MANDELA MINING PRECINCT
MINDS FOR MINES

LONGEVITY OF CURRENT MINING (LOCM)

Work Package 3: Production cycle

Final Report

ENTERPRISES
University of Pretoria

Research agency: Enterprises at the University of Pretoria

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List of abbreviations

°	:	Degree(s)
ASG	:	Advanced Strike Gully
Ag	:	Silver
Au	:	Gold
BC	:	Bushveld Complex
BIF	:	Banded Iron Formation
BPCM	:	Blue Print Cost Model
CG	:	Centre Gully
cm	:	Centimetre(s)
CLR	:	Carbon Leader Reef
COP	:	Code of Practice
CSDP	:	Closely Spaced Dip Pillars
DTH	:	Down-the-Hole
DSS	:	Development Service Strategy
ERR	:	Energy Release Rate
Fe	:	Iron
FoG	:	Fall of Ground
HLGE	:	Haulage
HPE	:	Hydro Power Equipment
hrs	:	Hour(s)
i.e.	:	Id Est (in other words)
km	:	Kilometre(s)
kN/m^2	:	Kilo-newton(s) per square-metre
mm	:	Millimetre(s)
m	:	Metre(s)
m^2	:	Square-metre(s)
min	:	Minute(s)
MJ/m^2	:	Mega-joule(s) per square-metre
MPa	:	Mega-Pascal
MRM	:	Mineral Resource Management

MSB	:	Massive Sulphide Body
RDO	:	Rock Drill Operator
RMR	:	Rock Mass Rating
RSE	:	Raise or Raise-line
SS	:	Shift Supervisor
WRR	:	Wide Raise Rig
X-cut	:	Crosscut
XLP	:	Extra Low Profile

Definitions

Blast frequency	:	Number of blasts per measuring month.
Advance per blast	:	Effective face advance per blast.
Blast Efficiency	:	Is the product of the blast frequency and advance per blast expressed as a percentage.
Face advance	:	The monthly advance per panel.
Crew advance	:	The monthly advance a stoping crew achieves when working on different panels during the measuring month.
Half-level	:	The level is divided into two portions.

EXECUTIVE SUMMARY

Most narrow reef gold and platinum mines are getting deeper, and increased travelling times reduce the time available to complete work requirements. Optimising the stoping cycle could help to improve productivity and occupational health and safety (OHS) in the South African mining industry (SAMI). Various considerations should be made when considering changes to stoping cycles. These considerations include those relating to operational requirements, legal requirements, OHS requirements, and employee needs. This framework was designed to assist operations to determine the most suitable stoping cycle systems that can be implemented to enhance productivity and efficiency while supporting the health, safety, and quality of life of the workforce.

The lower productivity in the mining industry is a great concern because Mines's cash flows are negative and force them to scale down operations or closes the operation. More activities are added to the early examination process and therefore the mining cycle cannot be completed daily. The main reasons for this are lesser time spent on the working panels, due to long travelling distances and longer early examination time. The shorter time spent on the working fronts may lead to that, employees are taking short cuts that may lead to sub-standard work and lower outputs.

There is a constant decrease in the blast efficiency of a shaft and travelling time is one of the major contributors to the decrease in blast efficiency. This report investigates the idea of splitting stoping activities in the mining cycle. The splitting of stoping activities namely: Drilling, support, blasting, and cleaning can be operated continuously. A specific stoping activity takes place in a raise line and the activities follow each other when work in the raise line is completed. A two-shift roster is used to ensure an effective six hours on the working front and the remainder of the shift time is used for travelling to and from the shaft head. This splitting of activities ensures a continuous operation on the working panels, and completion of the stoping cycle daily.

1 INTRODUCTION

The challenges in the mining industry grow daily because burning issues are not addressed in a way to solve them permanently. These issues contribute mainly to lower productivity due to less time spent on the working fronts where the main income stream is generated. The increased pressure from the stakeholders to work according to labour and working standards also hampers productivity. The stakeholders are pointing out sub-standard labour and working standards, this is a symptom of the real underlying cause of lower productivity in the mining industry.

