South Africa's coal reserves are estimated at 53 billion tonnes, and that, with present production rates, there should be almost 200 years of coal supply remaining.

2.3.3. *South African coal mining industry*

The South African coal mining industry is dominated by several large mining companies, including Exxaro Resources, Seriti Resources, Sasol, South32, Glencore, and Thungela Resources. The economics of coal mining are highly influenced by the depth and quality of the seams, as well as the geology and environmental considerations. South Africa's coal mining occurs mainly in Mpumalanga Province, which produces 81% of the country's total output. Limpopo Province with 11%, Free State Province with 6%, and KwaZulu-Natal Province with 2%, providing the rest (XMP Consulting, 2013). In 2021, coal production was 228.6 Mt. However, export

volumes were 21.5% lower, registering 46.8 Mt compared to the 59.7 Mt exported in 2020 (Minerals Council South Africa, 2021a).

The junior and emerging mining sector is significant, representing about 10% of the total industry, which, extrapolated, amounts to about 22.86 Mt of coal production in 2021 (Minerals Council South Africa, 2019a). Junior Miners are companies with an asset base of R50 million to R7 billion (Fossil Fuel Foundation, 2023). These miners had revenues of R54.4 billion in 2018 (Minerals Council South Africa, 2019a). Such revenues are the types of returns that have propelled the inundation of coal mining by Junior Miners in the Emalahleni region. Where the returns are seen to provide not only employment but also to create wealth for the communities and for miners who own the mining permits.

In 2017, junior coal miners had a total of 1417 mining rights registered in their names, with coal miners accounting for 85 of these rights (Minerals Council South Africa, 2019), which is quite significant. Export earnings were pegged at R63.7 billion in 2021, while local sales earnings, which are dominated by Eskom pricing contracts, also increased (Minerals Council South Africa, 2021a). Local coal sales volumes registered 177.3 million tonnes in 2021. Eskom is the country's largest consumer of coal, burning roughly 110 million tonnes annually (Minerals Council South Africa, 2021b).

The coal mining and diamond mining sectors have seen the largest participation by Junior Miners, refer to Figure 2.3 (Minerals Council South Africa, 2019).

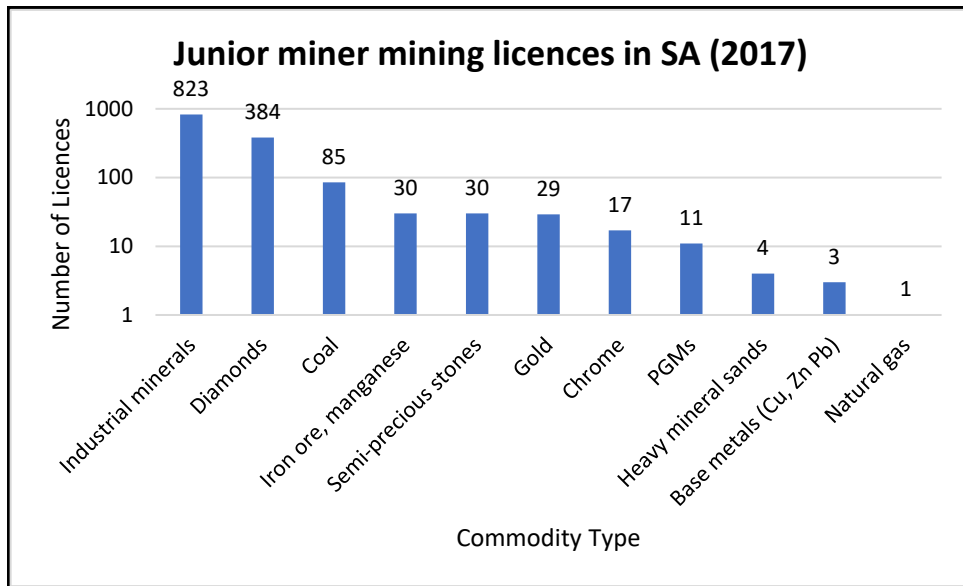


Figure 2.9: Junior Miner licences in South Africa, 2017 (Source: (Minerals Council South Africa, 2019a))

2.3.4. Classification of miners

The junior mining industry in South Africa is largely determined by the revenue each entity generates in a given year. According to the 2018 Mining Charter, Junior Miners are classified as mining right holders with single or multiple mining rights, having a combined annual turnover of ZAR 150 million. Table 2.1 provides the classification of Junior Miners.

Table 2.1: Miner classification according to various parameters (adapted from Chukwudumebi, 2018)

Type	MAJOR MINERS	JUNIOR MINERS			SMALL-SCALE MINERS
		Category A	Category B	Category C	
Operation Size	> 5000 Ha	< 5000 Ha	100 – 1000Ha	< 100 Ha	< 5 Ha
#Employees	> 10 000	500 – 1000	100 – 500	50 – 100	< 50
Turnover	> R10bn	R100m – R500m	R50m – R100m	R10m – R50m	< R10m
Mining Operation	Complex mining operations with advanced technological equipment. Highly diversified assets and investment portfolio.	Complex mining operations with advanced technological equipment. Simplified assets and investment portfolio.	Simplified mining operations and advanced equipment. Simple assets and investment portfolio.	Exploration studies.	Largely artisanal mining with rudimentary tools, equipment or machinery.
Social and Labour Plan Expense	> R150m	< R150m	R50m – R100m	< R50m	No Social and Labour Plan in place
Granted Licences	Prospecting right (PR), water use licence (WUL) and mining right (MR).	Prospecting right (PR), water use licence (WUL) and mining right (MR).	Prospecting right (PR), water use licence (WUL), mining right (MR), or mining permit (MP).	Prospecting right (PR) and mining right (MP)	Unregulated or illegal.

2.4. South African coal mining techniques and methods

According to Ratshomo and Nembahe (2018), approximately 51% of South African coal mining is done underground, and about 49% is produced by open-cast techniques (surface mining). A clear contrast to figures reported by XMP Consulting (2013). Both underground and opencast coal mining methods can be further divided into different sub-methods as shown in Figure 2.4.

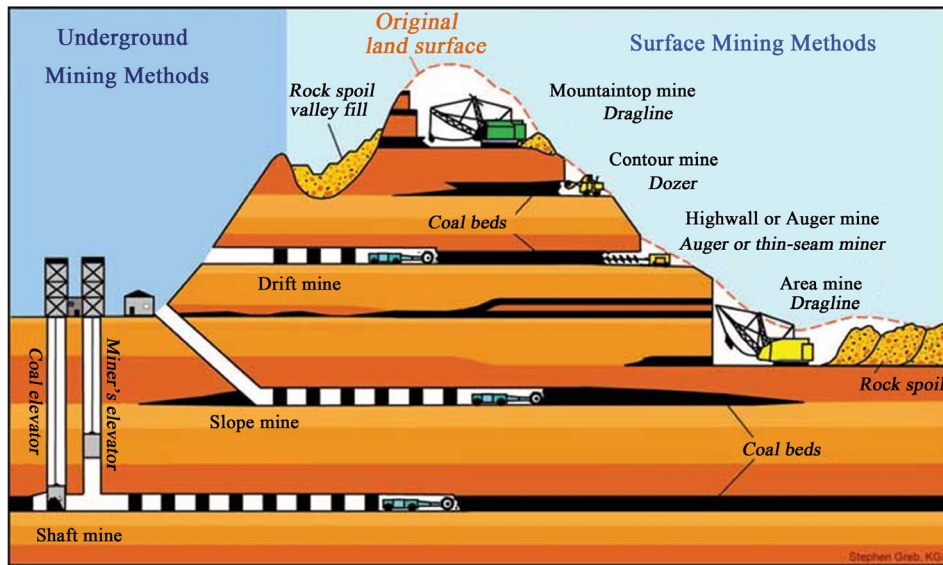


Figure 2.10: Different types of mining methods (Source: Iwuji et al., 2016)

Underground mining methods are largely dominated by bord and pillar, longwall mining, thick seam mining and shortwall mining. While opencast methods can be divided into contour strip mining, area strip mining (strip mining), open-pit mining and auger mining (Balasubramanian, 2016). In some cases, there is hydraulic mining as suggested by Dos Santos (2016), which is applied primarily to metal and aggregate stone deposits. Although coal, sandstone and metal mill tailings are also amenable to this method.

2.4.1. *Underground mining*

Various mining methods are used in underground mines in South Africa. The most common technique is the bord and pillar method, which accounts for just under half of total coal production (Ratshomo and Nembahle, 2018). This method is ideal for relatively shallow deposits where overlying rock pressure is low. Seams are mined, leaving in situ coal pillars that are large enough to support the roof indefinitely. This method currently permits around 65% of the available coal to be extracted.

According to McCarthy and Pretorius (2009), in bord and pillar mining, only a portion of the coal is extracted, the rest being left in place as pillars to support the overlying rocks. Towards the end of mining, pillars may be partially extracted (pillar robbing) to recover additional coal, but a considerable amount of coal is left in the ground. If sufficient support is left in place, the roof rocks can remain stable.

a) Bord and pillar mining

Fundamentally, the bord and pillar method of mining involves driving a series of narrow headings in the seam, parallel to each other. These are connected by cross headings to form pillars, which are then extracted partially or completely, depending on geological conditions or surface support requirements (Amie, 2020).

Amie (2020) further states that other variants of the bord and pillar method of mining coal seams include room and pillar, pillar and stall, chamber and pillar, breast and pillar, post and stall, etc. The basic principles of their design, however, remain almost the same. The process of mining in a bord and pillar layout (Figure 2.5) was previously performed using the conventional drilling and blasting method. However, the introduction of Continuous Miners (CM) has improved the conventional way of mining.

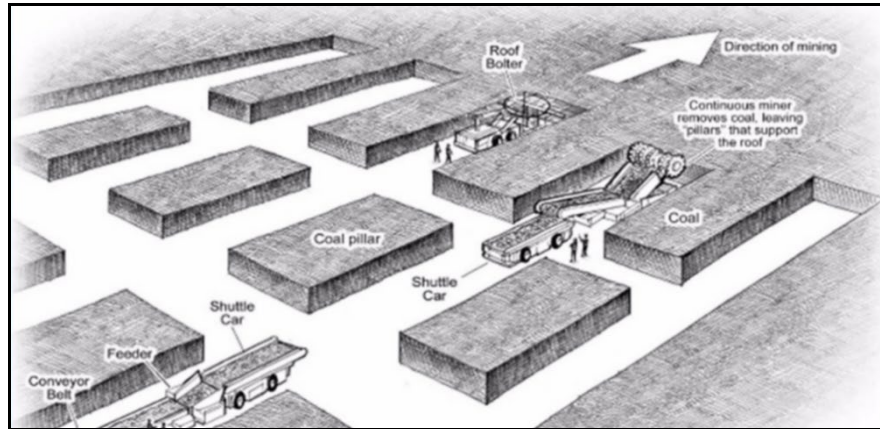


Figure 2.11: Bord and pillar mining (Source: Harraz, 2014)

Coal is extracted using a CM whose components, such as the rotating drum with sharp picks, allow it to cut and load the coal simultaneously. The extracted coal is loaded onto shuttle cars and/or conveyor belts and transported to the surface. A roof bolter is used to install support to the mining face (Baloyi and Meyer, 2020).

b) Longwall mining

According to Kohler (2020), longwall mining is applied to thin, bedded deposits with uniform thickness and large horizontal extent.

Typical deposits are coal seams, potash layers or conglomerates, trona, and gold reefs. The ore is extracted in a slice along this long wall. The region adjacent to the face is kept open, i.e., free of obstructions, to allow space for miners and equipment as shown in Figure 2.6. As the coal is removed entirely, the roof is allowed to collapse into the mined-out void. The mining face is protected by supports, which are moved forward as mining progresses. Collapse fractures the overlying rocks and can cause surface subsidence if mining is shallower than about 200 m. In such cases, fractures will extend through to the surface (McCarthy and Pretorius, 2009).

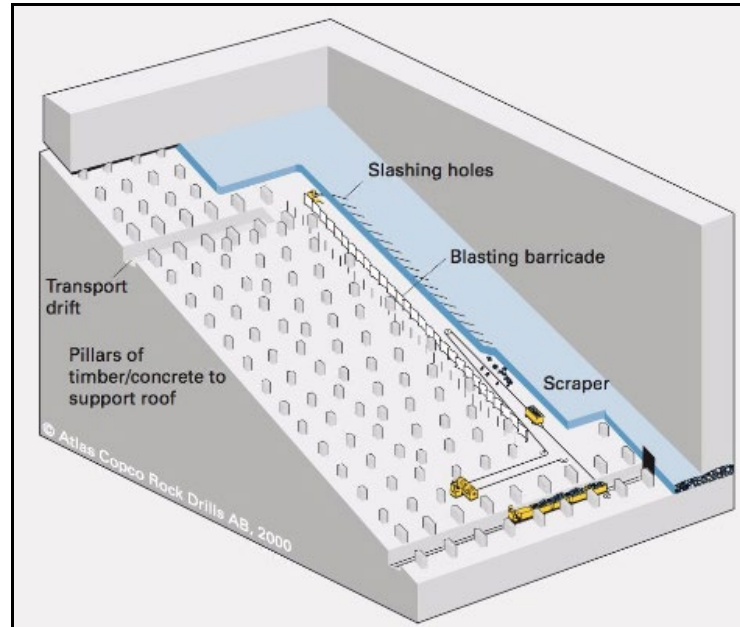


Figure 2.12: Longwall Mining Illustration (Source: Kohler, 2020)

In longwall mining, a coalbed is blocked out into a panel averaging nearly 244 m in width, 2100 m in length, and 2.1 m in height by excavating passageways around its perimeter (Kgweetsi, 2016). A panel of this size contains more than 1 million short tons of coal. In essence, the method involves removing large, rectangular coal panels. A section of the coal bed is blocked out in panels, and passageways are dug on three sides of the panel, starting from the main entry of the mine. Coal is then mined on “retreat”, meaning the extraction process moves from the far end of the panel towards the main entry (Kgweetsi, 2016).

2.4.2. Surface mining

Surface mining techniques explore the fundamental principles of opencast, strip and open pit mining methods.

a) Opencast mining

Opencast mining employs a conventional mining cycle of operations to extract minerals as shown in Figure 2.7.

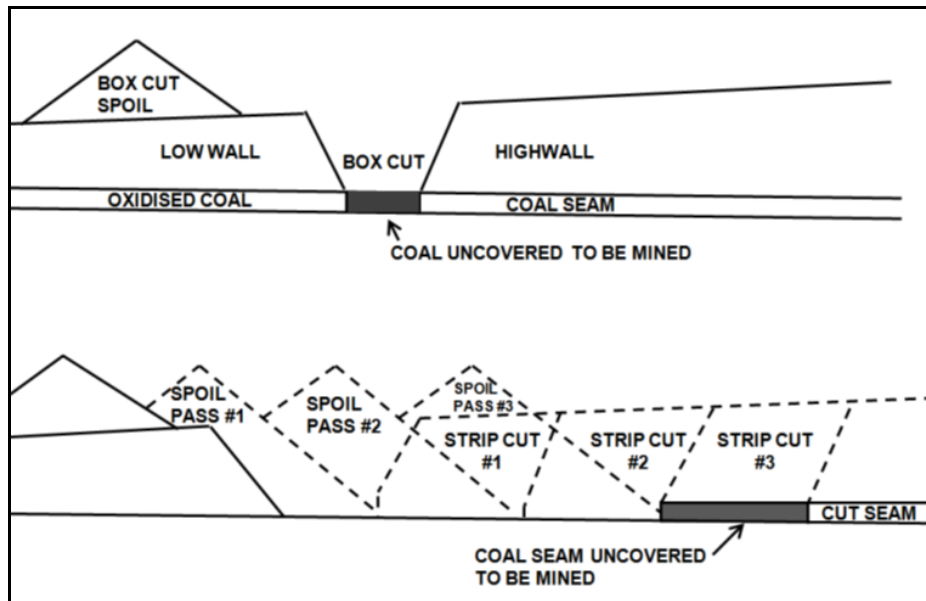


Figure 2.13: Illustration of box cut, strip cuts, and spoil piles in opencast mining (Source: Mitra and Saydam, 2012)

Rock breakage is usually accomplished by drilling and blasting for consolidated materials and by ripping or direct removal by excavators for unconsolidated soil and/or decomposed rock, followed by materials handling and transportation (Yamatomi and Okubo, 2009). Thus, in this form of mining, the soil cover is scraped off and stockpiled, the rocks overlying the coal seam are blasted and removed to one side, and the coal is then extracted. Next, the broken rock is returned to the pit, the site is landscaped, the soil is returned, and grass is planted (McCarthy and Pretorius, 2009).

b) Strip mining

According to Mitra and Saydam (2012), strip mining is ideally applied where the ground surface and the ore body are relatively horizontal and shallow, and where a wide area is available for mining in a series of strips.

Strip mining exposes coal by removing the earth above each coal seam as shown in Figure 2.8. This overburden is removed in long strips. The overburden from the first strip is deposited in an area outside the planned mining area and referred to as out-of-pit dumping. Overburden from

subsequent strips is deposited in the void left from mining the coal and overburden from the previous strip. This is referred to as in-pit dumping (Balasubramanian, 2016).

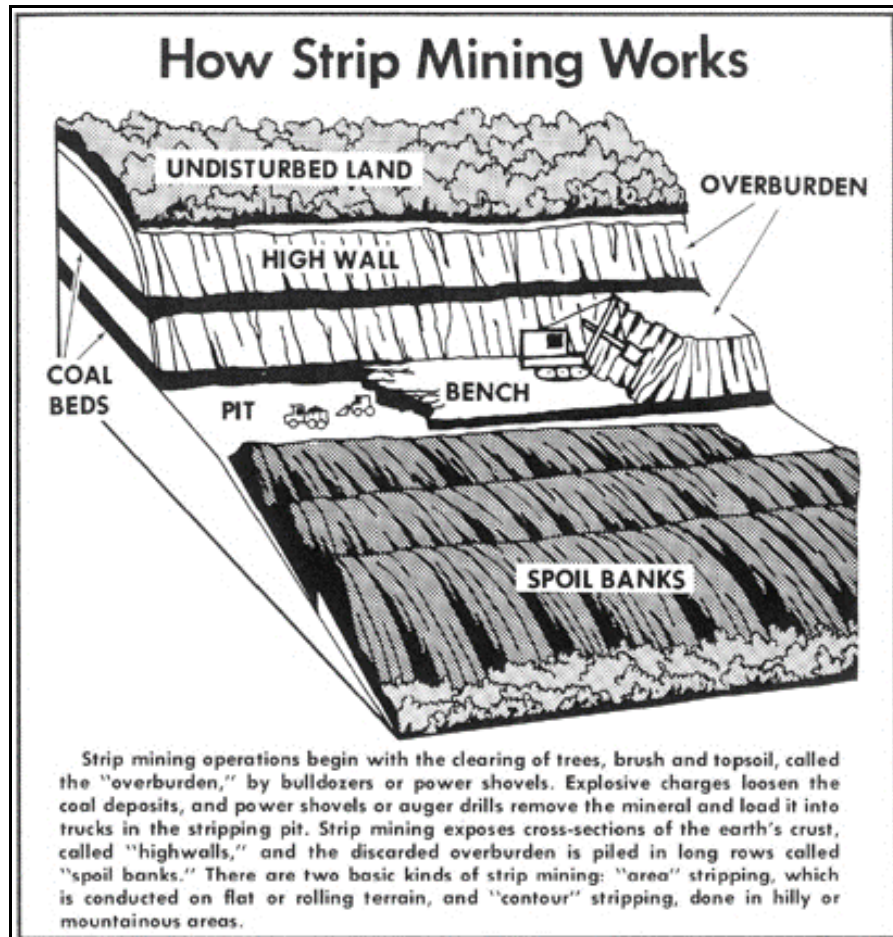


Figure 2.14: How strip-mining works (Source: Hamer, 1973)

c) Open-pit mining

This type of mining involves the extraction of rock or minerals from the earth by forming an open pit as shown in Figure 2.9 and Figure 2.10. This process differs from the other methods as it requires digging into the earth.

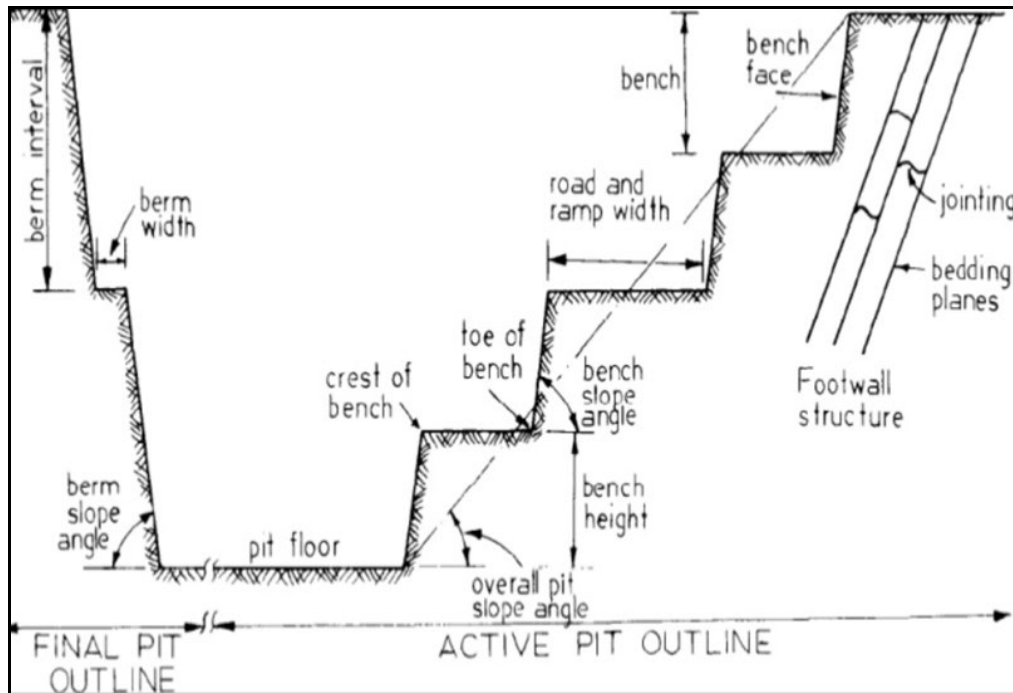


Figure 2.15: Main mine elements and parameters (Source: Mining Engineering, 2016)

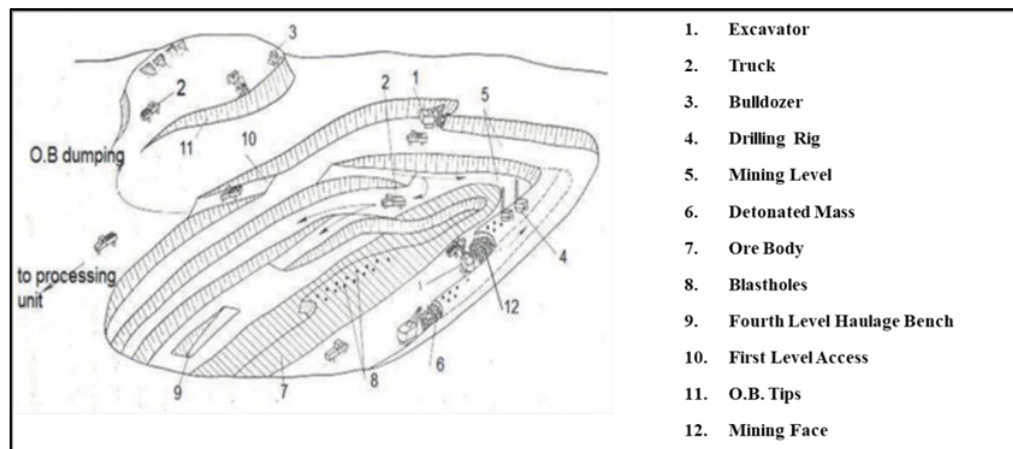


Figure 2.16: Detailed mining operation in an open pit (Source: Altit et al., 2021)

This mining method is used when useful minerals or rocks are found near the surface. The open-pit method is generally practised where thick seams are overlain by thick or thin overburden. It is also used for mining steeply pitching coal seams. In open-pit mining of the coal seam, several benches are established in both the overburden strata and the coal seam.

In the early stages of mining, considerable volumes of overburden must be stockpiled in large dump areas outside the mine (Balasubramanian, 2016). In essence, the above method illustrates the most dominant underground and surface mining methods worldwide for extracting minerals. In South Africa, the opencast coal mining environment largely employs area strip mining. Strip-mining is applied where the terrain is flat, commencing with a trench or box cut made through the overburden to expose a portion of the coal seam (Iwuji et al., 2016). Opencast pillar mining follows a layout and stripping sequence similar to those of conventional opencast mining (Ngwenyama et al., 2017).

The coal remaining in the ground as a result of bord and pillar mining is central to this study. These remnant pillars have attracted a large number of junior coal miners to Mpumalanga. These miners seek to recover the leftover coal through opencast extraction of these previously mined underground workings. The extraction of these pillars is carried out using similar conventional opencast (surface) mining methods. However, as noted by Van der Merwe and Mathey (2013), the concept of probability of failure (PoF) is much more meaningful for pillars. A concept that needs to be entrenched in every miner's operation concerned with the mining and extraction of pillars. This is particularly important from previous bord and pillar operations that have since ceased operating.

Even though Van der Merwe and Mathey (2013) raise arguments for the extraction of pillars in bord and pillar operations, this work could be useful in its application to operations that extract pillars using surface mining methods. Van der Merwe and Mathey (2013) further argue that the use of either the maximum likelihood or minimum overlap formulae can result in significant benefits in extraction. However, these benefits are predicated upon a design that is based on a PoF of 1% for general underground workings. This finding makes it increasingly important for miners planning or already extracting coal pillars from old underground workings to

understand the pillars' strength to ensure a safe working environment and ultimately a profitable operation.

2.5. South Africa's Junior Mining Sector value chain

According to Bascetin et al. (2011), prospecting by the Junior Mining Sector (JMS) is a key input to renewal and growth in the mining sector. Which (via mineral commodities) is a major driver of the wealth that is created by manufacturing and flows on through its derivative markets. In the past years, it was estimated that South Africa lagged behind its peers in exploration. In response, the Industrial Development Corporation (IDC), in partnership with the DMRE, initiated a junior mining exploration fund (JMEF) worth R400 million (Industrial Development Corporation, 2024).

The purpose of the JMEF is to assist businesses in undertaking prospecting work as well as to increase access and licences for Junior Miners to exploit ore bodies. With the aim to promote economic inclusion to support equitable economic growth (Industrial Development Corporation, 2024). As previously reported by the Minerals Council South Africa (2019b), this subsector of the mining industry generated more than R54 billion in revenue in 2018. The revenue generated by Junior Miners in 2022 was recorded at R88 billion (Peyper, 2023). Therefore, it is very important to have initiatives like those introduced by the IDC and DMRE. Such initiatives will ensure that Junior Miners participate in the full value chain of the mining industry in South Africa.

2.5.1. Junior Miner business model

Junior Miners mostly operate on a small scale, with work largely undertaken under mining permits rather than mining rights. Most likely due to the stringent technical and financial requirements for applying for a mining right. Applying for a mining permit is much easier and quicker than applying for a mining right. Most of these Junior Miners' business models appear to be

predicated on acquiring mineral tenements close to those held by more accomplished miners (Jamasmie, 2010).

Upon receiving prospecting or mining rights, Junior Miners will then either explore for mineable deposits or hold onto these rights. In most cases these rights are only activated once prospecting by more accomplished miners generates evidence of mineable deposits in neighbouring tenements. Alternatively, some Junior Miners prefer to acquire tenements previously mined by more accomplished miners but abandoned because the resources no longer met the required economic feasibility.

This latter approach was chosen by the mines included in this study. The advantages of mining old mine workings deemed to be economically inferior for the more accomplished miners is the risk-cost benefit afforded to Junior Miners. The Junior Miners have the advantage of knowing exactly what is underground as no exploration is required. They also benefit from infrastructure that has already been used. All these factors ultimately lead to fewer upfront capital outlays and requirements. As a rule of thumb, miners opting for the second option always mine abandoned operations using opencast methods, even though the operation might have previously been mined underground. The idea of mining these old workings using opencast methods stems from several factors, including cost (Rupprecht and Pieters, 2018), safety, capability associated with the ease of opencast mining, and a lack of processes, procedures, and skills to economically mine the coal.

Most operations are financed by the buyers of the coal known as “offtakers”. In an ideal situation, the offtaker will pay for the coal in advance (SA Mining, 2025). This affords the miner the opportunity to mine sufficient volumes of coal before collecting the product. This helps miners with cash flow but also ensures they do not need to raise capital through other instruments. For instance, Mine 1 in this research utilises this capital-raising strategy very well, where off-takers pay two weeks in advance to finance the mining of their own product. The strategy of Mine 2, on the other hand, is a little different. It still raises operational capital from coal buyers, who pay a

deposit for 50% of the volume they want. Coal collection occurs only 3 days after paying the 50% deposit. Thus, meaning that Mine 2 needs to have some capital of its own to ensure sustained operations, while Mine 1 can simply run on the finance supplied by the off-taker. Ever since the start of both Mine 1 and Mine 2 they have only been producing run of mine (ROM). This was due to higher coal prices, prices were even better for good-quality ROM.

Neither mine had ever thought of having a crushing and screening facility on its premises. However, the recent slump in coal prices has necessitated both mines to rethink their business model. Mine 1 has still not brought in or installed coal crushing and screening facilities on its premises, while Mine 2 has already mobilised and started crushing and screening coal to produce a finished product that sells at a premium.

2.5.2. Funding and investment for Junior Miners in South Africa

The lack of funding from traditional capital sources, such as debt financing and equity investments, has made it necessary for junior mining companies to discover and access alternative funding sources (van der Veen, 2022). It is said that funding Junior Miners in South Africa is a game of patience simply due to the two to five years that it takes from planning to implementation. According to Solomons (2018), the lag time is due to securing licences, attracting a strong team, compiling the Competent Persons Report, and securing a market for the product.

Developing and aligning mine plans to meet the market demand, designing a mineral process plant, and securing a logistics path to market are all time-consuming tasks that Junior Miners need to overcome before they can start producing. The current push for decarbonisation tends to make it difficult for investors and funders to support junior coal miners. Even with the ZAR400 million JMEF initiatives, as the JMEF is aimed at funding Junior Miners across all commodities, not just coal. Besides funding, Mackay (2022) notes

that South Africa's junior mining sector is held back by multiple obstacles, including well-documented problems with government policy and its implementation.

The historical lack of funding and investment for Junior Miners has left most of them struggling to either continue or expand operations. It is common knowledge that once a mining operation starts, it is always advisable to expand it to extend its life of mine and add value. This not only benefits the owners of the mines but also the surrounding communities where they are located. Therefore, production-based funding has become an increasingly common option for the junior mining sector. Production financing is conducted when companies secure funding by selling the right to future production at a mine (van der Veen, 2022). This method of funding is utilised by both Mine 1 and Mine 2, though to different degrees, and has been the method of operation for both mines.

2.6. Value proposition of junior coal miners

Junior coal miners supply both the domestic and international markets with various products. According to Eberhard (2011), in South Africa's economically recoverable coal reserves, 96% are bituminous coal while metallurgical coal accounts for approximately 2%, and anthracite for another 2%. Coal production is mainly from bituminous coal which is used for domestic power and synfuel production. This coal tends to have much lower calorific and higher ash values. Supply is mostly from screened run-of-mine production (although about a third of the coal supplied for electricity production is derived from the middlings fraction from coal washing). The coal quality specifications supplied to both domestic and international markets are summarised in Table 2.2.

Table 2.2: Coal qualities, specifications, and definitions (Source: GlobalCoal, 2019)

Parameter	Quality			
	RB4	RB3	RB2	RB1
Total moisture (ARB)	<12% (AR)	<14% (AR)	<13% (AR)	<12% (AR)
Volatile matter (ARB)	>18% (AR)	>20% (AR)	>21% (AR)	>22% (AR)
Total sulphur (ARB)	<1.5% (AR)	<1% (AR)	<1% (AR)	<1% (AR)
Calorific value (NAR)	>4500 (Kcal/kg)	>5300 (Kcal/kg)	>5700 (Kcal/kg)	>5850 (Kcal/kg)
Ash (ARB)	<32% (AR)	<22% (AR)	<17% (AR)	<15% (AR)
Hardgrove index	45 - 70	45 - 70	45 - 70	45 - 70
Ash fusion temperature	1250°C	1150°C	1250°C	1250°C

*ARB = As Received Basis, NAR = Net As Received

2.6.1. Types of coal products

South Africa's coal is mainly supplied to the domestic and export markets. Coal products are governed by the Standard Coal Trading Agreement (SCoTA) specification parameters for basic trading (Steyn and Minnitt, 2010). The SCoTA, provides commercial framework and technical specifications for coal transactions. It standardises terms, testing methods, and product benchmarks to reduce disputes and promote transparency across borders. The type of coal produced in South Africa follows the SCoTA naming framework. South African coal is dominated by RB4 which is the lower quality coal destined for the local market, while RB1, RB2 and RB3 are higher quality products and are exported to the international markets.

Most of the 4800 kcal/kg product is destined for Eskom in the local markets, although some is exported. In most cases, the ROM mined meets Eskom's quality specification and it does not need to be beneficiated. This often assists Junior Miners, since most of them do not own or have access to beneficiation facilities to upgrade (wash) the ROM. The ROM is simply dry-

crushed and screened on-site, then loaded onto trucks for delivery to Eskom. In some instances, Junior Miners even trade coal amongst themselves, with one Junior Miner buying ROM from another to either supplement their commitment to Eskom or export clients.

However, real value in the 4800kcal/kg coal lies in the value added (sizing it). Miners that can size the product can charge a premium for it. There are studies that have shown that the beneficiation of coal to improve its quality will directly and positively influence the performance of a power station's ability to generate electricity. However, this is not always possible, especially for Junior Miners who do not have access to these beneficiation facilities. Hence, most Junior Miners will only look for projects with superior raw coal qualities. Domestically, Eskom is the largest consumer of this coal, according to Minerals Council South Africa (2022). In the 2020/21 Integrated Report, Eskom indicated that it burnt 104.87 million tonnes of coal.

The export market for coal is dominated by RB1, RB2, and RB3. However, most coal mining companies in South Africa supply RB1 and RB3. Junior coal miners play a significant role in supplying these export coal products, since most major coal miners already have clients that they supply. It becomes difficult for new consumers to get supplies from the major miners, and this gap is filled by junior coal miners. In seasons of high demand, Junior Miners tend to achieve higher revenues and profits (Figure 2.11).

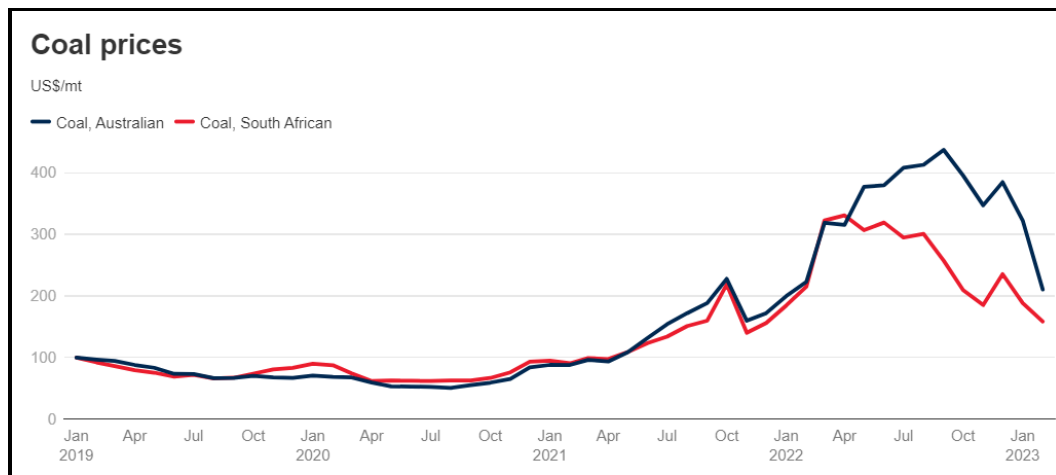


Figure 2.17: Coal prices between 2019 and 2023 (Source: Agnolucci et al., 2023)

Agnolucci et al. (2023), posit that increased exports by countries such as South Africa and Colombia—whose combined share in total European imports has been 35% since August 2022—have partially offset the reduction of Russian exports to Europe. Prices were expected to be lower in 2023 (on average) compared to 2022 (Figure 2.10) but remain high by historical standards. Some South African producers have shifted their production from NAR 5,700 kcal/kg product to NAR 5,500 kcal/kg coal. The shift was spurred by a tightening differential between the two grades (Elliot, 2023).

Global coal demand was set to rise slightly in 2022 as countries looked to meet rising energy demand while struggling with lower economic growth (International Energy Agency, 2022a). South Africa's coal exports have been steady, with positive changes seen in Asian markets in 2023 (Figure 2.12), even though international prices had receded.

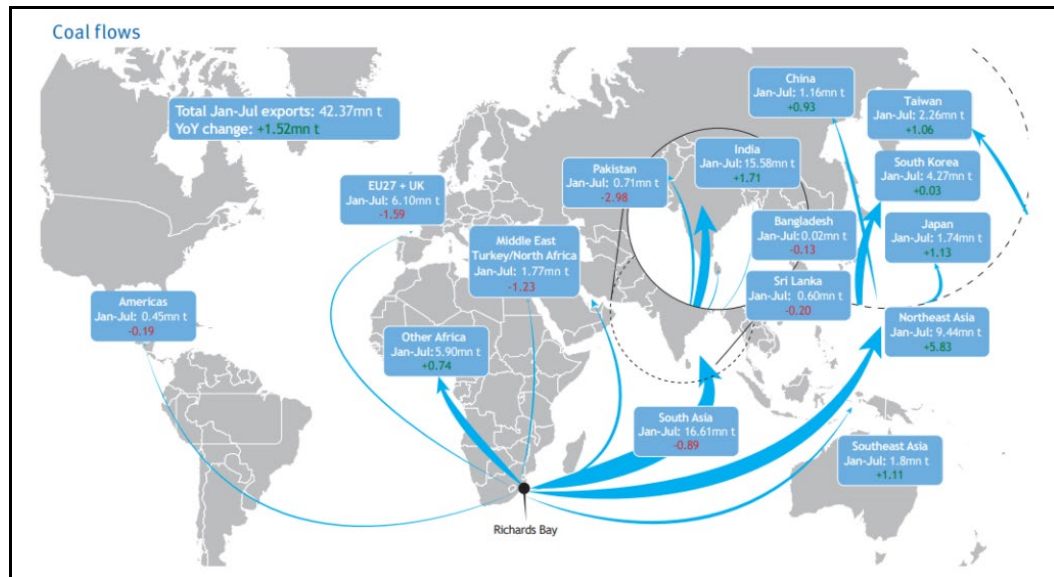


Figure 2.18: South African coal exports in 2023 (Source: Coal Hub, 2023)

The speed of the coal decline in subsequent years depends on the stringency with which countries pursue climate and environmental targets. As previously mentioned, there is a focus on the supply of RB3 and according to Elliot (2023), this focus is simply due to the yield loss of scrubbing the RB2 product.

2.6.2. Run of mine

Junior Miners tend to dominate the market for selling ROM, whereas major miners use their ROM to produce different types of products, mostly for domestic and export markets. Major miners have access to beneficiation facilities, which give them an advantage over Junior Miners. Therefore, customers who want to buy ROM are likely to obtain it from Junior Miners. For instance, both Mine 1 and Mine 2 are still supplying ROM to some of their customers even though Mine 2 seems to be gradually moving away from supplying ROM.

2.6.3. Corporate social responsibility

Corporate social responsibility (CSR) is often a major challenge for junior mining companies, which often cite a lack of funding or insufficient experience to implement a full-scale CSR programme (Vella, 2014). Most Junior Miners engage in mining activities not just for the benefit of the owners of these projects but also for the communities in which they operate. However, it is not always easy to deal with communities, as conflicts tend to arise for a number of reasons, with CSR being among them. Bezzola et al. (2022), have investigated the relationship between CSR payments and conflicts in African mining communities using econometric techniques.

They have shown how CSR programmes are sometimes used as a trade-off with the mine undertaking them to keep the community happy. The results of Bezzola et al. (2022) suggest that the higher the conflict intensity in mining areas, the greater the probability that mining companies will engage in CSR activities. Thus, CSR programmes become a means to an end rather than being undertaken to foster mutually beneficial relationships between mines and communities. A major part of miners' CSR programmes centres on their positive economic impact on the community. For Junior Miners, their CSR largely focuses on providing employment and business opportunities in what the South African mining charter has described as labour-sending areas.

According to Carr and Mann (2023), some Junior Miners have over 900 employees and 1500 contractors, 90 per cent of whom are local. For the purposes of this research, Mine 1 had approximately 260 employees and 83 contractors and Mine 2 had approximately 57 employees and 17 contractors. However, the one thing that they both lacked was commitment to their CSR programmes. This was simply because the funds were either insufficient to operate the mines or to carry out their CSR. In some instances, there were challenges with the municipality where mines were requested to undertake projects that were the municipality's responsibility.

Another factor that makes implementing CSR initiatives difficult is that most Junior Miners operate under mining permits. These permits are valid for a maximum of 2 years and can be renewed 3 times for a period not longer than 12 months per renewal cycle. Therefore, most Junior Miners will push to mine as much as possible so they can finish before the mining permit expires.

The absence of comprehensive CSR programmes often led to community protests, as local residents felt the mines operated solely for profit, without addressing community needs. During data collection for this study, it became evident that the only CSR initiatives both mines had successfully implemented were the employment of local residents and the provision of business opportunities to local suppliers. No additional community-based or broadly beneficial social initiatives had been undertaken.

2.6.4. Objectives and classifications of Junior Miners

The current trend is that some junior miners enter the industry solely to extract economic benefits from operations, rather than with a long-term sustainability perspective. As evidenced by the mines studied for this study, their main goal was to get the operation started, implement the basic requirements as legislated by law, and run it. This was simply due to the capital outlay required in every startup mining operation.

Junior Miners have been classified in many ways, as can be seen in the section below. According to Moodley (2021), Junior Miners comprise explorers, developers and smaller producers while Iddon et al. (2013) recognise the junior mining sector (JMS) as entities solely in an exploration and/or pre-mining developmental phase. The Mining Qualifications Authority (MQA), Centre for Sustainability in Mining and Industry (CSMI) and the Chamber of Mines regard Junior Miners as a mining or quarrying operation that has between 50 and 200 employees, gross assets of between

R4.5 and R18 million and a turnover of between R7.5 and R30 million, as reported by Chukwudumebi (2018).

According to Moodley (2021), classification is contrary to the MQA and CSMI classification and can be summarised as follows.