The real cause is that due to the financial pressure on the mining industry, the spending of capital on new projects is delayed. This delay causes the replacement main shaft infrastructures are not built-in time. Being late with replacement infrastructure, the majority of work areas are now being mined at a far distance from the shaft system and are widely spread, which results in lower productivity, increased traveling time, and higher operating costs. A minimum standard time of four hundred-and-sixty minutes is required to complete a mining cycle. The actual time spent on the working front is three-hundred minutes. Due to this less time spent on the working fronts, the mining cycle is not completed, and it leads to a lost blast. The shorter time spent on the working fronts may lead to that, employees are taking short cuts that may lead to sub-standard work and lower outputs.

There is a constant decrease in the blast efficiency of a shaft, which travelling time is one of the major contributors as a result of lesser time spent on the working front to complete the stoping cycle.

In conventional stoping different activities are performed to complete a mining cycle. The first activity of a stoping cycle is cleaning, the end activity of a stoping cycle is blasting, and this ensures a productive stoping cycle, as indicated in Figure 1. (Page2)

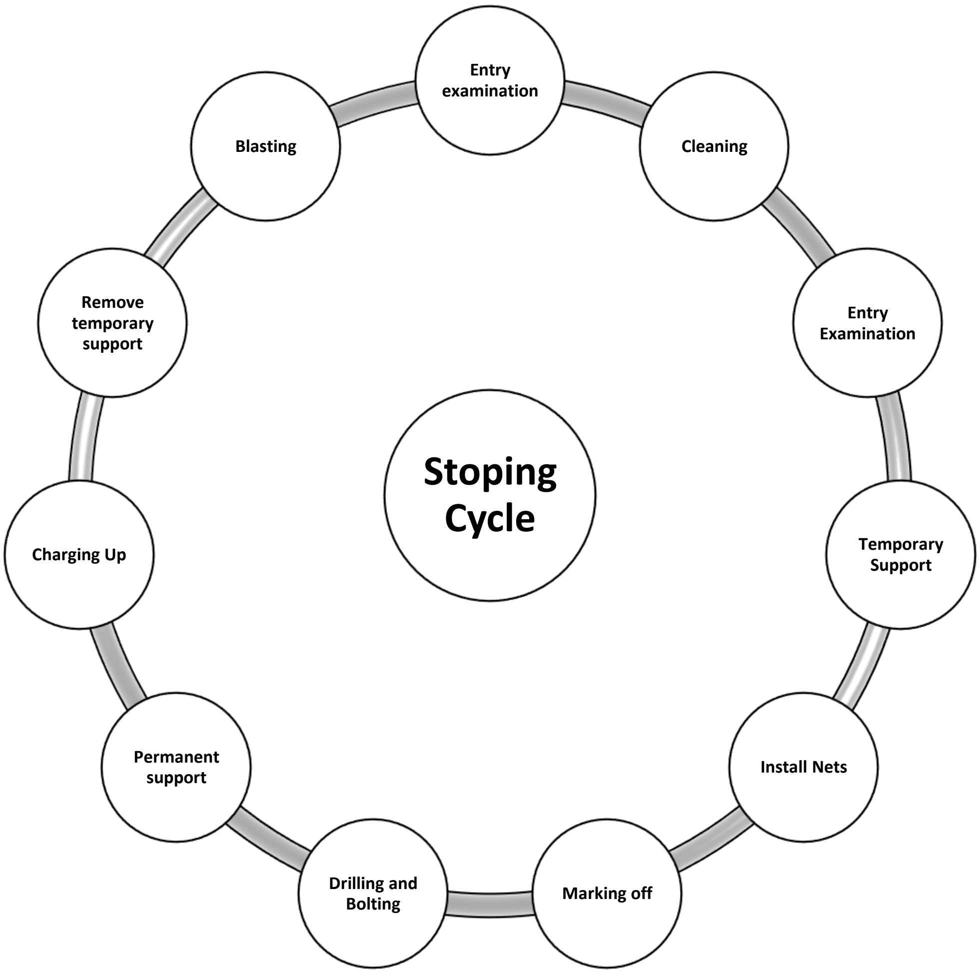

Figure 1: Stoping Cycle

The original mine design for an eight hour and twenty minutes stoping cycle allowed a travelling time of 60 minutes, the early examination time of 30 minutes, and the temporary support consisted of wooden sticks.