- Exploration companies are essential to the long-term survival of the South African mining sector. Without finding new deposits, a mining economy cannot survive in the long term. It becomes important for the state to support a high-risk activity, such as exploration, which largely relies on venture capital markets, by providing investment incentives.
- Developers take a known deposit and build it into a mine with a view to moving it into production. Most junior mining companies in South Africa that are explorers and developers wish to become established as miners in the long term.
- The third category of Junior Miners in South Africa consists of smaller and mid-tier producers who typically buy a small operation with the intention of mining. The Minerals Council defines these producers as having an annual turnover below R500m. They are found in most mineral commodities – coal, gold, platinum, manganese, chrome, and diamonds, for example. The biggest concentration is in coal, with many being wholly owned and managed BEE companies.

Chukwudumebi (2018) has classified miners into three categories as seen in Table 2.3. This classification is quite generic. However, it does cover the main components of the entire mining spectrum.

Table 2.3: Classification of large-scale, small-scale or artisanal and junior mining companies (Adapted from Chukwudumebi, 2018)

Large Scale Corporate Mining	Junior Mining	Small-Scale or Artisanal Mining
Covers bigger sizes or concession areas, up to 5000 hectares. Make up about 85% global production of a particular mineral commodity. 2.5 million Employees worldwide. Revenues higher than R40 billion. Heavy equipment, high-tech and large output operations. Highly diversified investment portfolios.	Much smaller concession areas of about 1000 hectares. Make up above 15% global production of a particular commodity. Employs a few hundred people but sometimes in thousands, with turnovers in tens to hundreds of millions of Rand. Focus on exploration with little or no revenue from production. High exploration investment risk, which is critical in the initial stages of the coal value chain. Mining operations are mechanised and sometimes high-tech.	Make up less than 15% global production of a particular commodity. Turnover of less than R7 million. Employs fewer than 50 people. Manual labour using rudimentary tools and equipment.

There is no single universal definition for what constitutes a Junior Miner. From the available research, Junior Miners are classified according to the stage of operation they are in, while other scholars classify Junior Miners according to their revenue and staff complement.

2.6.5. Development and constraints

There are very few Junior Miners in South Africa, out of the 77 members of the Minerals Council of South Africa, only 38 or about 50%, were juniors in 2018. However, the sector is growing exponentially. With how each mining sector contributed to this growth had not been determined. But it is suspected that coal juniors were a major contributor (Campbell, 2023). Furthermore, Campbell (2023) notes that South Africa's mining regulator was dysfunctional, leading to delays of up to years in issuing of mining licence. As previously stated, most junior coal miners tend to prefer applying for mining permits, since the costs are lower than that of applying for mining rights.

The historical, dysfunctional, and lengthy processes of the mining regulator also reinforce the preference for the quick, relatively easy process of applying for mining permits. Another factor hindering development is logistics: most miners struggle to transport their coal from the mine to the port for export markets. This challenge has persisted for many years, and Transnet's inability to accommodate Junior Miners has forced most of them to rely on road trucks to transport their coal. However, as with any sector, a sustainable solution is required since road transportation for coal only makes sense when coal prices are high.

In April of 2022, Transnet declared force majeure on contracts with producers, but with coal prices near record highs, most producers opted for truck transportation (Banya and Reid, 2022). Trucking coal costs about four times as much as rail, this is a financially unsustainable situation particularly for junior coal miners. Approximately 14% of junior coal miners use road to

transport their products, 4% use rail transport and 82% make use of both road and rail. Companies that use road transport usually supply the local market and the 13 Eskom power stations (Ncube, 2020). Furthermore, challenges faced by junior coal miners in terms of coal transportation were summarised as follows (Ncube 2020):

- I. Road transport – about 80% of the junior coal miners were facing challenges of damaged roads, 15% were of the opinion that road transport is expensive and only carries about 30 tonnes of coal per truck, 5% complained about truck breakdowns.
- II. Rail transport – Most companies mentioned that rail transport is too slow and raises port storage costs. They also pointed out that railway lines are located far from their mines and the port, requiring them to hire trucks to move between the mine and the railway station, as well as between the railway siding and the seaport.

Therefore, there is still considerable work to be done to help junior coal miners fully participate and achieve the economic benefits they seek from their mines and operations. Another constraint that significantly delays the development of Junior Miners is the lack of a cadastral system. The absence of a cadastral system places significant pressure on junior mining companies. Within the Southern African Development Community (SADC), South Africa is one of the few countries without a cadastral system. The elusive cadastral system is also putting serious brakes on Greenfields' exploration (Peyper, 2023). The cadastral system is a comprehensive recording of the defined mineral deposits, mineral distributions and mineral tenements in a country (Frost, 2023).

Furthermore, it is common knowledge that, for mining companies to continue operating, they need to replenish their pipelines, which can only be achieved through exploration. The Minerals Council South Africa and Johannesburg Stock Exchange (JSE) have been working in collaboration to attract junior mining and exploration companies to eventually list on the JSE. The JMEF initiative by the IDC and DMRE should alleviate some of the

pressures Junior Miners face in developing and expanding their operations. However, even with the JMEF being made available, it is imperative that development and the expansion of operations follow a well-constructed, well-thought-out model. A model that will not only yield positive results but also ensure sustainability going forward.

2.7. Remnant metal mines and Junior Miners

Mining in general, and South African hard rock mining industry in particular, has faced a number of challenges over the past three decades resulting in declining production and subsequent mine closure. Many mines that were closed were mostly abandoned without rehabilitation having been implemented or incomplete (Rupprecht and Pieters, 2018). Presently, South Africa is plagued with the opening of mostly old closed and abandoned mines by miners with licenses to operate and those without licenses. The re-opening of closed shafts in South Africa has shown that there is value that can still be extracted.

This presents an opportunity to make a positive impact to the mining industry, local communities and the country as a whole. The increase in metal prices and policy reform (Webster, 2026) has also been responsible for the ongoing activity into the opening of old mine-workings. The objective of re-opening some of these old and abandoned mines is to mine the remnant pillars. The operators in these old and abandoned remnant metal mines are mainly small-scale miners.

Remnant pillar mining in metal mines refers to the extraction of valuable ore pillars or isolated blocks of ground left behind due to difficult mining conditions (Sellers et al, 2005).

Pieters (2018) notes that the largest impact from introducing small-scale mining would be job creation within poor communities that have been previously affected by mine closures. Wienand and Ferreira (2007) also note that a multi approach that includes geotechnical extractability,

accessibility and economic viability are essential considerations that need to be taken into account when planning the extraction of remnant pillars. There are safety and risks considerations that need to be taken into account to successfully operate remnant mining operations. Gouvea (2024) notes that risk is an integral part of mining, therefore, 'acceptable risk' becomes a necessary and significant consideration when assessing the mineability of a block of ground.

Furthermore, it is suggested that a practical approach is to implement measures that result in acceptable levels of reliability and safety. One of the measures is thorough design, to ensure that all likely hazards have been satisfactorily addressed. Le Roux and Stacy (2008), developed a remnant failure index (RFI), based on the Mohr–Coulomb failure criterion. The RFI can be used to evaluate remnants for possible violent failure. Furthermore, it will enable practitioners to model proposed mining layouts for the remnant, identify possible areas within the remnant where failure can occur and identify the mining step at which it is expected to happen (Le Roux and Stacy, 2008).

There is still considerable work that need to be undertaken in the mining of remnant pillars in metal. Although there is a large volume of remnants to be extracted, very little research has been done to evaluate the risks involved (Singh et al, 2006). Additional evidence into the lack of substantial research into the mining of remnant pillars is provided. The work done by Esterhuyse and Malan (2018) shows that even literature surveys do not provide any recommendations for multi-reef mining and multi-reef remnant scenarios. The success of remnant metal operations lies in understanding each remnant's unique features. These features encompass physical characteristics and historical data, response to seismic hazards and geotechnical features management and economic viability of the project.

2.8. Legal framework

After 1994, stricter laws were passed to govern mining activities, as they impact the environment, water quality, air quality, protected areas, and heritage sites. Therefore, companies applying for prospecting/mining rights or permits needed to do so in accordance with this legislation framework (Chukwudumebi, 2018). In South Africa, the primary legislation governing mining and environmental activities is the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA) and the National Environment Management Act 107 of 1998 (NEMA). Mining Mirror (2017) notes the following as the objectives of the legal framework governing mining and environmental activities in South Africa.

The objectives of the MPRDA include:

- a) recognition of the right of the state to exercise sovereignty over all the mineral and petroleum resources within the Republic and to give effect to the principle of the state's custodianship of the nation's mineral and petroleum resources.
- b) promote equitable access to the mineral and petroleum resources to all people of South Africa.
- c) substantially and meaningfully expanding opportunities for historically disadvantaged persons.
- d) promote economic growth and mineral and petroleum resources development in the Republic.
- e) promote employment and advancing social and economic welfare of all South Africans.
- f) give effect to section 24 of the Constitution by ensuring that the nation's mineral and petroleum resources are developed in an orderly and ecologically sustainable manner. While promoting justifiable social and economic development.
- g) ensure that holders of mining and production rights contribute towards the socio-economic development of the areas in which they are operating.

The stated objectives of NEMA include:

- a) provide for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment.
- b) promote co-operative governance, and procedures for coordinating environmental functions (exercised by organs of state) and provide for certain aspects associated with this, including recognition that everyone has a right to an environment that is not harmful to his or her health or well-being.
- c) sustainable development, which requires the integration of social, economic and environmental factors in the planning, implementation and evaluation of decisions to ensure that development serves present and future generations.

In addition to the MPRDA and NEMA, the legislative framework includes important legislation such as the National Environmental Management: Protected Areas Act 57 of 2003 (NEM: PAA), the National Environmental Management: Waste Act 59 of 2008 (NEM: WA), the National Water Act 36 of 1998 (NWA), and the National Environmental Management: Biodiversity Act 10 of 2004 (NEM: BA).

Chukwudumebi (2018), also notes that other legislation may include the Mines Health and Safety Act (MHSA) of 1996, the Skills Development Act of 1998, and the Basic Conditions of Employment Act (BCEA) of 1997. Therefore, applicants are generally required to know this legislation before applying for prospecting and/or mining rights.

Thus, it is very important to be well-informed to ensure that decisions taken before embarking on mining any resources in South Africa are based on fully researched and understood information. Failure to use a decision-based approach when making decisions regarding mining projects and operations may result in consequences that may complicate the viability of the project and operation while also putting the owners of such projects in trouble with the law.

2.9. Chapter summary

This chapter focused on coal mining literature that is already available from other scholars. It was noted that different types of coal products are produced and sold to different markets based on the qualities of the coal. Furthermore, it was established that the mining industry is cyclical in that global trends and geopolitics tend to play an important role in coal pricing, availability and sales. Different coal mining methods (underground and surface) were explored with particular attention focused on methods that would ensure coal is efficiently extracted and the economic benefit is maximised.

The findings on the South African Junior Miners illustrated that the junior mining sector has a vague description of what constitutes a Junior Miner. It appears that revenue tends to be one of the most single important differentiators. Furthermore, gaps were identified in terms of the funding and operating models for Junior Miners when compared to the major and more established mining houses. Junior Miners tend to rely mostly on coal off-takers to fund their operations, where the off-takers would pay upfront for the coal to be mined.

The funding challenges often prompt Junior Miners to apply for mining permits instead of mining rights. In addition to funding challenges, most Junior Miners do not have access to reliable transportation for the products since most miners rely on road transportation. Lastly, it was noted that due to the nature of simply mining to generate revenue, most Junior Miners tend to relax their efforts on the legislation and regulations governing mining.

CHAPTER 3: EMPIRICAL DATA COLLECTION AND FIELD OBSERVATIONS

This chapter outlines the experimental work conducted and the data-collection methods used to compile this research. These included piloting blasting overburden up to approximately 0.5 m above the top of coal, cleaning around the coal pillars using a smaller excavator, site observation to study cycle times across the different stages of the operation, interviews with personnel at both mines, and document review and analysis. However, the interviews yielded little, as most personnel did not want lengthy discussions, so an anonymous interview questionnaire (Appendix G) was sent out.

3.1. Introduction

The two mines studied in this research were chosen because of their unique and similar circumstances of operation. Both mines are extracting pillars from previous underground operations, using mining permits. Lastly, the mines did not have much experience in mining prior to commencing with operations.

Mine 1 is a traditional truck-and-shovel coal pillar mining operation currently focused on selling ROM as it is mined. It is highly reliant on buyers funding it through a process where the buyers pay upfront for the coal. It has not used drilling and blasting as part of its daily production plan. This mine is located in the Emalahleni region in Mpumalanga, as previously mentioned. It is quite small compared to the surrounding operations and its potential.

Mine 2 is located near Balmoral, Mpumalanga. It is a historically bord-and-pillar operation that has since been converted to surface coal pillar mining. It is much more complex than Mine 1. This mine is mining two seams (Seam 4 and Seam 2); however, Seam 2 splits into Seam 2 Upper and Seam 2

Lower. Both Mine 1 and Mine 2 have a poor track record of retaining data and information useful for mining operations. Thus, gathering data from the two mines was a challenge.

The collected data included confirmation of the surveyed locations of the historical boreholes and cycle times between loading and hauling to the stockpiling area. Historical borehole data and analysis results were also used to interpret coal continuity and grade. The gathered data was analysed using Seequent's Leapfrog Geo and Edge software. This software was primarily used to analyse the spatial distribution and interpretation of the coal, as well as to produce a block model for mine planning and design. Studio OP software under Datamine® was used for pit designing, planning and production scheduling. Software analyses conducted for both mines during modelling include numerical modelling and basic geostatistics.

Two types of data collection methods were employed in this research: qualitative and quantitative (see Table 3.1). Qualitative data was mostly non-numerical, such as geology information, and usually descriptive or nominal in nature, as described by Kabir (2016). Quantitative data comprised all historical laboratory analyses, survey information, and collar information. This research was able to draw some statistical comparisons and graphs from the quantitative data.

Table 3.4: Data evaluation methods for the two studied mines in this research

Qualitative	Quantitative	
<u>Observations:</u> Observe how mining is carried out, time lags between loading and offloading, efficiency in the mining process, cause and effect of resource	<u>Document Analysis:</u> Analyse mine, production, and schedule plans, where available, to compare with production output.	Mined tonnages Numerical inputs for planning and scheduling

optimisation and maximisation.	Do a plan vs actual comparison.	
--------------------------------	---------------------------------	--

3.2. Methodological approach and rationale

A mixed-methods (quantitative and qualitative) approach, combined with primary and secondary sources, was adopted for this study to address key research objectives (Appendix H). According to Creswell and Plano Clark (2017), the mixed-methods approach focuses on collecting, analysing, and integrating quantitative and qualitative data within a single study or a series of studies. Its central premise is that combining quantitative and qualitative approaches provides a better understanding of research problems than either approach alone. Mixed-method research uses the practical method, and its logic of inquiry includes identifying patterns, testing theories and hypotheses, and abduction, as noted by Chavalala (2016).

Therefore, the mixed methods provided the best philosophical and numerical foundation for this study. This resulted in a comprehensive understanding of the models that miners will use to base their decisions on pursuing mining operations and the efficient extraction of coal pillars. The application of both methods allows for the expression and testing of all data gathered.

3.3. Research design

The research design process involves many interrelated decisions (Sileyew, 2019), with the intention to provide an appropriate framework for a study (Appendix H). A very significant decision in the research design process is the choice of research approach, since it determines how relevant information for a study will be obtained. The descriptive research design was chosen for this study due to its ability to accurately portray the individuals, working environments as well as different stakeholders in their entirety as shown in Figure 3.1.

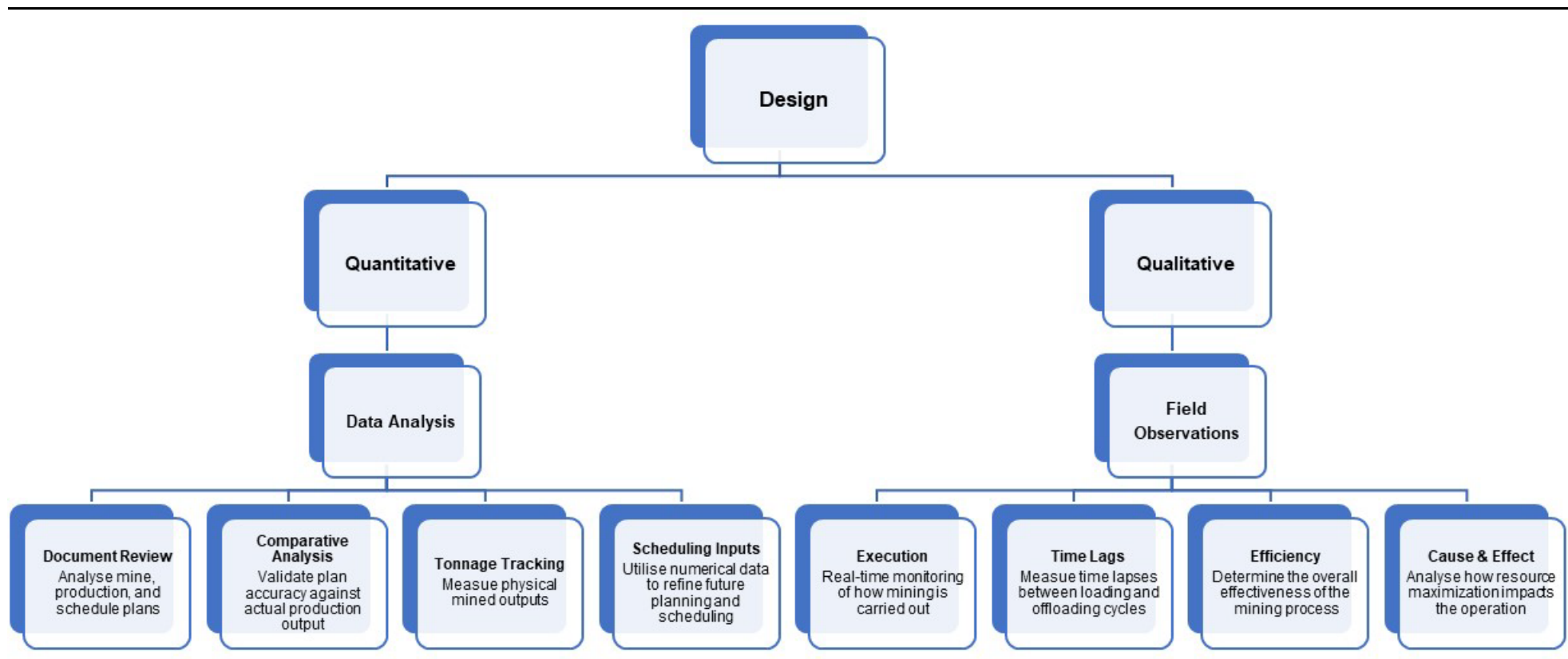


Figure 3.1. Descriptive design approach employed in this study

For the purposes of this research, the first part of the study was collecting historical data for analysis and interpretation. The second part of the study used a multiple-case study design, which allowed exploration of differences within and between cases. As noted by Sileyew (2019), this design offered the researcher a profile and perspective of individual miner's operations. Therefore, this design was pivotal in assisting the researcher in fully capturing, gathering, analysing, and interpreting data to produce a decision-based model for coal pillar miners.

This made it easier to have an in-depth comparison of sites, highlighting their uniqueness and similarities where applicable. The multiple case studies provided data that was specific to each case (mine), precisely detailing the functioning of each site. However, it is important to note that generalisation between the mines was difficult, a phenomenon also reported by Chavalala (2016) and Yin (2013). For the purposes and objectives of this study, generalisation to a certain extent is assumed.

Generalisation is based on site similarities in that they are all coal mines within the Emalahleni region, mining coal pillars from previously underground bord and pillar operations. Greene and David (1984) argue that generalising from a sample of cases can be justified only to the extent that relevant characteristics of the sample are representative of the same characteristics of the target population. Thus, for this study, generalisation to a certain extent can be made, all of which is underpinned by the mines' similar ways of extraction and experience in mining.

3.4. Data collection

The data was collected in two ways: first, by collecting any current and historical information. Secondly, it was studying how the mines operate on a daily basis, with a focus on the execution of their tasks in extracting the coal pillars. Primary data was collected through interviews with representatives of Junior Miners in this study and through site visits during

which operations were observed, as detailed in the following subsections. Secondary data was collected through documents such as previous production performance which were then reviewed and analysed.

3.4.1. Historical data

This research studied historical information from the mines regarding their mine designs, schedules, plans, and, where applicable, production data. The historical data collected included geological data, collar data, survey data, laboratory analysis (assay data), and reports from historical exploration conducted by third-party companies.

All this data was used as input to the construction of the geological model, which served as the basis for mine planning and design. The interpreted geological model was created using Sequeent's Leapfrog Geo software. The acquisition of this data was used to analyse net present value (NPV) maximisation, mine life optimisation, and the maximisation of extracted ore value using Datamine® software and Sequeent's Leapfrog Geo software.

The NPV is widely used to calculate the value of a mine project. It calculates the current value of a project's cash flows at the required rate of return relative to the initial investment. The NPV is calculated using Equation (3.1) below:

$$NPV = \sum_{n=0}^t \frac{R_t}{(1+r)^n} \quad (3.1)$$

Where:

NPV = net present value

R_t = net cash inflows – net cash outflows during a single period (Cashflow)

t = number of time periods (from initial year of investment to final year of production closedown)

r = discount rate

These parameters make it easier to maximise the total discounted profit, known as the net present value (NPV). To achieve the expected NPV, the operation needs to consider factors that affect mine planning and design, such as geological and geotechnical features/parameters (e.g., deposit size, dip, topography, and geotechnical parameters). The inputs that were used in the calculation of the NPV are summarised by Girardin and Skowronski (2023) as follows:

- Cash flows are the money spent or earned for the investment, including capital expenditures, interest, and loan payments. Each period's cash flow includes both outflows for expenses and inflows for profits, revenue, or dividends.
- The number of periods equals the number of months or years the project or investment will last.
- The discount rate is the company's weighted average cost of capital (WACC).
- A company's WACC is how much money it needs to make to justify the cost of operating. WACC includes the company's cost of capital, loan payments, and dividend payments.

The output of these calculations was the NPV, which was then used to determine whether the investments made by the two mines will be profitable in the future. It was very important to ascertain the profitability of the operations, as their existence and sustainability depended on the mines turning a profit. The discount rate ranges and benchmarks used to calculate the NPV were based on the work done by Ovalle (2020), as per Table 3.2.

Table 3.5: Discount rates by country for 100 System for Electronic Document Analysis and Retrieval (SEDAR)-filed projects, 2010-2020, and January 2020 values of country risk premiums (Source: Ovalle, 2020)

	Country	Discount Rate (%)	Projects	Country risk premium (%)
1	Argentina	5	1	8.88
2	Guatemala	5	1	2.46
3	Peru	5	6	1.18
4	Serbia	5	1	3.55
5	Mexico	5.63	8	1.18
6	South Africa	6.75	4	2.17

The Internal Rate of Return (IRR) of a project is the rate of growth or income expected from an internal project or investment. The formula for calculating IRR as shown in Equation (3.2):

$$0 = NPV = \sum_{n=0}^t \frac{R_t}{(1-IRR)^n} \quad (3.2)$$

Where:

NPV = net present value

t = holding period

R_t = net cash inflows – net cash outflows during a single period

n = number of time periods (from initial year of investment to final year of production closedown)

IRR = internal rate of return

This was then used to assess the correlation between what the mines are currently achieving and their mine plans. Through process monitoring, in which deviations were noted on the mine plans, this study investigated the causes of those deviations. The process monitoring involved comparing actual results with planned results to assess variability in differences and/or

changes. The benchmarks and industry acceptable ranges are discussed in further detail in Chapters 4 and 5. The collected data comprised drill hole as shown in Figure 3.2 and mine survey information. These geological logs were instrumental in creating the 3-dimensional (3D) geological model. Historical data was also collected from the two mines and used to create chemical and physical analyses of the mines. The geological database was created in Microsoft® Excel® and served as the basis for defining coal resources. 3D mining blocks were also designed to reflect the ground control plan, with sizes that provided sufficient resolution for mine scheduling. Each modelled mining block contained the estimated quantity and quality of the coal seam in that specific block.

BOREHOLE LOG				
Historical drilling campaign				
(m)				
FROM	TO	THICKNESS	DESCRIPTION	SAMPLE
0.00	2.38	2.38	Topsoil, mixed with transported pebbles	
2.38	9.55	7.17	HWT Sandstone	
9.55	10.02	0.47	Carbonaceous shale	
10.02	12.16	2.14	Alternating layers of sandstone and shale	
12.16	13.15	0.99	Carbonaceous shale	
13.15	16.58	3.43	Dull coal with pyrite stringers	
16.58	16.83	0.25	Carbonaceous Shale	
16.83	17.43	0.60	CMB with pyrite pathces in places	
17.43	23.55	6.12	Siltstone with wavy laminations	
23.55	24.17	0.62	Coaly shale	
24.17	26.23	2.06	Alternating layers of sandstone and shale	
26.23	26.59	0.36	Stringers of bright coal	
26.59	27.88	1.29	Alternating layers of sandstone and shale	
27.88	28.05	0.17	Coal dull	
28.05	40.98	12.93	Sandstone/Shale, interbedded	
40.98	55.64	14.66	Sandstone, containing shale layers at places	EOH

Figure 3.19: Typical borehole log at Mine 1

The mine design and production schedules were developed based on mining constraints. The inputs and outputs for the life of mine and coal extraction optimisation are summarised in Figure 3.2.

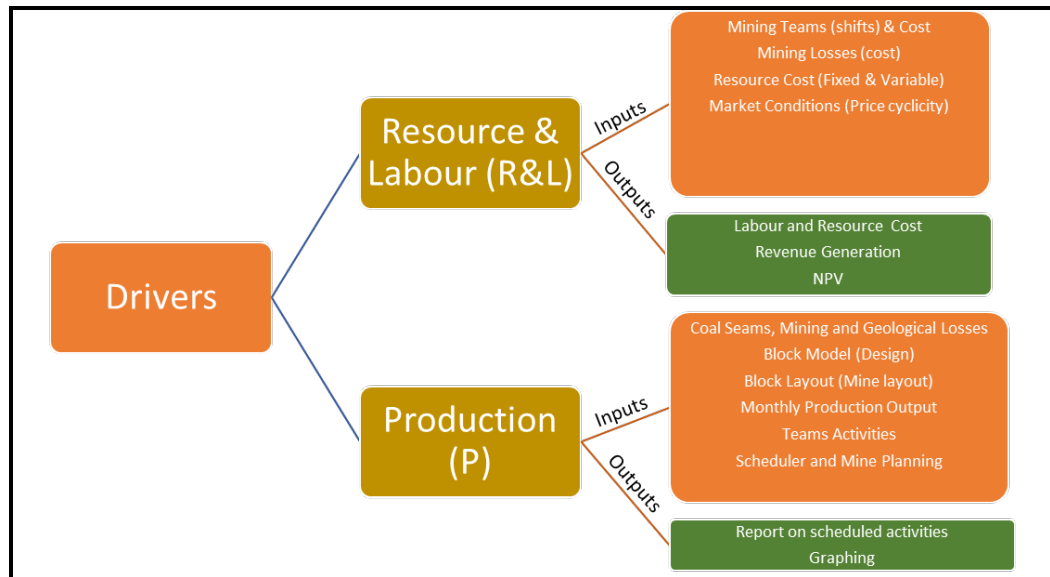


Figure 3.20: Inputs and outputs for the life of mine and pit optimisations

3.4.2. Site observations

Site observations also formed part of the data collection, with physical mining activity and operational practices observed in all participating coal mines. The researcher spent approximately 2 weeks at each mine to observe how they were operated. Three tools were used for the observation, the first tool was the running record tool, which was used to sequentially record data in real time. The data was later reflected upon and interpreted. The collected data included how machine operators were carrying out their duties and how they were interacting with their supervisors. The second tool used involved frequency counting, which comprised the number of scoops it took per excavator to load the Articulated Dump Trucks (ADTs) to full capacity in comparison to the capacity specified by the manufacturers of the equipment (see Figure 3.3 and Figure 3.4).



Figure 3.21: Loading time study under soft ground conditions at Mine 1



Figure 3.22: Loading time study of the bottom seam at Mine 2

The last tool used was productivity analysis, which comprised of the duration (time) it takes ADTs to be loaded to full capacity, the time ADTs take to haul to the offloading area and return to the pit to load again. This data was then graphed to check for any patterns (Figure 3.5 and Figure 3.6). During the time study, lag times were checked to ascertain how long it took ADT operators to return to the pit from the stockpiling area after offloading.

The coal in Mine 1 is extracted using traditional truck-and-shovel methods, with the topsoil first stripped and, where necessary, the hard overburden drilled and blasted.

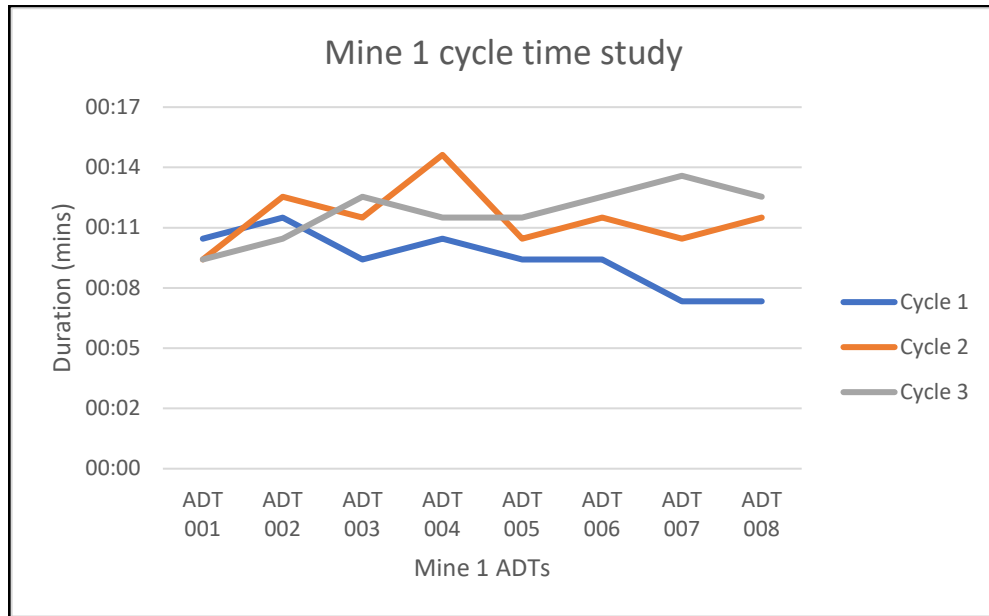


Figure 3.23: Cycle time study of Mine 1

The mining plan of Mine 1 is based on 50 x 50 m coal blocks. The drilling and blasting are outsourced to an independent third party.

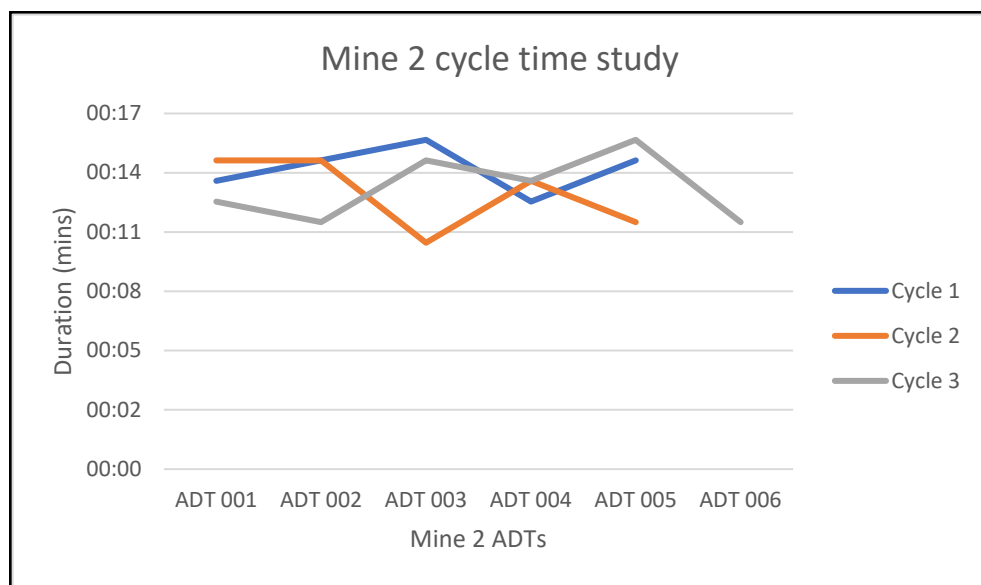


Figure 3.24: Cycle time study of Mine 2

The drilling and blasting teams come on a need basis. The mine will first open up and clean the block, and only once the block is clean will the drilling team commence drilling activities after consulting with the blasting team. However, in some instances, there is no need to drill and blast, the mining team is able to extract the coal by using an excavator as shown in Figure 3.7.



Figure 3.25: Coal pillar cleaning at Mine 1

The focus of the observation was on identifying the type of coal resource data collected and used by the mines for planning and scheduling. This observation was critical because it involved the actual execution of the mining activities. The mines were also observed to use data to optimise coal resources for sustainable mining (where applicable), thereby minimising mining losses. However, it became very clear that both operations were not particularly concerned with optimising coal resources. Rather, they seemed to be pushing for extracting as much coal tonnage as possible.

The key to site observations was knowing how to collate the data so it was useful and made sense during compilation. Creswell (2009) notes that, in field observations, the researcher takes field notes, often recorded in an unstructured or semi-structured way, using some prior questions that the enquirer wants to know.

3.5. Data analysis

The data analysed comprised of topography, geotechnical information, and geology, survey points, lithological data, and borehole collars, borehole collar coordinates, borehole depth, and total coal thickness. These parameters served as the primary basis for data analysis in mine design methods (Dunn, 2015) and sustainable mine planning and pit maximisation (Awuah-Offei et al., 2021). These parameters also serve as the basic inputs for mine design, planning, and scheduling. The last file was the ore analysis file, which comprised the main coal analysis parameters such as calorific (CV) value, total sulphur (TS), ash, volatile matter (VM), moisture content, etc. The analysis of this data underpinned the decisions miners need to make before commencing their mining projects.

Data was analysed using Leapfrog Geo and Datamine® software. The software included data management, organising data into different inputs for modelling, and producing geostatistical analyses. All the parameters used to create the primary geological model were successfully imported into Leapfrog Geo, which includes built-in validation checks for all datasets. The validation features included the identification of lithological and sampling overlaps, missing collars and lack of survey data (Figure 3.8). No additional errors were reported for the assay, collar, lithology and survey files. The data collected was in an Excel® format as shown in Appendix A, including topography, geology, and geotechnical data critical to mine design, planning, and scheduling. Using Leapfrog Geo and Datamine® software, a complete model was developed to ensure efficient coal extraction and resource optimisation through suitable mine plans. These software

packages were chosen for their ability to provide accurate, precise models that can be used for everyday mining operations.

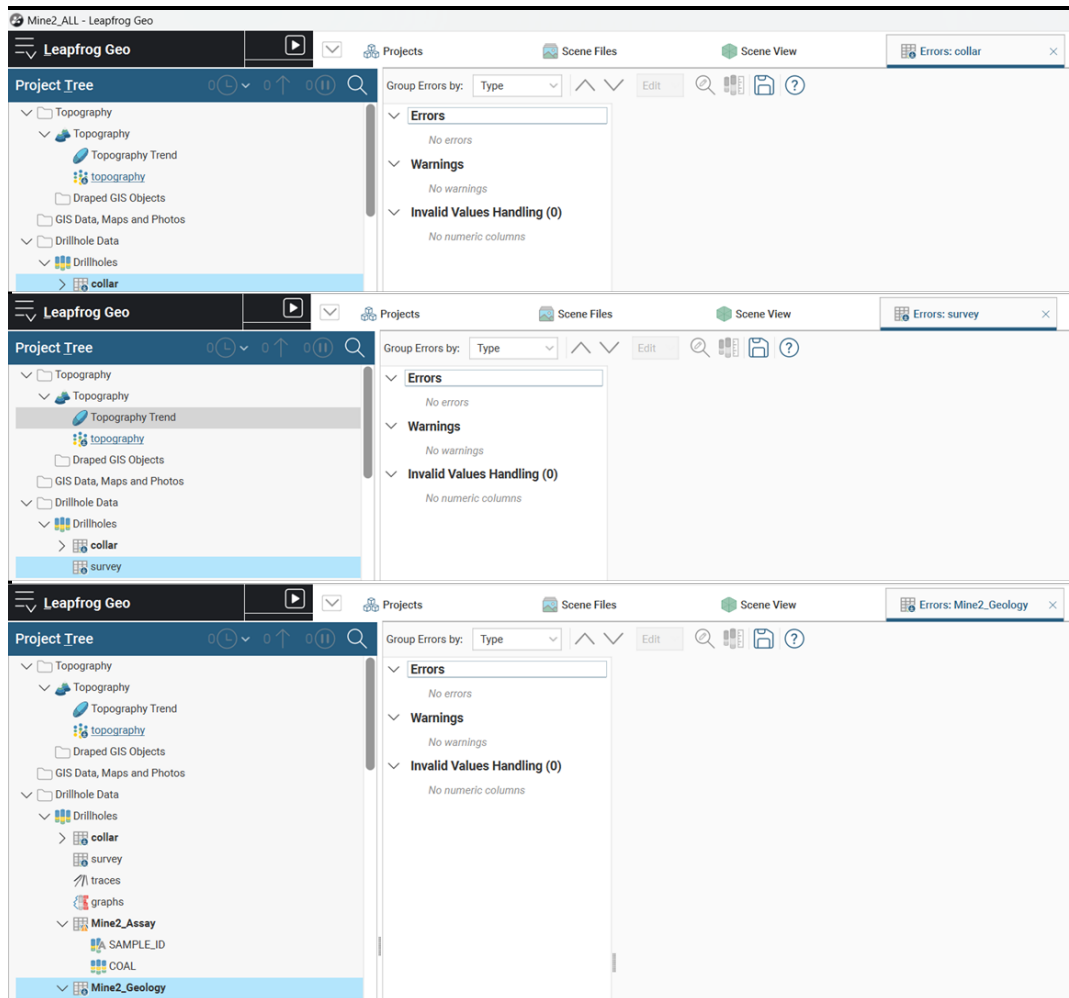


Figure 3.26: Error checks using the built-in verification and validation checks in Leapfrog Geo

Leapfrog Geo creates 3D interpretations of mineral deposits by integrating geological understanding with quantitative data. It uses geostatistical methods to predict how mineralisation is distributed within the subsurface (Seequent, 2019). Studio OP is a complete design and scheduling package for the medium to short term planning of open pit mines. With its visualisation and interactive environment, Studio OP makes it easy to design pits and waste dumps, prepare reserves and produce schedules. The software has optimisation capabilities that are essential for achieving desired financial outcomes or meeting product blend specifications with

minimal manual intervention (Datamine, 2020). Bogusz and Sulich (2020) note that a company's ability to achieve sustainability depends on its sensitivity to the surrounding dimensions: environmental, economic, and social.

The model was also used to check whether the NPV and internal rate of return (IRR) aligned with the company's strategy, which is embedded in both operations, and whether the operations had the required technical and management experience to be run commercially. Lastly, the model sought to determine whether these coal pillar operations imposed any opportunity costs on markets for Junior Miners.

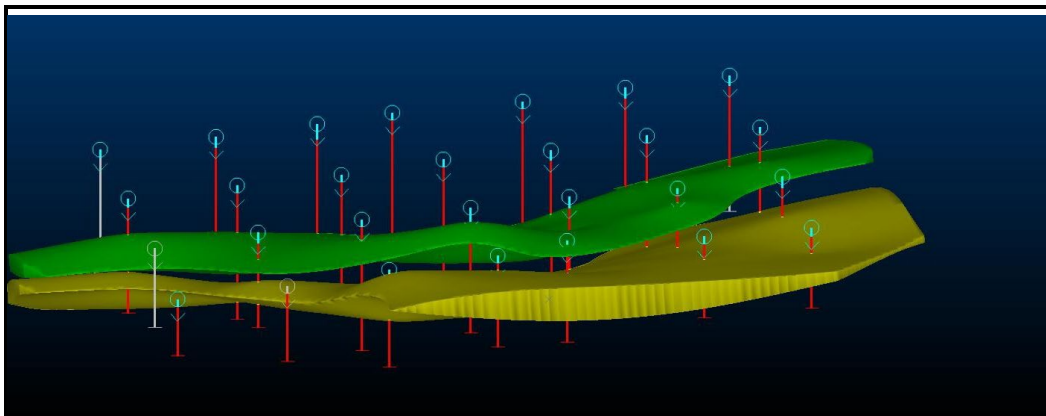


Figure 3.27: Simulation of the Seam 4 and inter-burden below the seam

The final collation of the data culminated in creating simulations of designs and plans of the participating operations using Datamine® software (Figure 3.9). The auto pit design tool simulated different scenarios allowing for slope setup, bench and road definitions, and pit/phase to achieve the optimal design for each operation. In addition, some modules in this auto pit design tool allowed for experimentation with different layouts for each scenario. Mines that adopt best practices in mine planning, scheduling, resource optimisation, and process improvements tend to reap rewards. These rewards can take the form of cost savings, increased productivity, greater predictability, and higher profitability.

3.6. Limitations and challenges

The challenges encountered included sporadic data availability from both mining operations. The data was poorly maintained, as it was primarily used to determine the presence of coal resources and potential mining sites. The limitations further stretched to lack of a clear point of communication, as the mine owners kept referring the researcher to different people for information, making the collation of such information difficult. Travelling to the site was also a challenge, due to community protests stemming from the mines' inability to meet their social and labour plan (SLP) obligations. The study was based on two mines in the Witbank Coalfield. The findings may not reflect other operations in different geological environments, even though they may also be mining coal pillars. Thus, research conducted over a few operations may provide variable findings.

In summary, the work undertaken in this chapter forms the basis of the results that are discussed in further detail in Chapter 4. All the collected and analysed data provided the researcher with firsthand knowledge and original insights into the operations of the different mines studied. The data collection methodologies employed in this study were key to defining and developing the model, which outlined the resources needed for coal pillar mining operations. The following chapter presents the findings, outcomes and interpretations.

CHAPTER 4: RESULTS

This study investigated two coal mines operating in the Witbank coalfield in Mpumalanga province. This chapter presents the findings for these two mines (Mine 1 and Mine 2), including daily operations and the financial implications of their activities. The operations of these two mines are very similar in how they extract coal pillars but vary in the methods they employ.

4.1. Introduction

The two studied mines are 100% black owned according to South Africa's Broad-Based Black Economic Empowerment Act (BBBEE Act), which forms part of the 39% total black ownership in the mining industry (Creamer, 2024). Both owners of these mines are single-asset owners, meaning they each hold a single prospecting right and/or mining permit with a stockyard. These mining operations use a crushing and screening plant, conveyors, and haulage trucks for the daily coal trade. The results of the two mines, covering their coal resources and financials, are presented in this Chapter.