In the latest drive to zero harm, additional health and safety requirements were added which extends the stoping cycle time beyond the allocated eight hours. The additional requirements are in-stope roof bolts, safety nets, and removable temporary support. Due to the tight control of the cash-flow, the planned new shaft systems are not established and it means that the travelling time to the working places doubled and the travelling in and out takes two hours and more. This adds two hours to the stoping cycle and brings the total stoping cycle time including traveling time to twelve hours and twenty minutes, which exceeds the legislative allowable nine hours and twenty minutes (bank to bank) by three hours. The impact is that the current stoping cycle cannot be completed in time and this leads to many lost blasts and loss in production.

1.1 SCOPE OF WORK

Work aims to conduct a study of the latest various technologies applied within the conventional mining for Gold and PGM mines within the Stoping production cycle, excluding the activity drilling, but including the activities support, cleaning, charging, and tramming to measure the cycle time of each activity, the capturing the costs associated to each activity, to establish a baseline cost model from the data obtained to effectively apply to the BluePrint Cost Model(BPCM) for evaluation purposes. The primary deliverables are to provide a detailed study report with a BluePrint Cost Model. The BluePrint evaluation should be tested against the baseline of each production cycle activity to ensure the model functions and calculations are correctly applied, then to do multiple scenario evaluations to compare against the conventional methodologies.

1.2 PROJECT DELIVERABLES, METHODOLOGY & TIMELINE

The objectives are to provide a BPCM which can evaluate multiple scenarios of current conventional mining practices, where different technologies per production activity can be selected with a value proposition of each scenario application for comparison purposes. The following aims/ objectives of the project is envisaged as listed in Table 1.

Table 1: LoCM 3 Work Package Activities

Milestones		Start Month	End Month	Sub-Objective	Methodology
No	Activity				
3.1	Start-Up presentation and project plan collaboration meeting	16 Jun 2020	30 Jun 2020	Information sharing	Action Plan
3.2	Literature review of current stoping practices within the production cycle which include various technology applications within these activities	01 Jul 2020	31 Jul 2020	Analytical model include various technology applications within these activities	To determine the optimum current stoping practices within the production cycle
3.3	Determine the cycle time for each technology application within each production cycle activities Baseline Cycle Times per technology for each activity	1 Aug 2020	30 Sep 2020	Determine the Baseline Cycle Times per technology for each activity	Draft a document on cycle times.
3.4	Determine the baseline cost measures for each technology application within each production cycle activity Baseline costing model	1 Oct 2020	31 Oct 2020	Conduct a literature study regarding the production shift cycle	Draft Baseline costing model.
3.5	Capture baseline cost measures for each technology application within each production cycle	01 Nov 2020	15 Nov 2020	Capture the baseline cost measures for each technology application within each production shift cycle	Draft Baseline costing measures.
3.6	Establish a BPCM per technology for each activity	16 Nov 2020	30 Nov 2020	Test model against actual applications	Summary of findings
3.7	Compare BPCM against results of baseline models comparisons against tested and measured results	01 Dec 2020	31 Dec 2020	Summarise results from baseline models	Compare BPCM
3.8	Draft Final Report	02 Jan 2021	31 Jan 2021	Draft Final Report	QAQC
3.9	TSC approve Final Report	01 Feb 2021	15 Feb 2021	Submit a final report	Get approval from TSC

Table 2 Project plan

Project Plan - LoCM20WP4									
Item	Work Component	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
3,1	Start Up								
3,2	Literature review of current stoping practices within the production cycle								
3,3	Determine the cycle time for each technology applications within each production cycle activities								
3,4	Determine the baseline cost measures for each technology application within each production cycle activity								
3,5	Capture baseline cost measures for each technology appliaction within each production cycle								
3,6	Establish a BPCM per technology for each activity								
3,7	Compare BPCM against results of baseline models								
3,8	Draft Final Report								
3,9	Final Report								

2 LITERATURE REVIEW OF CURRENT STOPING PRACTICES WITHIN THE PRODUCTION CYCLE

This literature review study will focus on current conventional mining operations in the narrow reef hard rock environment. Current conventional mining practices are mainly undertaken in the gold and PGM mines.

Table 3: Summary of stoping cycle activities

Activity	Sub-Activity	Cycle time	Remarks
Ore-Reserve Management	Depletion and replacement rate		Ensure equipped panels availability.
Labour	Complement		Allocate the correct number of employees per half-level.
Face Length	Optimum Length	Face length is a function of drilling, face preparation, support, charging, and cleaning time.	The correct length will ensure the competing of the daily stoping cycle
Support	Temporary	Hydraulic prop	Do not remove before the blast to save time and avoid incidents when removing the temporary support
		Hydraulic Camlok	Better force than a mechanical jack. Easier to install and to remove due to hydraulic mechanism.
		Sticks	Do not remove before the blast to save time and avoid incidents when removing the temporary support.
	Netting	Permanent - Hedgehog/ wire force blast on nets	
	In-stope roof-bolting	Various bolting systems	Require drilling of support holes
	Rolling scatter pile	Blyvooruitzicht Gold mine – Re-sue mining	
	Back-fill	Quickset and drain.	Only applicable where required
	Dip pillars	Suggested new mining method – mechanised drill and blast.	
	Permanent	A hydraulic prop with all the accessories cost about R 900 (headboard and footplate included) A timber pole (200mm) (basic) with a jackpot, is R300.	No sawing of a stick, just add extensions.
	Re-work	That is not including any blast outs and a fire risk.	
Cleaning	Water jets - Excalibur	High water usage and wastage	A new design from HPE is highly effective. The effective face length is twenty metres to reduce the cleaning time.
	Remote winches	Start after the blast	Was tested at Randfontein Estates.

Activity	Sub-Activity	Cycle time	Remarks
Drilling	Electro-Hydraulic	Good results but expensive	Faster drilling time than pneumatic drilling. Lower noise than pneumatic drilling.
	Hydropower	Lightweight - promising	In the trial phase
	Drill-jig	Drilling accuracy results in better advance per blast and less hanging and footwall damage, and less blast-out support.	Failed previously due to the lack of a change management program.
Charging	Underground tanks		
	Pumps		
	Exciter		
Tramming	Development	Afternoon cleaning	Successful at Sibanye-Stillwater Lonmin operation.
	Stoping	Night shift cleaning	All the locomotives are used for tramming of reef tons, which results in fewer full ore-passes during the cleaning phase. Fewer locomotives are required for reef tramming, thus less congestion on Nightshift.
	Hoppers	U-cam – ramps on both sides of the tip	Discharging effective, because the ore in the hoppers compacts during the tramming on the rails due to motion forces.
	Locomotive	Millennium loco's	Can be operated from both sides and remotely. Guard car part of the locomotive.
		10-ton locomotives	Replace or upgrade all the 5-ton locomotives to reduce the number of locomotives on a level and more labour efficient because fewer locomotive drivers are required to drive the locomotives.
	Conveyer belt	Requires an additional haulage	High output per half-level.
	Continuous rope haulage	Requires an additional haulage	Continuous operation

2.1 Blast Efficiency

The current blast frequency is 15 out of 23 shifts, which equates to 65 percent and advance per blast is 0.81meters out of an effective drilled blast hole of 1.05 meters, which gives an advance per blast of 77 percent. The gives a blast efficiency of 50 percent (blast frequency times advance per blast).