4.2. Results produced from Mine 1

Mine 1 was a historical underground mine that was operated by extracting coal using bord and pillar mining methods. Upon reaching the end of its life, the underground mining operation ceased. However, the mine was reopened and mined using conventional surface mining methods solely to extract the coal pillars left behind in the early 20th century.

The mine produces between 240 000 and 360 000 tonnes of run-of-mine per annum, which works out to 20 000 – 30 000 tonnes of coal per month. Approximately 60% of the coal produced is sold to the domestic market, while the balance is sold to the export market. The domestic coal market is dominated by cement, timber, and paper companies. The life of mine (LOM)

is 48 months, as per the recent renewal of the mining permit. The mine has plans to convert the mining permit into a fully-fledged mining right. However, the challenges associated with converting to a mining right need to be addressed first. One of those challenges is continuous exploration to ensure the mine's sustainability. At present, the mine does not have an extensive exploration programme. It relies on production drill holes for planning.

4.2.1. Resources and reserves of Mine 1

The mine only has approximately three years of life of mine remaining as of the beginning of 2025 as shown in Table 4.1. in case there is no exploration work undertaken to extend the life of the mine, production will stop by 2027. The current mining method involves extracting Seams 1 and 2. The qualities of both seams are suitable for both the domestic and export markets are shown in Table 4.2. Seam 2 mainly occurs as pillars, while Seam 1 is predominantly solid across the project area where it is found.

Table 4.6: Coal resources and reserves of Mine 1

Block	Seam	Category	Area	Thickness	Volume	Relative Density (RD)	Gross tonnes in-situ (GTIS)	Burden	Geo Loss	Mining loss	Total tonnes in-situ (TTIS)	Extraction	Discounted (Pillars)	ROM
			(ha)	m	(m ³) 000	(g/cm ³)	Mt	(BCM) 000	%	%	Mt	%	Tonnes	(000)
Mine 1	Seam 2	Indicated	1282	3.08	1 920	1.55	2 976	10 464	10	5	2 530	60	1 012	1 518
	Seam 1	Indicated	857	1.40	1 008	1.5	1 800	6 926	10	5	1 530	60	612	918
	Total													2 436

Table 4.7: Qualities of raw coal at Mine 1

Raw Uncontaminated Qualities (air-dried basis)						
Seam	Inherent Moisture	Ash	Volatile Matter	Fixed Carbon	Calorific Value	Total Sulphur
	%	%	%	%	MJ/kg	%
Seam 2	2.9	19.8	21.2	56.1	22.59	0.52
Seam 1	1.8	16.2	30.1	51.9	27.85	0.67

4.2.2. Present mining activities in Mine 1

Presently, Mine 1 does not have a mine plan or design to follow. These two components are critical to ensuring the optimisation of coal resources. The mine is simply making use of a mine layout that is superimposed on the old underground pillars as illustrated in Figure 4.1. This practice is used to try and locate exactly where these historical pillars are found underground. The pillars are approximately 3-4 m apart and approximately 4-6 m in height.

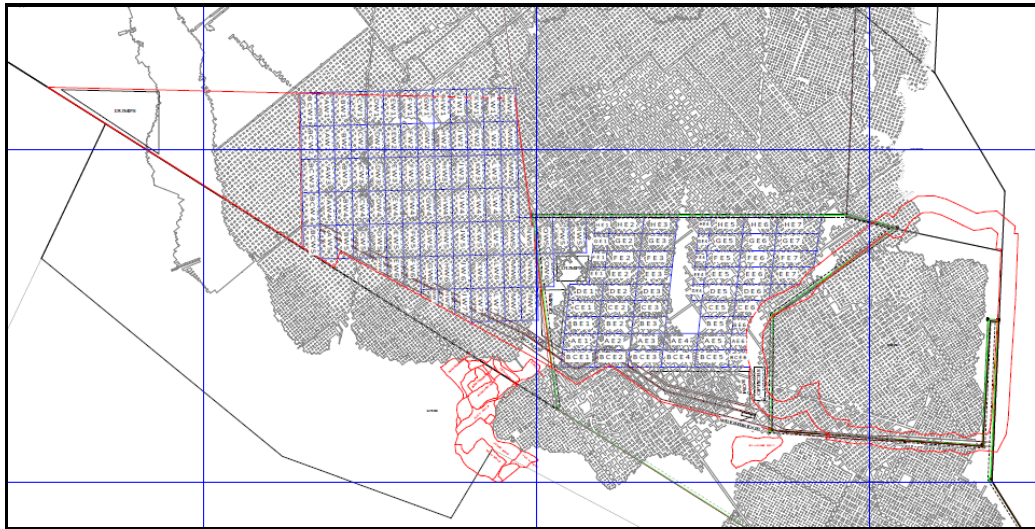


Figure 4.28: Historical layout of Mine 1 superimposed on underground coal pillars

Once the superimposition of old underground maps onto the topography is complete, the mine collapses the pillars, similar to method 1 of collapsing bords suggested by Clough and Morris (1985). The loading of the collapsed pillars is undertaken using the traditional truck-and-shovel (T and S) method to extract the coal. Essentially, this method employs cleaning the overburden around the coal pillars with 50t excavators, then trucking it with 30t and 40t articulated dump trucks (ADT). However, one drawback of this method is that, as the overburden is cleaned around the pillars, contamination tends to occur, and dilution is not addressed. The contamination arises from the large excavator's difficulty in fully cleaning the area around the pillars, as it must position itself on top of them to do so. This method works to some degree, albeit it is not always reliable and does not

produce consistent results. In its current state, Mine 1 only considers short-term planning, which is mainly focused on the immediate extraction of coal tonnage to generate revenue. This method of operation abandons key mine planning principles, which encompass short-term, medium-term and long-term planning.

4.2.3. Challenges encountered at Mine 1

The challenges experienced in this mine are fundamentally at a technical level, where essential data (geological and mine plans) required to optimise coal pillar resources is not available. The challenges are detailed in the subsequent paragraphs.

The lack of a precise, reliable block model poses significant challenges for this operation. Having a block model would greatly assist the operation in optimising its resource base. However, at present, the lack of accurate geological models is reflected in increased costs and reduced revenue. Over and above the capital cost, a block model would ensure the mine's planning and strategy is executed seamlessly. Having a block model means the mine can continuously update it as new information becomes available with the progress of mining.

In operations where block models are available, the input data into these models is obtained from production drilling and exploration campaigns. The data is provided in real time, enabling immediate support for ongoing mining activities. Thus, as mining progresses, it becomes critical to collate data made available through blasthole drilling and/or near mine exploration. This collated data plays a significant role in updating the block model, ensuring that coal resource data is up to date in real time.

Any mining operation operating with high levels of uncertainty exposes itself to risks that can lead to an unsustainable operation. Mining is already a high capital-intensive exercise therefore, one incorrect call and judgment could mean shutting down the operation. This is particularly relevant to Junior

Miners who are known to operate within highly confined and lean financial structures. The major uncertainty is geological, as it relates to everything the mine does daily. This uncertainty correlates to coal quality, coal continuity and chemical characterisation, an important factor in coal mining, especially with total sulphur playing a crucial role. For instance, Erdem et al. (2012) posit that 70 per cent of small mining companies in South Africa failed during the 1980s, mainly because of overestimation of reserve tonnage and grade. Therefore, understanding uncertainties in mining projects is vitally important. Fontes et al. (2020) have suggested conducting a sensitivity analysis to evaluate the impact of the main variables on mining projects. Fontes et al. (2020) have suggested that another way to measure uncertainties is through Monte Carlo simulation (MCS). The MCS can investigate stochastic permutations of uncertainties and produce unbiased and consistent estimations (Erdem et al., 2012).

The dumping of waste (overburden) is a serious challenge at the mine because, at times, waste material is dumped over blocks containing coal that has yet to be mined. This results in double handling of material, which introduces capital inefficiencies, ineffective equipment utilisation and prolongs activities that could be completed optimally. The poor utilisation of space at the mine means that the mine will miss out on opportunities to identify areas that would be ideal for future development. Furthermore, an opportunity to identify areas that could limit spontaneous combustion once the pillars are open.

Surface mining requires the use of surface mining equipment, including articulated dump trucks, excavators, front-end loaders, and dozers. Therefore, the deployment of this equipment needs to be strategic and align with the operational plan's schedule. However, it is quite evident that in this operation, equipment is deployed on a need basis rather than on a scheduled deployment.

Factors affecting mine planning and design include strip ratio, equipment to be utilised/mining method, capital availability, commodity prices, material

processing, government authorisations and legislation where applicable. Thus, a good understanding of these parameters ensures realistic and relevant mine plans and designs. In turn, these plans guide the miners' decision on whether to continue or discontinue the project. Caciagli (2021) has shown that any one of these inputs can influence all the other parameters. For example, any constraint associated with the processing method can affect the optimisation of the cut-off grade, which, in turn, would influence production schedules. Changes in production schedules would affect output across the different mining phases.

4.2.4. Opportunities identified at Mine 1

There is an opportunity to collect data as the mine advances its operations. Data can also be collected from production drilling in preparation for the next mining block. The team can collect data which can form part of their database.

An appropriate mine plan and schedule will ensure that all significant variables are accounted for as accurately as possible. A well-designed mine plan will also minimise production costs, increase coal resource utilisation and use best practices to account for product demand and price. Once all these variables are accounted for, the production schedule will be optimised and the best value realised from the coal.

4.2.5. Efficiency and optimisation model of Mine 1

This study aims to propose a design that will aid the mine in better planning its coal pillar extraction, optimising coal resources, and efficiently operating to realise its full potential. Currently, Mine 1 does not employ any drilling and blasting instead, all coal is extracted through free digging using the traditional truck and shovel method. This study recommends introducing drilling and blasting of the overburden to approximately 0.50 m above the coal seam. And use a smaller excavator to clean around the pillars as

illustrated in Figure 4.2. The recommendation of drilling and blasting is based on the observed diminished throughput seen in the cycle time study undertaken. Additionally, the mine's efficiency and optimisation of machinery was not maximised as discussed in Chapter 5.

In places where the 0.50 m of overburden may cause resistance, it can then be ripped with a dozer and loaded using an excavator and hauled to the waste dump. Extra caution is required when carrying out this exercise, as it can lead to severe contamination if not executed according to plan.



Figure 4.29: Pilot blast of overburden to approximately 0.50 m top of coal

To achieve full benefit and excellent results, the T&S method requires creating a block model of the coal deposit, as this model will contain individual parameters and characteristics of the coal blocks. Parameters such as CV, TS, Ash and VM can be used for optimisation and, where necessary, for blending strategies. These parameters as discussed in Chapter 3, Section 3.5, were used to feed into the calculations of discount factors and profitability of the operations, as demonstrated in the block model. The mine's full layout is illustrated by Figure 4.3. However, for the mine to make use of this full layout, it needs to convert its current mining

permit into a mining right, as the southern portion of the layout falls outside the permitted 5 hectares.

An optimised mine layout shown in Figure 4.4 was produced, after integrating the cut off parameters determined in the geological model such as coal recoveries, forecasted economic sustainability imperatives (NPV and IRR) and environmental considerations of the mine to ensure maximisation of coal resources. The optimised mine layout yielded a total resource base of just over 4 million tonnes. However, due to the nature of the mine, approximately 60% of the coal resources are estimated to be mineable. And the mine has a total of 2.4 million tonnes available for mining.

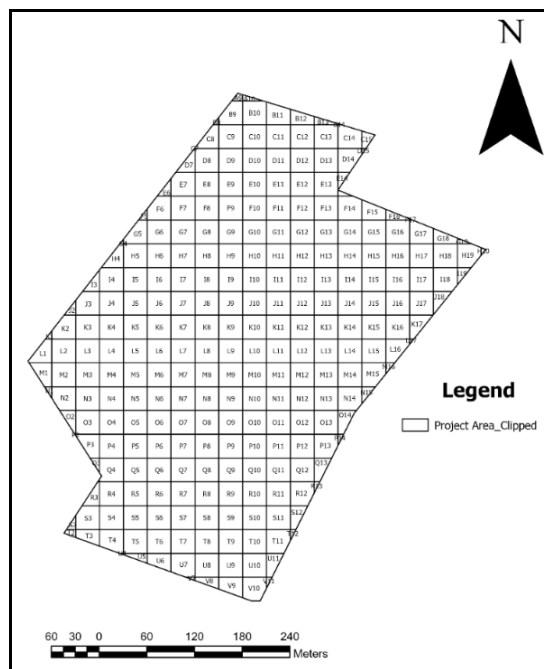


Figure 4.30: Full layout of Mine 1

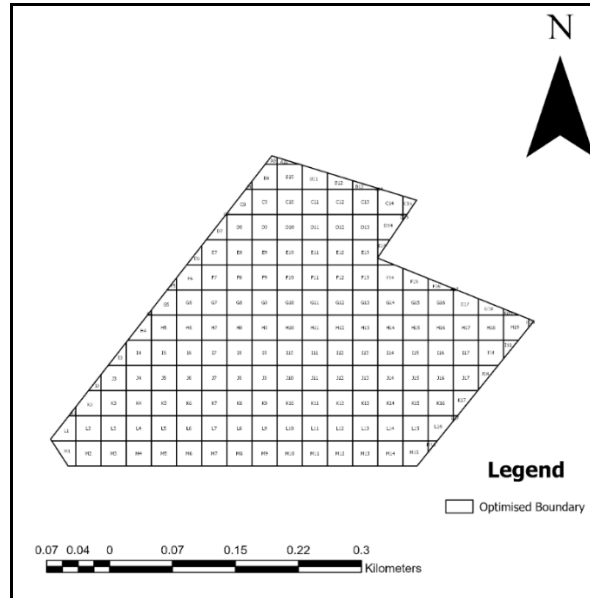


Figure 4.31: Optimised layout of Mine 1

The geological modelling that was undertaken used historical data provided by the mine, which entailed boreholes, laboratory analysis, survey and collar data. Modelling was undertaken using Leapfrog Geo, which through its implicit modelling capability, a geological model was produced. The produced model was checked for robustness shown in Figure 3.8 to ensure its reliability for informed decision making. From the geological model shown in Figure 4.5, it is evident that Seam 4 has a northeast to southwest trend while Seam 2 is trending north-south. There is a minor occurrence of Seam 3, but it is not of sufficient volume to make it economically viable. The mine may need to investigate it further to determine whether it is economically viable.

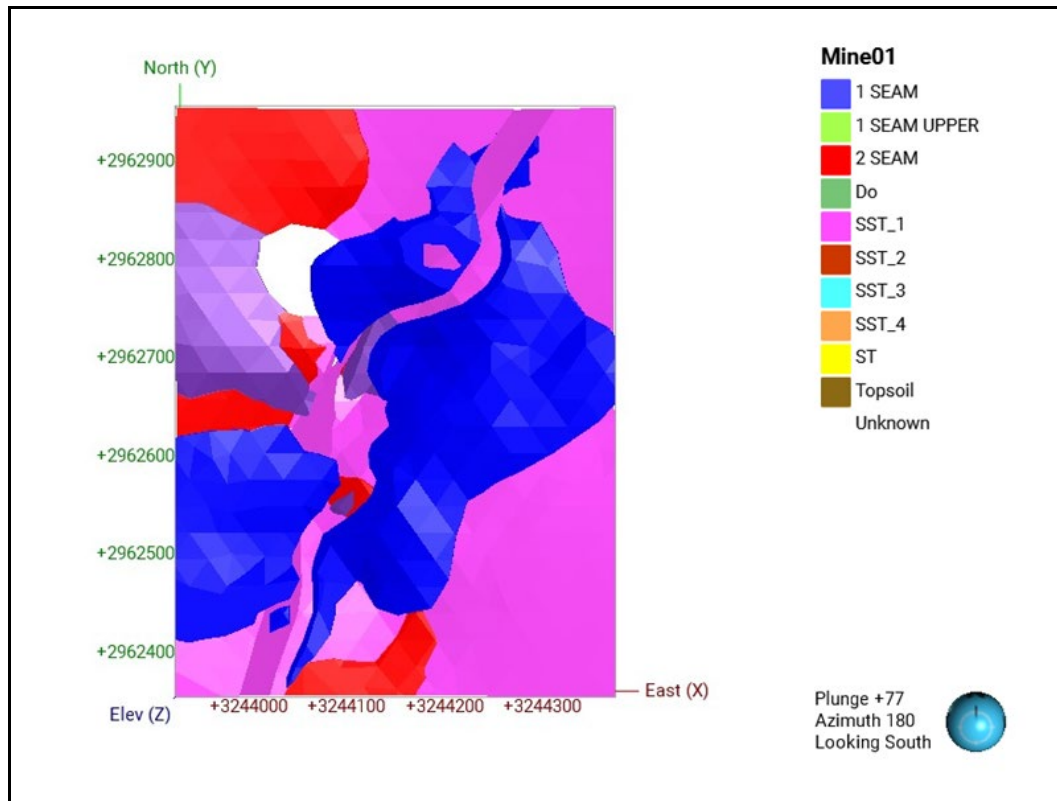


Figure 4.32: Plan view of the geological model of Mine 1 generated using Leapfrog

4.2.6. Economic benefit and maximisation model of Mine 1

As discussed in Chapter 3, the NPV presents an opportunity to analyse the value of money over a given time period. Based on the remaining life of mine for this operation, the mine would need approximately R12.82 million as initial investment shown in Appendix A. The NPV rule states that when the NPV is positive, then the project should be accepted, and when it is negative, then the project should be rejected (Le, 2021; Lai, 2024). Based on this rule, the project should be accepted, as it shows a positive NPV of almost R35 million if the operation produces only ROM. And as per the schedule, it would be able to mine 574,254 tonnes of coal in year one and progressively increase, with a reduction in ROM production in the final year. Table 4.3 and Appendix D show the reduction in ROM in year four as a result of resource depletion.

Table 4.8: Production data over four years – Mine 1

Mine sequencing	Waste	Coal	SR	% Change
1	3 374 053	574 254	5.9	-
2	5 196 440	633 797	7.3	10
3	5 528 392	717 145	7.8	13
4	3 298 316	490 160	8.6	-32
Total	17 397 201	2 415 356	7.2	

When undertaking a discounted cash flow analysis, the sum of all the project's future cash inflows against outflows from the initial year of capital investment through to the final production year is discounted back to the present using a rate of return. This rate of return in Equation (3.1) in Chapter 3 is the discount rate. The data in Table 4.4 shows the amount of money that would need to be invested back into the mine over a period of one (1) year.

Table 4.9: ROM present values at different discount rates over a period of four years for Mine 1

Year	0%	4%	10%	12%	15%	18%	22%	30%
0	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704
1	R343 144 410	R329 946 548	R311 949 464	R306 378 938	R298 386 443	R290 800 347	R281 265 910	R263 957 238
2	R374 027 407	R345 809 363	R309 113 559	R298 172 359	R282 818 455	R268 620 660	R251 294 952	R221 317 992
3	R418 910 696	R372 410 083	R314 733 806	R298 172 359	R275 440 582	R254 961 982	R230 697 005	R190 673 963
4	R293 237 487	R250 660 633	R200 285 149	R186 357 724	R167 659 485	R151 248 634	R132 367 134	R102 670 595

Table 4.10: ROM NPV and profit incremental increase of 10% for Mine 1 over a period of four years at hurdle rate of 12% based on projections in Appendix B

Year	0	1	2	3	4
	R253 814 704	R88 639 706,15	R97 503 677	R107 254 044	R117 979 449
		R77 078 005	R73 726 788	R70 521 275	R67 455 133
Total after 4 years at 10% incremental increase on profits = R288 781 201					
NPV = R34 966 497,24					

Table 4.11: NPV of crushed and screened products from Mine 1 at a discount rate of 15% based on projections in Appendix B over a period of four years

0	1	2	3	4
R322 616 011.35	R175 250 813.65	R192 775 895.01	R217 836 761.36	R148 128 997.73
R322 616 011.35	R152 392 011.87	R145 766 272.22	R143 231 206.62	R84 693 235.22
R322 616 011.35	R526 082 725.92			
R203 466 714.57				

The ROM present value shown in Table 4.4 shows that there is no time preference for money at a 0% discount rate. However, it is quite evident that as the discount rate increases, the value of money decreases over time. Furthermore, a present value of R253.8 million today is seen in year 4 at a discount rate of 4% and in year 2 at a discount rate of 22%. Similarly, the value of R253.8 million today is seen in year 3 at a discount rate of 18%. Table 4.5 shows the ROM NPV at the minimum hurdle rate of 12% using cash flow as per the mining schedule shown in Appendix B. Table 4.6 shows the crushed and screened NPV at the minimum hurdle rate of 12% using profits generated as per the mining schedule shown in Appendix B for mine 1 over a period of four years.

The ROM NPV for Mine 1 is R34.97 million at a 15% discount rate. However, the NPV for the crushed and screened product is R203.47 million at a 15% discount rate as shown in Table 4.6. Therefore, based on the NPV decision rule, the operation can continue as it shows a positive NPV since the project will create significant value for Mine 1. Furthermore, to achieve a better economic return, the operation would have to be a crushed-and-screened operation.

IRR is the discount rate at which the net present value of all cash flows at the start of the project is equal to zero (Volkman et al., 2019; Huang, 2022). Understanding and knowing the IRR, the mine can use that information to either accept or reject the project. The IRR rule states that if the IRR exceeds the discount rate (the opportunity cost), the project should be accepted. The ROM IRR for Mine 1 is 21.32% while the IRR for the crushed-and-screened product is approximately 45.98%.

The estimated operational cash flow of Mine 1 is illustrated by the graphs below in Figure 4.6. The cash flow has only accounted for income taxes and has not considered depreciation, outstanding interest, or any other loans the mine may have. The coal price was also not changed over the four-year period since the change in coal prices is expected to range between a positive 0.6% to a negative 3% in the estimated four-year life of mine.

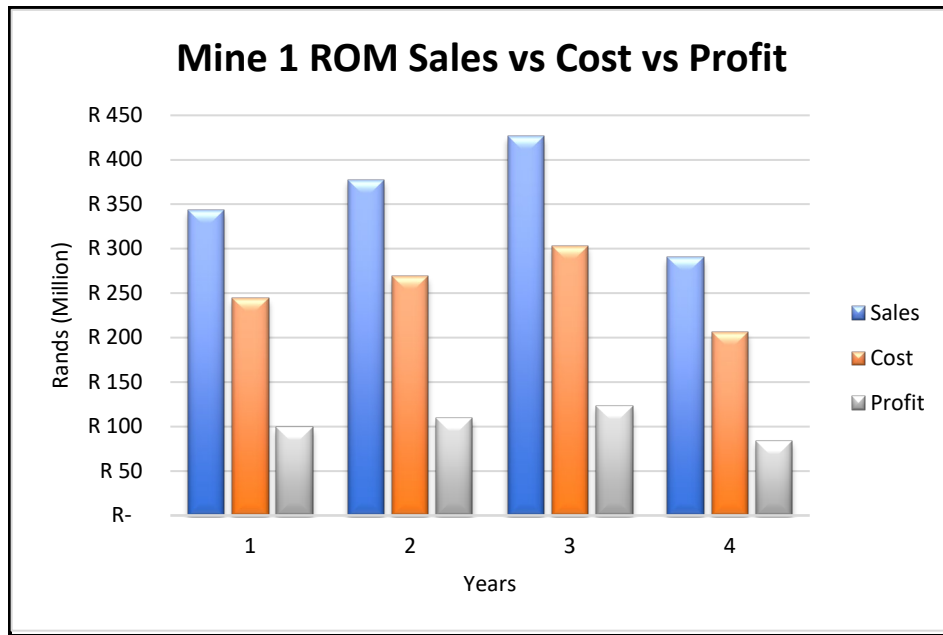


Figure 4.33: Sales, cost, and profits of ROM material over four years for Mine 1

From Figure 4.6, it is evident that, should the mine fulfil the planned and scheduled production targets, it should be in a healthy position to continue with its current operation of just selling ROM. The sales peaking in year three (3), is indicative of the mine reaching steady state. However, year four (4) presents a challenge, as it marks the mine's end of life if the operation cannot be successfully extended beyond this point. The total profit is estimated at approximately R415 million over the four-year life of the mine. Figure 4.7 shows the crushed and screened sales vs cost vs profit graph. It can be seen that the mine could unlock additional value if it were to enter the market for crushed and screened coal products (Figure 4.7). The trend is similar to the one seen in Figure 4.6 where the mine is just selling ROM. However, the major difference lies in the profits generated with the crushed and screened coal totalling approximately R886 million over the four years, thus, representing a difference of almost R479 million between the two types of operations.

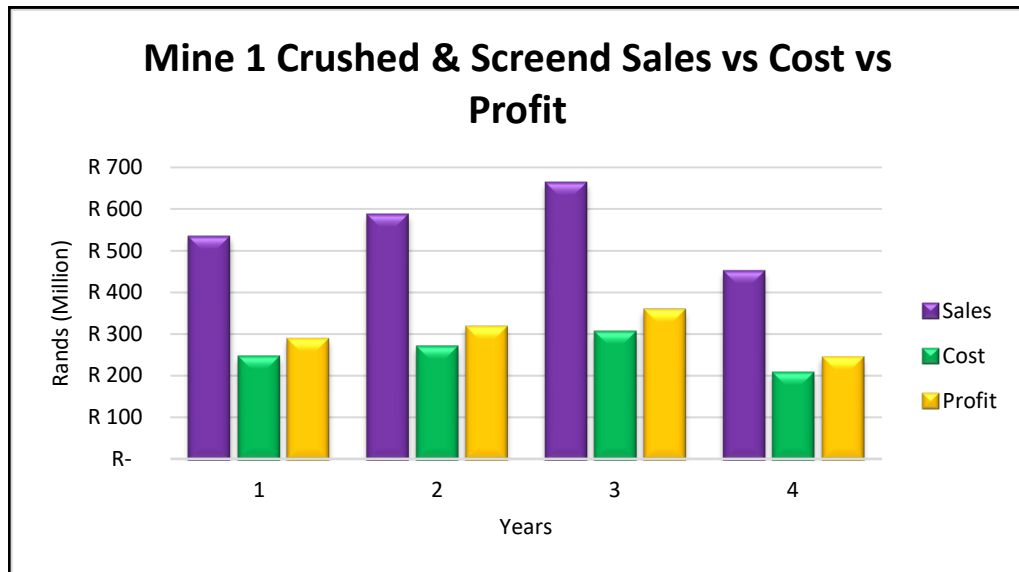


Figure 4.34: Sales, costs, and profits of crushed and screened products over four years for Mine 1

4.2.7. Model of Mine 1 to reduce dilution and contamination during extraction

Typical characteristics and parameters contained in each block are the quantity and quality of coal per block as shown in Figure 4.8. The block model is a grid that was divided into 25 m x 25 m blocks. Each block shows available coal seams, coal qualities and physical properties of coal available in that specific block.

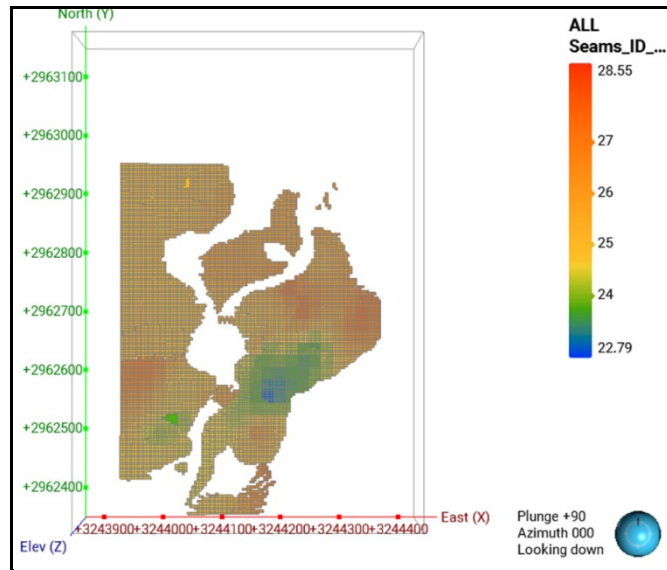


Figure 4.35: Block model of Mine 1 generated in Leapfrog

These quantity and quality parameters are critical inputs for planning and scheduling which blocks to mine. This block model was designed with dilution and contamination factors of 5% and 15%, respectively, due to the difficulty of mining coal pillars. Cut-off parameters used during the creation of this model are as follows: coal width limit 1.00 m, coal volatile matter limit 18%, raw coal ash limit 35% and geological loss 10%. These cut-off parameters were chosen because they represent the minimum values at which the operation is profitable.

4.3. Results produced from Mine 2

This mine is a traditional surface mining operation that extracts coal using the truck-and-shovel method. It has been mined for many decades and has changed ownership several times. The current owners acquired the mine in 2021 and began mining in the second half of 2022. However, the one advantage the current owners have is the availability of information that came with the purchase of the mine as well as the associated infrastructure. The mine is currently operating under a mining permit, which is a portion of the prospecting right for the property. The holders aim to convert it into a full-scale mining right. Similar to Mine 1, this mine does not have an

extensive exploration programme and all available information is historical. The mine produces between 15 000 tonnes and 20 000 tonnes per month, at an average of 210 000 tonnes per year. Unlike Mine 1, this mine relies heavily on drilling and blasting for coal extraction.

4.3.1. Resources and reserves at Mine 2

Table 4.7 shows that Mine 2 has a total of 7.22 million tonnes of coal over the area covered by the prospecting right. Raw coal qualities are shown in Table 4.8. However, this coal has been discounted to reflect the 60% extraction rate. As a result, the mine essentially has just over 4 million tonnes of coal available for extraction.

Table 4.12: Resources of Mine 2 over the entire mining permit and prospecting right area

Description	Seam	Category	Area	Volume	RD	Thickness	GTIS	Geo. Loss	Mining loss	TTIS	Extraction	ROM Sale
			(ha)	(m ³) 000	(g/cm ³)	m	Mt	%	%	Mt	%	Mt
Mine 2	Seam 4	Measured	355.26	3 552	1.55	1.15	5.33	10	5	4.80	60	2.74
	Seam 2	Measured	179.24	1 795	1.5	3.49	2.69	10	5	2.42	60	1.38
Total												4.12

Table 4.13: Qualities of raw coal at Mine 2

Raw Uncontaminated Qualities (air-dried basis)						
	Moisture	Ash	Volatile Matter	Fixed Carbon	Calorific Value	Total Sulphur
	%	%	%	%	MJ/kg	%
Seam 4	2.4	29.6	19.7	48.3	22.13	1.04
Seam 2	2.1	20.9	25.6	51.4	25.3	1.06

There are only two coal seams of economic interest: Seam 4 at the top, underlain by Seam 2. The bottom Seam 1 could be economical in some parts of the mine, but it is not consistently developed. It does not form part of the coal resources of the mine. Seam 4 is ideal for the domestic market, as it can produce thermal coal used to generate electricity by entities such as Eskom. While Seam 2 coal is largely for the export market, it can also be used as metallurgical coal. However, like Mine 1, this operation seeks to convert its mining permit into a mining right, which would allow it to access a large portion of the resource base. Currently, the mine is only legally permitted to access resources within the 5 hectares covered by the mining permit. Once the mining right has been granted, the mine will ramp up production to 100 000 tonnes a month, effectively changing the life-of-mine plan (LOMP) to approximately 6 years.

4.3.2. Planning and design of Mine 2

The mine does not have an updated mine plan. It is using an old design and plan used by the previous owners before selling the mine. The current plan simply involves opening up blocks until the end of the area covered by the mining permit is reached. The new owners need to produce new designs and plans that account for the current situation at the mine. Currently, the mine is planned to mine a maximum of 20 000 tonnes of coal from Seams 4 and 2 each month. However, an inspection of the financials suggests it would be prudent to increase the planned tonnage output to approximately 40 000 tonnes per month. The current plan is to mine Seam 4 coal for both the local and export markets as a crushed and screened product, while Seam 2 is mined solely to supply the export market. Seam 1 is not accounted for as it is not economically viable in most parts of the project area.

4.3.3. Challenges encountered at Mine 2

The challenges experienced by Mine 2 are mainly technical, where issues arise from poor equipment utilisation and selective mining practices. Additionally, the mine does not have a geological model which resulted in inefficiencies and poor mine planning.

The biggest challenge this mine faces is selective mining, particularly in Seam 2. The sandstone splitting Seam 2 (split into Seam 2 Upper and Seam 2 Lower) varies in thickness from 20 cm to 30 cm, posing serious challenges for the mining team. In order to mine this thin unit of sandstone, the mine must use a smaller machine. This approach results in a slower mining rate, which can affect productivity and the ability to meet the production schedule. Selective mining also requires constant monitoring by the equipment operator and supervisor.

This requires the supervisor to potentially forego some of their own work to keep a close eye on the machine during selective mining. The mine already employs a very lean workforce. Adding more pressure to it will only intensify the pressure. Another challenge with selective mining is that the equipment is specifically allocated to this therefore, it is hardly suitable for any other job at the mine. Mining is already a capital-intensive undertaking, having equipment and machines onsite that cannot be optimised, and may not be ideal for the mine.

The equipment utilisation at the mine needs to be strategically planned, as the operation is becoming more complex with the Seam 2 split, particularly as the mine progresses towards the northeastern portion of the mine. The equipment selection needs to account for selective mining and the monthly production target as per the production schedule. Ideally, the chosen equipment may need to be allocated to different mining activities to maximise utilisation and optimise the coal resource, with special focus on split Seam 2.

The historical information needs to be updated to account for the historical coal extractions and reconciliations. It is very important to have a geological model that is current and relevant to current conditions, as plans and schedules must be produced based on it. Currently, the mine is mining Seams 4 and 2 by simply stripping overburden in blocks approximately 50 m x 40 m in dimension. Once the overburden is removed, the coal block is drilled and blasted. However, the end-result is contamination and dilution of the coal, which diminishes its value. To fully optimise and maximise coal resources, the mine needs a block model that optimises drilling and blasting to unlock the full value. Having an updated geological model is important for reconciliation purposes, as the mine can always compare its planned production target with what it actually achieves. In the event of discrepancies, this method streamlines the process, enabling the mine to address its root causes in a timely manner.

4.3.4. Opportunities identified at Mine 2

The mining of all mineable coal seams plays a vital role in ensuring that the mine gets the full economic benefit from its production. Presently, the mine is focused only on Seams 4 and 2. However, there is a business case to mine Seam 1 to some extent, which would diversify the product offering of the mine. The depth of interception for Seam 1 is approximately 7 m to 8 m below Seam 2, and the cost to extract this seam will be offset by the price of selling the resulting product. Seam 1 is premium-quality coal, and at 2025 prices, the unwashed finished product of this quality was selling for approximately R650 per tonne. Therefore, adding it to the mine's product mix would broaden its market access, as it would offer three product types instead of the two it currently offers.

There is an opportunity to better understand Seam 2 variability within the mine. This opportunity presents itself in the form of undertaking a near-mine exploration campaign to gather information to better understand the Seam 2 variability and continuity at the mine. Historically, Seam 2 was mined as a

single unit. It was not split into two units, as is the case with the blocks the mine has been opening. Understanding the drivers of the split in Seam 2 will enable the mine to better prepare its planning and equipment selection.

4.3.5. Efficiency and optimisation model of Mine 2

Mine 2 does not operate with any official mine plan and/or design. The team is opening blocks from the last face opened by the previous owners. Therefore, it becomes difficult to check and compare whether the mine is on the right track to achieve its intended target. Figure 4.9 illustrates a full mine layout developed by the research. The developed mine layout is capable of mining all areas where coal occurrence has been noted (see Figure 4.9). However, a full mine layout may not be feasible or practical due to the dolerite encountered in the mine. These dolerites not only dilute and contaminate the coal but also degrade its quality through devolatilization and increasing ash content, mainly localised in coal in contact with the dolerites.

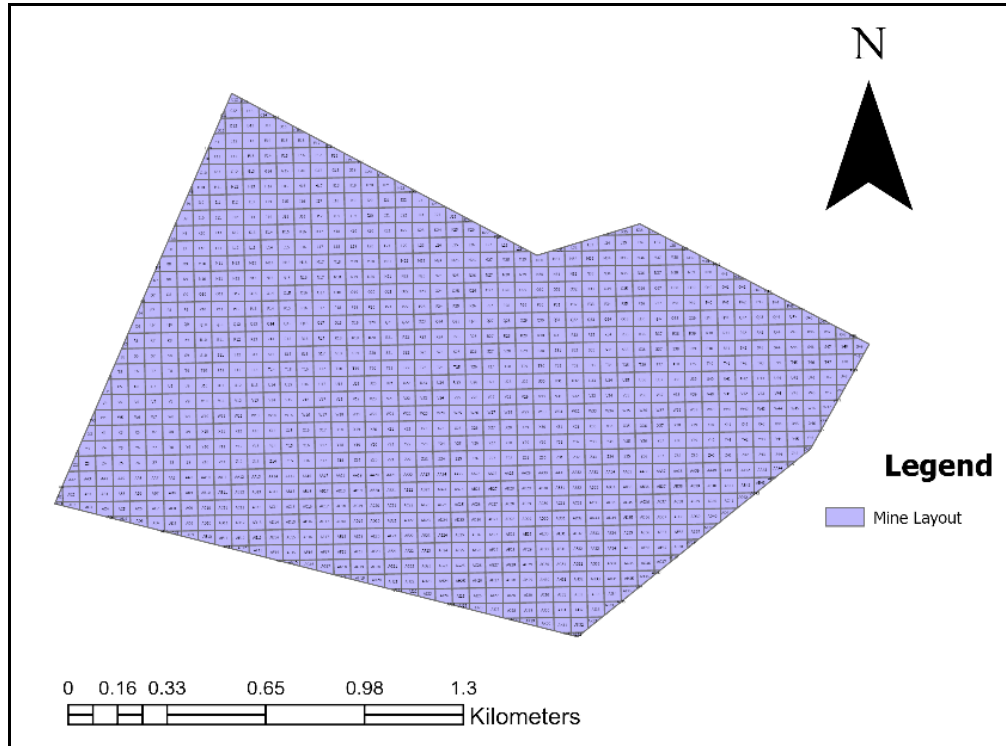


Figure 4.36: Full layout plan of Mine 2

Therefore, to ensure that coal resources are optimised and efficiently mined, this research has proposed an optimised mine layout and design. Figure 4.10 shows the optimised layout and designed for the extraction of coal pillars such that contamination and coal dilution are reduced (Figure 4.10).

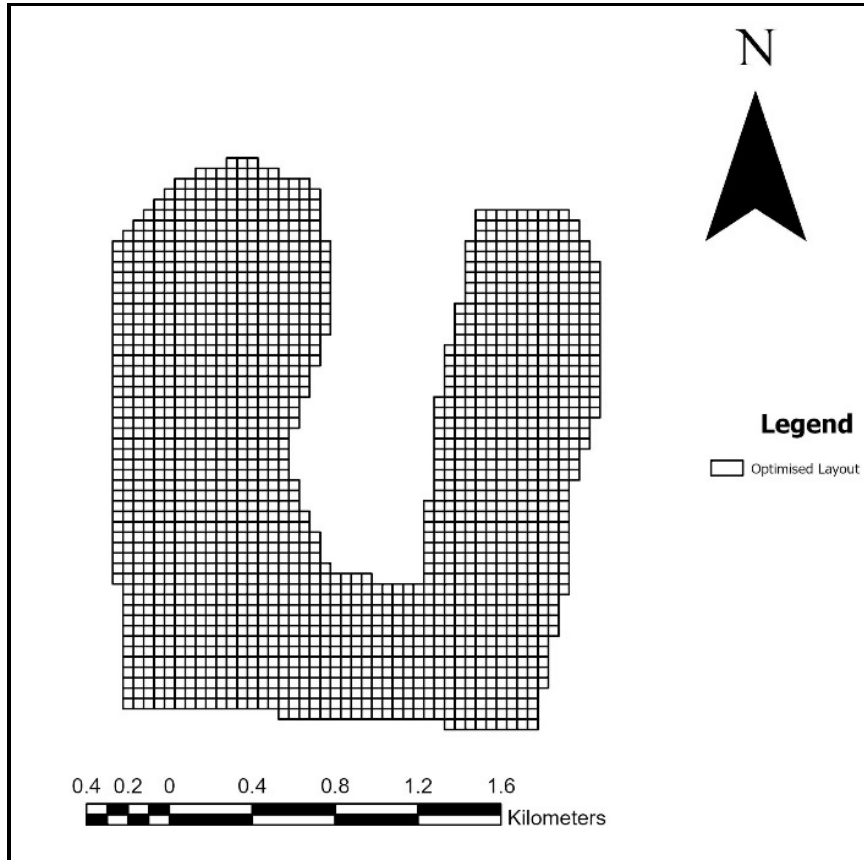


Figure 4.37: Optimised layout of Mine 2

This new layout plan will unlock considerable value for the mine, as all economic coal seams have been included in the plan. Additionally, a buffer has been added to the mine layout to ensure that inferior coal resulting from dolerite intrusions is not mined. The massive dolerite that dissects the coal seams into two distinct mining blocks (i.e., eastern and western blocks) is shown in Figure 4.11. The southern portion of the mine is still intact and characterised by the occurrence of both Seam 4 and Seam 2 (Figure 4.11).

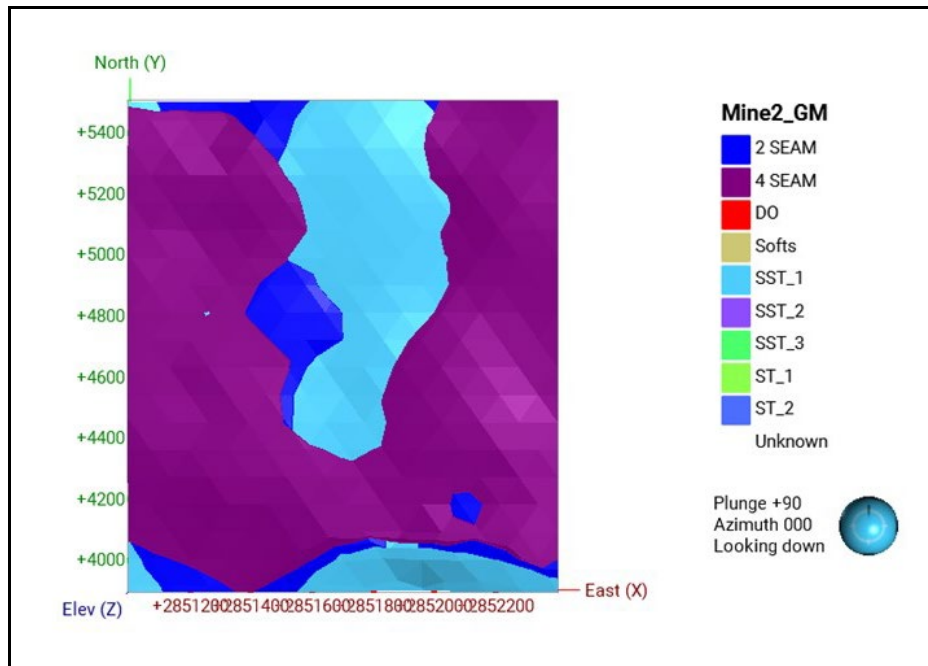


Figure 4.38: Plan view of the geological model of Mine 2 generated using Leapfrog

4.3.6. Economic benefit and maximisation model of Mine 2

The success of mining operations is informed by the financial sustainability of the operation. This section will detail the NPV and IRR rates required by the mine to optimise and maximise its resources, while also illustrating how the mine can realise the full economic benefit from both ROM and sized product sales.