2.2 Face Length

The face length is a function of drilling, face preparation, support, charging, and cleaning time. A Platinum mine is testing the efficiency of a 20-metre long panel to ensure that the stoping cycle is completed in a shift.

2.3 Support

Temporary support

Mechanical Jacks or sticks are used for temporary support. In the shift cycle, it takes forty-five minutes to install the jacks and another thirty minutes to remove the jacks.

A trial is being conducted at the moment on a mine to use blast-on hydraulic props instead of mechanical jacks. The advantages are:

- Immediate active support close to the working panel
- Not necessary to remove the support, which saves time and prevents fall-of-ground incidents when removing the jack.

The cost of the blast-on hydraulic prop is higher than the current mechanical jack (re-use) and a pencil stick and a jackpot. The blast out frequency of the blast-on hydraulic prop is much lower than the pencil sticks. The unsupported area (due to blast-out sticks) may cause fall-of-ground. The blast out of the pencil sticks may increase the risk for employees to re-install the pencil stick, and additional costs for the rework, and lost blasts.

Netting

Nylon netting is used to prevent chips to fall. In the shift cycle, it takes forty-five minutes to install the nets and another thirty minutes to remove the nets.

A trial is being conducted on a mine to use steel netting instead of nylon netting. The advantages are:

- A permanent installation
- Not necessary to remove the nets, which saves time and prevents fall-of-ground incidents when removing the net.
- Save time in the cycle time because it is not necessary to remove the netting which then saves thirty minutes and that may be the time required to complete the stoping cycle for ensuring a blast for the shift.

The cost of steel netting is higher than the current nylon netting (re-use).

2.4 Cleaning

Winches

The starting of winches after a blast was tested, to save on cleaning time; by not waiting for the blast fumes to clear; at Randfontein Gold Estates in the eighties, but was not successful. A new concept of automatic winches is tested at a Platinum mine at the moment, but no results were published.

Water jetting

Waterjet cleaning with an HPE unit is tested on a mine and the cleaning time of a 20-metre long panel takes two hours and thirty-eight minutes tested over thirty days (Van Rooyen, 2018).

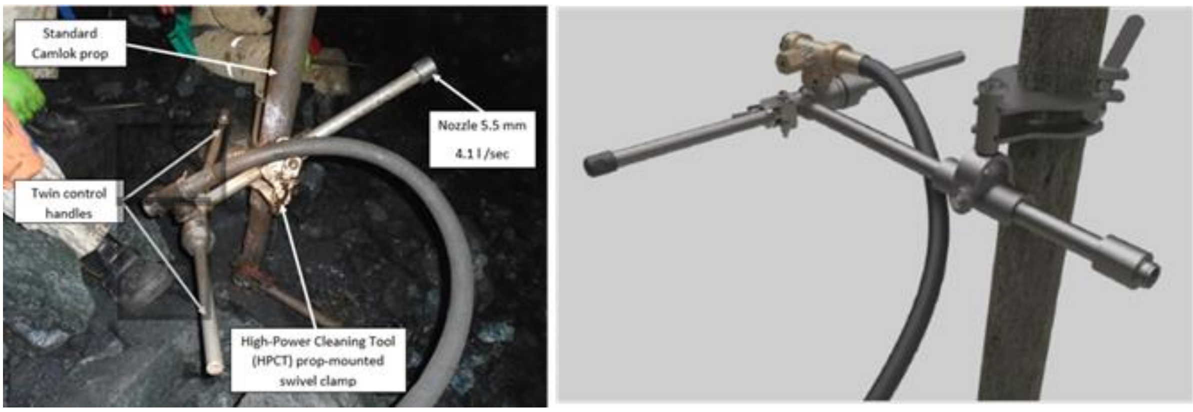

Figure 2: High-Performance Panel Cleaning Tool (HP-PCT)

The power packs were supplied by individual 50NB hoses (single wire braid) from Mine Service Water passing through a 50-micron quad bag-filter assembly at the bottom of the travelling way. While the MSW quality should have conformed to the Mine Ventilation Society of South Africa, solids loadings were higher than the 30 mg/l limits specified. Despite being dirtier than is desirable, this had no noticeable effect on the power pack reliability. The filtered MSW also supplied all other equipment, both low- and high- pressure. The power pack can operate with inlet pressures between 5 and 16 bar. A PRV was installed to reduce the pressures to that required by the Epiroc drill (about 5 bar).

A 32NB HPE jet pump was used to lift water off the footwall/rock pile in the gully and deliver it into a gravity drain. The jet pump is simple, has no moving parts, is light-weight, robust, and can handle up to 8 mm solid particles. Initially, the jet pump delivered dirty water off the footwall into a 50NB PVC mine hose, but this was not ideal as it sometimes "kinked" closed or was not correctly laid on a constantly downward grade allowing gravity to drain the water and wash any solids down to the Vertical Spindle Pump (VSP) near the haulage. Going forwards a correctly sized, steel pipe is recommended (Van Rooyen, 2018).

Figure 3: Jet pump draining a "puddle" in the gully (HPE, 2018)

2.5 DRILLING

Pneumatic

The conventional S25 pneumatic machines are mainly used in the narrow reef hard rock environment. The drill is attached to an air-leg which assists the operator to collar and drill the holes. This is operated using compressed air, which due to the far distance of shaft infrastructure, is very low efficiency and running at high electricity cost.

Hydro Power

The power pack can operate with inlet pressures between 5 and 16 bar. A PRV was installed to reduce the pressures to that required by the hydro-drill (about 5 bar).

Electro-Hydraulic drilling

The HRD-100 rock drill, just as the electro-hydraulic rock is designed to improve efficiency, reliable performance, comfortable and safe operation, low maintenance, and environmental conditions. The design is compact and lightweight and has improved performance as compared to the previous hydraulic drill. The electro-hydraulic drilling is being tested on a platinum mine now. The HRD-100 comes with the following features:

- The astounding power-to-weight ratio meets the mining industry requirement (weighs 25.8 kg with 1.2m tail hoses).
- Delivers a torque between 10 – 25 Nm and runs at 37% efficiency.
- Significantly decreased noise levels. (Sound pressure level of 102 dB (A), which is still higher than the legal sound level of 85 dB (A) at a duration of eight hours exposure.
- Water consumption of 12 l/min.
- No oil exhaustion from the drill. The oil used in the hydraulic drill is biodegradable and the power pack switches itself off if any pressure loss is detected as a result of possible oil spillage.
- Quick and easy chuck replacement, which can be done underground. And this is only necessary after 500m of drilling.
- Can operate at ambient temperatures ranging from +5°C to +40°C.
- Power packs can be transported at any angle. It can operate at different angles up to 45°.

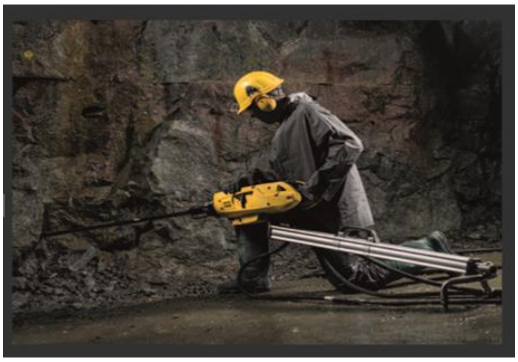

Figure 4: New HRD-100 Hydraulic rock drill (Source: Atlas Copco)

2.6 CHARGING

The ideal design for each explosive type has to take into consideration the explosive energy, rock type, and the desired blast outcome. Failure to account for these factors can have down the line financial implications that are more the explosive cost for blasting operations (De Graaf, 2010).

Ore fragmentation, effective blast advance, and extent of overbreak are the most important aspects of a blast operation. Brinkmann (1994) states the factors affecting these considerations as environmental conditions, geology, VOD, explosive performance, blast energy, and drilling practices. He further elaborates that these factors are usually ignored due to production pressures, short term savings on explosives costs, and lack of awareness.