The mine will require a total investment of R157 million in the first year. The estimated initial investment in month one for ROM operations is approximately R10 million. The crushed and screened operations are estimated to require R13 million in month one. The expected coal tonnes to be mined are pegged at 677 993 tonnes, with an average monthly mining rate of 56 000 tonnes. The mining sequence can be summarised as shown in Table 4.9. The mining ramp-up is evident from year 2, with year 3 being more pronounced as the ramp-up continues. Ideally, the mine should aim to mine a minimum of 40 000 tonnes per month. From Table 4.9, it is evident

that this steady state can be achieved from year 3 and maintained until the closure of the mine. There is a significant decrease in monthly coal mining, indicating resource depletion.

Table 4.14: Mining sequence including prospecting the right resources of Mine 2

Mine sequencing	Waste (cm ³)	Coal (t)	SR	% Change
1	3 096 514	677 993	4.6	-
2	3 339 615	790 827	4.2	17
3	4 193 801	980 214	4.3	24
4	4 312 500	1 061 955	4.1	8
5	5 090 972	1 206 609	4.2	14
6	5 543 635	1 259 985	4.4	4
7	5 424 409	1 285 684	4.2	2
8	2 559 186	634 737	4.0	-51
Total	33 560 632	7 898 004	4.2	

The ROM NPV is shown in Table 4.10 and it is just over R212 million at a discount rate of 15% over a period of 8 years. This can be achieved at an initial mining rate of just over 50,000 tonnes per month.

Table 4.15: NPV of the ROM material from Mine 2 over a period of 8 years at a discount rate of 15%

Year	0	1	3	5	8
	R156 935 702	R53 100 898	R70 225 937	R92 873 802	R141 249 444
PV	R156 935 702	R46 174 694	R46 174 694	R46 174 694	R46 174 694
	R156 935 702	R369 397 550			
NPV	R212 461 848				

The NPV for crushed and screened product is approximately R344 million over the same period at the same discount rate of 15% (Table 4.11).

Table 4.16: NPV of crushed and screened products from Mine 2 over a period of 8 years based on a discount rate of 15%

Year	0	1	3	5	8
	R215 529 448	R93 598 827	R113 254 581	R137 038 043	R182 397 635
PV	R215 529 448	R81 390 285	R74 466 725	R68 132 127	R59 626 110
	R215 529 448	R560 202 114			
NPV	R344 672 666				

However, it should also be noted that since a mining permit can only be renewed for a period not exceeding 5 years, this research has also analysed the mine's NPV over this five-year period. Therefore, the ROM NPV would be R73.94 million over the legally permitted time limit of the mining permit, while the crushed-and-screened NPV would be R157.54 million.

McKeown et al. (2024) conducted a study to determine the expected IRR for mine development projects as shown in Figure 4.39. Their study noted that the expected IRRs for mine development projects range from 15% to 80%, with a median of 28% and a mean of 33%. Using the work done by McKeown et al. (2024), it is evident that IRR for both ROM as well as crushed and screened products compare well with other Junior Miners.

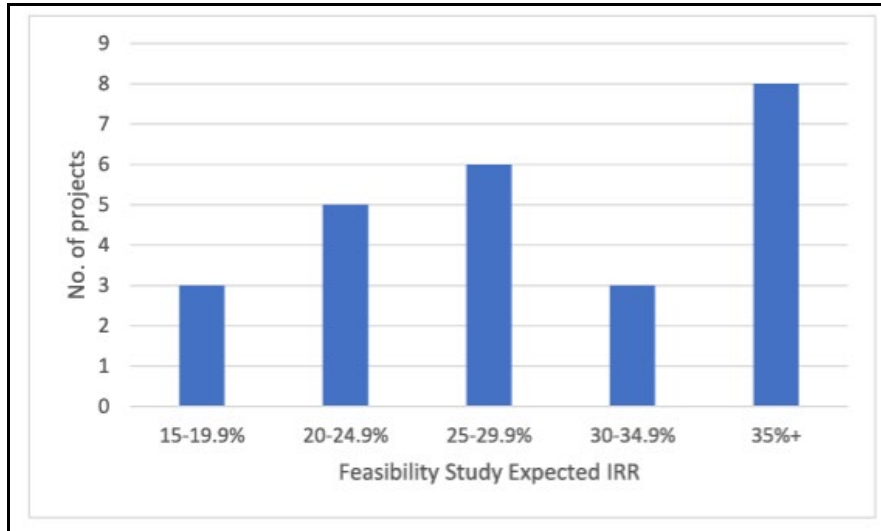


Figure 4.40: Distribution of expected IRRs in feasibility studies for projects developed by select Junior Miners listed on the Toronto Stock Exchange TSX (Source: McKeown et al., 2024)

Furthermore McKeown et al. (2024) have shown that 100% of the studied projects in Figure 4.12 had expected IRRs above 15% while almost 90% of the projects had expected IRRs above 20% and almost 70% had expected IRRs above 25%. The IRR for crushed and screened product for Mine 2 is shown in Table 4.12 over a period of eight years.

Table 4.17: IRR for crushed and screened products from Mine 2 over a period of eight years

Year	0	1	3	5	8
	R215 529 448	R93 598 827	R113 254 581	R137 038 043	R182 397 635
PV	R215 529 448	R81 390 285	R74 466 725	R68 132 127	R59 626 110
	R215 529 448	R560 202 114			
IRR	49.75%				

It should be noted that the IRR from selling crushed and screened product is well above the median and mean for Junior Miners, as it is noted at approximately 49.75% (Table 4.12). The ROM IRR for Mine 2 is shown in Table 4.13.

Table 4.18: IRR for the ROM material from Mine 2 over a period of eight years

Year	0	1	3	5	8
	R156 935 702	R53 100 898	R70 225 937	R92 873 802	R141 249 444
		R47 411 516	R49 985 435	R52 699 090	R57 048 281
	R156 935 702	R416 820 857			
IRR	42.88%				

Therefore, it would imply that Mine 2 would be better served by focusing on selling crushed and screened product.

ROM sales are shown in Figure 4.15 over five years. Sales show a steady increase throughout the life of the mine. The cost and revenue generated are based on a 10% yearly increase, which is normally the standard practice when dealing with mining costs. Furthermore, well-planned and designed mines typically ramp up production until they reach a steady state where the mine is comfortable with the cost-to-revenue curve. ROM sales show a steady increase from R210 million in the first year to approximately R308 million in year five shown in Figure 4.13.

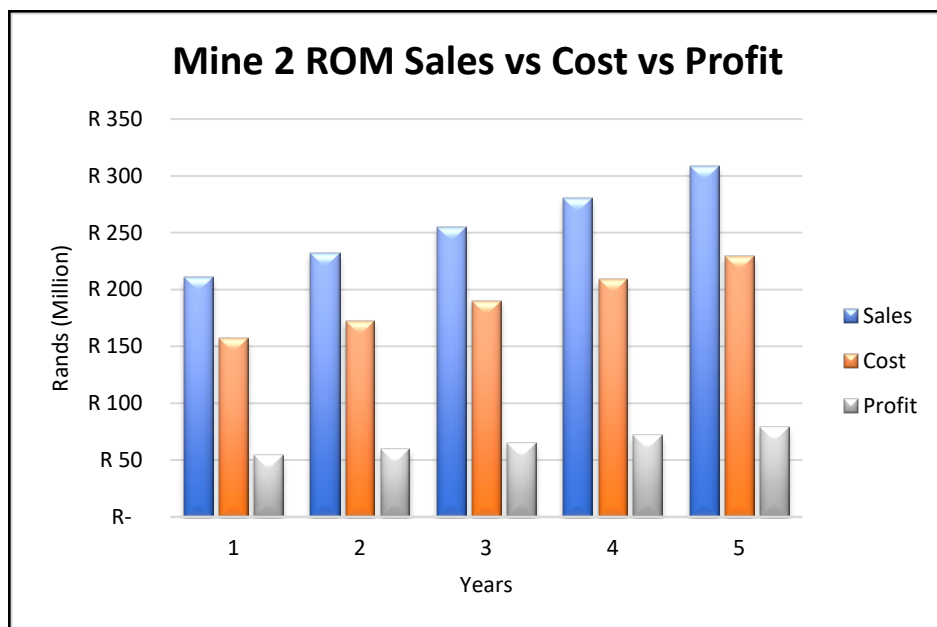


Figure 4.41: Sales, cost, and profit of the ROM material from Mine 2 over a period of five years

The revenue generated by the mine only selling ROM would amount to R1.28 billion over a five-year period, with profits of approximately R328 million. Sales performance of crushed and screened product are shown in Figure 4.14. Based on the plan and design suggested by this research, the mine could double its revenue selling a finished product (refer to crushed and screened products in Figure 4.14).

In total, the mine will generate just under R2 billion in sales and approximately R575 million in profit over a five-year period. The projected sales are within industry norms for most emerging and major coal suppliers. As of 2023, South Africa mines produced nearly 232 million tonnes of coal per annum, as noted by Minerals Council South Africa (2024). About 80% of this production was sold to the local market while 20% was sold to the export markets.

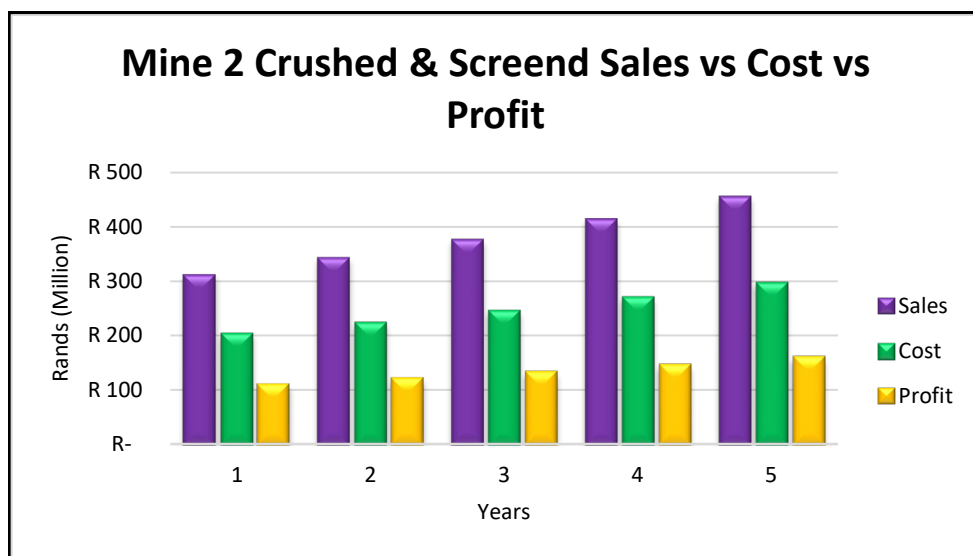


Figure 4.42: Sales, cost and profit of crushed and screened products from Mine 2 over a period of five years

Mine 2 would realise better economic returns if it focused and prioritised the local markets like Eskom, since about 80% of local sales in 2023 were dominated by Eskom (Minerals Council South Africa, 2024). Another added advantage is that most coal sold in the local market does not need to be

washed. Whereas coal sold to international markets only fetches premium prices when washed.

4.3.7. Model of Mine 2 to reduce dilution and contamination during extraction

Currently, the mine is experiencing issues with dilution and contamination, which are only identified after the coal is dispatched to the stockpiling area. For the mine to address these issues, it will need to undertake a couple of exercises. Firstly, Seam 2 needs to be mined selectively as the seam splits into two seams; namely, Seam 2 Upper and Seam 2 Lower as shown in Figure 4.15 towards the north-eastern portion of the mine. Seam 2 Upper and Seam 2 Lower are separated by a thin band of sandstone that varies between 20 cm and 30 cm in thickness.

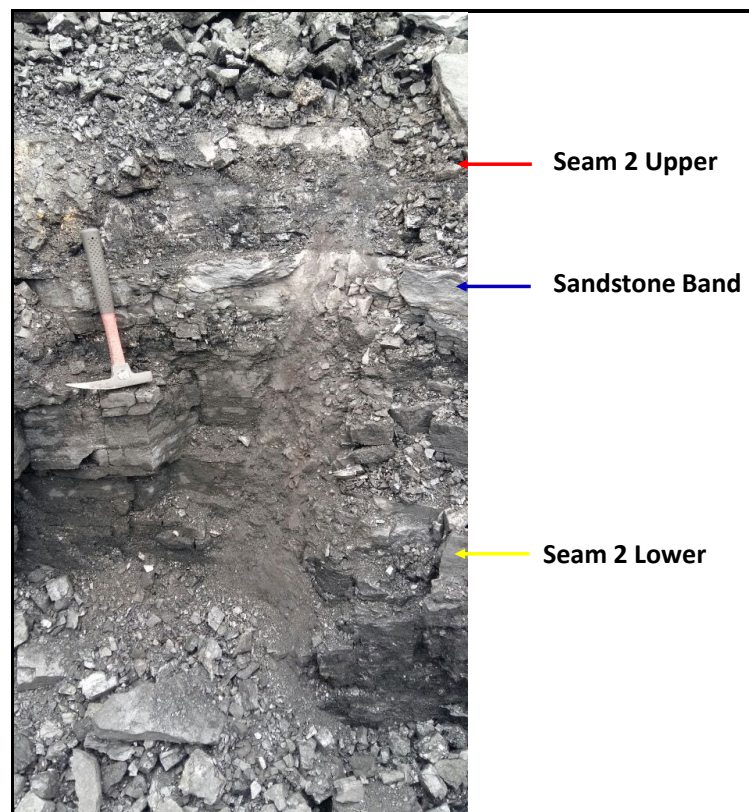


Figure 4.43: Seam 2 split into Seam 2 Upper and Seam 2 Lower by a sandstone band

Secondly, the mine needs to re-evaluate the machines it is using. Currently, three (3) 50-tonne excavators are opening blocks and loading trucks. Ideally, the mine will need to remove one 50-tonne excavator from its fleet and bring in a 30-tonne excavator. The 30-tonne excavator's smaller bucket will be ideal to selectively load the Seam 2 coal as separate units. The smaller 30t excavator will also be able to remove the 20 - 30cm thin layer of sandstone parting between Seam 2 Upper and Seam 2 Lower. The contamination and dilution experienced by the mine is illustrated in Figure 4.16. The contamination and dilution observed occurred from the use of a 50t excavator loading Seam 2 Upper coal. The excavator operator loaded the coal together with the sandstone parting. The block model in Figure 4.17 illustrates the difficulties Mine 2 faces in fully extracting coal pillars because of the presence of dolerite.



Figure 4.44: Contaminated coal at the stockpiling area of Mine 2

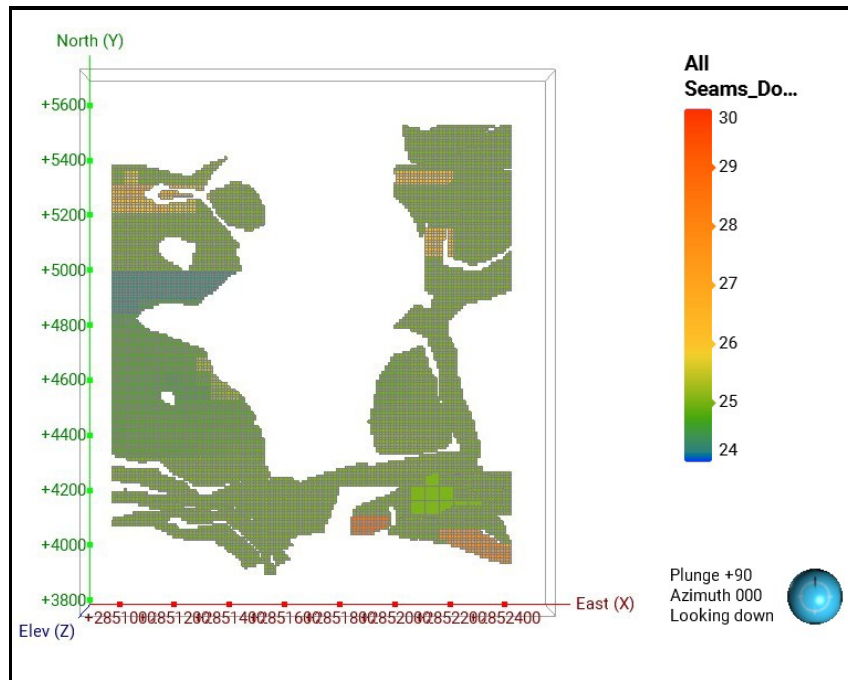


Figure 4.45: Block model of the coal seam of Mine 2 generated in Leapfrog

Results from Mine 2 have shown that the mine can be profitable and sustainable at an average of producing 40 000 tonnes a month, with an NPV of R73.94m and an IRR of 42.88% for ROM. On the other hand, the NPV and IRR for crushed and screened product are R157.54m and 49.75% respectively.

4.4. Comparison of the performance of the two mines

Mine 1 produces between 20 kt to 30 kt of coal a month compared to Mine 2 which produces between 15 kt and 20 kt every month. The LOM of both operations is very different, Mine 1 has a LOM of 48 months while Mine 2 does not have an official LOM in place. Mine 1 has 2.44 Mt in total resource base while Mine 2 has 7.22 Mt. Both mines have been experiencing similar problems in terms of historical information that is available. However, the information gap from Mine 2 is not as excessive as that of Mine 1. The only information available to Mine 1 is the old underground workings map, that the mine uses to try and locate pillars. Mine 2 is old design and plan used

by the previous owners. Both mines are experiencing very similar technical problems, the lack of an accurate geological model as an input into their operations has created fundamental problems for both mines. The lack of a resource model significantly contributes to the dilution and contamination challenges they are experiencing. Essentially, these miners are chasing coal, while that strategy may yield some results in the short term, it will definitely not sustain the mine in the long term. Both mines struggle with equipment utilisation because of their approach to simply mine to generate revenue without looking at the sustainability of their decision making. The NPV and IRR for both mines clearly illustrates that both operations are above the nominal mean based on the work by McKeown et al., 2024. Thus, it is reasonable to assume that should these miners employ a decision-based approach in their operations, they can operate mines that are sustainable in the long term.

4.5. Junior Miner Coal Pillar Mining Matrix

Having studied the daily operations of both Mine 1 and Mine 2, it was clear that Junior Miner would benefit from having a comprehensive mining implementation plan prior to commencing operations. This study has shown that a Junior Miner coal pillar mining matrix will help these miners set up operations geared for success and sustainability. The matrix is illustrated in Table 4.14, Table 4.15 and Table 4.16.

Table 4.19: Mining Projects Analytic Hierarchy Process Values

	Ore Quality	Mineral Resources	Commodity Price	Hurdle Rate	NPV	IRR
Ore Quality	1	8	5	4	5	5.5
Mineral Resources	0.13	1	5	4.8	0.15	0.13
Commodity Price	0.20	0.2	1	0.17	0.14	0.14
Hurdle Rate	0.25	0.21	6	1	0.17	2
NPV	0.20	6.50	7	6	1	0.5
IRR	0.18	8	7	0.5	2	1

Table 4.20: Normalised Pairwise Comparison Matrix

	Ore Quality	Mineral Resources	Commodity Price	Hurdle Rate	NPV	IRR	Criteria Weights
Ore Quality	0.51	0.33	0.16	0.24	0.59	0.59	0.41
Mineral Resources	0.06	0.04	0.16	0.29	0.02	0.01	0.10
Commodity Price	0.10	0.01	0.03	0.01	0.02	0.02	0.03
Hurdle Rate	0.13	0.01	0.19	0.06	0.02	0.22	0.10
NPV	0.10	0.27	0.23	0.36	0.12	0.05	0.19
IRR	0.09	0.33	0.23	0.03	0.24	0.11	0.17

According to Bogdanović et al. (2019), it is very important for the project to identify all potential risks in advance and prepare appropriate measures to prevent them. Therefore, risk mitigation is essential to the success of all projects, not just mining operations. This research has employed the Analytic Hierarchy Process (AHP) and the checklist method to assist Junior Miners with their decision-making.

Table 4.21: Junior Miner's checklist prior to starting a new mining project

Description	Consideration	Yes	No
Capital Cost / Hurdle Rate	Does the company have a hurdle rate and does the project meet the average industry acceptable hurdle rate of 15%		
Commodity Price	Does the commodity price projection support full scale mine development		
Infrastructure	Is the existing infrastructure the project can use or did the project account for the required infrastructure		
Internal Rate of Return (IRR)	Is the IRR better than the company's hurdle rate		
Legal Framework	Has the project taken into account all the legal requirements to ensure compliance		
Location	Did the project communicate with the surrounding community structures and include them in the project plan		
Management Capacity	Will the operation be able to employ a suitably qualified management team to ensure the project succeed		
Market Accessibility	Does the product offering cater to the current market needs		
Mineral Reserves	Do the mineral resources and reserves support an economically viable business case		
Net Present Value (NPV)	Does the NPV support an economically viable mine project		
Ore Quality	Will the ore quality meet industry standard (domestic or export market) to support sustainability		
Political Environments	Is the project located in a politically stable environment (does the project have support of the local municipality)		
Profitability / Operating Cost	Will the modelled profitability offset the long-term operating cost		
Social and Environmental	Are the project social and labour plans and environmental authorisations approved by the relevant departments		
Technical Resource Accessibility	Will the project have access to the required technical resources to ensure long term sustainability		

4.6. Summarised findings

The results presented in this chapter have shown that there is a significant opportunity for both mines with the appropriate application of financial and technical models. The results established that challenges are currently experienced by both operations mainly due to poor execution of equipment selection which leads to inaccurate application of selective mining methods. However, it was also established that for Mine 1 to achieve sustained growth with a positive NPV and IRR, the mine would need to mine a minimum of 50 000 tonnes per month. On the other hand, Mine 2 would need to mine a minimum of 40 000 tonnes per month to achieve sustainability and growth. However, Mine 2 can mine up to a maximum of 80 000 tonnes per month from year 3.

The optimisation of mine plans and designs would result in profits of over R400m for Mine 1 when supplying only ROM while crushed and screened product would result in profits exceeding R800m over a period of four years. Mine 2 would realise profits in excess of R320m over a period of five years supplying ROM, while the supply of crushed and screened product would result in double the profits for Mine 1.

CHAPTER 5: DISCUSSIONS OF MODELS AND PLANS

In this chapter, the models and plans are discussed at length. The models and plans aim to optimise the extraction of coal from coal pillars using efficient methods. The proposed methods will maximise output and general overall sustainability of the two mines. The results of these models and plans presented in Chapter 4 form the basis of the discussions in this chapter.

5.1. Introduction

This study has shown that Junior Miners need to employ a multi staged approach to ensure long term sustainability prior to commencing with coal pillar mining projects. This approach needs to be comprehensive with a roadmap for implementation.

5.2. Modelling and planning of Mine 1

5.2.1. Analysis of dilution and contamination at Mine 1

The two coal seams mined in this operation are both of good quality and can be exported as dry-crushed and screened product when mined cleanly. However, dilution and contamination pose a serious concern. In instances where dilution is inherent in the coal, the mine can do very little to mitigate for that. It is in instances where contamination is caused by human involvement that the mine needs to be extra vigilant. The pillars in this operation exhibit little internal dilution but most of the dilution is external, due to the mining method employed. The equipment used is not necessarily fit for purpose and there is also human error, thus controlling the causes of external dilution is very important.

This mine requires a management team that is technically skilled and adequately equipped to consistently assess the mining methods employed.

The extraction of coal pillar requires ongoing monitoring and innovation. Drilling and blasting have been proposed as part of the mining method to minimise contamination for each block. The relationship between bench height and diameter for drilling and blasting is shown in Figure 5.1. Maintaining the diameter drilling and blasting and bench height is crucially important for coal resources optimisation during blasting. The mine's practice of drilling and blasting on an as-needed basis is not sustainable and has not yielded positive and sustainable results. The proposed drilling-and-blasting method was based on 50 m x 50 m mining blocks with a 3.5 m x 4.5 m burden and spacing pattern respectively using a hole diameter of 127 mm.

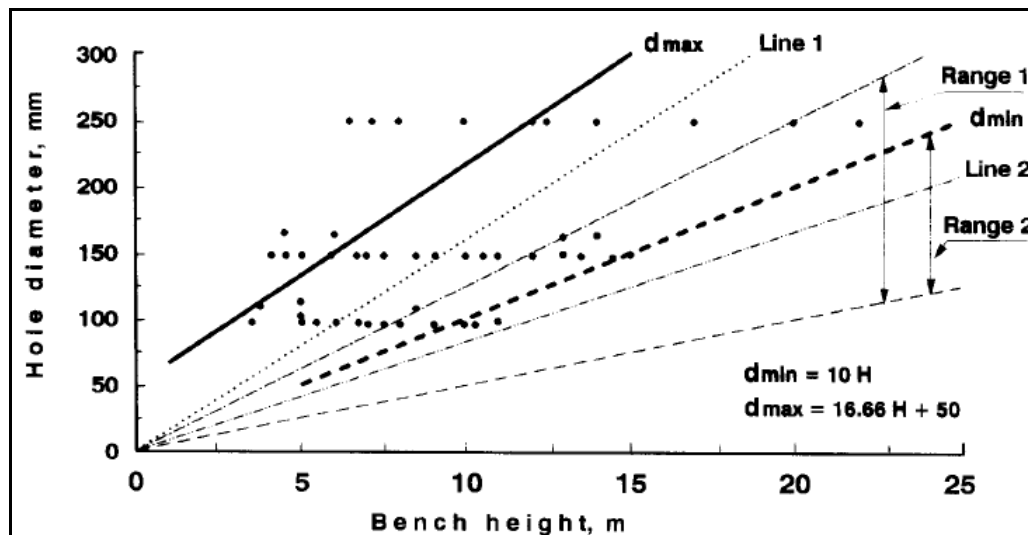


Figure 5.46: Relationship between bench height and diameter for drilling and blasting (Source: Adhikari, 1999)

Additionally, since coal pillar blasting is very sensitive and requires extra caution (Ngwenyama et al., 2017), a bench height of 15–20m was used for the 127 mm diameter trial blast. This diameter was the most optimal compared to the 115 mm and 165 mm diameters (Figure 5.1), as suggested by Adhikari (1999). Furthermore, the recommended hole diameter of 127 mm was chosen based on rock properties, bench height, the required degree of fragmentation, drilling costs, and size of operation. It was found that a diameter of 127 mm was optimal for producing the required

fragmentation without significant ground vibrations or excessive flyrock. Even though flyrock is largely a function of stemming length (Oates and Spiteri, 2021).

When the chosen diameter is executed accurately, it can reduce overcharging of blast holes and reduce cost, as noted by Adhikari (1999). It was therefore determined that at these block, burden, and spacing dimensions, the mine would be blasting a total of approximately 156 holes. Making use of Equation (5.1), the number of holes is determined by the dimensions, burden, and spacing of blocks.

An accurate number of holes, amongst other parameters, is important. For example, working with a small number of holes will yield a poor blast. Thus, leading to poor rock breakage and fragmentation thus requiring extra effort during loading and hauling. Similarly, overestimating the number of holes will result in an overblast, which is one of the primary causes of contamination and dilution outside the actual mining. Therefore, with a 50 m x 50 m mining block dimension, the block model predicts an average of 3 750 tonnes of coal would be produced.

$$\begin{aligned}\text{Total holes} &= \left(\frac{L}{S}\right) \times \left(\frac{W}{B}\right) & (5.1) \\ &= \left(\frac{50}{3.5}\right) \times \left(\frac{50}{4.5}\right) = 14 \times 11 = 156 \text{ holes to be blasted}\end{aligned}$$

Where:

L = length, which is the full length of a blast block

W = width, which is the full width of a blast block

S = spacing, which is the distance between blastholes in the same row

B = burden, which is the distance between adjacent rows.

Equation (5.1) is critical since burden and spacing are very important for fragmentation, ground vibrations and the overall efficiency of the blast. Drilling and blasting result in fragmentation that can affect downstream processes. The resulting oversized or undersized fragments influence the productivity of the excavator and loader and will determine the value of the

final product, the production cost and the energy consumption (Kecojevic and Komljenovic, 2006; Kinyua et al., 2022).

To optimally extract coal and achieve productivity efficiency aligned with resource maximisation, this research recommends a staggered drill-and-blast design with presplitting. This will reduce intense backbreak and have appropriately squared mine blocks. Figure 5.2 shows the recommended blast design pattern. Even though this will add a significant cost to the operation, the recommended pattern in Figure 5.2 will improve the stability of the final excavation. The recommended blast design is based on the results obtained from two trial blasts undertaken by the mine. The staggered pattern was trialled first and the square pattern was trialled as a second option.

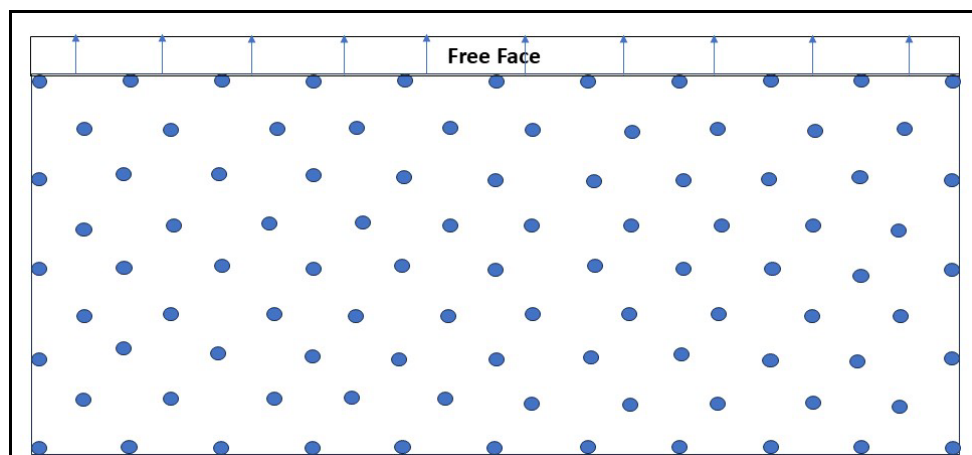


Figure 5.47: Example of blast design as piloted in one of the blocks of Mine 1

The square pattern resulted in large boulders and excessive fines because it did not produce uniform and consistent fragmentation. Back break was also another noted issue, which was creating rockfall hazards. Lastly, the square pattern was more costly as it required more explosives overall. The recommended staggered pattern is less costly, but most importantly it produces more consistent fragmentation since the energy is distributed evenly across the block. The value of the staggered pattern is seen in the improved cycle time and improved machine utilisation.

Presplitting enhances the stability of the remaining rock face by controlling the fracturing process and improves overall highwall stability, requiring less time and effort to stabilise the final excavation line (Taiwo, 2024; Eades and Perry, 2019). This will also result in fewer remediation efforts due to increased stability (Eades and Perry, 2019). The implementation of the recommended staggered pattern (Figure 5.2) will yield better resource optimisation, reduce contamination and dilution, and maximise efficiency and time. Drilling and blasting processes are costly but the initial capital outlay will be offset by the long-term benefits.

The mine will be able to increase its productivity rates with improved wall stability. It is also worth noting that the recommended overall blast design can significantly increase the time spent drilling, which can affect blast economics (Eades and Perry, 2019). When executed correctly, this presplit design helps ensure safer working conditions, improve operational efficiency, and reduce the need for costly reinforcement measures (Taiwo, 2024).

The implementation of blasting will eliminate the current free-digging method, increase efficiency, reduce downstream costs, and improve overall productivity. In an operation like Mine 1, free digging not only slows down production, but it also produces oversized fragments, as noted by Ngoroyemoto et al. (2023). In its simplest form, free digging is the method of excavating and hauling materials without drilling and blasting. It often leads to increased mining costs far above what is normally anticipated and planned by the mine, especially in rock mining operations.

The present method of free digging goes against the intended principles of running a mining operation. Essentially, mining is underpinned by profit making through extracting, processing, and selling minerals from a mineral deposit (Sebutsoe, 2017). It is important to optimise the extraction of the mineral resource given that there are always time, capital, and space constraints. Holistically, free-digging coal has too many disadvantages such

as spending too much time on excavation due to the difficulty of breaking hard rock without explosives.

Additionally, there are frequent machinery breakages due to forcing equipment to perform work that it is not equipped to handle. Ultimately this leads to slower production rates on machines, even though machine availability is always above 85% and utilisation is approximately 90%. The mine is not making full use of the available equipment and machinery. By incorporating drilling and blasting into the operation, the mine can realise an increase of approximately 33% in production. This increase translates into an additional 6 600–9 900 tonnes of coal per month. Had an efficiency strategy been in place from the beginning, the coal that is usually diluted, contaminated, and returned to the pit as backfill could have been salvaged.

However, due to a combination of factors, including the mine's lack of a beneficiation plant, it was unable to separate contaminated coal from uncontaminated coal. As a result, the contamination resulted in a loss of R1.58 million for the mine. As a Junior Miner with limited resources, a financial loss such as that could make or break the operation. In the case of Mine 1, the 3 500 tonnes of contaminated coal accounted for 17.5% of the mine's monthly turnover.

Figure 5.3 shows the resource model that was created for Mine 1. The resource illustrated that dilution is largely localised to the southeastern part of the mine. This dilution accounts for only a small portion of the entire resource. Therefore, Mine 1 has more of contamination issues than dilution, even though dilution is noted in some parts of the operation as per the block model (Figure 5.3).

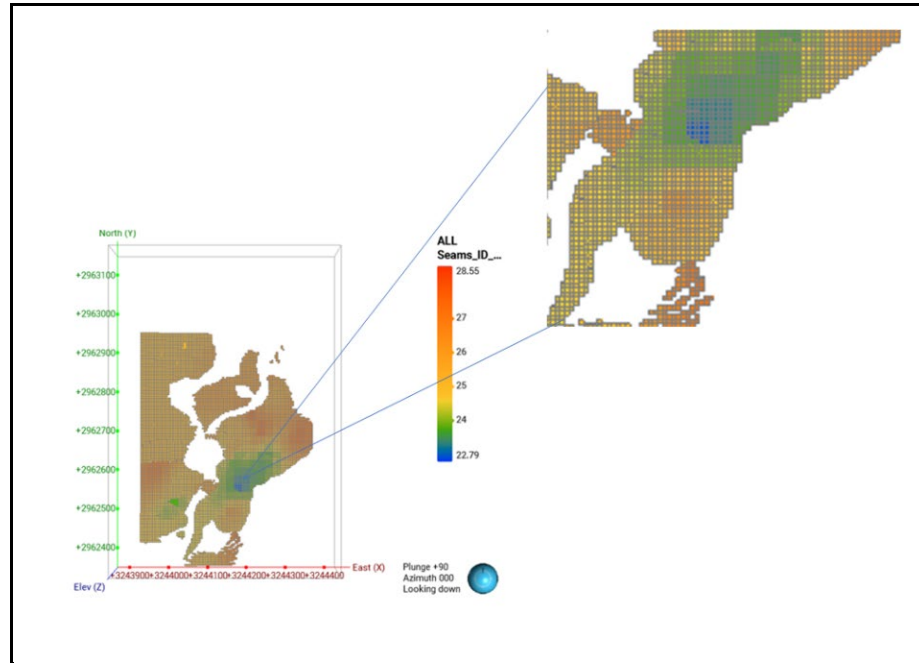


Figure 5.48: Dilution localised to the southeastern portion of the mine

5.2.2. Mitigation strategies for contamination and dilution at Mine 1

There is not much that can be done with dilution since it is an inherent feature of the coal deposit. This operation is mostly affected by contamination more than dilution in the traditional sense. However, contamination can be mitigated by implementing sufficient controls, such as drilling and blasting optimisation strategies, efficient material handling, and optimised bench design. Having a drilling and blasting strategy that maximises coal recovery is critical, as it will reduce the amount of waste material incorporated into the coal.

An efficient material-handling plan will limit contamination as it must account for loading and hauling and finally processing once the coal is at the plant or ROM pad. Lastly, an appropriate mining sequence will significantly reduce the amount of overburden falling into mining blocks during excavation and loading. Another mitigation strategy is employee awareness and training in contamination control and prevention. Therefore, employees

need to be trained to recognise contamination and understand its implications for the overall value chain of the operation.

Additionally, there is a need for continuous tracking of contamination, where planned tonnages are reviewed against the resource model. This involves comparing the planned tonnages to the plant feed, which is also one of the first steps in the reconciliation process. Furthermore, the mine must use the sandstone/siltstone band as a marker zone, noted in Chapter 4 as part of its contamination control measure. Marker zones are consistently marked so that supervisors are aware when they reach each zone enabling them to advise operators accordingly.

In addition to the above, the mine needs to employ a technically competent management team. This team must put in place mitigation measures, such as robust grade control plans, to inform how coal mining is managed and controlled as mining progresses across different blocks. This will foster a culture of proactivity rather than one of reactivity, as is the case currently. As continuous improvement is implemented, the management team must also use appropriate mining methods for specific blocks. A blanket approach will not work as it might miss critical areas that require an area-specific mining approach.

Monitoring these measures will enable the mine to evaluate the operation's performance in real time and give the management team the flexibility to address emerging issues. With the incorporation of drilling and blasting into its operations, the mine will need to be highly vigilant in monitoring coal pillar features and adjust its blasting parameters accordingly (i.e., burden and spacing, powder factor, etc.). However, key the strategies in monitoring dilution and contamination will have to be adjusting the mining culture. This will mean that the operation will not focus solely on achieving production targets at the expense of quality.

Therefore, the balance between quality and quantity needs to be closely monitored to ensure the long-term sustainability of the operation. Lastly, the

mine needs to have proper procedures and processes in place to ensure sustainability and maximise coal resources. These procedures and processes must be documented in standard operating procedures (SOPs), including guidelines for handling diluted zones and blocks, as well as avoiding coal contamination during mining.

5.3. Modelling and planning of Mine 2

5.3.1. Analysis of dilution and contamination at Mine 2

Contamination problems at Mine 2 are not as pronounced as those seen in Mine 1, even though they have had some incidents. The main issue for this operation is the dilution caused by the sandstone/siltstone layer in Seam 2. This band of sandstone/siltstone has a minimum thickness of 10 cm and a maximum thickness of 64 cm, with an overall average of 30cm. It has split the seam into Seam 2 Upper and Seam 2 Lower, and, as previously mentioned, its thickness does not always allow selective mining. Therefore, it becomes very important to understand and quantify the expected dilution in any given block of the mine. Dilution for this mine was calculated as follows (Wang et al., 2011):

$$\text{Dilution} = \frac{\text{Waste tonnages}}{\text{Ore tonnages} + \text{Waste tonnages}} \times 100\% \quad (5.2)$$

The mining operation needs to understand the implications of dilution, as they may determine the success or failure of the project. Ebrahimi (2013) notes that quantifying dilution during the study stage is necessary for a more robust economic evaluation of the project. The dilution percentages that have been suggested by this research at different thicknesses of the sandstone/siltstone band are presented in Table 5.1.

Table 5.22: Dilutions for a mining block that is 50 m x 50 m in dimension, with an average coal thickness of 2.24 m at a 60% yield

SST/ST Thickness	20 cm	30 cm	50 cm
Waste volume	300	450	750
Coal volume	3360	3360	3360
Dilution (%)	8.92	13.39	22.32

From Table 5.1, it is evident that the thicker the sandstone/siltstone layer, the higher the tonnage loss and, in some cases where it is significantly thicker, it will reduce the coal quality to levels that would render it uneconomic to mine. A reduction in coal quality due to higher dilution was observed in an exercise undertaken by the mine to assess coal quality at different dilution percentages, as shown in Table 5.1. The current industry practice is to allow a dilution factor of no more than 10% (Xingwana, 2016).

However, for this type of coal pillar operation, it is highly recommended to use a dilution rate of 15%, as the industry norm of 10% is not practical. The 15% dilution factor suggested for this mine has considered that dilution will vary within the mine (Table 5.1) for different blocks and benches (Ebrahimi, 2013). Mining coal pillars is already a marginal exercise, with output about 40% lower than that from a solid coal block. Thus, the goal in coal pillar mining is to achieve the best possible coal recovery. The lower the dilution, the more coal will be recovered, but it is extremely difficult to mine pillars without dilution (Ngwenyama and De Graaf, 2021).

A 15% dilution factor is reasonable, as it means that for every expected 3 360 tonnes of coal, only 2 856 tonnes will be classified as ROM and sent to the processing plant. It was also noted that when coal with sandstone is sent to the processing plant, the mine tends to have multiple breakdowns, which cause delays and slow down the movement of coal out of the mine. During downtime, the mine must cover the costs, adding another expense to an already lean coal mining operation. Therefore, quantifying the dilution

for this operation is very important to its continued sustainability and profitability.

However, in areas of the mine where the sandstone/siltstone marker zone is thick enough, the mine will need to use a smaller machine, like a 20-tonne excavator, to mine it. In areas where it is not feasible and practical to selectively mine the sandstone/siltstone layers, the operation will need to apply the appropriate dilution factors. It is also important to note that dilution factors may need to be adjusted based on the scheduled mining block. Applying a blanket approach may not necessarily work in operations where coal pillars make up the bulk of the coal resources. Figure 5.4, shows coal distribution without the inherent sandstone/shale unit. Without the inherent sandstone/siltstone dilution, the bulk of the coal in Mine 2 (Figure 5.4) could be for the export market as it meets the required coal quality for this market.