The Initiation pattern, drilling accuracy, round timing, explosive properties, rock type, and geology usually dictate the possible advance. Where the explosive has more gas energy that penetrates the hanging wall, the advance per blast may be decreased to decrease the length of unsupported ground (Prout, 2010).

2.7 TRAMMING

Locomotives and hoppers

A Platinum Mine clean the development ends on the afternoon shift and use all the locomotives for the tramming of broken rock out of the stopes, this arrangement requires fewer locomotives per half-level and thus reduces the congestion on the half-level which will ensure more effective cleaning and tramming operations.

Millennium locomotives are in use in some mines. The advantage of using the millennium locomotives is the locomotive got two carts in front and at the back of the hoppers to ensure that the driver always sees the oncoming tramming. The locomotive guard can sit in the back of the hoppers in a cabin and give signals to the locomotive driver.

Battery Electric

Battery electric power is simple, reliable, and has a moderate range of action. Because they are easier to maintain than diesel, battery locomotives are preferred for operation in trunk tunnels. However, if they are worked with heavy trains on steep grades the battery charge may not last a shift and their operation becomes uneconomical. The lack of a safe means of discharging a battery in the event of an accident and the dangers of sparks causing a methane explosion restricts the use of battery-powered locomotives near an ore face. Efficient and regular maintenance is essential to extend the working life of batteries.

Recent developments in sodium/sulphur batteries have led to considerable improvements in the ratios of energy to weight and volume. Compared with a lead/acid battery the same electrical energy can be drawn from a sodium/sulphur battery one-seventh of the weight and one-third of the volume. The major problem in the application of this type of battery to mine transport is that the cells must be maintained at over 300°C to ensure that the products of the chemical reaction in the cell remain liquid at all states of charge.

Automation of Rail Transport Systems

Remote control and automation are long overdue in South Africa. However, it has been successfully applied in the USA and other countries, particularly in metalliferous mines for the transport of minerals. At Grangesburg in Sweden, a remotely controlled haulage system has been installed where six diesel-electric trains are operated from a central control room. A display board gives the position of all rail-mounted objects at any time. The trains are directed according to the level of ore in storage bunkers. No drivers are required for the locomotives, all the loading, transportation, and discharging arrangements are either automated or remotely controlled. All the loading and discharging points are monitored by closed-circuit television.

Mount Isa Mine in Australia has installed a minicomputer underground in an air-conditioned central control room to help with the running of their locomotive mineral transport system. Train drivers are directed according to the availability of ore in the bunker systems. The operator presses two route selection buttons, one for the start and one for the destination point, and then an 'accept' button which feeds the information into the computer. The computer then checks the track conditions of the selected route, sets the points, and clears the signals. Failure of the computer, or overriding selection by the operator, enables the track points and signals to be manually controlled. At all times radio voice communication is available between the operator, train haulage crew, and the haulage shift supervisor. The operator is informed at regular intervals of those ore passes which are being used for ore delivery. Information on the availability of ore, track conditions, and breakdown can be passed on rapidly, so delays to the haulage operations are minimized. The haulage capacity is ten million tons per year and a 25% reduction of haulage costs has been predicted with the automation.

At the General Blumenthal mine, FRG, a completely automatic locomotive system, without drivers has been in operation since 1967. This installation, which is for ore haulage, has advantages in cost, efficiency, and safety over manual locomotive and conveyor systems. In the USA a detailed investigation has been made into the design of an automated rail haulage system, using 50-ton pantograph electric locomotives. Each locomotive has an on-board computer. As an example of the sophistication of the system, the computer detects wheel slip and automatically initiates sanding whilst reducing power to the wheels. An infrared train presence detector is recommended for critical areas such as track intersections and also an automatic derailment detector that switches on the emergency brakes. One of the largest and most advanced underground automatic train transport systems is at