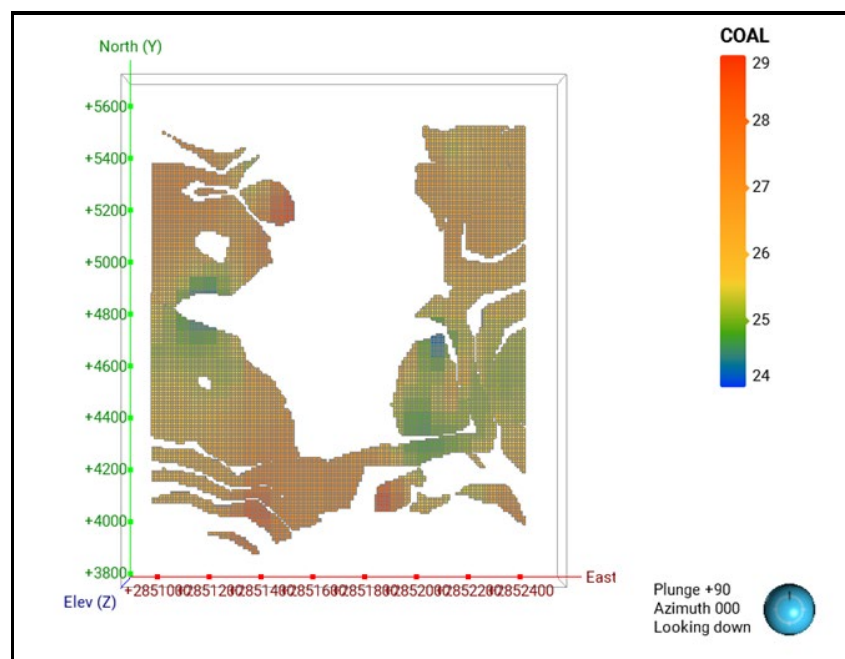


Figure 5.49: Coal distribution without the inherent sandstone/siltstone dilution at Mine 2

It is imperative for the mine to continuously enhance its resource model to achieve optimal accuracy. This enhanced model will facilitate timely updates to the crushing and screening plant regarding the anticipated run-of-mine

(ROM) material to be dispatched, thereby ensuring efficient operations and resource management. When dilution is expected, the mine will need to calculate a blending ratio to mitigate it. Blending is the process of mixing different types of coal qualities to achieve a desired quality for processing and ultimately sales to clients. An example of blending ratios for Mine 2 is presented in Table 5.2.

Table 5.23: Typical blending parameters for the different types of coal using raw qualities for Mine 2

# Scoops	2		2		2		6	Scenario 1			
	Seam 1	S1 Calc	Seam 2_U	S2U Calc	Seam 2_L	S2L Calc		Actual	Target	Category	% Complete
TM	6	12	7.3	14.6	8.1	16.2		7.13	8.1		99.12
IM	3.1	6.2	3.4	6.8	4.7	9.4		3.73	3.5		98.93
ASH	24.4	48.8	37.1	74.2	29.6	59.2		30.37	29.4		98.97
VM	22	44	18	36	27	54		22.33	20.86		98.93
FC	50.5	101	41.5	83	38.7	77.4		43.57	46.24		99.06
TS	0.7	1.4	0.8	1.6	1.1	2.2		0.87	1.3		99.33
CV (ad)	21.5	43	18.5	37	20.5	41		20.17	22.5		99.10
Percentage		33%		33%		33%		100%	100%		
Tons Volumes		1000		1000		1000		3000			

The calculated blending ratio for this operation was 3:1, which would be more beneficial for blending Seam 2 and Seam 1 coal after dilution was considered. Over a month and a half, the mine conducted grade-control sampling from both the pit face and the stockpile. The results showed a contrast between the historical information and the grade-control samples taken from late February 2024 to mid-April 2024. Persistent grade control issues are shown in Figure 5.5. It is evident that the mine had grade control issues during the period in which the exercise was undertaken.

The data shows calorific values below the expected values for this seam. Historical data indicate that the expected calorific values (CV) for Seam 2 range from 21 to 25 MJ/kg when mined clean. Figure 5.5 shows consistent peaks and valleys, which are a clear indication of the struggles the mine faced during this period. In some instances, the CV dropped below 18 MJ/kg, meaning that coal was not even meeting the qualities required at Eskom power stations. Thus, the mine had to blend the coal so that its

qualities could be upgraded. However, this meant more of the better coal had to be used in the blending process.

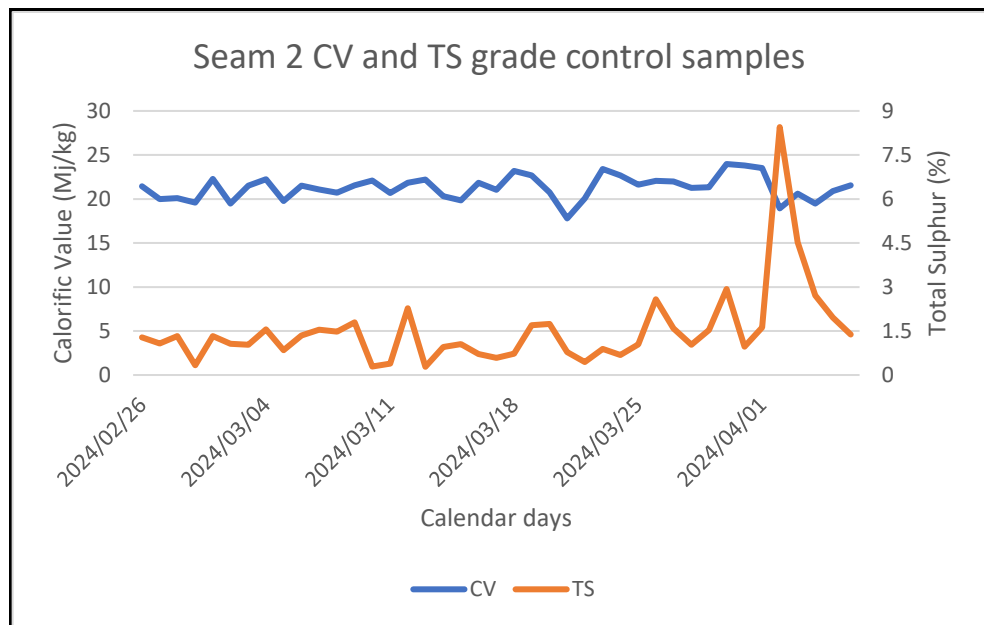


Figure 5.50: CV and TS grade control samples from Seam 2 at Mine 2 between February and April 2024

Thus, there was less good-quality coal available to sell to customers buying better-quality coal. Although the mine was able to recover some money but the cost to mine the block, which produced highly contaminated coal on 21 March 2024 (Figure 5.5) was never recovered, even after blending. An exercise was also undertaken to conduct grade control for split Seam 2. However, it seemed the grade control problem was experienced across the entire mining profile during this period. The same trend can be seen in both Seam 2 Upper and Seam 2 Lower as shown in Figure 5.6.

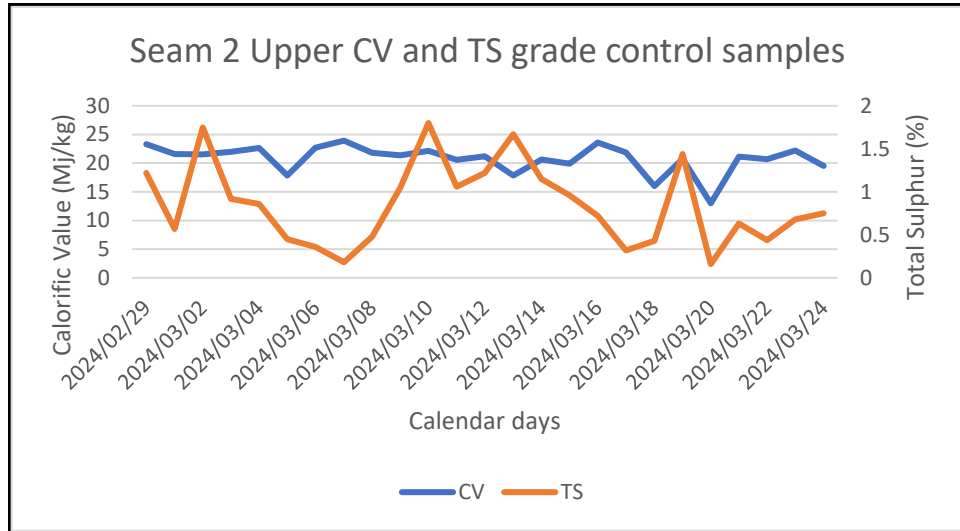


Figure 5.51: CV and TS grade control samples from Seam 2 Upper at Mine 2 between February and April 2024

Grade control samples for the CV collected from Seam 2 Upper appear to be stable (Figure 5.6) from when the exercise commenced till 15 March, when the grades became more erratic. Towards the end of March, the CV qualities began to drop sharply, even though they had improved around 19 March. This drastic drop in CV quality indicates significant dilution in the coal. The total sulphur also shows a quite unstable trend, without any well-defined trend trajectory projecting either higher or lower sulphur content.

This type of trend is most commonly seen in units rich in sulphide minerals (pyrite and siderite). The grade control for Seam 2 Lower started out well, but the mine experienced difficulties from 13 to 30 March. After this period, the coal being mined was much cleaner, which is shown by the upward trend on the graph in Figure 5.7. The mine recognised that it had quality issues with its coal. However, because it did not regularly implement grade control, the mine missed an opportunity to implement corrective measures in time.

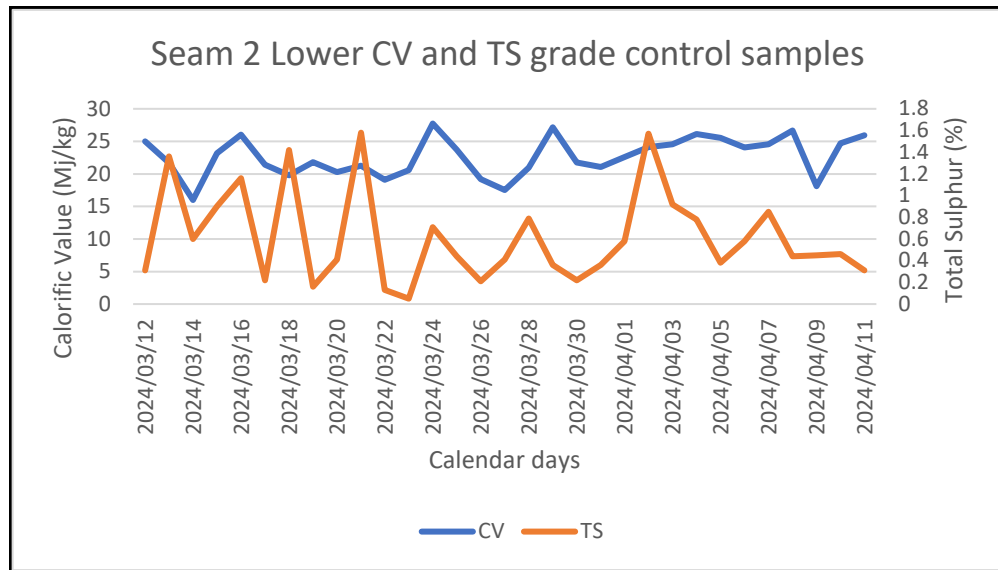


Figure 5.52: CV and TS grade control samples from Seam 2 Lower at Mine 2 between February and April 2024

This oversight led to significant problems that ultimately harmed the operation. Additionally, it was found that the mine could use Seam 2 Lower to supply the export market. However, if the coal qualities are low, it would be difficult to meet the requirements of that market. An alternative for operations of this nature would be to wash the coal, but since most Junior Miners lack coal-washing plants, blending is the only option. This is exactly what Mine 2 did with the coal that did not meet specifications, blending inherently low-quality coal with good-quality coal.

In this instance, the mine had to cautiously mine the Seam 2 Lower coal as cleanly as possible and use it to slowly blend the lower-quality Seam 2 coal mined during the grade control exercise at the beginning. The total sulphur for Seam 2 Lower presents an interesting dynamic, as it appears to follow the same trend as the CV. It represents a direct relationship in which both variables increase together. As the CV quality gets better, the total sulphur content also increases (Figure 5.7).

5.3.2. Mitigation strategies for dilution at Mine 2

Dilution is inherent in the coal, so there is not much that can be done to mitigate it. In this operation, dilution bands can reach a maximum thickness of 64 cm, but average approximately 30 cm throughout the entire project. Even though there is not much that can be done to mitigate for dilution, it can be quantified and controlled as suggested by Ebrahimi (2013). One way to address dilution is through a reconciliation process. This process involves taking samples from the feed in the crushing plant and comparing them with the resource model created from drillhole data.

Furthermore, Ebrahimi (2013) has suggested that, where no operational data is available, quantifying dilution during the study stage is necessary to provide a better economic evaluation of the project. In addition to achieving a more accurate economic evaluation, quantifying dilution will help improve mine design.

It is also critically important for the operation to have an ongoing sampling programme of its production drillholes, which can be used to study how the sandstone band causing dilution behaves as the mine progresses. The mine may also need to undertake an opportunity cost analysis for the Seam 2 coal. The analysis will determine whether there is a benefit to mining the Seam 2 coal as a single package in some areas, thereby increasing productivity. However, this research has shown that, currently, it would serve the mine best to mine the Seam 2 coal as a split package of Seam 2 Upper and Seam 2 Lower.

This split will reduce contamination, thus prolonging the life of the crushing and screening plant, as it will not be forced to crush sandstone/siltstone. However, it should be noted that this study did not undertake an exhaustive assessment of the benefit-versus-cost of mining Seam 2 as a single package. Furthermore, Ebrahimi (2013) suggested that a cut-off grade calculation based on different selling prices can assist operations with major dilution issues, as these factors determine the project's success or failure. This research calculated the sale price of coal across different coal qualities

to illustrate the effects that dilution and contamination can have on overall revenue generation for the mine.

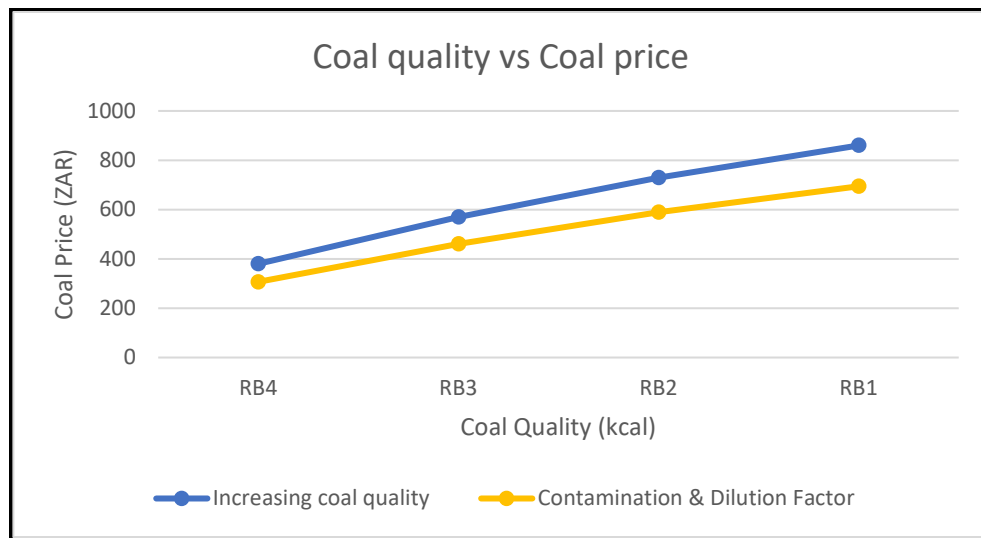


Figure 5.53: Price of coal at different qualities and associated mining cost

The graph in Figure 5.8 shows that as coal quality decreases, so does coal price, and vice versa. This relationship directly affects the ability of the mine to generate revenue, as higher coal quality yields better prices. The mining cost remains constant when only mining ROM as shown in Figure 5.9. However, this cost increases when mining ROM that involves crushing and screening. It is important to note that this cost stability does not reflect the expenses associated with reduced coal quality.

When dilution and contamination factors are considered, the mining cost shows a significantly different trend. The mining cost was adjusted by the same dilution and contamination factor (Table 5.1) that has been suggested for this mine, as well as accounting for the saleable product, which is taken at about 95% of the coal produced. It is clear that the sale price of RB4 is significantly below the mining cost if the mine decides to only extract and sell RB4 ROM. This suggests that selling only the RB4 ROM would render the operation uneconomical.

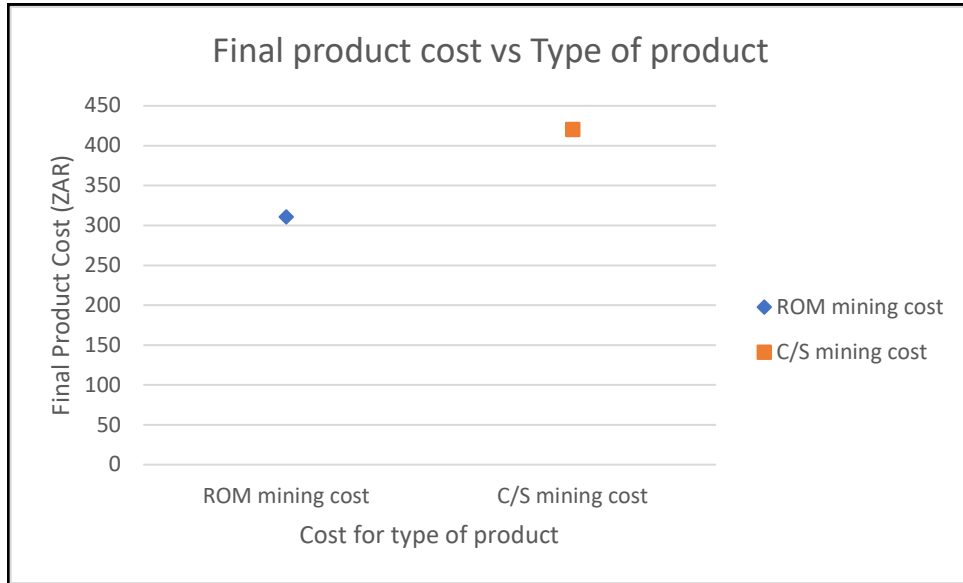


Figure 5.54: Cost of mining ROM vs cost of mining and sizing the same ROM material

It is also worth noting that contaminated and diluted RB3 will exhibit qualities associated with RB4 in some instances. Thus, even mining RB3 and RB4 might not make economic sense for the operation if contamination and dilution are left unaddressed. Therefore, clean and eventually selective mining is essential for this mine to produce saleable coal products that can be supplied to the market. Finally, since these miners lack washing plants, their only hope for economically viable operations lies in applying sound, effective mining principles suited to the type of coal they extract.

5.4. Operational efficiency and process optimisation

Both mines have efficiency and optimisation issues related to mine design that need to be resolved urgently if they are to run not only profitable but sustainable operations. As a rule of thumb, the minimum ramp width should be at least 4 times the width of the hauling equipment (Yarmuch et al., 2020). However, both ramp designs of the mine do not meet this standard. Thus, this research has proposed a minimum of 10 m hauling length per 1 m depth of the block, based on the work done by Golestanifar et al. (2018).

This means that a block that is 5-m deep, it will require a ramp length of 50 m. Tannant and Regensburg (2001) were able to illustrate this relationship using a scenario-based assumption of a final ramp with a 10% grade that makes one full circle around the pit wall.

Therefore, where the first seam is encountered at a depth of 11 m, the mine needs a minimum of 110 m of haulage ramp length to ensure slope stability and integrity are maintained, thus minimising haul load losses. In areas where another seam underlies the first, the required access ramp length was calculated from the bottom of the overlying seam.

5.4.1. Process optimisation of Mine 1

The current design was not developed using the resources block model as a foundation. It has several issues, such as double-handling of material, and does not employ the sequence mining method. Currently, the mine has more than 15 waste stockpiling areas, but all coal is stockpiled on a single material-handling pad. Another issue noted with Mine 1 is the presence of too many roads in and out of the pit, which introduces not only production concerns but also safety risks. Inadequate mine configuration can lead to numerous challenges, the mine needs effective management plans in place to address all associated risks and concerns appropriately.

Similar to the operational design plan, an effective management plan will introduce additional costs, whether through hiring extra personnel or purchasing necessary road and warning signs. Therefore, as a mitigation, this study has proposed a simple design that the mine will need to further refine after gathering additional data. The additional data will be used to undertake a comprehensive geotechnical study to have a full understanding of all required geotechnical parameters and inputs for pit design. Borehole correlations conducted in Mine 1 shown in Figure 5.10 demonstrates significant variations in the lithological profile, which is crucial for effective slope design.

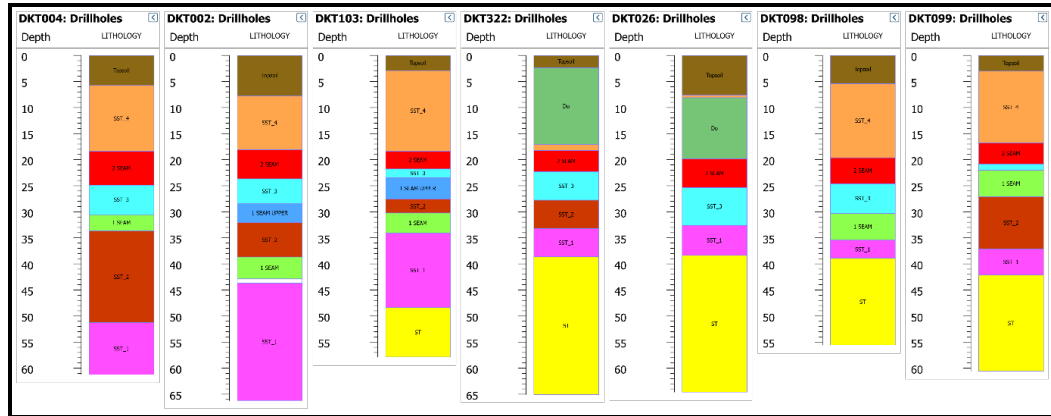


Figure 5.55: NE-SW borehole correlation at Mine 1

The inconsistent nature of the soft rock profile throughout Mine 1 necessitates that the slope stability design addresses these discrepancies. Additionally, it is essential to propose an efficient slope design method, accompanied by adequate monitoring strategies to ensure ongoing safety and stability. Thus, having geotechnically representative data of the mine is essential for ensuring efficient mine design and operation. The design for Mine 1 used the parameters that are shown in Table 5.3.

Table 5.24: Parameters used in the mine design for Mine 1

Parameter	Measurement
Slope Angle	35°
Bench Height	15 m
Berm Width	6.5 m
Ramp Angle	8°

The Mine 1 pit was designed with two roads, as shown in Figure 5.11. This design minimises traffic into the active mining pit but still enables the mine access dumping areas from multiple directions. The pit was designed with only three dumping areas: one for topsoil, one for soft material, and one for hard material (blasted material). This should streamline operations and optimise production time.

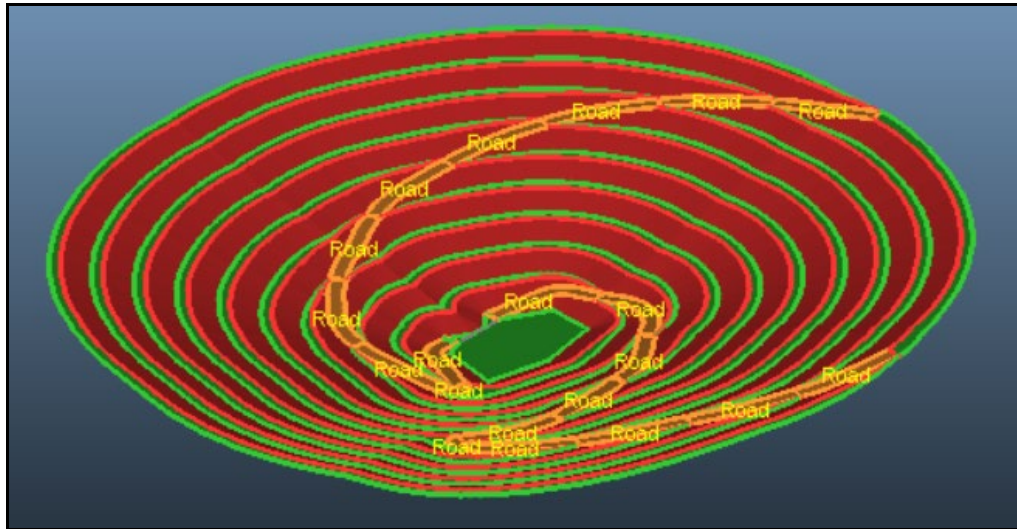


Figure 5.56: Simplistic pit design for Mine 1

Furthermore, it is imperative that miners realise that the data used at the beginning of the project needs to be updated regularly, as profiles change from one cut of the mine to the next. The more data the mine collects, the better it positions itself to have up-to-date, relevant design for its operations. Fillion and Hadjigeorgiou (2016) suggested that data collection should be a continuous process throughout the timeline of a mine operation. Data collected should span the entire mine cycle from exploration to conceptual or preliminary feasibility, final feasibility, design and construction, operations (early production/late production), and mine closure. This collected data becomes a very important input into the whole mine design and plan.

Parameters like slope design rely on a variety of information, such as geotechnical data, safety, and economics. Mine 1 lacks a mine design that adequately addresses its operational challenges, as data collection to improve mining operations is not regularly conducted. One notable area lacking consistent monitoring is the gradient on the mining block ramps. The gradient on the ramps varies from gentle to very steep, ranging from 5° to 22° , which is not conducive to hauling heavy equipment. Ramps with a very steep gradient are characterised by the loss of loaded material as ADTs exit the mined block. Thus, this introduces significant amounts of unnecessary inefficiencies.

Efficiency is also characterised by a set production schedule or plan of which Mine 1 does not have one. The mine manager determines which blocks to mine based on the need for that particular month. Running an operation in this manner introduces planning challenges and limits the mine's ability to be efficient and optimise its coal resources. In some instances, the mine has a block that produces high-quality coal that exceeds the customer's specifications. Instead of this being a positive outcome, it puts the mine in a precarious position, forcing it to either negotiate for a better price or secure a customer who will take that specific coal.

However, this is not always practical, as the mine may be delayed while trying to secure a customer who will purchase the unexpectedly higher-quality coal. Alternatively, the operation may need to mine another lower-quality block to blend the different coal products. Another challenge with extracting coal pillars is the fact that remnant coal pillars are highly susceptible to spontaneous combustion as shown in Figure 5.12.



Figure 5.57: Spontaneous combustion of coal pillars at Mine 1

Spontaneous combustion results in reduced coal quality, dangerous working environments, and overheated equipment, which directly affect output by requiring production to be halted. Managing and limiting the risk of spontaneous combustion is pivotal hence the need for a well-designed mine plan. A well-coordinated and implemented plan is critically important for mining operations, especially for coal pillar extraction. The absence of such a plan could be detrimental to the operation and could lead to a host of other safety risks. Another important factor the mine needs to consider is the availability and utilisation of machinery, as well as the payload capacity of each production machine.

Mine 1 mainly uses Sumitomo 70-tonne and Komatsu 70-tonne excavators, with bucket capacities of 2.9 m³ and 4.0 m³ respectively. According to the manufacturers guide, a 70-tonne excavator should fill a 40-tonne articulated dump truck in just six passes. Having the correct equipment specification for an operation is very important, as these machines not only speed up production but also bring significant cost savings to the mine. The CAT 966 front-end loader can fill a 30-tonne truck in just 4 passes, which is significant in mining. Once coal pillars are opened and exposed, they need to be loaded and hauled to the coal pad to avoid longer delays, which in turn reduces the potential of spontaneous combustion.

To maximise and optimise machinery and coal resources, Mine 1 was planned to produce an average of 70 000 tonnes per month for the first 12 months. Nonetheless, this research believes that an optimal mining rate of 50 000 tonnes per month would be ideal for the entire LOM. The suggested monthly coal target will balance production targets in ensuring the mine meets its obligations to its clients. Secondly, this will ensure quality control is maintained while achieving the best possible economic outcomes, given the mine's operational constraints. Lastly, the suggested monthly targets will ensure that the mine's SLP targets are met, while also achieving its own economic targets in a balanced and sustained manner.

The average mining rate of 70 000 tonnes over the first 12 months was aimed at reducing the high cost of double-handling the material that had already been mined during the mine alignment process. Once the mine was aligned and the double handling issues were resolved, this research concluded that adopting a steady mining rate of 50 000 tonnes was essential for long-term sustainability, as stated above. Mine 1 was estimated to generate R17.68 million in revenue against mining costs of R9.78 million. Thus, producing an effective gross profit return of R10.83 million on ROM.

The crushed and screened product, on the other hand, would generate R35.10 million against a mining cost of R23.65 million. This would produce R11.45 million in gross profits at the optimised mining rate of 50 000 tonnes per month (Appendices B and C). It is advisable to mine out the coal in Mine 1 in the shortest period of time possible due to the susceptibility of the area to spontaneous combustion, unlike in Mine 2. The suggested 50 000 tonnes of mined coal a month fits in perfectly with the capacity of the pit. Therefore, it would not be realistic to mine more coal to shorten the LOM, as the pits cannot accommodate any additional fleet of machinery beyond what has already been planned.

5.4.2. Process optimisation of Mine 2

This mine uses historical and legacy designs that were acquired when the current owners purchased the mine. However, these legacy designs are outdated for the current situation at the mine. Though some areas of the plan remain valid, a new plan was needed to account for the new reality of the mine. The new block model produced using historical information from the mine required division of the pit into three blocks: Western, Eastern, and Southern. The Southern block has the best coal qualities, but the least amount of mineable coal resources. Thus, a blending ratio needs to be applied to balance out the available mineable resources.

Similar to the proposed 3:1 blending ratio for coal quality, the ratio to balance available mineable resources will extend the LOM of the operation. Therefore, the plan for this mine is to produce slightly larger volumes of coal from the other two blocks. The Southern block produces the least amount of coal by volume, thereby balancing the LOMP. Mine 2 also has double handling issues similar to Mine 1, but not as severe. The main issue with the double handling is that the previous owners were stockpiling waste material in areas with coal that was of no interest to them. Thus, mineable coal pillars were sterilised in the process, and the current owners then decided to start moving some of that material back into the pit, while some was allocated a permanent space for waste stockpiling.

The mine decided to permanently allocate four ADTs and one 50-tonne excavator to move this waste material back to the pit and the new stockpiling area. The biggest challenge with the double handling of this historical waste material has been an increase in fuel consumption with the mine refuelling equipment daily instead of every second day as usual. This fuel consumption excludes the normal consumption by equipment that is allocated to production.

Double handling at this mine is relatively manageable, and as such, the operation has since allocated one area that is divided into three portions, just like in Mine 1. The topsoil, soft and hard overburden are all stockpiled separately. The mine uses rollover mining, where blasted material from the new block is first moved to the old block using a D9 bulldozer. Once sufficient material has been dozed, a ramp is created to allow ADTs to enter the block and assist the bulldozer in hauling waste material into previously mined blocks.

Rollover mining has been very effective, allowing the mine to recover time that would otherwise be spent hauling to the waste stockpiling area, which is approximately 200 m away from the pit. The new design for Mine 2 is shown in Figure 5.13. The new design only has one entrance and exit into the active mining pit (see Figure 5.13), but with multiple ramps going to the

different blocks of the mine. The pit has four (4) ramps going to different blocks. A simple bench height of 8 m and a berm width of 5 m were used in the design. However, due to the size of the blocks currently being mined, this mine can accommodate only two excavators per block at any given time to mitigate safety concerns and risks.

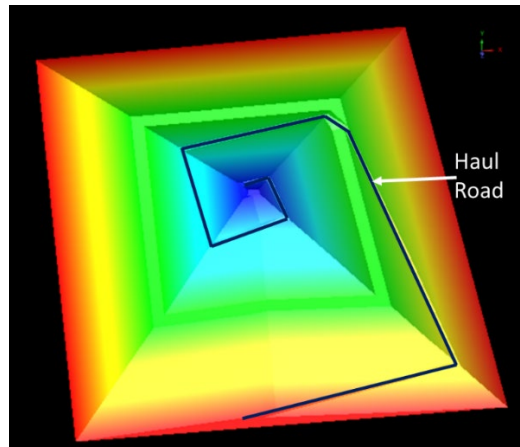


Figure 5.58: Pit design of Mine 2 for the optimisation of pillar extraction optimisation

Thus, it is very important for miners to have an in-depth understanding of their operations so that they can develop and implement appropriate designs that will ensure efficiency and optimisation. Another consideration that needs to be accounted for when efficiently optimising resources is the utilisation of practical geotechnical parameters, as shown in Table 5.4 as a guide to improve on the designs proposed by this research study.

Table 5.25: Pit slope design parameters and critical areas of operation (modified after Sullivan, 2006)

Slope Design Parameter	Considered Elements	Main control or influential Features			Affected Component/Area	
		Geotechnical	Mining	Environmental Considerations	Safety	Commercial
Bench Geometry	Angle	1	1	2	1	1
	Height	1	1	2	1	2
	Berm Width	1	1	2	1	2

Inter-ramp	Angle	1	2	-	3	1
	Height	1	-	-	3	1
Overall	Angle	1	2	-	3	1
	Height	1	-	-	3	1

1 – Critical Risk, 2 – Medium Risk, and 3 – Low Risk. The mine has a pit slope SOP available, and it is implemented

The parameters shown in Table 5.4 are very important in mine design. Any incorrect parameter may negatively impact production. For instance, as mining depth increases, trucks need to haul loads at steeper inclines, thus decreasing driving speeds and increasing hauling cycle times. Junior Miners should recognise that pit slope design must incorporate specific slope design parameters, in conjunction with a comprehensive understanding of the geology of the area. The design of Mine 2 poses efficiency challenges which impact cycle times and overall productivity.

The pit is located approximately 800 m away from the coal handling pad, making it difficult to transport coal to the material handling area. This issue is further complicated by the fleet of mining equipment, which includes several 30-tonne ADTs that are not well-suited for this type of coal production environment. The 30-tonne ADT payload capacity does not maximise distance to the coal handling area, as seen in the cycle time study undertaken. In addition to the time study, the 30-tonne ADTs each need to make about 11 loads to the material handling area before there is sufficient coal to feed the crushing and screening plant.

Using small mining equipment for such a large operation slows production and incurs direct costs. The smaller machines need to make many trips to the material handling area, which in turn, increases fuel costs while production is not maximised. Whereas, for optimal productivity, the mine could have opted to use 45-tonne ADTs, which have a higher payload capacity and can negotiate uphill drives better than the smaller 30-tonne ADT. However, it should be noted that the geology in Mine 2 tends to support better slope designs, which may be the reason why the management opted to include 30-tonne ADTs in their fleet.

However, it is also worth noting that, apart from the geology, this mine is generally better developed than Mine 1. Flooding represents an additional significant risk that must be considered, particularly for Mine 2 (see Figure 5.14). This mine tends to experience flooding from water that is accumulated in the old underground working panels while water accumulation at Mine 1 is mainly from natural groundwater. This research study proposes that both mines undertake water monitoring and dewatering systems to help them identify areas and blocks that are waterlogged and require dewatering. An effective dewatering system is critical at the mine design stage, as any oversight, error, or miscalculation could affect the mine's financials.



Figure 5.59: Block flooding after Seam 4 extraction in Mine 2

With coal pillar extraction operations already under financial pressure, an error in the mine design could negatively impact the overall viability of the operation. This could reduce productivity, leading to delays in achieving set targets. The nature of coal pillar mining means that time plays an important

role and is directly linked to cost, in that delays result in increased costs. However, an effective, forward-looking plan will ensure that operations of this nature not only thrive but also remain sustainable in the long term. As mentioned above, the main challenge is flooding of the pit from underground water, especially once a cavity from old underground workings is exposed.

After extracting Seam 4, the mine must pump out water from the pit before commencing activities to expose the inter-burden for Seam 2 extraction. This exercise incurs costs for fuel used in pumping the water out.

Additionally, there are time costs associated with the personnel required to monitor and maintain the pump. Therefore, it is imperative that miners factor in all these implications, as they have a direct economic impact on the operation.

Mine 2 was planned to mine an average of 40 000 tonnes a month for the first 12 months, with a peak of approximately 56 000 tonnes only in month 10. The reason for this ramp-up is simply to prepare for the upcoming decrease in production as the mine opens a new box cut. It was also suggested that, to maintain sustainability and maximise revenue, Mine 2 should mine at a minimum rate of 40 000 tonnes per month.

Furthermore, it was suggested that Mine 2 should not exceed 80 000 tonnes per month to maximise revenue and ensure the resource is mined in accordance with the proposed ratios for the three blocks. Coal extracted from the Southern block would need to be blended with coal extracted from the Northern and Eastern Blocks. At this mining rate, Mine 2 would generate an average revenue of R19.70 million, against mining costs of R13.94 million. Therefore, the expected gross profit would be R6.76 million on ROM, while the crushed and screened product would generate R28 million against the mining cost of R19.04 million. Thus, generating almost R9 million gross profit.

5.5. Resources optimisation: Maximising NPV and IRR in coal extraction

According to Huang et al. (2022), most company project investment decisions involve large long-term capital expenditures. Therefore, for companies to reduce investment risk and make sound decisions, it is necessary to utilise investment decision-making methods such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP). Among them, the NPV and IRR methods have been widely utilised in investment decision-making by mining companies (Yan and Zhang, 2022).

Net present value and internal rate of return are the most extensively used and accepted discounted cash flow (DCF) indices to assess in business and project investment (Yan and Zhang, 2022). DCF is a valuation method used to estimate the attractiveness of an investment opportunity through future free cash flow projections and discount them. Most often the weighted average cost of capital (WACC) is used to arrive at a present value, which is used to evaluate the potential for investment (Mirakovski et al., 2012). Therefore, all these indices are paramount inputs into investment decisions in projects such as mining.

Additionally, the hurdle rate is another important index that is key in making investment decisions. It is the minimum acceptable financial rate of return required for an investment project to be considered worthwhile (McKeown et al., 2024). A positive NPV is usually required for the mine to be considered viable with regard to the declaration of mineral reserves according to the SAMREC Code (Birch, 2016). Therefore, it is good practice for miners to have an in-depth financial understanding of their prospective mining operations. A DCF analysis was done for both Mine 1 and Mine 2 using different discount rates (see Appendices C and E). Creating a specific DCF model with relevant rates for the mining industry helps miners make informed investment decisions regarding their projects and operations.

The weighted average cost of capital (WACC) was calculated to demonstrate what both mines need to focus on for sustainable operations and positive returns. In some instances, where determining the WACC is difficult, the hurdle rate can be used as the WACC; however, for this research, the WACC was calculated for each mine. It is also worth noting that the mining industry hurdle rate is pegged at approximately 15% (Jenner et al., 2018). Thus, for any mining project to compare well with its industry peers, a 15% hurdle rate should be non-negotiable before commencing.

5.5.1. Calculated weighted average cost of capital for Mine 1

The calculated WACC for Mine 1 was based on the capital market rates of 9.04% and the cost of equity of 15% published by the South African Reserve Bank in 2025. According to the model developed in this research using information in Chapter 4 and Appendix B, this mine needed to raise just over R12 million for its operations. This research used a 70/30 split, with 70% representing equity financing and 30% representing debt financing. Therefore, the WACC was calculated as follows (Modigliani and Miller, 1963):

$$WACC = \frac{E}{V} \times Re + \frac{D}{V} \times Rd \times (1 - Tc) \quad (5.3)$$

Where:

E = Market value of the company's equity in ZAR

D = Market value of the company's debt in ZAR

V = combined market value of equity and debt

Re = Cost of equity

Rd = Cost of debt

E/V = Percentage of financing that is equity

D/V = Percentage of financing that is debt

Tc = Corporate tax

Thus, using the parameters mentioned above, Mine 1 would need to finance approximately R8.4 million in equity and R3.6 million in debt at costs of 15% and 9.04% respectively. The South African corporate tax rate is pegged at 28%. Using the above formula, the calculated WACC was as follows:

$$\begin{aligned}
 \text{WACC} &= 70\% \times 15\% + 30\% \times 9.04\% \times (1 - 0.28) & (5.4) \\
 &= 0.7 \times 0.15 + 0.3 \times 0.0904 \times (0.72) \\
 &= 0.105 + 0.3 \times 0.05 = 0.105 + .0195 \\
 &= 0.1245
 \end{aligned}$$

Therefore, Mine 1 WACC is 12.45% which means that on average, Mine 1 would need to pay its investors a 12.45% return on every Rand of capital it finances. Using the mining industry's typical return rate of 15%, this mine would create 2.55% in value if the current figures are used in its evaluation.

A discount rate of 15% for the combined cut-off grade of 25.63 MJ/kg (Figure 5.15) was found to be the ideal rate for mine optimisation. The NPV was calculated for both ROM and crushed and screened products (Appendix G). The overall ROM NPV was R532.81 million with an IRR of 23.35%. Additionally, the overall crushed and screened NPV was R779.90 million, with an IRR of 62.19% over a 4-year life-of-mine.

Therefore, it is evident that there is considerable value in developing Mine 1 as a mine that prioritises a finished coal product that is crushed and screened. Any coal produced below this cut-off grade would result in the mine incurring losses. Therefore, it is important for the miner to appreciate the significance of the information presented in the grade-tonnage curve. This cut-off grade is important to maintain in normal operations where solid coal is mined. It is also important for the miner to ensure that mitigation measures and precautions are rigorously implemented during coal pillar extraction operations.

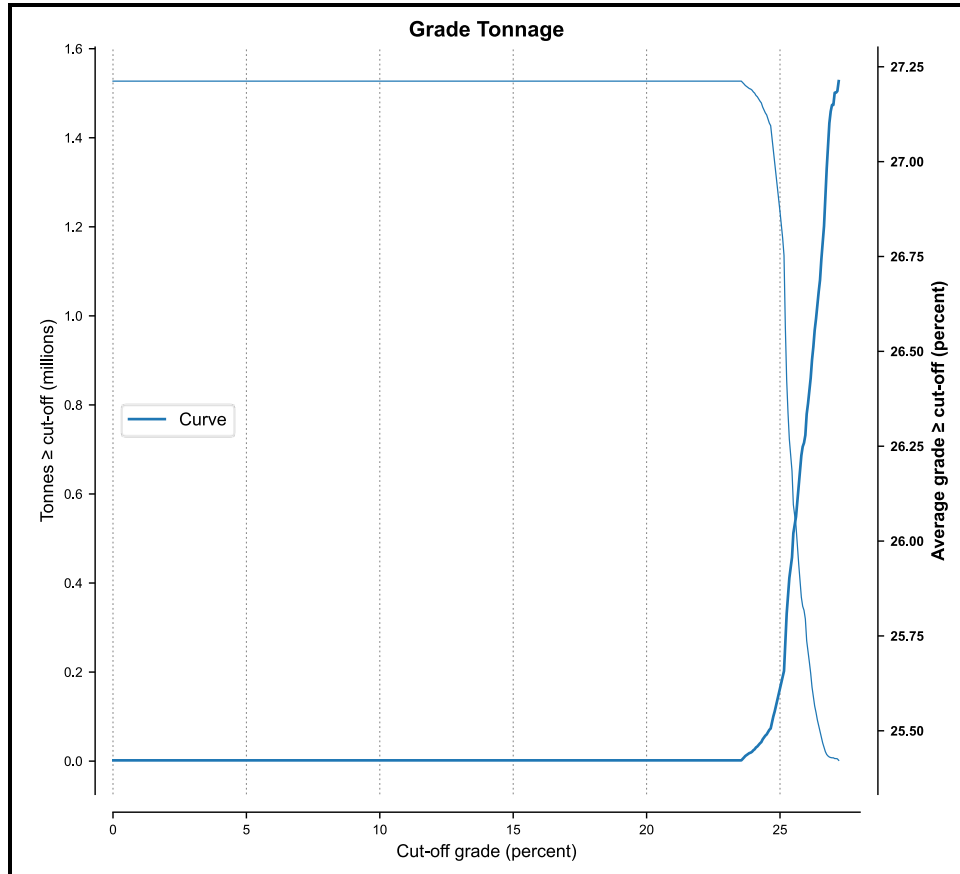


Figure 5.60: Grade tonnage curve for Seams 1 and 2 at Mine 1

5.5.2. Calculated weighted average cost of capital for Mine 2

The calculated WACC for Mine 2 was also based on the capital market rates of 9.04% published by the Reserve Bank in 2025. The cost of equity was pegged at 18%, due to the associated risk, unlike in Mine 1. The higher cost of capital is due to the larger amount required for Mine 2 as compared to Mine 1. The mine needed to raise R25 million in total for its operations. This research adopted an 80/20 financing split, with 80% allocated to equity financing and 20% to debt financing. Specifically, R20 million was obtained through equity financing and R5 million through debt financing.

This split was chosen because, as the required funds increased, the need for equity financing tended to rise, as loans often came with restrictive terms. Equity financing is also a suitable option for mining projects and

assets given their volatile nature. Monthly repayments for mining operations can be challenging due to volatility caused by factors such as natural disruptions that may halt operations. Other unforeseen issues, including sudden changes in the political and environmental landscapes, can also severely disrupt the normal functioning of mining operations. The WACC for this mine was calculated as follows:

$$WACC = \frac{E}{V} \times Re + \frac{D}{V} \times Rd \times (1 - Tc) \quad (5.5)$$

$$\begin{aligned} WACC &= 80\% \times 18\% + 20\% \times 9.04\% \times (1 - 28\%) \\ &= 0.8 \times 0.18 + 0.2 \times 0.0904 \times (1 - 0.28) \\ &= 0.144 + 0.2 \times 0.0904 \times (0.72) \\ &= 0.144 + 0.2 \times 0.065 = 0.144 + 0.013 \\ &= 0.1570 \approx 15.70\% \end{aligned}$$

The WACC of Mine 2 is 15.70%, meaning that on average, Mine 2 would need to pay its investors a 15.70% return on every Rand of capital it finances. Using the mining industry's typical hurdle rate of 15%, it would appear that this mine is destroying value, since its WACC is 15.70% while the industry average return is about 15%. The same 15% discount rate used in Mine 1 was also applied in Mine 2, where the overall ROM NPV was calculated at R212.46 million with an IRR of 42.88%. Furthermore, the overall crushed and screened NPV was R344.67 million, with an IRR of 49.75%. Both the NPV and IRR appear to be very high.

However, it should be noted that this is the case because of the relatively low initial input investments coupled with the higher-than-normal returns in this operation, as is the case in Mine 1. Normalised against initial investments, the NPVs for both ROM and crushed and screened products were calculated at R132.08 million and R165.84 million, respectively. The IRR was 27.84% for the ROM and 23.09% for the crushed and screened products. The combined grade tonnage curve for both Seam 4 and Seam 2

is illustrated in Figure 5.16. The NPV and IRR were optimised at a cut-off grade of 24.11 MJ/kg. The grade becomes very flat and linear at approximately 27 MJ/kg because there are few data points above this value in the original data. The cut-off grade for the entire prospecting area is similar to that shown for the Measured Resources area, as the bulk of the data is concentrated around the area currently being exploited. Therefore, the mine needs to prioritise the remaining prospecting area to determine the accurate cut-off grade, which may result in changes to the resources shown in Table 4.9 of Chapter 4.

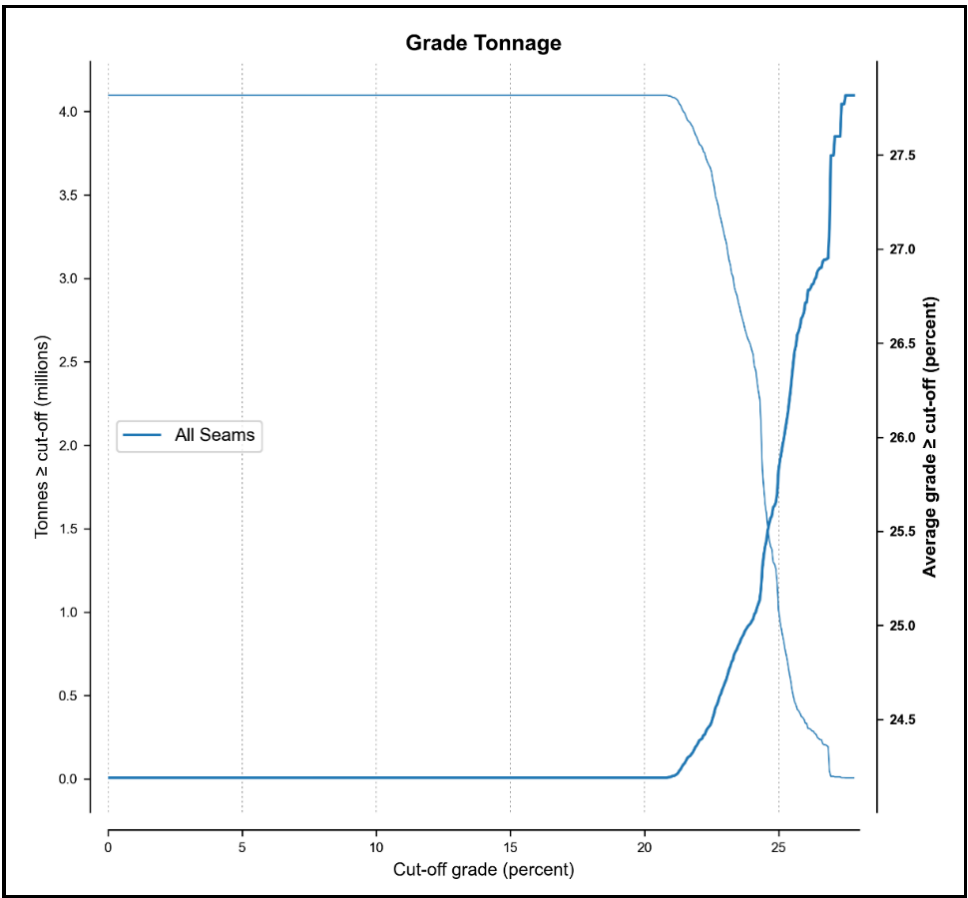


Figure 5.61: Grade tonnage curve for Seams 4 and 2 at Mine 2

In conclusion, the mining of coal pillars using surface mining methods carries with it a significant amount of risk. The mitigation of contamination and dilution was shown to be a key component in the sustainability of these mining operations. Furthermore, the NPV and IRR optimisation models

illustrated the importance of not prioritising optimisation solely for the highest possible returns on investment. These models have shown that operational efficiency should be at the centre of any model to ensure that both short-term and long-term goals are achieved. It is recommended that both Mine 1 and Mine 2 use the rollover mining method to optimise and maximise the time and resources available for mining. In Mine 1, productivity is highly impacted by double-handling of materials, a practice aggravated by a lack of foresight to mine for the future and sustainability.

Mine 1 has many waste dumps that are not planned, these dumps appear to be more for convenience. The miners tend to create waste dumps wherever there is space available. Often, this practice results in either sterilisation of coal that could have been available for mining or double handling. Challenges associated with the waste dump at Mine 2 are similar to those at Mine 1 in that the mine has created multiple areas used as waste dumps out of convenience, not necessarily as a choice borne of measured planning.

This is not ideal, as it tends to cause issues and encourages mining practices. Operators tend to dump at a waste stockpiling area that is either close to where they are loading or appears less full. This practice tends to work against the mine such that when the closest stockpiling area is full, the mine needs to move a dozer that is busy elsewhere to assist with the waste dump. In some instances, the TLB is also called upon to fix the catchment berm as it becomes impossible to catch all the falling rocks from the overfilled waste dump.

5.6. Discussion of the main findings from Mine 1 and Mine 2

One of the main differences between the two mines is in their application and incorporation of drilling and blasting in their operations. Mine 2 employs drilling and blasting as part of its plan and design, while Mine 1 has been employing the free digging strategy. The effect of drilling and blasting

manifest mainly in dilution and contamination. The majority of dilution in Mine 1 is external, caused by the mining method employed. Mine 1 is mostly affected by contamination more than dilution. Mine 2 does not have a massive contamination problem, the main issue of the operation is the dilution caused by the sandstone/siltstone layer in Seam 2.

Both mines do not have sufficiently developed mine plans and designs, which has resulted in inconsistent ramp designs at Mine 1, which cause major coal losses during hauling. Designs and plans of Mine 2 are outdated; they do not accommodate the current activities undertaken by the operation. Mine 2 requires a blending strategy to maximise on resources and extend LOMP. The financial modelling of both mines is promising, with the WACC at 12.45% and 15.70% for Mine 1 and Mine 2, respectively. The Positive NPV and above average IRR are also encouraging but Mine 1 shows a much high NPV and IRR for both ROM and crushed and screened product.

5.7. Significance of the findings

The lack of sufficient and relevant geological data, mine plans and mine designs will always result in the failure of mining operations. The analysis of data available for both Mine 1 and Mine 2 have shown that, it is impossible to plan and mitigate for contamination and dilution without access to appropriate geological information. Mine strategies were found to be critically important for operational efficiency and resource optimisation. It was also established that financial modelling, especially NPV and IRR, is a key component that Junior Miners need to understand, together with the impact that may result from inaccurately determined NPV and IRR analysis.

The DCF model demonstrated the importance of understanding mining projects valuation to evaluate the potential for investment. Additionally, the hurdle rate was shown to play a significant role when making decisions to invest in coal pillar mining projects.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Concluding remarks

The mining of historical underground coal pillars using surface mining methods presents unique challenges that require modern solutions to ensure safe, sustainable and profitable operations. The work that was undertaken by this study has shown the importance of having systems and processes that work. Systems geared to ensuring operational excellence, especially for Junior Miners. In the South African mining landscape, Junior Miners are those with a turnover of less than ZAR500 million, as discussed in Chapter 3. South African Junior Miners rank third in terms of the number of mining licences held. The largest holders of mining licences are those operating in the industrial minerals sector, with a total of 823 mining licences (Minerals Council South Africa, 2019a).

As the junior mining sector continues to grow, it has become increasingly important for miners to employ sustainable practices in their operations. Having a detailed understanding of operations prior to deploying and establishing machines on-site has become critically important for all Junior Miners across the junior mining spectrum. The current trend of focusing on profits while neglecting the overall project sustainability poses serious problems. This study has shown that both Mine 1 and Mine 2 tend to experience significant issues related to coal contamination and dilution. Largely due to poor planning and a lack of proper designs that would greatly benefit both mines.

A model with a variety of inputs was put forward as one way to mitigate contamination and dilution where possible, even though it is difficult to address inherent dilution. Dilution must always be quantified by factoring in a cut-off grade that optimises and maximises coal resources. After applying the dilution and contamination factors, the mines will need to adjust their mining costs accordingly. Equally important is understanding the main

drivers of coal pillar extraction, such as the runout distance, which is critical in ensuring slope stability and integrity.

Mine 2 had an issue of inconsistently steep ramps, well above the standard 8° ramp angle and consequently, the mine was losing a considerable amount of coal from the pit to the coal handling pad. The loss of coal from haul trucks has a ripple effect, where other pit activities need to be delayed and halted as the ramp is cleaned regularly. Therefore, intentionally monitoring ramp angles is critically important to improve efficiency, extend equipment life, and optimise coal resources from the pit to the plant.

Coal pillar mining using surface mining methods requires a fully competent management team capable of navigating the challenges associated with such an undertaking. A competent team will ensure that fit-for-purpose mine designs and plans are developed for the mines. Relevant mine designs and plans will directly inform the mine production scheduling team. An appropriate mine plan will detail the sequence of the mining operation and consider all health, safety, and environmental considerations that may hinder or stop the operation from reaching its full potential.

As seen already, especially in Mine 2, where Seam 2 is split into Seam 2 Upper and Seam 2 Lower, a good mine plan will detail exactly how the extraction of that seam will be undertaken. Such a mine plan will also detail necessary mitigation measures in the event that an error is made during extraction. Therefore, a detailed and effective mine plan will ensure mitigation of coal contamination and dilution.

An appropriate mine design will provide operations with the geotechnical information necessary to predict and manage the ground's response to mining activity. Thus, ensuring the sustainable and efficient extraction of coal pillars through an optimised mine layout and operational sequencing. Therefore, ensuring that mining activities are streamlined and optimised, minimising rehandling and maximising resource utilisation. As such, the

operation's economic viability will be maintained while ensuring environmental and safety considerations are also considered.

Other important aspects that arise in such projects are the environmental and safety components. Unlike in traditional, straightforward surface mining operations, environmental and safety concerns in pillar operations pose a serious risk. Additionally, access to accurate historical information is very important for planning purposes, to avoid cavities and voids in the old underground workings. In both mines, the lack of adequate historical information on the old underground workings made running these operations challenging. The mines rely on what they see as mining progresses, even though Mine 2 has some legacy data, it is insufficient.

Another issue noted is that both mines need accurate dewatering plans, specifically for Mine 2. Mine 1 experiences less flooding from the previous underground workings than Mine 2. It is Mine 2 that needs to accurately account for the anticipated flooding. This study suggests that a dewatering system needs to be part of the design and plan of the mine. A design plan that incorporates an effective method to address water accumulation issues is not only important for the viability of the mine but also for ensuring safe working conditions. Water challenges at Mine 1 are mainly associated with groundwater.

A constant water-monitoring programme is required for mine 1, with continuous pumping. Water issues in Mine 2 require continuous pumping, but at a much slower rate than in Mine 1, since little water is encountered from the old underground workings. Mine 2 water monitoring programme needs to track expected water accumulations as per the mine design and plan. Once the water monitoring programme has been initiated, it is also suggested that the water be used for dust suppression, provided relevant authorities have been consulted.

A well-established, detailed mine plan will outline the required equipment for each stage of mining, from drilling and blasting to hauling and

processing. The design and plans for both mines have drilling and blasting playing an important role in the extraction of coal pillars. With the use of bord and collapse as the suggested drilling and blasting technique for both operations. This method allows the pillars to remain intact or partially collapsed after blasting, making it easier to clean around them. Thus, limiting the effect of coal and roof waste material interlocking. However, this method will result in coal losses from the blast, but contamination will be minimised.

Ultimately, a good mine design must also incorporate a financial model based on sound financial management principles, given the sensitivity of operations of this nature. A minor misjudgement could break these operations. Therefore, it becomes important for miners to employ sound financial management models and principles. An appropriately developed financial model will include all critical aspects of the mine for a minimum of 12 months for a newly granted mining permit or 60 months for mining rights granted for periods longer than 60 months, as shown in Appendix B. The financial model should include detailed cost estimates, required budgets, and all associated financial implications (social responsibilities and projects, mine rehabilitations and closures, etc.), thus striking a balance between mining costs and turnover.

A financial model should serve as a guiding light for the mines and be updated as operations continue. It will provide real-time health status for the mine and identify where it is being negatively impacted. Thus, allowing the necessary adjustments and amendments to ensure the sustainability of the operation. For this study, the internal rate of return and hurdle rate were discussed, and it was observed that both Mine 1 and Mine 2 have internal rates of return well above the average across the mining industry. Meaning that their operations presented good value for money. However, it should be noted that these above-average returns were only possible once the operations had streamlined their production activities.

This ensured that decisions were taken based on sound planning models. Based on current mining trends, both operations were found to be below the accepted hurdle rate of 12%. The financials for Mine 1 are based solely on funding from coal buyers, it lacks a set financial structure to guide performance against the planned outcome.

6.2. Factors affecting the sustainability of junior mining projects

In South Africa, it is common for Junior Miners to have Social and Labour Plans (SLPs) accepted by the Department of Mineral Resources and Energy (DMRE) as part of their applications for mining rights, but these plans are never implemented. This lack of SLP implementation is mainly driven by the cost of implementing such plans. Another important reason for a practical mine design is that it ensures operations are properly rehabilitated and the mine is closed after operations cease. Thus, it avoids the plague of illegal mining that has engulfed South Africa in recent times.

Furthermore, a checklist was created to aid miners not only in working productively but also in ensuring that all important items are not forgotten or overlooked. This will help reduce activities that may need to be reworked and/or double-handled, leading to improved quality and maximised resource utilisation. Lastly, Junior Miners, just like established major mining houses, need to consider multiple factors that are critical to having a sustainable project, and these factors are summarised below.

6.2.1. Demand and supply inherent to the market

Fossil fuel mining has entered a phase in which it must be balanced with the just transition agenda. Therefore, miners need to have a clear understanding of which direction markets will take before opening new coal mining operations. Junior Miners should only consider investing in coal operations that have been studied and are understood. Coal pillar extraction operations should be considered only after supply contracts have been

signed with coal off-takers. This is essential as it will clarify payment security, risk allocation, and provide a clear scope of work. Miners will be required to have a plan to meet their supply obligations.

6.2.2. Understanding coal resource to optimise mining cost

The cost of mining is highly influenced by the strip ratio. Therefore, Junior Miners must ensure that all geological features and mining feasibility studies are clearly understood and documented to avoid unplanned surprises. Striving for a complete understanding of the resources will aid miners to optimise resources and better design and plan their operations. Lastly, understanding resources will ensure that the financial models developed and produced are geared towards efficient, economically viable mining operations.

A financial model can be generated using technology with many software packages offering this functionality. Most mine design and planning software is equipped with utility functions such as NPV, which can then be built upon to determine the IRR for the mine. These utility functions are very important, as they can provide mines with different scenarios and offer the best possible solutions for optimisation and efficiency.

6.2.3. Price volatility and cyclical nature of mining

All financial models used for coal pillar extraction must account for the inherent volatility of coal prices. These financial models need to be as robust as possible. Thus, ensuring that operations are insulated and cushioned against market changes, as is often the case with most commodities. In the past years, coal prices fluctuated between \$56/t and \$302/t, forcing mines with marginal financials to either close or place their operations on care and maintenance.

The highest price was reached around 2022, which coincided with the Russia/Ukraine war. However, in 2024 the prices had levelled back to \$104/t. Thus, Junior Miners need to better prepare themselves for the cyclicity and volatility that is associated with the coal sector. This will ensure their operations are better prepared and equipped to deal with these unpredictable occurrences.

6.2.4. Overall project risk

Lastly, detailing risks that could hinder coal mining projects is essential for success. The mining environment is characterised by risks ranging from minor to major. These risks include a lack of understanding of the factors that drive dilution and contamination in the mine, as well as inadequate site-specific mine designs and plans, as demonstrated by this research. All these risks play a significant role in maximising resources and optimising operations. Therefore, understanding them is paramount to the sustainability of mining operations.

6.3. Recommendations for future work

This research concludes that both Mine 1 and Mine 2 would benefit from the following recommendations:

- Undertake a campaign to map out and understand exactly where these historical pillars are, as this will assist with better mine design and planning.
- Create dilution and contamination models that are geared towards identifying areas where dilution and contamination can be expected, and plan accordingly.
- Continuously refine the resource and reserves model as new information is collected, especially information from production drill holes, as that represents data in real time.

- Make use of properly and appropriately designed mine plans and layouts, which are specifically suited for coal pillar extraction.
- Undertake a comprehensive water monitoring programme that will be in line with the mine design and plan.
- Implement strategies that will ensure mine sustainability in the long term through quality and grade control programmes.
- Continuously update financial models as new data becomes available, which will ensure that the mine management is always ahead of any potential sustainability issues that may arise.
- Mine 2 needs to undertake an extensive exploration campaign that will upgrade coal resources from the inferred category to the Measured category as per the SAMREC.
- Mine 1 needs to ensure its rehabilitation plan is aligned with the operation as it continues to exploit coal resources.

REFERENCES

- Adhikari, G.R., 1999. Selection of blasthole diameter for a given bench height at surface mines. *International Journal of Rock Mechanics and Mining Sciences*, Vol. 36, no. 6, pp. 843–847.
- Agnolucci, P., Nagle, P., Temaj, K., 2023. Declining coal prices reflect a reshaping of global energy trade. Available at: <https://blogs.worldbank.org/opendata/declining-coal-prices-reflect-reshaping-global-energy-trade>, (Accessed: 17 June 2023).
- Altiti, A.H., Alrawashdeh, R.O., Alnawafleh, H.M., 2021. Open pit mining. In *Mining Techniques - Past, Present and Future*, pp. 1–22.
- Alzahrani, M., 2018. Principles of mining and metallurgical engineering - The main stages of mining project, pp. 1–18.
- Amie., 2020. Exploitation of mineral deposits - Bord & pillar mining methods. Available at: www.amiestudycircle.com (Accessed: 26 September 2023).
- Awuah-Offei, K., Que, S., Rehman, A.U., 2021. Evaluating mine design alternatives for social risks using discrete choice analysis. *Sustainability*, vol. 13, no. 16, pp. 1–15.
- Balasubramanian, A., 2016. Coal mining methods. Technical Report, University of Mysore, pp. 1–9.
- Baloyi, V., Meyer, L.D., 2020. The development of a mining method selection model through a detailed assessment of multi-criteria decision methods. *Results in Engineering*, vol. 8, pp. 1–19.
- Banks, J.P., Boersma, T., Ebinger, C.K., Greenley, H.L., 2015. Coal markets in motion. Available at: www.worldenergyoutlook.org/publications/weo-2014/ (Accessed: 18 January 2024).

- Banya, N., 2026. South Africa's Richards Bay coal exports up 11% on rail improvements, Available at: <https://www.cnbcafrica.com/2026/south-africas-richards-bay-coal-exports-up-11-on-rail-improvements> (Accessed: 10 February 2026).
- Banya, N., Reid, H., 2022. Focus: South African coal miners turn to trucks as rail service deteriorates | Reuters. Reuters. Available at: <https://www.reuters.com/world/africa/south-african-coal-miners-turn-trucks-rail-service-deteriorates-2022-05-03/> (Accessed: 06 December 2023).
- Bascetin, A., Tuylu, S., Nieto, A., 2011. Influence of the ore block model estimation on the determination of the mining cutoff grade policy for sustainable mine production. *Environmental Earth Sciences*, vol. 64, no. 5, pp. 1409–1418.
- Bezzola, S., Günther, I., Brugger, F., Lefoll, E., 2022. CSR and local conflicts in African mining communities. *World Development*, vol. 158, pp. 1–12.
- Birch, C., 2016. Impact of discount rates on cut-off grades for narrow tabular gold deposits. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 116, no. 2, pp. 115–122.
- Blignaut, J., 2012. Climate change: The opportunity cost of Medupi and Kusile power stations. *Journal of Energy in Southern Africa*, vol. 23, no. 4, pp. 67–75.
- Bogdanović, D., Jovanović, I., Stojanović, A., 2019. Multi-criteria analysis of risks and phases in mining project. 5th IPMA SENET Project Management Conference (SENET 2019), pp. 189–192.
- Bogusz, K., Sulich, A., 2020. The sustainable development strategies in mining industry. In: Soliman K.S. (Eds.). *Education Excellence and Innovation Management through Vision 2020*. International Business Information Management Association, pp. 6893–6911.

- Caciagli, N., 2021. Mine planning. In: Daya Sagar, B., Cheng, Q., McKinley, J., Agterberg, F. (Eds.), Encyclopedia of Mathematical Geosciences, Encyclopedia of Earth Sciences Series, Springer, Cham. Available at: https://doi.org/10.1007/978-3-030-26050-7_208-1 (Accessed: 17 September 2025).
- Campbell, R., 2023. Serious challenges face the South African junior coal mining sector. Mining Weekly. Available at: <https://www.miningweekly.com/article/serious-challenges-face-the-south-african-junior-coal-mining-sector-2023-02-03> (Accessed: 03 August 2023).
- Carr, R., Mann, J., 2023. Msobo coal: Mining in Majestic Mpumalanga. Available at: <https://www.mining-outlook.com/commodities/coal-mining-sector/msobo-coal-mining-in-majestic-mpumalanga>, (Accessed: 15 June 2023).
- Chavalala, B., 2016. An assessment of South Africa's coal mining sector response to climate change adaptation demands. PhD thesis, University of South Africa.
- Chukwudumebi, O.R., 2018. The Witbank Junior Coal Miners: A blue print for success in the South African coal industry. Master of Science dissertation, University of the Witwatersrand, Johannesburg.
- Clough, W.D., Morris, R., 1985. The opencast mining of previously underground-mined coal seams. Journal of the Southern African Institute of Mining and Metallurgy, vol. 85, no. 12, pp. 435–439.
- Coal Hub, 2023. South African coal export trends 2023. Available at: <https://thecoalhub.com/report-presentation/south-african-coal-export-trends-2023> (Accessed: 29 November 2024).
- Cole, M.J., Mthenjane, M., Van Zyl, A.T., 2023. Assessing coal mine closures and mining community profiles for the “just transition” in

South Africa. Journal of the Southern African Institute of Mining and Metallurgy, vol. 123, no. 6, pp. 329–342.

Council for Geoscience, 2003. Internal report. Pretoria, South Africa

Creswell, J.W., 2009. Research design: Qualitative, quantitative, and mixed methods approaches, 3rd Edition. Thousand Oaks, Sage Publications Inc.

Creswell, J.W., Plano Clark, V.L., 2017. Designing and conducting mixed methods research. Thousand Oaks, Sage Publications.

Creswell, J.W., Plano Clark, V.L., 2017. What is mixed methods research?: considering how mixed methods research is defined. In: Mixed Methods Research, Sage Publications Inc, pp. 55–78.

Datamine, 2020. Comprehensive open pit design & scheduling STUDIO OP mine planning engineers. Available at: www.dataminesoftware.com (Accessed 12 February 2024).

Dos Santos, R., 2016. Traditional surface mining methods. Available at: <https://ronaldocrdossantos.wordpress.com/2016/07/23/traditional-surface-mining-methods/> (Accessed: 19 October 2023).

Dunn, M., 2015. How reliable are your design inputs. In Potvin Y. (Eds.), Design Methods 2015: Proceedings of the International Seminar on Design Methods in Underground Mining, Australian Centre for Geomechanics, Perth, pp. 367–381.

Eades, R.Q., Perry, K., 2019. Understanding the connection between blasting and highwall stability. International Journal of Mining Science and Technology, Vol. 29, no. 1, pp. 99–103.

Eberhard, A., 2011. The future of South African coal: Market, investment, and policy challenges. Available at: https://pesd.fsi.stanford.edu/publications/the_future_of_south_africa

[n coal market investment and policy challenges](#) (Accessed: 09 March 2023).

Ebrahimi, A., 2013. The importance of dilution factor for open pit mining project. World Mining Congress & Expo, Quebec, Canada, pp. 1–12.

Eckert, V., Sims, T., 2022. Energy crisis fuels coal comeback in Germany. Available at: <https://www.reuters.com/markets/commodities/energy-crisis-fuels-coal-comeback-germany-2022-12-16/> (Accessed: 18 December 2023).

Elliot, J., 2023. South African coal exports shift to Asia as European demand wanes. Available at: www.argusmedia.com (Accessed: 16 June 2024).

Erdem, Ö., Güyagüler, T., Demirel, N. 2012., Uncertainty assessment for the evaluation of net present value: a mining industry perspective. Journal of the Southern African Institute of Mining and Metallurgy, vol. 112, no. 5, pp. 405–412.

Eskom, 2021. Coal in South Africa. Available at: www.eskom.co.za (Accessed: 21 April 2023).

Esterhuysen, J.C., Malan, D.F., 2018. Some rock engineering aspects of multireef pillar extraction on the Ventersdorp Contact Reef. Journal of the Southern African Institute of Mining and Metallurgy, vol. 118, no. 12, pp. 1285–1296.

Fillion, M.H., Hadjigeorgiou, J., 2016. Implications of collecting additional data for slope design in an open pit operation. Journal of the Southern African Institute of Mining and Metallurgy, vol. 116, no. 5, pp. 357–366.

Fontes, M.P., Koppe, J.C., Albuquerque, N., 2020. Comparison between traditional project appraisal methods and uncertainty analysis

applied to mining planning. REM: International Engineering Journal, vol. 73, no. 2, pp. 261–265.

Fossil Fuel Foundation, 2023. Junior Coal Miners. Available at: <https://fffcarbon.co.za/junior-coal-miners/> (Accessed: 07 November 2024).

Frost, H., 2023. Coal, platinum of most interest in growing junior space. Mining Weekly. Available at: <https://www.miningweekly.com/article/coal-platinum-of-most-interest-in-growing-junior-space-2023-05-19> (Accessed: 03 August 2023).

Girardin, M., Skowronski, J., 2023. How to calculate net present value (NPV). Forage. Available at: <https://www.theforage.com/blog/skills/npv> (Accessed 19 May 2024).

GlobalCoal, 2019. SCoTA specifications and definitions. Available at: <https://www.globalcoal.com/scota/specifications.cfm> (Accessed: 20 June 2023).

Golestanifar, M., Ahangari, K., Goshtasbi, K., Akbari Dehkharghani, A., Terbrugge, P., 2018. Governing risk elements through open pit slope optimization. Journal of the Southern African Institute of Mining and Metallurgy, vol. 118, no. 1, pp. 47–55.

Gouvea, J.P., 2024. Remnants and isolated blocks of ground in the Klerksdorp Goldfield. Journal of the Southern African Institute of Mining and Metallurgy, vol. 124, no. 2, pp. 75–84.

Greene, D., David, J.L., 1984. A research design for generalizing from multiple case studies. Evaluation and Program Planning, vol 7, no. 1, pp. 73–85.

- Hamer, J., 1973. Strip mining. CQ Researcher. Available at: <https://library.cqpress.com/cqresearcher/document.php?id=cqresrre1973111400> (Accessed: 17 May 2024).
- Hancox, P.J., Gotz, A.E., 2014. South Africa's coalfields – A 2014 perspective. *International Journal of Coal Geology*, vol. 132, pp. 170–254.
- Harraz, H.Z., 2010. The mining cycle [PowerPoint Presentation]. Tanta University, Tanta, Egypt. 10 March. Available at: <https://doi.org/10.13140/RG.2.1.2717.2729> (Accessed: 29 July 2023).
- Huang, J., Tong, J., Wang, P., Zheng, X., 2022. Application and comparison of NPV and IRR methods in the company investment decision. *Advances in Economics, Business and Management Research*, vol. 648, pp. 71–78.
- ICN Bureau, 2026. IEW 2026: Coal to anchor India's energy push as demand set to triple. Available at: <https://www.indianchemicalnews.com/energy/iew-2026-coal-to-anchor-indias-energy-push-as-demand-set-to-triple-29123>, (Accessed: 24 February 2026).
- Iddon, C., Hettihewa, S., Wright, C.S., 2013. Junior mining sector capital-raising: The effect of information asymmetry and uncertainty issues. *Journal of Applied Business and Economics*, vol. 15, no. 3, pp. 56–67.
- Industrial Development Corporation, 2024. Junior mining exploration fund. Available at: <https://www.idc.co.za/junior-mining/> (Accessed: 13 October 2024).
- International Energy Agency, 2022a. Coal 2022 coal analysis and forecast to 2025. Available at: www.iea.org (Accessed: 17 August 2023).

- International Energy Agency, 2022b. World energy outlook 2022. Available at: www.iea.org/t&c/ (Accessed: 27 November 2023).
- International Energy Agency, 2023. Global coal demand set to remain at record levels in 2023 - News - IEA. Available at: <https://www.iea.org/news/global-coal-demand-set-to-remain-at-record-levels-in-2023> (Accessed: 07 September 2023).
- International Energy Agency, 2024. Coal 2024 analysis and forecast to 2027 - News - IEA. Available at: <https://www.iea.org/news/coal-2024-analysis-and-forecast-to-2027> (Accessed: 17 September 2025).
- International Energy Agency, 2025. Coal 2025 analysis and forecast to 2030 - News - IEA. Available at: <https://www.iea.org/news/coal-2025-analysis-and-forecast-to-2030> (Accessed: 20 February 2026).
- Iwuji, C.C., Okeke, O.C., Ezenwoke, B.C., Amadi, C.C., Nwachukwu, H., 2016. Earth resources exploitation and sustainable development: Geological and engineering perspectives. Engineering, vol. 8, no. 1, pp. 21–33.
- Jamasmie, C., 2010. Junior companies mine their own business. Available at: <https://www.mining.com/junior-companies-mine-their-own-business/> (Accessed: 13 May 2026).
- Jeffrey, L., Henry, G., McGill, J., 2015. Introduction to South African coal mining and exploration. In: A Guide for Applying Geophysics to Coal Mining Problems in South Africa, Struik Nature, South Africa, pp. 4–21.
- Jenner, K., Walker, A., Close, C., Saunders, T., 2018. Mining investment beyond the boom, pp. 1–15.
- Kabir, M.S.S., 2016. Methods of data collection. In: Basic Guidelines for Research: An Introductory Approach for All Disciplines, Chittagong: Book Zone Publication.

- Kazanci, H., 2026. Global coal demand peaks in 2024, to plateau until 2027: IEA - International coal trade is set to reach record of 1.55 billion tonnes in 2024, IEA's Coal 2024 report shows. Available at: <https://www.aa.com.tr/en/energy/coal/global-coal-demand-peaks-in-2024-to-plateau-until-2027-iea/46323> (Accessed: 15 January 2025).
- Kecojevic, V., Komljenovic, D., 2006. Impact of burden and spacing on fragment size distribution and total cost in quarry mining. Society for Mining, Metallurgy, and Exploration, vol. 320. pp. 133–141.
- Kgweetsi, G., 2016. Longwall mining synopsis. Botswana International University of Science and Technology, Notes.
- Kinyua, E.M., Jianhua, Z., Kasomo, R.M., Mauti, D., Mwangangi, J., 2022. A review of the influence of blast fragmentation on downstream processing of metal ores. Minerals Engineering, vol. 186, pp. 1–19.
- Kohler, J., 2020. Longwall mining. Available at: <https://www.e-education.psu.edu/geog000/node/913> (Accessed: 22 September 2023).
- Lai, M., 2024. Analyze and improvement of NPV and IRR methods. Highlights in Business, Economics and Management, vol. 42, pp. 204–208.
- Le, S., 2021. The applications of NPV in different types of markets. Advances in Economics, Business and Management Research, vol. 203, pp. 1054–1059.
- Mackay, D., 2022. Odds stacked against SA's junior miners yet some intrepid explorers break the mould. Available at: <https://www.miningmx.com/news/markets/51467-odds-stacked-against-sas-junior-miners-yet-some-intrepid-explorers-break-the-mould/> (Accessed: 18 June 2023)

- McCarthy, T.S., Pretorius, K., 2009. Coal mining on the Highveld and its implications for future water quality in the Vaal River system. International Mine Water Conference, 19 – 23 October 2009, Pretoria, Cilla Taylor Conferences, pp. 56–65.
- McKeown, B., Coulton, J., Saydam, S., Dempster, A.G., 2024. What is an appropriate investment hurdle rate for commercial space resource development projects. Space Policy, vol. 70, pp. 1–18.
- Minerals Council South Africa, 2019a. Junior and emerging miners' desk research report. Available at: www.mineralscouncil.org.za (Accessed: 08 December 2023).
- Minerals Council South Africa, 2019b. Junior and emerging miners. Mining Charter Workshop, pp. 1–4.
- Minerals Council South Africa, 2020. Facts and Figures Pocketbook 2020.
- Minerals Council South Africa, 2021a. Facts and Figures 2021.
- Minerals Council South Africa, 2021b. Integrated Annual Review 2021, pp. 1–128
- Minerals Council South Africa, 2022. Facts & Figures Pocketbook 2022.
- Minerals Council South Africa, 2024. 2023 - Comprehensive facts and figures. Minerals Council South Africa.
- Mining Engineering, 2016. Surface mining. Available at: <https://miningengineeringsite.wordpress.com/2016/07/20/surface-mining/> (Accessed: 12 July 2024).
- Mining Mirror, 2017. Legislation governing mining and environmental matters in SA. Available at: <https://www.hoganlovells.com/en/publications/legislation-governing-mining-and-environmental-matters-in-sa> (Accessed: 06 December 2023).

- Mining Technology, 2024. Coal production in South Africa and major projects. Available at: <https://www.mining-technology.com/data-insights/coal-in-south-africa/?cf-view> (Accessed: 18 October 2024).
- Mirakovski, D., Krstev, B., Krstev, A., Petrovski, F., 2012. Mine project evaluation techniques, pp. 1–7.
- Mitra, R., Saydam, S., 2012. Surface coal mining methods in Australia. In: Mining Methods, pp. 1–22
- Modigliani, F., Miller, M.H., 1963. Corporate income taxes and the cost of capital: A correction. American Economic Review, vol. 53, no. 3, pp. 433–443.
- Mohutsiwa, M., Musingwini, C., 2015. Estimation of capital costs for establishing coal mines in South Africa. Journal of the Southern African Institute of Mining and Metallurgy, vol. 115, no. 8, pp. 789–797.
- Moodley, N., 2021. Junior mining in South Africa - Making the right moves. <https://businessmediamags.co.za/mining/sa-mining/junior-mining-in-south-africa/> (Accessed: 19 November 2023).
- Moolman, C., Canbulat, I., 2003. Economic and safe extraction of pillars and associated reserves using underground mining methods. Report, COALTECH 2020.
- Morley, C., Snowden, V., Day, D. 1999. Financial impact of resource/reserve uncertainty. Journal of the South African Institute of Mining and Metallurgy, vol. 99, no. 6, pp. 293 –301.
- Ncube, H., 2020. An in-depth study on challenges faced by junior coal mining companies in South Africa. Industrial Engineering and Operations Management, 10–12 March 2020, Dubai, pp. 2845–2852.

- Ngwenyama, P.L., de Graaf, W.W., Preis, E.P., 2017. Factors and challenges affecting coal recovery by opencast pillar mining in the Witbank coalfield. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 117, no. 3, pp. 215–222.
- Ngwenyama, P.L., de Graaf, W.W., 2021. Risks and challenges affecting opencast pillar mining in previously mined underground bord and pillar workings. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 21, no. 12, pp. 623–631.
- Ngoroyemoto, T.F.K., Ashley, R.S., Rahul, V., Tsidzinye, T., Nyamagudza, T., Suglo, S.R., 2023. Effects of fragmentation on production at Peak mine Midlands, Zimbabwe. *Disaster Advances*, vol. 16, no. 8, pp. 28–38.
- Oates, T.E., Spiteri, W., 2021. Stemming and best practice in the mining industry: A literature review. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 121, no. 8, pp. 415–425.
- Ovalle, A., 2020. Analysis of the discount rate for mining projects. *MassMin 2020: Proceedings of the Eighth International Conference & Exhibition on Mass Mining*, University of Chile, Santiago, pp. 1048–1064.
- Palit, D., Khurana, T., 2025. Paradox of India's energy transition - Coal phase out or renewables phase in. Available at: <https://www.crfindia.org/publications/opinion-column/paradox-of-indias-energy-transition-coal-phase-out-or-renewables-phase-in> (Accessed: 24 February 2026).
- Pasch, O., Uludag, S., 2018. Optimization of the load-and-haul operation at an opencast colliery. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 118, no. 5, pp. 449–456.
- Peyper, L., 2023. Coal resurgence gives SA junior miners R34bn boost. Available at: <https://www.miningmx.com/news/energy/52058-coal->

[resurgence-gives-sa-junior-miners-r34bn-boost-in-revenue/](#)

(Accessed: 31 October 2023)

Pieters, J., 2018. Re-opening of closed mines for small-scale mining in South Africa. Master of Technology dissertation, University of Johannesburg.

Ratshomo, K., 2021. The South African energy sector report. Department of Mineral Resources and Energy, Pretoria.

Ratshomo, K., Nembaye, R., 2018. South African coal sector report - Directorate: Energy Data Collection, Management and Analysis. Department of Mineral Resources and Energy, Pretoria.

Rupprecht, S.M., Pieters, J.E., 2018. Re-opening of old gold mines for small scale mining in South Africa - The process of creating a small scale mine in a historically mined out South African gold field. ASM Conference 2018, Electra Mining, NASREC, Johannesburg, pp. 1–8.

SA Mining, 2025. The junior miner conundrum. Available at: <https://businessmediamags.co.za/mining/sa-mining/the-junior-miner-conundrum/> (Accessed: 14 May 2026)

Schernikau, L., 2010. Economics of the international coal trade. Springer.

Sebutsoe, T.C., 2017. Characterizing a mining production system for decision-making purposes in a platinum mine. Journal of the Southern African Institute of Mining and Metallurgy, vol. 117, no. 2, pp. 199–206.

Seequent, 2019. Leapfrog Edge fundamentals. Training Manual, Leapfrog Geo + Edge version 4.5, Seequent.

Sellers, E.J., Kataka, M.O., Milev, A.M., Singh, N., Spottiswoode, S.M., 2007. Characterisation of hazards and rockmass response during remnant mining in South African gold mines. In Potvin, Y., Hudyma,

- M. (Eds.). RaSiM6: Proceedings of the Sixth International Symposium on Rockburst and Seismicity in Mines Proceedings, Australian Centre for Geomechanics, Perth, pp. 183–189.
- Sileyew, K.J., 2019. Research design and methodology. In Cyberspace, IntechOpen, pp. 1–12.
- Singh, N.A., Kataka, M.A., Mileva A., Sellers, E., 2006. Remnant mining in South African gold mines. Proceedings of the 41st U.S. Symposium on Rock Mechanics, Golden, CO. American Rock Mechanics Association, Alexandria, VA. Paper no. ARMA-06-1038.
- Singh, S.K., Kumar, D., 2024. Optimizing coal mine planning and design for sustainable development in the context of mass exploitation of coal deposits. Heliyon, vol. 10, no. 7, pp. 1–10.
- Solomons, S., 2018. South Africa: Investing in junior mining is a game of patience. Available at: <https://www.miningreview.com/international/south-africa-investing-junior-mining-game-patience/> (Accessed: 03 January 2024).
- Statistics South Africa, 2019. Four facts about the mining industry (2019) | Statistics South Africa. Available at: <https://www.statssa.gov.za/?p=14682> (Accessed: 28 May 2024).
- Steyn, M., Minnitt, R.C.A., 2010. Thermal coal products in South Africa. Journal of the Southern African Institute of Mining and Metallurgy, vol. 110, no. 10, pp. 593–599.
- Sullivan, T.D., 2006. Pit slope design and risk – A view of the current state of the art. Proceedings of the International Symposium of Rock Slope Stability in Open Pit Mining and Civil Engineering, 3–6 April 2006, Cape Town, South Africa, The Southern African Institute of Mining and Metallurgy, pp. 51–80.

- Taiwo, B.O., 2024. Presplitting techniques and design in open pit mining: Enhancing stability and minimizing overbreak. Personal Notes.
- Tannant, D., Regensburg, B., 2001. Guidelines for mine haul road design. Notes, University of British Columbia Library, Vancouver.
- U.S. Energy Information Administration, 2016. International energy outlook 2016. Report, Washington, D.C.
- Van der Merwe, J. N., Mathey, M., 2013. Probability of failure of South African coal pillars. Journal of the Southern African Institute of Mining and Metallurgy, vol. 113, no. 12, pp. 849–857.
- Van der Veen, B., 2022. Funding for junior miners. SA Mining. Available at: https://issuu.com/sundaytimesza/docs/sam_strung_mayjun-2022_digital/s/15889013 (Accessed: 19 July 2023).
- Van Eck, N., 2016. Improved utilization of underground coal reserves. Report, Coaltech, South Africa
- Vella, H., 2014. Highlighting CSR excellence among the mining juniors. Mining Technology. Available at: <https://www.mining-technology.com/features/featurehighlighting-csr-excellence-among-the-mining-juniors-4159587/> (Accessed: 07 January 2024).
- Volkman, S.E., Lehnen, F., Kukla, P.A., 2019. Estimating the economics of a mining project on seafloor manganese nodules. Mineral Economics, vol. 32, no. 3, pp. 287–306.
- Vorster, C.J., 2003. Map of the coalfields of South Africa. Council for Geoscience Publication.
- Wagner, H., 1980. Pillar design in coal mines. Journal of the South African Institute of Mining and Metallurgy, vol. 80, no. 1, pp. 37–45.
- Wang, W., Huang, S., Wu, X., Ma, Q., 2011. Calculation and management for mining loss and dilution under 3D visualization technical

condition. *Journal of Software Engineering and Applications*, vol. 4, no. 5, pp. 329–334.

Webster, J., 2026. News analysis: South Africa's mining sector rides precious metals boom into 2026. Available at: <https://www.businessday.co.za/companies/2026-01-07-news-analysis-south-africas-mining-sector-rides-precious-metals-boom-into-2026/> (Accessed: 17 May 2026)

Wienand, G.A., Ferreira, R.I.L., 2007. Planning and practice of remnant pillar mining — A case study. In Potvin Y. (Eds.), *Deep Mining 2007: Proceedings of the Fourth International Seminar on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 141–162, https://doi.org/10.36487/ACG_repo/711_11

Xingwana, L., 2016. Monitoring ore loss and dilution for mine-to-mill integration in deep gold mines: A survey-based investigation. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 116, no. 2, pp. 149–160.

XMP Consulting, 2013. *Review of the South African coal mining industry*. Pretoria.

Yamatomi, J., Okubo, S., 2009. Surface mining methods and equipment. *Encyclopedia of Life Support Systems*, vol. 2, pp. 1–7.

Yan, R., Zhang, Y., 2022. The introduction of NPV and IRR. *Advances in Economics, Business and Management Research*, vol. 211, pp. 1472–1476.

Yin, R.K., 2013. Validity and generalization in future case study evaluations. *Evaluation*, vol. 19, no. 3, pp. 321–332.

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

APPENDICES

Appendix A. All data used in the creation of the geological model, mine designs and plans for Mine 1

A1. Mine 1 – Simplified Lithological Data

HOLE_ID	FROM	TO	LITHOLOGY	WEATHERING
DKT001	0	2.82	Topsoil	LOW
DKT001	2.82	17.85	SST_4	
DKT001	17.85	20.84	4 SEAM	
DKT001	20.84	22.05	SST_3	
DKT001	22.05	26.38	3 SEAM	
DKT001	26.38	27.07	SST_2	
DKT001	27.07	29.87	2 SEAM	
DKT001	29.87	44.95	SST_1	
DKT001	44.95	50.36	ST	
DKT002	0	7.8	Topsoil	LOW
DKT002	7.8	18.1	SST_4	
DKT002	18.1	23.68	4 SEAM	
DKT002	23.68	28.47	SST_3	
DKT002	28.47	32.03	3 SEAM	
DKT002	32.03	38.68	SST_2	
DKT002	38.68	42.88	2 SEAM	
DKT002	43.68	66.25	SST_1	
DKT003	0	5.6	Topsoil	LOW
DKT003	5.6	15.52	SST_4	
DKT003	15.52	18.57	4 SEAM	
DKT003	18.57	55.74	SST_3	
DKT004	0	5.77	Topsoil	LOW
DKT004	5.77	18.36	SST_4	
DKT004	18.36	24.87	4 SEAM	
DKT004	24.87	30.55	SST_3	
DKT004	30.55	33.65	3 SEAM	
DKT004	33.65	51.25	SST_2	
DKT004	51.25	61.25	SST_1	
DKT005	0	4.62	Topsoil	LOW
DKT005	4.62	9.85	Do	
DKT005	9.85	12.14	SST_4	
DKT005	12.14	18.01	4 SEAM	
DKT005	18.01	63.4	SST_3	
DKT006	0	3.86	Topsoil	LOW
DKT006	3.86	6.91	SST_4	
DKT006	6.91	14.23	Do	
DKT006	14.23	17.25	SST_3	
DKT006	17.25	21.05	3 SEAM	

DKT006	21.05	28.03	SST_2	
DKT006	28.03	33.25	2 SEAM	
DKT006	33.25	49.54	SST_1	
DKT006	49.54	65.77	ST	
DKT007	0	3.78	Topsoil	LOW
DKT007	3.78	10.8	SST_4	
DKT007	10.8	13.69	SST_3	
DKT007	13.69	17.05	3 SEAM	
DKT007	17.05	21.8	SST_2	
DKT007	21.8	24.97	2 SEAM	
DKT007	24.97	33.69	SST_1	
DKT007	33.69	59.89	ST	
DKT008	0	5.55	Topsoil	LOW
DKT008	5.55	17.33	SST_4	
DKT008	17.33	21.79	4 SEAM	
DKT008	21.79	22.88	SST_3	
DKT008	22.88	27.45	SST_2	
DKT008	27.45	30.15	2 SEAM	
DKT008	30.15	34.51	SST_1	
DKT008	34.51	56.55	ST	
DKT009	0	4.35	Topsoil	LOW
DKT009	4.35	10.53	Do	
DKT009	10.53	12.52	SST_4	
DKT009	12.52	16.86	4 SEAM	
DKT009	16.86	18.61	SST_3	
DKT009	18.61	52.99	ST	
DKT025	0	5.29	Topsoil	LOW
DKT025	5.29	18.87	SST_4	
DKT025	18.87	22.68	4 SEAM	
DKT025	22.68	27.12	SST_3	
DKT025	27.12	30.25	3 SEAM	
DKT025	30.25	35.56	SST_2	
DKT025	35.56	40.09	2 SEAM	
DKT025	40.09	61.07	ST	
DKT026	0	7.6	Topsoil	LOW
DKT026	7.6	8.12	SST_4	
DKT026	8.12	19.87	Do	
DKT026	19.87	25.36	4 SEAM	
DKT026	25.36	32.59	SST_3	
DKT026	32.59	38.37	SST_1	
DKT026	38.37	64.64	ST	
DKT027	0	2.82	Topsoil	LOW
DKT027	2.82	17.89	SST_4	
DKT027	17.89	21.56	4 SEAM	
DKT027	21.56	28.19	SST_3	

DKT027	28.19	32.92	2 SEAM	
DKT027	32.92	43.92	SST_2	
DKT027	43.92	58.09	ST	
DKT028	0	2	Topsoil	LOW
DKT028	2	19.87	SST_4	
DKT028	19.87	24.63	4 SEAM	
DKT028	24.63	30.1	SST_3	
DKT028	30.1	41.04	SST_2	
DKT028	41.04	46.51	SST_1	
DKT028	46.51	55.64	ST	
DKT029	0	7.55	Topsoil	LOW
DKT029	7.55	17.96	SST_4	
DKT029	17.96	22.12	4 SEAM	
DKT029	22.12	28.7	SST_3	
DKT029	28.7	35.28	SST_2	
DKT029	35.28	48.44	SST_1	
DKT029	48.44	53.07	ST	
DKT030	0	3.01	Topsoil	LOW
DKT030	3.01	4	SST_4	
DKT030	4	37.03	SST_3	
DKT030	37.03	55.09	SST_2	
DKT030	55.09	61.89	SST_1	
DKT031	0	5	Topsoil	LOW
DKT031	5	20.87	SST_4	
DKT031	20.87	26.35	4 SEAM	
DKT031	26.35	33.25	SST_3	
DKT031	33.25	38.74	2 SEAM	
DKT031	38.74	48.97	SST_2	
DKT031	48.97	59.2	SST_1	
DKT031	59.2	63.79	ST	
DKT032	0	7.5	Topsoil	LOW
DKT032	7.5	15.12	SST_4	
DKT032	15.12	20.69	2 SEAM	
DKT032	20.69	41.85	SST_1	
DKT032	41.85	55.55	ST	
DKT033	0	5.8	Topsoil	LOW
DKT033	5.8	13.88	SST_4	
DKT033	13.88	18.25	4 SEAM	
DKT033	18.25	23.38	SST_3	
DKT033	23.38	28.13	3 SEAM	
DKT033	28.13	34.87	SST_2	
DKT033	34.87	41.25	2 SEAM	
DKT033	41.25	50.61	SST_1	
DKT077	0	7.88	Topsoil	LOW
DKT077	7.88	11.02	SST_4	

DKT077	11.02	14.89	4 SEAM	
DKT077	14.89	25.36	SST_3	
DKT077	25.36	29.23	2 SEAM	
DKT077	29.23	36.64	SST_1	
DKT077	36.64	56.07	ST	
DKT078	0	0.5	Topsoil	LOW
DKT078	0.5	19.81	SST_4	
DKT078	19.81	23.81	4 SEAM	
DKT078	23.81	28.03	SST_3	
DKT078	28.03	34.07	2 SEAM	
DKT078	34.07	41.19	SST_1	
DKT078	41.19	57.55	ST	
DKT079	0	7.1	Topsoil	LOW
DKT079	7.1	20.8	SST_2	
DKT079	20.8	24.76	2 SEAM	
DKT079	24.76	33.12	SST_3	
DKT079	33.12	54.43	ST	
DKT080	0	4.53	Topsoil	
DKT080	4.53	15.66	Do	
DKT080	15.66	16.66	SST_4	
DKT080	16.66	19.89	4 SEAM	
DKT080	19.89	27.18	SST_3	
DKT080	27.18	34.47	SST_2	
DKT080	34.47	41.76	SST_1	
DKT080	41.76	60.45	ST	
DKT081	0	6.62	Topsoil	LOW
DKT081	6.62	17.05	SST_4	
DKT081	17.05	21.52	4 SEAM	
DKT081	21.52	23.1	SST_3	
DKT081	23.1	25.52	SST_2	
DKT081	25.52	29.44	2 SEAM	
DKT081	29.44	34.44	SST_1	
DKT081	34.44	58.04	ST	
DKT082	0	3.59	Topsoil	LOW
DKT082	3.59	11.02	SST_4	
DKT082	11.02	19.02	4 SEAM	
DKT082	19.02	24.02	SST_3	
DKT082	24.02	27.02	SST_2	
DKT082	27.02	31.1	2 SEAM	
DKT082	31.1	37.02	SST_1	
DKT082	37.02	63.17	ST	
DKT083	0	7.2	Topsoil	LOW
DKT083	7.2	17.88	SST_4	
DKT083	17.88	21.88	4 SEAM	
DKT083	21.88	25.52	SST_3	

DKT083	25.52	29.36	3 SEAM	
DKT083	29.36	35.23	SST_2	
DKT083	35.23	38.77	2 SEAM	
DKT083	38.77	49.79	ST	
DKT083	49.79	54.86	SST_1	
DKT084	0	4.35	Topsoil	LOW
DKT084	4.35	16.36	SST_4	
DKT084	16.36	20.15	4 SEAM	
DKT084	20.15	25.89	SST_3	
DKT084	25.89	29.58	2 SEAM	
DKT084	29.58	39.83	SST_1	
DKT084	39.83	57.87	ST	
DKT098	0	5.42	Topsoil	LOW
DKT098	5.42	19.63	SST_4	
DKT098	19.63	24.63	4 SEAM	
DKT098	24.63	30.3	SST_3	
DKT098	30.3	35.45	2 SEAM	
DKT098	35.45	38.9	SST_1	
DKT098	38.9	55.6	ST	
DKT099	0	3.02	Topsoil	LOW
DKT099	3.02	16.79	SST_4	
DKT099	16.79	20.87	4 SEAM	
DKT099	20.87	22.03	SST_3	
DKT099	22.03	27.12	3 SEAM	
DKT099	27.12	37.14	SST_2	
DKT099	37.14	42.15	SST_1	
DKT099	42.15	60.61	ST	
DKT100	0	4.02	Topsoil	LOW
DKT100	4.02	15.88	SST_4	
DKT100	15.88	19.27	4 SEAM	
DKT100	19.27	22.27	SST_3	
DKT100	22.27	26.36	3 SEAM	
DKT100	26.36	34.87	SST_2	
DKT100	34.87	45.01	SST_1	
DKT100	45.01	61.07	ST	
DKT101	0	3.54	Topsoil	LOW
DKT101	3.54	15.36	SST_4	
DKT101	15.36	19.14	4 SEAM	
DKT101	19.14	26.89	SST_3	
DKT101	26.89	59.99	SST_2	
DKT101	59.99	62.2	SST_1	
DKT102	0	5.93	Topsoil	LOW
DKT102	5.93	17.63	SST_4	
DKT102	17.63	21.77	4 SEAM	
DKT102	21.77	24.08	SST_3	

DKT102	24.08	26.09	3 SEAM	
DKT102	26.09	28.18	SST_2	
DKT102	28.18	31.05	2 SEAM	
DKT102	31.05	46.25	SST_1	
DKT102	46.25	56.28	ST	
DKT103	0	2.9	Topsoil	LOW
DKT103	2.9	18.36	SST_4	
DKT103	18.36	21.79	4 SEAM	
DKT103	21.79	23.5	SST_3	
DKT103	23.5	27.58	3 SEAM	
DKT103	27.58	30.23	SST_2	
DKT103	30.23	34.07	2 SEAM	
DKT103	34.07	48.38	SST_1	
DKT103	48.38	57.88	ST	
DKT104	0	5.15	Topsoil	LOW
DKT104	5.15	16.86	Do	
DKT104	16.86	19.45	SST_4	
DKT104	19.45	23.06	4 SEAM	
DKT104	23.06	31.69	SST_3	
DKT104	31.69	40.32	SST_2	
DKT104	40.32	59.34	ST	
DKT203	0	3.82	Topsoil	LOW
DKT203	3.82	15.87	Do	
DKT203	15.87	17.17	SST_4	
DKT203	17.17	21.07	4 SEAM	
DKT203	21.07	23.04	SST_3	
DKT203	23.04	26.91	2 SEAM	
DKT203	26.91	45.5	SST_1	
DKT203	45.5	60.77	ST	
DKT210	0	2.55	Topsoil	
DKT210	2.55	19.82	SST_4	LOW
DKT210	19.82	23.96	4 SEAM	
DKT210	23.96	30.3	SST_3	
DKT210	30.3	43.96	SST_2	
DKT210	43.96	56.78	SST_1	
DKT210	56.78	59.18	ST	
DKT215	0	1.9	Topsoil	LOW
DKT215	1.9	17.39	SST_4	
DKT215	17.39	21.57	4 SEAM	
DKT215	21.57	29.31	SST_3	
DKT215	29.31	35.85	SST_2	
DKT215	35.85	42.39	SST_1	
DKT215	42.39	58.95	ST	
DKT251	0	3.81	Topsoil	LOW
DKT251	3.81	15.81	SST_4	

DKT251	15.81	19.66	4 SEAM	
DKT251	19.66	49.84	SST_3	
DKT251	49.84	55.73	SST_2	
DKT251	55.73	60.6	SST_1	
DKT256	0	3.49	Topsoil	LOW
DKT256	3.49	18.65	SST_4	
DKT256	18.65	22.25	4 SEAM	
DKT256	22.25	25.25	SST_3	
DKT256	25.25	29.56	2 SEAM	
DKT256	29.56	40.75	SST_1	
DKT256	40.75	63.65	ST	
DKT322	0	2.36	Topsoil	LOW
DKT322	2.36	17.09	Do	
DKT322	17.09	18.26	SST_4	
DKT322	18.26	22.33	4 SEAM	
DKT322	22.33	27.77	SST_3	
DKT322	27.77	33.21	SST_2	
DKT322	33.21	38.65	SST_1	
DKT322	38.65	65.09	ST	
DKT333	0	3.95	Topsoil	LOW
DKT333	3.95	21.49	SST_4	
DKT333	21.49	25.73	4 SEAM	
DKT333	25.73	33.18	SST_3	
DKT333	33.18	48.08	SST_2	
DKT333	48.08	55.53	SST_1	
DKT333	55.53	58.97	ST	

A2. Mine 2 – Simplified Lithological Data

HOLE_ID	FROM	TO	LITHOLOGY	WEATHERING
GDT01	0	4.05	Softs	LOW
GDT01	4.05	7.5	SST_3	
GDT01	7.5	11.53	4 SEAM	
GDT01	11.53	12.87	SST_2	
GDT01	12.87	13	ST_1	
GDT01	13	16	2 SEAM	
GDT01	16	29.88	DO	
GDT01	29.88	56.36	SST_1	
GDT02	0	5.93	Softs	LOW
GDT02	5.93	9.36	SST_3	
GDT02	9.36	14.23	4 SEAM	
GDT02	14.23	16.09	SST_2	
GDT02	16.09	19.87	2 SEAM	
GDT02	19.87	50.36	SST_1	
GDT03	0	2.9	Softs	LOW
GDT03	2.9	7.56	SST_3	
GDT03	8.28	12.87	4 SEAM	
GDT03	12.87	13.87	SST_2	
GDT03	13.87	15.69	ST_2	
GDT03	15.69	17.91	2 SEAM	
GDT03	17.91	58.47	SST_1	
GDT04	0	3.37	Softs	LOW
GDT04	3.37	7.48	SST_3	
GDT04	7.48	12.93	4 SEAM	
GDT04	12.93	23.28	SST_2	
GDT04	23.28	64.36	ST_2	
GDT05	0	3.31	Softs	LOW
GDT05	3.31	8.78	SST_3	
GDT05	8.78	12.96	4 SEAM	
GDT05	12.96	15.95	SST_2	
GDT05	15.95	20.31	2 SEAM	
GDT05	20.31	35.66	SST_1	
GDT05	35.66	49.25	DO	
GDT05	49.25	61.46	ST_1	
GDT06	0	5	Softs	LOW
GDT06	5	14.22	SST_3	
GDT06	14.22	15.53	SST_2	
GDT06	15.53	20.67	ST_2	
GDT06	20.67	62.65	SST_1	
GDT07	0	5.15	Softs	LOW
GDT07	5.15	12.35	SST_3	
GDT07	12.35	16.72	ST_2	

GDT07	16.72	57.58	SST_1	
GDT08	0	5.15	Softs	LOW
GDT08	5.15	6.06	SST_3	
GDT08	6.06	10.22	4 SEAM	
GDT08	10.22	13.06	SST_2	
GDT08	13.06	13.19	ST_2	
GDT08	13.19	17.3	2 SEAM	
GDT08	17.3	58.36	SST_1	
GDT09	0	3.82	Softs	LOW
GDT09	3.82	5.69	SST_3	
GDT09	5.69	10	ST_2	
GDT09	10	14.1	4 SEAM	
GDT09	14.1	41.87	DO	
GDT09	41.87	66.06	SST_1	
GDT10	0	3.25	Softs	LOW
GDT10	3.25	12.96	SST_3	
GDT10	12.96	13.17	SST_2	
GDT10	13.17	17.5	ST_2	
GDT10	17.5	33.27	DO	
GDT10	33.27	58.36	SST_1	
GDT11	0	3.62	Softs	LOW
GDT11	3.62	8.94	SST_3	
GDT11	8.94	10.81	SST_2	
GDT11	10.81	14.81	4 SEAM	
GDT11	14.81	65.36	SST_1	
GDT12	0	1.9	Softs	
GDT12	1.9	20.91	SST_3	LOW
GDT12	20.91	39.78	ST_2	
GDT12	39.78	65.36	SST_1	
GDT13	0	2.55	Softs	LOW
GDT13	2.55	11.05	SST_3	
GDT13	11.05	14.97	4 SEAM	
GDT13	14.97	16.06	SST_2	
GDT13	16.06	17.28	ST_2	
GDT13	17.28	21.41	2 SEAM	
GDT13	21.41	45.06	DO	
GDT13	45.06	59.34	SST_1	
GDT14	0	7.35	Softs	LOW
GDT14	7.35	8.94	SST_3	
GDT14	8.94	13.05	4 SEAM	
GDT14	13.05	29.54	SST_2	
GDT14	29.54	48.25	ST_2	
GDT14	48.25	65.36	SST_1	
GDT15	0	3.81	Softs	LOW
GDT15	3.81	7.95	SST_3	

GDT15	7.95	12.24	4 SEAM	
GDT15	12.24	28.81	SST_2	
GDT15	28.81	44.89	ST_2	
GDT15	44.89	62.86	SST_1	
GDT16	0	3.49	Softs	LOW
GDT16	3.49	7.4	SST_3	
GDT16	7.4	11.35	4 SEAM	
GDT16	11.35	13.04	SST_2	
GDT16	13.04	16.87	2 SEAM	
GDT16	16.87	57.36	SST_1	
GDT17	0	2.36	Softs	LOW
GDT17	2.36	6.98	SST_3	
GDT17	6.98	11.29	4 SEAM	
GDT17	11.29	11.53	SST_2	
GDT17	11.53	12.34	ST_2	
GDT17	12.34	16.41	2 SEAM	
GDT17	16.41	68.36	SST_1	
GDT18	0	6.8	Softs	LOW
GDT18	6.8	8.59	SST_3	
GDT18	8.59	12.78	4 SEAM	
GDT18	12.78	25.29	SST_2	
GDT18	25.29	29.49	2 SEAM	
GDT18	29.49	54.23	DO	
GDT18	54.23	61.71	SST_1	
GDT19	0	7.74	Softs	LOW
GDT19	7.74	8.4	SST_3	
GDT19	8.4	12.31	4 SEAM	
GDT19	12.31	22.71	SST_2	
GDT19	22.71	27.22	2 SEAM	
GDT19	27.22	44.49	DO	
GDT19	44.49	65.12	SST_1	
GDT20	0	2.74	Softs	LOW
GDT20	2.74	6.5	SST_3	
GDT20	6.5	10.74	4 SEAM	
GDT20	10.74	15.46	SST_2	
GDT20	15.46	22.71	ST_2	
GDT20	22.71	26.88	2 SEAM	
GDT20	26.88	57.83	SST_1	
GDT21	0	5.66	Softs	LOW
GDT21	5.66	11.91	SST_3	
GDT21	11.91	22.97	SST_2	
GDT21	22.97	34.65	ST_2	
GDT21	34.65	58.61	SST_1	
GDT22	0	4.43	Softs	
GDT22	4.43	5.07	SST_3	LOW

GDT22	5.07	6.74	SST_2	
GDT22	6.74	9.3	ST_2	
GDT22	9.3	13.63	4 SEAM	
GDT22	13.63	56.31	SST_1	
GDT23	0	2.15	Softs	LOW
GDT23	2.15	8.8	SST_3	
GDT23	8.8	13.02	4 SEAM	
GDT23	13.02	23.71	SST_2	
GDT23	23.71	33.94	ST_2	
GDT23	33.94	37.97	2 SEAM	
GDT23	37.97	68.61	SST_1	
GDT24	0	7.33	Softs	LOW
GDT24	7.33	11.05	SST_3	
GDT24	11.05	15.11	4 SEAM	
GDT24	15.11	20.35	SST_2	
GDT24	20.35	24.54	2 SEAM	
GDT24	24.54	61.71	SST_1	
GDT25	0	2.85	Softs	LOW
GDT25	2.85	15.16	SST_3	
GDT25	15.16	15.4	SST_2	
GDT25	15.4	19.93	ST_2	
GDT25	19.93	62.9	SST_1	
GDT26	0	4.1	Softs	LOW
GDT26	4.1	7.39	SST_3	
GDT26	7.39	11.46	4 SEAM	
GDT26	11.46	11.93	SST_2	
GDT26	11.93	12.23	ST_2	
GDT26	12.23	16.26	2 SEAM	
GDT26	16.26	39.58	DO	
GDT26	39.58	60.83	SST_1	
GDT27	0	4.35	Softs	LOW
GDT27	4.35	7.36	SST_3	
GDT27	7.36	11.39	4 SEAM	
GDT27	11.39	12.88	SST_2	
GDT27	12.88	12.93	ST_2	
GDT27	12.93	17.07	2 SEAM	
GDT27	17.07	58.61	SST_1	
GDT28	0	3.02	Softs	LOW
GDT28	3.02	11.2	SST_3	
GDT28	11.2	15.43	4 SEAM	
GDT28	15.43	35.83	SST_2	
GDT28	35.83	46.15	ST_2	
GDT28	46.15	66.31	SST_1	
GDT29	0	2.6	Softs	LOW
GDT29	2.6	8.9	SST_3	

GDT29	8.9	12.96	4 SEAM	
GDT29	12.96	15.08	SST_2	
GDT29	15.08	18.24	ST_2	
GDT29	18.24	22.29	2 SEAM	
GDT29	22.29	37.18	DO	
GDT29	37.18	58.01	SST_1	
GDT30	0	5.42	Softs	LOW
GDT30	5.42	8.03	SST_3	
GDT30	8.03	12.24	4 SEAM	
GDT30	12.24	32.85	SST_2	
GDT30	32.85	53.66	DO	
GDT30	53.66	63.1	SST_1	
GDT31	0	1.92	Softs	LOW
GDT31	1.92	8.61	SST_3	
GDT31	8.61	12.61	4 SEAM	
GDT31	12.61	23.06	SST_2	
GDT31	23.06	33.35	ST_2	
GDT31	33.35	37.66	2 SEAM	
GDT31	37.66	59.36	SST_1	
GDT32	0	2.42	Softs	LOW
GDT32	2.42	7.12	SST_3	
GDT32	7.12	11.19	4 SEAM	
GDT32	11.19	12.76	SST_2	
GDT32	12.76	14.2	ST_2	
GDT32	14.2	18.35	2 SEAM	
GDT32	18.35	60.28	SST_1	
GDT33	0	2.62	Softs	LOW
GDT33	2.62	10.87	SST_3	
GDT33	10.87	14.91	4 SEAM	
GDT33	14.91	35.44	SST_2	
GDT33	35.44	56.38	DO	
GDT33	56.38	66.5	SST_1	
GDT34	0	4.19	Softs	LOW
GDT34	4.19	7.25	SST_3	
GDT34	7.25	24.91	ST_2	
GDT34	24.91	35.68	SST_2	
GDT34	35.68	60.26	SST_1	
GDT35	0	6.1	Softs	LOW
GDT35	6.1	7.59	SST_3	
GDT35	7.59	10	SST_2	
GDT35	10	21.09	ST_2	
GDT35	21.09	25.23	2 SEAM	
GDT35	25.23	66.8	SST_1	
GDT36	0	3.4	Softs	LOW
GDT36	3.4	14.84	SST_3	

GDT36	14.84	19.05	4 SEAM	
GDT36	19.05	30.74	SST_2	
GDT36	30.74	43.54	DO	
GDT36	43.54	59.09	SST_1	
GDT37	0	3.13	Softs	LOW
GDT37	3.13	27.84	SST_3	
GDT37	27.84	31.09	2 SEAM	
GDT37	31.09	44.34	SST_2	
GDT37	44.34	56.47	ST_2	
GDT37	56.47	69.47	SST_1	
GDT38	0	4.38	Softs	LOW
GDT38	4.38	14.22	SST_3	
GDT38	14.22	65.23	SST_2	
GDT39	0	4.3	Softs	LOW
GDT39	4.3	17.1	SST_3	
GDT39	17.1	23.35	4 SEAM	
GDT39	23.35	35.84	SST_2	
GDT39	35.84	48.17	ST_2	
GDT39	48.17	66.48	SST_1	
GDT40	0	3.4	Softs	LOW
GDT40	3.4	18.63	SST_3	
GDT40	18.63	24.98	4 SEAM	
GDT40	24.98	33.26	SST_2	
GDT40	33.26	56.52	ST_2	
GDT40	56.52	65.66	SST_1	
GDT41	0	4.3	Softs	LOW
GDT41	4.3	17.1	SST_3	
GDT41	17.1	21.4	4 SEAM	
GDT41	21.4	34.78	SST_2	
GDT41	34.78	48.01	ST_2	
GDT41	48.01	63.08	SST_1	
GDT42	0	2.36	Softs	LOW
GDT42	2.36	17.43	SST_3	
GDT42	17.43	21.46	4 SEAM	
GDT42	21.46	31.66	SST_2	
GDT42	31.66	42.06	DO	
GDT42	42.06	46.13	2 SEAM	
GDT42	46.13	66.63	SST_1	
GDT43	0	1.4	Softs	LOW
GDT43	1.4	16.2	SST_3	
GDT43	16.2	20.83	4 SEAM	
GDT43	20.83	25.68	SST_2	
GDT43	25.68	28.36	2 SEAM	
GDT43	28.36	67.52	SST_1	
GDT44	0	6.62	Softs	LOW

GDT44	6.62	18.14	SST_3	
GDT44	18.14	24.55	4 SEAM	
GDT44	24.55	28.66	SST_2	
GDT44	28.66	33.47	ST_2	
GDT44	33.47	37.51	2 SEAM	
GDT44	37.51	60.37	SST_1	
GDT45	0	4.3	Softs	LOW
GDT45	4.3	20.26	SST_3	
GDT45	20.26	25.5	4 SEAM	
GDT45	25.5	29.54	SST_2	
GDT45	29.54	33.74	ST_2	
GDT45	33.74	37.66	2 SEAM	
GDT45	37.66	63.14	SST_1	
GDT46	0	3	Softs	LOW
GDT46	3	20.31	SST_3	
GDT46	20.31	24.48	4 SEAM	
GDT46	24.48	27.32	SST_2	
GDT46	27.32	29.02	ST_2	
GDT46	29.02	34.14	2 SEAM	
GDT46	34.14	61.29	SST_1	
GDT47	0	3.6	Softs	LOW
GDT47	3.6	24.8	SST_3	
GDT47	24.8	29.34	4 SEAM	
GDT47	29.34	38.5	SST_2	
GDT47	38.5	45.38	DO	
GDT47	45.38	54.7	ST_2	
GDT47	54.7	58.37	2 SEAM	
GDT47	58.37	60.67	SST_1	
GDT48	0	5.5	Softs	LOW
GDT48	5.5	6.37	SST_3	
GDT48	6.37	25.4	DO	
GDT48	25.4	29.31	SST_3	
GDT48	29.31	35.37	4 SEAM	
GDT48	35.37	38.78	SST_2	
GDT48	38.78	39.84	ST_2	
GDT48	39.84	43.89	2 SEAM	
GDT48	43.89	63.51	SST_1	
GDT49	0	4.09	Softs	LOW
GDT49	4.09	8.5	SST_3	
GDT49	8.5	12.91	4 SEAM	
GDT49	12.91	13.15	SST_2	
GDT49	13.15	13.5	ST_2	
GDT49	13.5	17.65	2 SEAM	
GDT49	17.65	68.69	SST_1	

A3. Mine 1 – Coal calorific value and coal thicknesses

HOLE_ID	4S_From	4S_To	4S_Thick	4S_IM	4S_Ash	4S_VM	4S_CV	4S_FC	4S_TS	3S_From	3S_To	3S_Thick	3S_IM	3S_Ash	3S_VM	3S_CV	3S_FC	3S_TS	2S_From	2S_To	2S_Thick	2S_IM	2S_Ash	2S_VM	2S_CV	2S_FC	2S_TS
DKT001	17.5	20.87	3.37	1.9	24.5	25.2	23.6	48.4	0.67	22.05	26.38	4.33	4.1	26.35	22.58	22.3	46.97	0.98	27.07	29.87	2.8	4	14.3	29.2	29.1	52.5	0.92
DKT002	18.1	23.68	5.58	1.8	25.7	20.2	25.89	52.3	0.72	28.47	32.03	3.56	3.8	28.74	24.1	20.63	43.36	0.46	38.68	42.88	4.2	3.4	11.9	29	28.36	55.7	0.78
DKT003	15.52	18.57	3.05	1.9	42.8	22.2	21.52	33.1	0.99																		
DKT004	18.36	24.87	6.51	3.4	21.4	21.1	23.69	54.1	1.06	30.55	33.65	3.1	3.5	26.05	24.12	21.78	46.33	0.73									
DKT005	12.14	18.01	5.87	2.8	21.2	28.8	27.36	47.2	1.02																		
DKT006	17.25	21.05	3.8	3.2	23.7	21.47	24.82	51.63	0.75	28.03	33.25	5.22	3.6	29.98	24.07	20.99	42.35	0.19									
DKT007										13.69	17.05	3.36	2.9	28.36	24.54	21.74	44.2	1.07	21.8	24.97	3.17	3.5	17.7	23.6	25.3	55.2	0.45
DKT008	17.33	21.79	4.46	2.3	22.69	20.73	23.6	54.28	0.66										27.45	30.15	2.7	4.1	15.6	26	26.92	54.3	0.46
DKT009	12.52	16.86	4.34	2.3	22.29	23.92	25.02	51.49	0.77																		
DKT025	18.87	22.68	3.81	2.1	22.89	23.31	25.42	51.7	0.42	27.12	30.25	3.13	3.8	26.08	24.71	22.03	45.41	0.72	35.56	40.09	4.53	3.7	18.1	27.6	26.22	50.6	0.38
DKT025																											
DKT025																											
DKT026	18.1	25.36	7.26	3.3	21.08	25.43	23.64	50.19	0.79																		
DKT027	17.89	21.56	3.67	2.1	20.08	24.79	22.79	53.03	0.56										28.19	32.92	4.73	2.8	21.4	29.1	25.64	46.7	0.31
DKT028	19.87	24.63	4.76	3.3	22.93	24.82	25.17	48.95	0.77																		
DKT029	17.96	22.12	4.16	2.3	20.03	23.22	26.75	54.45	1.05																		
DKT031	20.87	26.35	5.48	3.3	22.67	21.28	25.22	52.75	0.34										33.25	38.74	5.49	3.4	14.2	24.7	26.19	57.7	0.58
DKT032																			15.12	20.69	5.57	3.2	23.56	24.6	23.46	48.64	0.85
DKT033	13.88	18.25	4.37	1.9	22.23	26.4	26.19	49.47	0.69	23.38	28.13	4.75	4.1	27.36	25.91	21.88	42.63	0.53	34.87	41.25	6.38	2.8	11	20.73	27	65.47	0.44
DKT077	11.02	14.89	3.87	3	22.22	25.69	24.55	49.09	0.51										25.36	29.23	3.87	3.1	22.98	23.92	25.65	50	1.13
DKT078	19.81	23.81	4	2.8	22.31	25.52	27.8	49.37	0.92										28.03	34.07	6.04	4.2	12.36	23.31	28.55	60.13	0.54
DKT079																			20.38	24.76	4.38	3.8	22.74	25.69	24.74	47.77	0.79
DKT080	16.66	19.89	3.23	2.2	20.76	26.29	25.34	50.75	1.13																		
DKT081	17.05	21.52	4.47	2.5	24.1	22.18	26.61	51.22	0.54										25.52	29.44	3.92	2.7	15.36	25.43	27.25	56.51	0.77
DKT082	19.02	24.21	5.19	2.6	24.55	20.49	24.08	52.36	1.04										27.02	31.1	4.08	4.1	20.14	24.79	24.74	50.97	1.05
DKT083	17.88	21.88	4	3.2	24.12	17.11	25.45	55.57	0.78	25.52	29.36	3.84	4.2	25.89	18.12	22.76	51.79	0.25	35.23	38.77	3.54	3.5	16.05	24.82	26.07	55.63	1.04
DKT084	16.36	20.15	3.79	2.5	25.54	23	26.61	48.96	0.44										25.89	29.58	3.69	2.9	14.28	23.22	27.25	59.6	1.08
DKT098	19.63	24.63	5	3.6	24.07	21.85	23.49	50.48	0.42										30.3	35.45	5.15	3.7	15.36	21.28	26.58	59.66	0.56
DKT099	16.79	20.87	4.08	3.8	24.54	24.06	24.74	47.6	0.69	22.03	27.12	5.09	3.9	29.58	24.66	20.3	41.86	0.92									
DKT100	15.88	19.27	3.39	1.8	24.66	22.1	24.27	51.44	1.02	22.27	26.39	4.12	4.2	31.25	22.36	19.41	42.19	1.17									
DKT101	15.36	19.14	3.78	2.2	24.71	22.89	26.35	50.2	0.36																		
DKT102	17.63	21.77	4.14	2.8	25.91	22.15	25.96	49.14	1.08	24.08	26.09	2.01	3.3	34.25	25.54	18.25	36.91	1.18	28.18	31.05	2.87	3.8	16.08	25.52	26.33	54.6	0.87
DKT103	18.36	21.79	3.43	2.7	19.12	22.84	26.66	55.34	0.79	23.5	27.58	4.08	3.4	24.99	24.55	22.74	47.06	1.05	30.23	34.07	3.84	4.1	13.74	26.29	28.47	55.87	1.08
DKT104	19.45	23.06	3.61	3.3	20.14	20.58	24.69	55.98	1.17																		
DKT203	17.17	21.07	3.9	3.8	14.7	23.19	27.69	58.31	1.03										23.04	26.91	3.87	2.7	11.09	26.4	28.11	59.81	1.12
DKT210	19.82	23.96	4.14	3.7	25.52	22.92	22.99	47.86	0.96																		
DKT215	17.39	21.57	4.18	2.9	22.36	24.36	23.67	50.38	0.34																		
DKT251	15.81	19.66	3.85	3.1	13.52	21.28	27.02	62.1	0.57																		
DKT256	18.65	22.25	3.6	2.5	25.69	23.92	22.64	47.89	0.62										25.25	29.56	4.31	4.1	24.55	24.78	23.05	46.57	0.96
DKT322	18.26	22.33	4.07	3.2	12.69	23.31	28.12	60.8	0.48																		
DKT333	21.49	25.73	4.24	2.6	11.58	25.69	29.44	60.13	1.23																		

A4. Mine 2 – Coal calorific value and coal thicknesses

HOLE_ID	4S_From	4S_To	4S_Thick	4S_IM	4S_Ash	4S_VM	4S_CV	4S_FC	4S_TS	2S_From	2S_To	2S_Thick	2S_IM	2S_Ash	2S_VM	2S_CV	2S_FC	2S_TS
GDT01	7.5	11.53	4.03	3.7	26.8	23.6	22.1	45.9	0.5	13	16	3	0.9	13.4	29.6	25.2	56.1	0.6
GDT02	9.36	14.23	4.87	4.9	27.2	25.8	21.8	42.1	1.3	16.09	19.87	3.78	3.5	20.8	29.8	24.5	45.9	0.4
GDT03	8.28	12.87	4.59	5.2	26.1	20.8	22.2	47.9	0.4	15.69	17.91	2.22	2.5	20.2	28.2	25.1	49.1	0.5
GDT04	7.48	12.93	5.45	4.4	25.6	22.5	21.3	47.5	0.8									
GDT05	8.78	12.96	4.18	4.4	24.7	23.3	22.3	47.6	0.5	15.95	20.31	4.36	1.6	15.7	24.6	28.1	58.1	0.6
GDT08	6.06	10.22	4.16	3.8	25.5	24.3	22.8	46.4	1.1	13.19	17.3	4.11	3.3	16.6	27.8	26.6	52.3	0.4
GDT09	10	14.1	4.1	4.1	26.5	21.1	23	48.3	0.4									
GDT11	10.81	14.81	4	3.6	29.3	22.2	20.9	44.9	1.6									
GDT13	11.05	14.97	3.92	4.1	24.1	23.4	23.5	48.4	1.5	17.28	21.41	4.13	2.7	23.8	25.5	24	48	0.6
GDT14	8.94	13.05	4.11	4.3	26.1	22.9	22.7	46.7	0.5									
GDT15	7.95	12.24	4.29	3.4	27.3	25.5	22.6	43.8	1.8									
GDT16	7.4	11.35	3.95	5	26.5	24.8	22.1	43.7	0.8	13.04	16.87	3.83	2.9	22.6	26.9	25.8	47.6	0.6
GDT17	6.98	11.29	4.31	4.2	24.8	25.3	23.8	45.7	0.7	12.34	16.41	4.07	0.9	19.2	25.5	25	54.4	0.6
GDT18	8.59	12.78	4.19	3.9	23.8	22.8	23.4	49.5	0.6	25.29	29.49	4.2	1.9	10.1	26.1	28.9	61.9	0.6
GDT19	8.4	12.31	3.91	2.8	23.4	23.5	23.2	50.3	1.1	22.71	27.22	4.51	2.2	18.4	26.9	27	52.5	0.8
GDT20	6.5	10.74	4.24	3.8	28.3	21.9	21.4	46	1.2	22.71	26.88	4.17	3.5	21.1	24.7	25.6	50.7	0.5
GDT22	9.3	13.63	4.33	4.7	26.9	22.5	21.9	45.9	1									
GDT23	8.8	13.02	4.22	5.2	24.8	21.9	22.2	48.1	0.4	33.94	37.97	4.03	1.9	15.5	22.7	26.4	59.9	0.7
GDT24	11.05	15.11	4.06	3.6	27.9	23.5	21.2	45	0.9	15.35	19.54	4.19	4	13.8	24.8	27.4	57.4	0.7
GDT26	7.39	11.46	4.07	5	25.4	24.9	22.2	44.7	0.9	12.23	16.26	4.03	1.8	22	26.3	24.8	49.9	1
GDT27	7.36	11.39	4.03	3.3	26.8	23.7	21.8	46.2	1.4	12.93	17.07	4.14	1.4	15.6	24.5	26.4	58.5	0.9
GDT28	11.2	15.43	4.23	5.3	29.1	22.4	21	43.2	1.2									
GDT29	8.9	12.96	4.06	5.6	28.6	21.1	21.5	44.7	0.4	18.24	22.29	4.05	1.4	15.1	28.2	29.2	55.3	0.9
GDT30	8.03	12.24	4.21	3.5	26.6	23.7	21.9	46.2	1									
GDT31	8.61	12.61	4	4.8	25.8	22.7	21.2	46.7	0.8	33.35	37.66	4.31	1.8	20.2	30.3	25.6	47.7	0.82
GDT32	7.12	11.19	4.07	2.8	29.8	21.8	20.6	45.6	0.8	14.2	18.35	4.15	3.5	12.8	24.4	29.9	59.3	0.79
GDT33	10.87	14.91	4.04	3.1	26.8	22.7	21.9	47.4	0.4									
GDT35										21.09	25.23	4.14	3.9	16.4	27.5	26.9	52.2	1.28
GDT36	14.84	19.05	4.21	5.3	28.5	23.8	21.9	42.4	0.9									
GDT37										27.84	31.09	3.25	2.9	13.4	24.2	28.7	59.5	0.67
GDT39	17.1	23.35	6.25	5.1	26.4	25.6	21.6	42.9	0.7									
GDT40	18.63	24.98	6.35	5.3	25.3	22.8	22	46.6	0.7									
GDT41	17.1	21.4	4.3	5.4	26.8	22.4	21.4	45.4	0.4									
GDT42	17.43	21.46	4.03	4.7	22.6	25.4	24.1	47.3	0.8	42.06	46.13	4.07	4.1	15.9	24.7	28.3	55.3	1.66
GDT43	16.2	20.83	4.63	5.3	24.8	23.1	23.6	46.8	1	25.68	28.36	2.68	3.7	17.9	27.1	26	51.3	1.22
GDT44	18.14	24.55	6.41	5.2	27.1	22.8	22.3	44.9	0.8	33.47	37.51	4.04	3.4	19.6	25.8	25.1	51.2	1.06
GDT45	20.26	25.5	5.24	5.7	29.7	24.7	20.3	39.9	1	33.74	37.66	3.92	3.5	13.8	26.8	27.2	55.9	0.98
GDT46	20.31	24.48	4.17	4.5	22.9	23.9	23.9	48.7	1.2	29.02	34.14	5.12	3.2	15.8	27.7	26.9	53.3	0.94
GDT47	24.8	29.34	4.54	4.7	24.8	21.8	22.8	48.7	0.8	51.7	58.37	6.67	3.1	16.7	23.3	26.6	56.9	0.79
GDT48	29.31	35.37	6.06	4.1	23.1	22.8	24	50	0.6	35.37	43.89	8.52	3.5	10.1	20.9	28.3	65.5	0.74
GDT49	8.5	12.91	4.41	3.7	22.9	23.9	24.1	49.5	1	13.5	17.65	4.15	4.2	11.8	26.7	27.4	57.3	1.02

Appendix B. Mine 1 and Mine 2 – Monthly projections and forecasts based on ROM and finished product sales

B1. Mine 1 – First Year Monthly Projections and Forecast (ROM)

				Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12		ACTUAL
																	Total
INCOME				R -	R 17 676 750.00	R 27 688 920.00	R 32 314 800.00	R 33 924 240.00	R 34 014 540.00	R 33 703 740.00	R 29 434 230.00	R 32 640 930.00	R 34 164 900.00	R 33 812 730.00	R 33 768 630.00		R 343 144 410.00
Cost per ton	R 420.00																
Coal tons mined					42087.50	65926.00	76940.00	80772.00	80987.00	80247.00	70081.50	77716.50	81345.00	80506.50	80401.50		R 817 010.50
																	R -
COST OF SALES				R 3 943 350.00	R 9 977 400.00	R 9 584 100.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00		R 112 183 650.00
	R/Hr	Hours	Hours														R -
ADT (40T)	R 900.00	207.00	414.00	R 1 490 400.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00		R 42 476 400.00
ADT (30T)	R 800.00	207.00	414.00	R 331 200.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00		R 14 904 000.00
FEL 966	R 650.00	207.00	414.00	R 269 100.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00		R 5 920 200.00
50t Exca	R 950.00	207.00	414.00	R 393 300.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00		R 9 045 900.00
70t Exca	R 1 450.00	207.00	414.00	R 900 450.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00		R 20 710 350.00
Water Bowser	R 600.00	207.00	414.00	R 248 400.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00		R 5 713 200.00
D9 Dozer	R 1 350.00	207.00	414.00	R -	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00		R 6 147 900.00
Grader (140)	R 700.00	207.00	414.00	R 144 900.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00		R 3 332 700.00
TLB	R 650.00	207.00	414.00	R 134 550.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00		R 3 094 650.00
Lighting Plant	R 150.00	207.00	414.00	R 31 050.00	R 186 300.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00		R 838 350.00
GROSS PROFIT				-R 3 943 350.00	R 7 699 350.00	R 18 104 820.00	R 22 461 600.00	R 24 071 040.00	R 24 161 340.00	R 23 850 540.00	R 19 581 030.00	R 22 787 730.00	R 24 311 700.00	R 23 959 530.00	R 23 915 430.00		R 230 960 760.00
TOTAL INCOME				-R 3 943 350.00	R 7 699 350.00	R 18 104 820.00	R 22 461 600.00	R 24 071 040.00	R 24 161 340.00	R 23 850 540.00	R 19 581 030.00	R 22 787 730.00	R 24 311 700.00	R 23 959 530.00	R 23 915 430.00		R 230 960 760.00
EXPENSES				R 8 876 065.04	R 9 496 833.38	R 12 249 252.59	R 15 995 431.98	R 16 230 682.85	R 15 893 615.54	R 16 092 753.11	R 15 790 119.12	R 16 295 748.62	R 16 530 339.10	R 16 475 068.15	R 16 856 981.87		R 176 782 891.35
																	R -
Personnel				R 461 621.04	R 571 025.69	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56		R 7 067 092.33
Diesel				R 2 345 850.00	R 2 349 450.00	R 3 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00		R 51 695 300.00
Contingency				R 263 259.00	R 146 776.50	R 197 820.00	R 242 316.00	R 182 961.00	R 150 741.00	R 210 244.50	R 233 149.50	R 244 035.00	R 241 519.50	R 241 204.50	R 630 000.00		R 2 984 026.50
Commencement Cost				R 1 011 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 1 011 000.00
Once Off Cost				R 2 116 845.00	R 400 000.00	R 50 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 2 566 845.00
Professional Cost				R 270 000.00	R 274 640.63	R 445 095.00	R 411 662.25	R 339 167.25	R 473 050.13	R 524 586.38	R 549 078.75	R 543 418.88	R 542 710.13	R 542 710.13	R 542 710.13		R 5 458 829.63
Crushing & Screening			55.00	R -	R 2 314 812.50	R 3 625 930.00	R 4 231 700.00	R 4 442 460.00	R 4 454 285.00	R 4 413 585.00	R 3 854 482.50	R 4 274 407.50	R 4 473 975.00	R 4 427 857.50	R 4 422 082.50		R 44 935 577.50
Other				R -	R 428 878.07	R 515 713.03	R 695 059.17	R 851 400.04	R 400 844.86	R 529 642.67	R 738 713.81	R 819 192.68	R 857 439.91	R 848 601.47	R 847 494.68		R 7 532 980.40
Drilling and Blasting				R 2 307 490.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00		R 34 331 240.00
Repayment				R -	R -	R -	R -	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00		R 2 000 000.00
Security				R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00		R 1 200 000.00
Operating profit				-R 12 819 415.04	-R 1 797 483.38	R 5 855 567.41	R 6 466 168.02	R 7 840 357.15	R 8 267 724.46	R 7 757 786.89	R 3 790 910.88	R 6 491 981.38	R 7 781 360.90	R 7 484 461.85	R 7 058 448.13		R 54 177 868.65
Less:																	R -
Net profit before dividends				-R 12 819 415.04	-R 1 797 483.38	R 5 855 567.41	R 6 466 168.02	R 7 840 357.15	R 8 267 724.46	R 7 757 786.89	R 3 790 910.88	R 6 491 981.38	R 7 781 360.90	R 7 484 461.85	R 7 058 448.13		R 54 177 868.65
Dividends				R -	R -	R -	R -	R 1.00	R 2.00	R 3.00	R 4.00	R 5.00	R 6.00	R 7.00	R 8.00		R 36.00
Net profit before taxation				-R 12 819 415.04	-R 1 797 483.38	R 5 855 567.41	R 6 466 168.02	R 7 840 356.15	R 8 267 722.46	R 7 757 783.89	R 3 790 906.88	R 6 491 976.38	R 7 781 354.90	R 7 484 454.85	R 7 058 440.13		R 54 177 832.65
Taxation				-R 3 589 436.21	-R 503 295.35	R 1 639 558.87	R 1 810 527.05	R 2 195 299.72	R 2 314 962.29	R 2 172 179.49	R 1 061 453.93	R 1 817 753.39	R 2 178 779.37	R 2 095 647.36	R 1 976 363.24		R 15 169 793.14
Net profit after taxation				-R 9 229 978.83	-R 1 294 188.04	R 4 216 008.54	R 4 655 640.98	R 5 645 056.43	R 5 952 760.17	R 5 585 604.40	R 2 729 452.95	R 4 674 222.99	R 5 602 575.53	R 5 388 807.49	R 5 082 076.89		R 39 008 039.51
																	R -
- Cashflow				-R 9 229 978.83	-R 10 524 166.86	-R 6 308 158.33	-R 1 652 517.35	R 3 992 539.07	R 9 945 299.24	R 15 530 903.65	R 18 260 356.60	R 22 934 579.59	R 28 537 155.12	R 33 925 962.61	R 39 008 039.51		

B2. Mine 1 – First Year Monthly Projections and Forecast (Finished Product)

				Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	ACTUAL
																Total
INCOME				R -	R 23 148 125.00	R 36 259 300.00	R 42 317 000.00	R 44 424 600.00	R 44 542 850.00	R 44 135 850.00	R 38 544 825.00	R 42 744 075.00	R 44 739 750.00	R 44 278 575.00	R 44 220 825.00	R 449 355 775.00
Cost per ton	R 550.00															
Coal tons mined					42087.50	65926.00	76940.00	80772.00	80987.00	80247.00	70081.50	77716.50	81345.00	80506.50	80401.50	R 817 010.50
																R -
COST OF SALES				R 3 943 350.00	R 9 977 400.00	R 9 584 100.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 9 853 200.00	R 112 183 650.00
	R/Hr	Hours	Hours													R -
ADT (40T)	R 900.00	207.00	414.00	R 1 490 400.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 3 726 000.00	R 42 476 400.00
ADT (30T)	R 800.00	207.00	414.00	R 331 200.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 1 324 800.00	R 14 904 000.00
FEL 966	R 650.00	207.00	414.00	R 269 100.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 538 200.00	R 5 920 200.00
50t Exca	R 950.00	207.00	414.00	R 393 300.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 9 045 900.00
70t Exca	R 1 450.00	207.00	414.00	R 900 450.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 1 800 900.00	R 20 710 350.00
Water Bowser	R 600.00	207.00	414.00	R 248 400.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 496 800.00	R 5 713 200.00
D9 Dozer	R 1 350.00	207.00	414.00	R -	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 6 147 900.00
Grader (140)	R 700.00	207.00	414.00	R 144 900.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 3 332 700.00
TLB	R 650.00	207.00	414.00	R 134 550.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 269 100.00	R 3 094 650.00
Lighting Plant	R 150.00	207.00	414.00	R 31 050.00	R 186 300.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 838 350.00
GROSS PROFIT				R 3 943 350.00	R 13 170 725.00	R 26 675 200.00	R 32 463 800.00	R 34 571 400.00	R 34 689 650.00	R 34 282 650.00	R 28 691 625.00	R 32 890 875.00	R 34 886 550.00	R 34 425 375.00	R 34 367 625.00	R 337 172 125.00
TOTAL INCOME				R 3 943 350.00	R 13 170 725.00	R 26 675 200.00	R 32 463 800.00	R 34 571 400.00	R 34 689 650.00	R 34 282 650.00	R 28 691 625.00	R 32 890 875.00	R 34 886 550.00	R 34 425 375.00	R 34 367 625.00	R 337 172 125.00
EXPENSES				R 8 876 065.04	R 9 496 833.38	R 12 249 252.59	R 15 995 431.98	R 16 230 682.85	R 15 893 615.54	R 16 092 753.11	R 15 790 119.12	R 16 295 748.62	R 16 530 339.10	R 16 475 068.15	R 16 856 981.87	R 176 782 891.35
																R
Personnel				R 461 621.04	R 571 025.69	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 7 067 092.33
Diesel				R 2 345 850.00	R 2 349 450.00	R 3 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 4 800 000.00	R 51 695 300.00
Contingency				R 263 259.00	R 146 776.50	R 197 820.00	R 242 316.00	R 182 961.00	R 150 741.00	R 210 244.50	R 233 149.50	R 244 035.00	R 241 519.50	R 241 204.50	R 630 000.00	R 2 984 026.50
Commencement Cost				R 1 011 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R 1 011 000.00
Once Off Cost				R 2 116 845.00	R 400 000.00	R 50 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R 2 566 845.00
Professional Cost				R 270 000.00	R 274 640.63	R 445 095.00	R 411 662.25	R 339 167.25	R 473 050.13	R 524 586.38	R 549 078.75	R 543 418.88	R 542 710.13	R 542 710.13	R 542 710.13	R 5 458 829.63
Crushing & Screening			55.00	R -	R 2 314 812.50	R 3 625 930.00	R 4 231 700.00	R 4 442 460.00	R 4 454 285.00	R 4 413 585.00	R 3 854 482.50	R 4 274 407.50	R 4 473 975.00	R 4 427 857.50	R 4 422 082.50	R 44 935 577.50
Other				R -	R 428 878.07	R 515 713.03	R 695 059.17	R 851 400.04	R 400 844.86	R 529 642.67	R 738 713.81	R 819 192.68	R 857 439.91	R 848 601.47	R 847 494.68	R 7 532 980.40
Drilling and Blasting				R 2 307 490.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 34 331 240.00
Repayment				R -	R -	R -	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R 2 000 000.00	R -
Security				R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 1 200 000.00
Operating profit				R 12 819 415.04	R 3 673 891.62	R 14 425 947.41	R 16 468 368.02	R 18 340 717.15	R 18 796 034.46	R 18 189 896.89	R 12 901 505.88	R 16 595 126.38	R 18 356 210.90	R 17 950 306.85	R 17 510 643.13	R 160 389 233.65
Less:																R -
Net profit before dividends				R 12 819 415.04	R 3 673 891.62	R 14 425 947.41	R 16 468 368.02	R 18 340 717.15	R 18 796 034.46	R 18 189 896.89	R 12 901 505.88	R 16 595 126.38	R 18 356 210.90	R 17 950 306.85	R 17 510 643.13	R 160 389 233.65
Dividends				R -	R -	R -	R -	R 1.00	R 2.00	R 3.00	R 4.00	R 5.00	R 6.00	R 7.00	R 8.00	R 36.00
Net profit before taxation				R 12 819 415.04	R 3 673 891.62	R 14 425 947.41	R 16 468 368.02	R 18 340 716.15	R 18 796 032.46	R 18 189 893.89	R 12 901 501.88	R 16 595 121.38	R 18 356 204.90	R 17 950 299.85	R 17 510 635.13	R 160 389 197.65
Taxation				R 3 589 436.21	R 1 028 689.65	R 4 039 265.27	R 4 611 143.05	R 5 135 400.52	R 5 262 889.09	R 5 093 170.29	R 3 612 420.53	R 4 646 633.99	R 5 139 737.37	R 5 026 083.96	R 4 902 977.84	R 44 908 977.84
Net profit after taxation				R 9 229 978.83	R 2 645 201.96	R 10 386 682.14	R 11 857 224.98	R 13 205 315.63	R 13 533 143.37	R 13 096 723.60	R 9 289 081.35	R 11 948 487.39	R 13 216 467.53	R 12 924 215.89	R 12 607 657.29	R 115 480 222.31
																R -
- Cashflow				R 9 229 978.83	R 6 584 776.86	R 3 801 905.27	R 15 659 130.25	R 28 864 445.87	R 42 397 589.24	R 55 494 312.85	R 64 783 394.20	R 76 731 881.59	R 89 948 349.12	R 102 872 565.01	R 115 480 222.31	R -

B3. Mine 2 – First Year Monthly Projections and Forecast (ROM)

				Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12		ACTUAL
																	Total
INCOME				R 4 195 800.00	R 9 138 823.31	R 9 169 965.00	R 9 169 961.06	R 12 883 500.00	R 14 826 420.00	R 20 402 550.00	R 26 114 760.00	R 27 530 370.00	R 28 451 430.00	R 36 914 850.00	R 29 871 450.00		R 228 669 879.38
Cost per ton	R 420.00																
Coal tons mined				9 990	21 759	21 833	21 833	30 675	35 301	48 578	62 178	65 549	67 742	87 893	71 123		R 544 452
																	-
COST OF SALES				R 1 552 500.00	R 4 905 900.00	R 4 491 900.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00		R 59 947 200.00
	R/Hr	Hours	Hours														-
ADT (40T)	R 900.00	207.00	414.00	R 372 600.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 372 600.00
ADT (30T)	R 800.00	207.00	414.00	R 165 600.00	R 1 324 800.00	R 1 324 800.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00		R 20 700 000.00
FEL 966	R 700.00	207.00	414.00	R 144 900.00	R 579 600.00	R 289 800.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00		R 6 230 700.00
50t Exca	R 950.00	207.00	414.00	R 196 650.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00		R 8 849 250.00
70t Exca	R 1 450.00	207.00	414.00	R 300 150.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00		R 6 903 450.00
Water Bowser	R 450.00	207.00	414.00	R 93 150.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00		R 4 191 750.00
D9 Dozer	R 1 350.00	207.00	414.00	R -	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00		R 6 147 900.00
Grader (140)	R 700.00	207.00	414.00	R 144 900.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00		R 3 332 700.00
TLB	R 500.00	207.00	414.00	R 103 500.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00		R 2 380 500.00
Lighting Plant	R 150.00	207.00	414.00	R 31 050.00	R 186 300.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00		R 838 350.00
GROSS PROFIT				R 2 643 300.00	R 4 232 923.31	R 4 678 065.00	R 3 725 861.06	R 7 439 400.00	R 9 382 320.00	R 14 958 450.00	R 20 670 660.00	R 22 086 270.00	R 23 007 330.00	R 31 470 750.00	R 24 427 350.00		R 168 722 679.38
TOTAL INCOME				R 2 643 300.00	R 4 232 923.31	R 4 678 065.00	R 3 725 861.06	R 7 439 400.00	R 9 382 320.00	R 14 958 450.00	R 20 670 660.00	R 22 086 270.00	R 23 007 330.00	R 31 470 750.00	R 24 427 350.00		R 168 722 679.38
EXPENSES				R 5 343 136.04	R 5 097 984.32	R 5 951 694.14	R 7 046 225.04	R 7 665 530.42	R 8 413 173.94	R 9 223 901.01	R 10 065 191.02	R 10 295 827.02	R 10 425 149.00	R 11 282 488.55	R 10 949 067.27		R 101 759 467.77
																	-
Personnel				R 461 621.04	R 571 025.69	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56		R 7 067 092.33
Diesel				R 593 658.00	R 1 187 316.00	R 1 780 974.00	R 2 137 168.80	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40		R 23 746 320.00
Contingency				R 263 259.00	R 146 776.50	R 197 820.00	R 242 316.00	R 182 961.00	R 150 741.00	R 210 244.50	R 233 149.50	R 244 035.00	R 241 519.50	R 241 204.50	R 630 000.00		R 2 984 026.50
Commencement Cost				R 1 011 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 1 011 000.00
Once Off Cost				R 2 116 845.00	R 400 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 2 516 845.00
Professional Cost				R 270 000.00	R 274 640.63	R 445 095.00	R 411 662.25	R 339 167.25	R 473 050.13	R 524 586.38	R 549 078.75	R 543 418.88	R 542 710.13	R 542 710.13	R 542 710.13		R 5 458 829.63
Crushing & Screening		43.00		R -	R 935 641.43	R 938 829.75	R 938 829.35	R 1 319 025.00	R 1 517 943.00	R 2 088 832.50	R 2 673 654.00	R 2 818 585.50	R 2 912 884.50	R 3 779 377.50	R 3 058 267.50		R 22 981 870.03
Other				R -	R 428 878.07	R 515 713.03	R 695 059.17	R 851 400.04	R 400 844.86	R 529 642.67	R 738 713.81	R 819 192.68	R 857 439.91	R 848 601.47	R 847 494.68		R 7 532 980.40
Drilling and Blasting				R 526 853.00	R 1 053 706.00	R 1 369 817.80	R 1 917 744.92	R 2 013 632.17	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00		R 27 260 503.89
Repayment				R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		
Security				R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00		R 1 200 000.00
Operating profit				-R 2 699 936.04	-R 865 061.00	-R 1 273 629.14	-R 3 320 363.98	-R 226 130.42	-R 969 146.06	-R 5 734 548.99	-R 10 605 468.98	-R 11 790 442.98	-R 12 582 181.00	-R 20 188 261.45	-R 13 478 282.73		-R 66 963 211.61
Less:																	
Net profit before dividends				-R 2 699 936.04	-R 865 061.00	-R 1 273 629.14	-R 3 320 363.98	-R 226 130.42	-R 969 146.06	-R 5 734 548.99	-R 10 605 468.98	-R 11 790 442.98	-R 12 582 181.00	-R 20 188 261.45	-R 13 478 282.73		-R 66 963 211.61
Dividends				R -	R -	R -	R -	R 1.00	R 2.00	R 3.00	R 4.00	R 5.00	R 6.00	R 7.00	R 8.00		R 36.00
Net profit before taxation				-R 2 699 936.04	-R 865 061.00	-R 1 273 629.14	-R 3 320 363.98	-R 226 131.42	-R 969 144.06	-R 5 734 545.99	-R 10 605 464.98	-R 11 790 437.98	-R 12 582 175.00	-R 20 188 254.45	-R 13 478 274.73		-R 66 963 175.61
Taxation				-R 755 982.09	-R 242 217.08	-R 356 616.16	-R 929 701.91	-R 63 316.80	-R 271 360.34	-R 1 605 672.88	-R 2 969 530.19	-R 3 301 322.63	-R 3 523 009.00	-R 5 652 711.25	-R 3 773 916.92		-R 18 749 689.17
Net profit after taxation				-R 1 943 953.95	-R 622 843.92	-R 917 012.98	-R 2 390 662.07	-R 162 814.62	-R 697 783.72	-R 4 128 873.11	-R 7 635 934.78	-R 8 489 115.35	-R 9 059 166.00	-R 14 535 543.20	-R 9 704 357.81		-R 48 213 486.44
																	-
- Cashflow				-R 1 943 953.95	-R 2 566 797.87	-R 3 483 810.85	-R 5 874 472.92	-R 6 037 287.54	-R 5 339 503.82	-R 1 210 630.70	-R 6 425 304.08	-R 14 914 419.42	-R 23 973 585.43	-R 38 509 128.63	-R 48 213 486.44		

B4. Mine 2 – First Year Monthly Projections and Forecast (Finished Product)

				Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12		ACTUAL
																	Total
INCOME				R 5 994 000.00	R 13 055 461.88	R 13 099 950.00	R 13 099 944.38	R 18 405 000.00	R 21 180 600.00	R 29 146 500.00	R 37 306 800.00	R 39 329 100.00	R 40 644 900.00	R 52 735 500.00	R 42 673 500.00		R 326 671 256.25
Cost per ton	R 600.00																
Coal tons mined				9 990	21 759	21 833	21 833	30 675	35 301	48 578	62 178	65 549	67 742	87 893	71 123		544 452
																	-
COST OF SALES				R 1 552 500.00	R 4 905 900.00	R 4 491 900.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00	R 5 444 100.00		R 59 947 200.00
	R/Hr	Hours	Hours														-
ADT (40T)	R 900.00	207.00	414.00	R 372 600.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 372 600.00
ADT (30T)	R 800.00	207.00	414.00	R 165 600.00	R 1 324 800.00	R 1 324 800.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00	R 1 987 200.00		R 20 700 000.00
FL 966	R 700.00	207.00	414.00	R 144 900.00	R 579 600.00	R 289 800.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00	R 579 600.00		R 6 230 700.00
50t Exca	R 950.00	207.00	414.00	R 196 650.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00	R 786 600.00		R 8 849 250.00
70t Exca	R 1 450.00	207.00	414.00	R 300 150.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00	R 600 300.00		R 6 903 450.00
Water Bowser	R 450.00	207.00	414.00	R 93 150.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00	R 372 600.00		R 4 191 750.00
D9 Dozer	R 1 350.00	207.00	414.00	R -	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00	R 558 900.00		R 6 147 900.00
Grader (140)	R 700.00	207.00	414.00	R 144 900.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00	R 289 800.00		R 3 332 700.00
TLB	R 500.00	207.00	414.00	R 103 500.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00	R 207 000.00		R 2 380 500.00
Lighting Plant	R 150.00	207.00	414.00	R 31 050.00	R 186 300.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00	R 62 100.00		R 838 350.00
GROSS PROFIT				R 4 441 500.00	R 8 149 561.88	R 8 608 050.00	R 7 655 844.38	R 12 960 900.00	R 15 736 500.00	R 23 702 400.00	R 31 862 700.00	R 33 885 000.00	R 35 200 800.00	R 47 291 400.00	R 37 229 400.00		R 266 724 056.25
TOTAL INCOME				R 4 441 500.00	R 8 149 561.88	R 8 608 050.00	R 7 655 844.38	R 12 960 900.00	R 15 736 500.00	R 23 702 400.00	R 31 862 700.00	R 33 885 000.00	R 35 200 800.00	R 47 291 400.00	R 37 229 400.00		R 266 724 056.25
EXPENSES				R 5 343 236.04	R 5 097 984.32	R 5 951 694.14	R 7 046 225.04	R 7 665 530.42	R 8 413 173.94	R 9 223 901.01	R 10 065 191.02	R 10 295 827.02	R 10 425 149.00	R 11 282 488.55	R 10 949 067.27		R 101 759 467.77
																	-
Personnel				R 461 621.04	R 571 025.69	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56	R 603 444.56		R 7 067 092.33
Diesel				R 593 658.00	R 1 187 316.00	R 1 780 974.00	R 2 137 168.80	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40	R 2 255 900.40		R 23 746 320.00
Contingency				R 263 259.00	R 146 776.50	R 197 820.00	R 242 316.00	R 182 961.00	R 150 741.00	R 210 244.50	R 233 149.50	R 244 035.00	R 241 519.50	R 241 204.50	R 630 000.00		R 2 984 026.50
Commencement Cost				R 1 011 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 1 011 000.00
Once Off Cost				R 2 116 845.00	R 400 000.00	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		R 2 516 845.00
Professional Cost				R 270 000.00	R 274 640.63	R 445 095.00	R 411 662.25	R 339 167.25	R 473 050.13	R 524 586.38	R 549 078.75	R 543 418.88	R 542 710.13	R 542 710.13	R 542 710.13		R 5 458 829.63
Crushing & Screening		43.00		R -	R 935 641.43	R 938 829.75	R 938 829.35	R 1 319 025.00	R 1 517 943.00	R 2 088 832.50	R 2 673 654.00	R 2 818 585.50	R 2 912 884.50	R 3 779 377.50	R 3 058 267.50		R 22 981 870.03
Other				R -	R 428 878.07	R 515 713.03	R 695 059.17	R 851 400.04	R 400 844.86	R 529 642.67	R 738 713.81	R 819 192.68	R 857 439.91	R 848 601.47	R 847 494.68		R 7 532 980.40
Drilling and Blasting				R 526 853.00	R 1 053 706.00	R 1 369 817.80	R 1 917 744.92	R 2 013 632.17	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00	R 2 911 250.00		R 27 260 503.89
Repayment				R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -		-
Security				R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00	R 100 000.00		R 1 200 000.00
Operating profit				R 901 736.04	R 3 051 577.56	R 2 656 355.86	R 609 619.33	R 5 295 369.58	R 7 323 326.06	R 14 478 498.99	R 21 797 508.98	R 23 589 172.98	R 24 775 651.00	R 36 008 911.45	R 26 280 332.73		R 164 964 588.48
Less:																	R
Net profit before dividends				R 901 736.04	R 3 051 577.56	R 2 656 355.86	R 609 619.33	R 5 295 369.58	R 7 323 326.06	R 14 478 498.99	R 21 797 508.98	R 23 589 172.98	R 24 775 651.00	R 36 008 911.45	R 26 280 332.73		R 164 964 588.48
Dividends				R -	R -	R -	R -	R 1.00	R 2.00	R 3.00	R 4.00	R 5.00	R 6.00	R 7.00	R 8.00		R 36.00
Net profit before taxation				R 901 736.04	R 3 051 577.56	R 2 656 355.86	R 609 619.33	R 5 295 368.58	R 7 323 324.06	R 14 478 495.99	R 21 797 504.98	R 23 589 167.98	R 24 775 645.00	R 36 008 904.45	R 26 280 324.73		R 164 964 552.48
Taxation				R 252 486.09	R 854 441.72	R 743 779.64	R 170 693.41	R 1 482 703.20	R 2 050 530.74	R 4 053 978.88	R 6 103 301.39	R 6 604 967.03	R 6 937 180.60	R 10 082 493.25	R 7 358 490.92		R 46 190 074.69
Net profit after taxation				R 649 249.95	R 2 197 135.84	R 1 912 576.22	R 438 925.92	R 3 812 665.38	R 5 272 793.32	R 10 424 517.11	R 15 694 203.58	R 16 984 200.95	R 17 838 464.40	R 25 926 411.20	R 18 921 833.81		R 118 774 477.79
- Cashflow				R 649 249.95	R 1 547 885.89	R 3 460 462.11	R 3 899 388.03	R 7 712 053.41	R 12 984 846.73	R 23 409 363.85	R 39 103 567.43	R 56 087 768.37	R 73 926 232.78	R 99 852 643.98	R 118 774 477.79		R

Appendix C. Mine 1 – Discount Rates from 0% through to 30% over four years

Run of Mine Discount Rates														
Year	0%	2%	4%	7%	9%	10%	12%	15%	18%	20%	22%	25%	28%	30%
0	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704	R253 814 704
1	R343 144 410	R336 416 088	R329 946 548	R320 695 710	R314 811 385	R311 949 464	R306 378 938	R298 386 443	R290 800 347	R285 953 675	R281 265 910	R274 515 528	R268 081 570	R263 957 238
2	R374 027 407	R359 503 467	R345 809 363	R326 690 023	R314 811 385	R309 113 559	R298 172 359	R282 818 455	R268 620 660	R259 741 255	R251 294 952	R239 377 540	R228 288 212	R221 317 992
3	R418 910 696	R394 748 905	R372 410 083	R341 955 912	R323 475 919	R314 733 806	R298 172 359	R275 440 582	R254 961 982	R242 425 171	R230 697 005	R214 482 276	R199 752 186	R190 673 963
4	R293 237 487	R270 906 111	R250 660 633	R223 709 475	R207 736 829	R200 285 149	R186 357 724	R167 659 485	R151 248 634	R141 414 683	R132 367 134	R120 110 075	R109 239 477	R102 670 595

Crushed and Screened Product Discount Rates														
year	0%	2%	4%	7%	9%	10%	12%	15%	18%	20%	22%	25%	28%	30%
0	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011	R322 616 011
1	R498 556 825	R488 781 201	R479 381 563	R465 940 958	R457 391 583	R453 233 477	R445 140 022	R433 527 674	R422 505 784	R415 464 021	R408 653 135	R398 845 460	R389 497 520	R383 505 250
2	R543 426 939	R522 325 009	R502 428 753	R474 650 135	R457 391 583	R449 113 173	R433 216 629	R410 908 839	R390 280 766	R377 379 819	R365 108 129	R347 793 241	R331 681 481	R321 554 402
3	R608 638 172	R573 533 343	R541 077 119	R496 830 048	R469 980 342	R457 278 867	R433 216 629	R400 189 478	R370 435 982	R352 221 164	R335 181 233	R311 622 744	R290 221 296	R277 031 485
4	R413 873 957	R382 355 562	R353 781 193	R315 742 460	R293 198 745	R282 681 481	R263 024 382	R236 633 778	R213 471 583	R199 591 993	R186 822 327	R169 522 773	R154 180 064	R144 908 777

Appendix D. Mine 1 – Production Information for the Life of Mine

Mine sequencing	Waste	Coal	SR	% Change
1	3 374 053	574 254	5.9	-
2	5 196 440	633 797	7.3	10
3	5 528 392	717 145	7.8	13
4	3 298 316	490 160	8.6	-32
Total	17 397 201	2 415 356	7.2	

Appendix E. Mine 2 – Discount Rates from 0% through to 30% over eight years

Run of Mine Discount Rates														
Year	0%	2%	4%	7%	9%	10%	12%	15%	18%	20%	22%	25%	28%	30%
0	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702	R 156 935 702
1	R 171 059 915	R 167 705 799	R 164 480 688	R 159 869 080	R 156 935 702	R 155 509 014	R 152 732 067	R 148 747 753	R 144 966 030	R 142 549 930	R 140 213 045	R 136 847 932	R 133 640 559	R 131 584 550
2	R 189 876 506	R 182 503 370	R 175 551 503	R 165 845 494	R 159 815 256	R 156 922 732	R 151 368 388	R 143 573 918	R 136 366 350	R 131 858 685	R 127 570 886	R 121 520 964	R 115 891 422	R 112 352 962
3	R 227 851 807	R 214 709 847	R 202 559 427	R 185 994 947	R 175 943 402	R 171 188 435	R 162 180 416	R 149 816 262	R 138 677 644	R 131 858 685	R 125 479 560	R 116 660 125	R 108 648 208	R 103 710 427
4	R 262 029 578	R 242 074 828	R 223 983 982	R 199 901 111	R 185 628 359	R 178 969 728	R 166 524 534	R 149 816 262	R 135 151 942	R 126 364 573	R 118 279 913	R 107 327 315	R 97 613 625	R 91 743 839
5	R 301 334 015	R 278 386 052	R 257 581 579	R 229 886 277	R 213 472 613	R 205 815 187	R 191 503 214	R 172 288 701	R 155 424 733	R 145 319 259	R 136 021 900	R 123 426 413	R 112 255 668	R 105 505 415
6	R 346 534 117	R 320 143 959	R 296 218 816	R 264 369 219	R 245 493 505	R 236 687 465	R 220 228 696	R 198 132 006	R 178 738 443	R 167 117 148	R 156 425 185	R 141 940 375	R 129 094 019	R 121 331 227
7	R 398 514 235	R 368 165 553	R 340 651 638	R 304 024 602	R 282 317 531	R 272 190 585	R 253 263 001	R 227 851 807	R 205 549 209	R 192 184 720	R 179 888 962	R 163 231 431	R 148 458 121	R 139 530 911
8	R 458 291 370	R 423 390 386	R 391 749 384	R 349 628 292	R 324 665 161	R 313 019 172	R 291 252 451	R 262 029 578	R 236 381 590	R 221 012 428	R 206 872 307	R 187 716 145	R 170 726 840	R 160 460 548

Crushed and Screened Product Discount Rates														
year	0%	2%	4%	7%	9%	10%	12%	15%	18%	20%	22%	25%	28%	30%
0	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448	R 215 529 448
1	R 234 927 098	R 230 320 684	R 225 891 440	R 219 558 036	R 215 529 448	R 213 570 089	R 209 756 338	R 204 284 433	R 199 090 761	R 195 772 582	R 192 563 195	R 187 941 678	R 183 536 795	R 180 713 152
2	R 260 769 079	R 250 643 098	R 241 095 672	R 227 765 813	R 219 484 117	R 215 511 635	R 207 883 513	R 197 178 888	R 187 280 292	R 181 089 638	R 175 200 940	R 166 892 210	R 159 160 815	R 154 301 230
3	R 292 061 368	R 275 215 950	R 259 641 493	R 238 409 075	R 225 524 964	R 219 430 029	R 207 883 513	R 192 035 091	R 177 757 565	R 169 016 996	R 160 840 207	R 149 535 421	R 139 265 713	R 132 936 444
4	R 335 870 574	R 310 292 493	R 287 103 574	R 256 234 052	R 237 939 182	R 229 404 121	R 213 451 822	R 192 035 091	R 173 238 305	R 161 974 621	R 151 611 671	R 137 572 587	R 125 121 539	R 117 597 624
5	R 386 251 160	R 356 836 367	R 330 169 110	R 294 669 160	R 273 630 059	R 263 814 739	R 245 469 595	R 220 840 354	R 199 224 051	R 186 270 814	R 174 353 421	R 158 208 475	R 143 889 770	R 135 237 267
6	R 444 188 834	R 410 361 822	R 379 694 477	R 338 869 534	R 314 674 568	R 303 386 950	R 282 290 034	R 253 966 407	R 229 107 659	R 214 211 436	R 200 506 434	R 181 939 746	R 165 473 235	R 155 522 858
7	R 510 817 159	R 471 916 096	R 436 648 648	R 389 699 965	R 361 875 753	R 348 894 993	R 324 633 539	R 292 061 368	R 263 473 808	R 246 343 151	R 230 582 400	R 209 230 708	R 190 294 221	R 178 851 286
8	R 587 439 732	R 542 703 510	R 502 145 945	R 448 154 959	R 416 157 116	R 401 229 241	R 373 328 570	R 335 870 574	R 302 994 879	R 283 294 624	R 265 169 759	R 240 615 314	R 218 838 354	R 205 678 979

Appendix F. Mine 2 – Production Information for the Life of Mine

Mine sequencing	Waste (cm ³)	Coal (t)	SR	% Change
1	3 096 514	677 993	4.6	-
2	3 339 615	790 827	4.2	17
3	4 193 801	980 214	4.3	24
4	4 312 500	1 061 955	4.1	8
5	5 090 972	1 206 609	4.2	14
6	5 543 635	1 259 985	4.4	4
7	5 424 409	1 285 684	4.2	2
8	2 559 186	634 737	4	-51
Total	33 560 632	7 898 004	4.2	

Appendix G. Participants' Questionnaire

Personal Details

Gender	Male: ☐ Female: ☐
Age	18 – 25: ☐ 26 – 35: ☐ 36 – 45: ☐ 46 – 55: ☐ >55: ☐
Highest Level of Qualification	
Position Title	
How long have you been mining/involved with mining (years)?	

Operational and Performance

Site Location			
Operation Type			
Commodity mined and quality/grade			
Activities undertaken onsite	Mining: ☐ Processing: ☐		
Authorisation for operation	Mining permit: ☐	Mining right: ☐	Prospecting right with bulk sampling: ☐
Number of employees (Breakdown by direct employees and on-site contractors)			

What is the projected life of mine (LOM)?

What is the monthly/annual production target (tonnes extracted)?

What mining methods are employed at your workplace: (e.g., drilling and blasting, free digging)?

What equipment fleet do you make use of onsite?

What is your shift schedule: (e.g., hour shifts, days a week)?

How are daily shift logs and production data recorded and stored?

How is product transported/delivered to clients once mined?

Safety, Health, Environment and Quality

Safety Protocols: Do you know the process to manage risks to people and risks to the environment associated with your operations? If yes, please describe the emergency response plan and rescue team availability?

Are documented standard operating procedures (SOPs) and code of practice (COPs) for all active sites as required by law available?

How often are workplace hazard inspections and risk assessments conducted?

Are all employees provided with personal protective equipment (PPE) and what PPE is mandatory for employees?

Do you record all incidents occurring on site (even those that did not cause injury but did have, or could have had, a significant impact on people or the environment)? If yes, how are occupational injuries and near-miss incidents tracked and reported?

Rehabilitation Plan: Are you aware of your progressive rehabilitation and closure strategy? If yes, please elaborate.

**Does your mine monitor any of the following related to the actual or potential impacts of your activities? Water quality: ☐ Dust level: ☐
Noise level: ☐**

Community and Stakeholder Relations

Local Employment: What percentage of the workforce is hired from local or host communities?

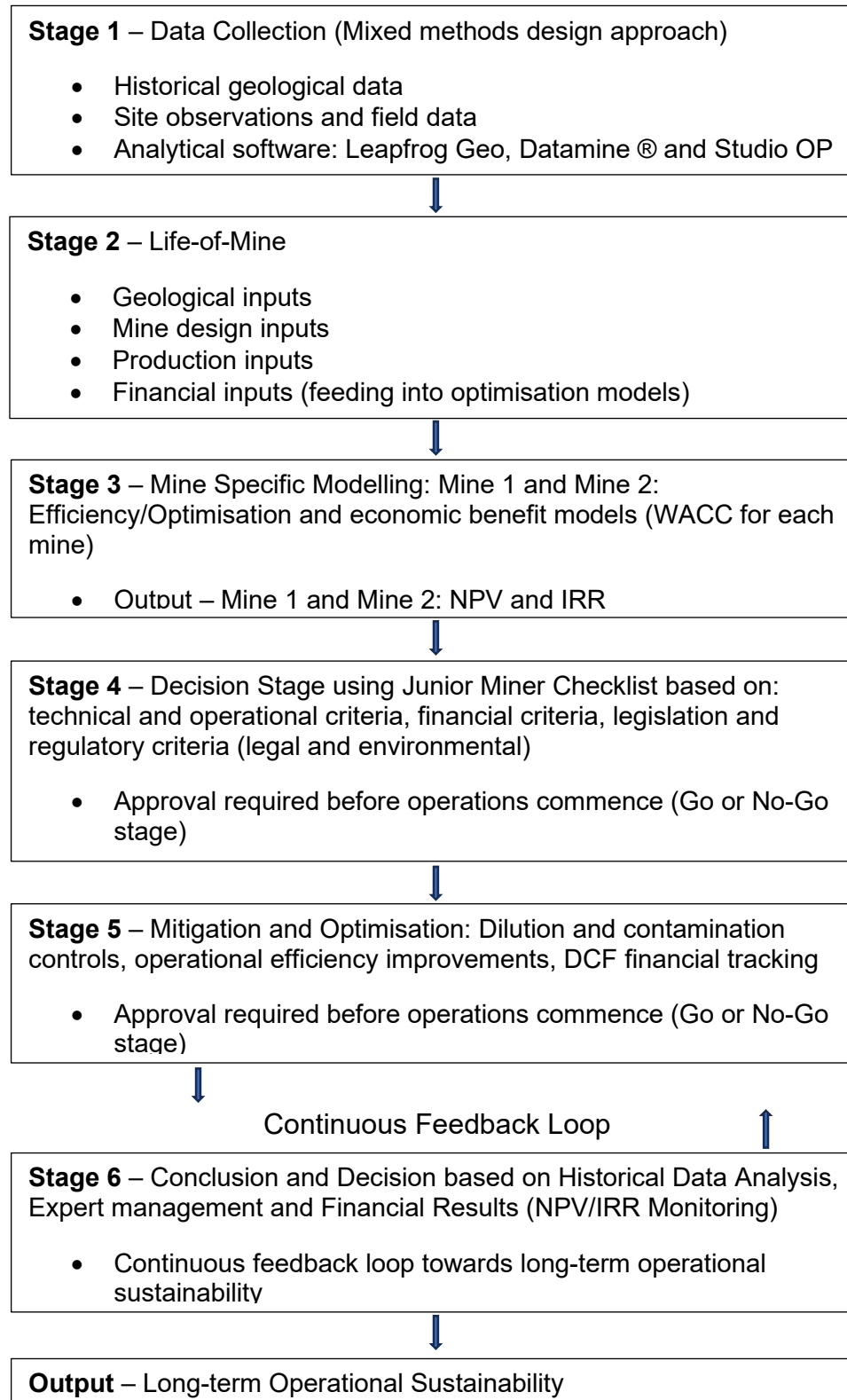
Does the operation contribute to the local and surrounding community in any other way except through employment and business opportunities? If yes, please specify.

Do you know how does the mine capture and resolve issues arising from surrounding communities?

General

Please use the space below to reflect on your personal experiences in the mining sector, and the challenges faced by junior miners.

Appendix H. Decision-Based Framework



Feedback from Stage 6 feeds back into Stages 1 – 5 for continuous improvement

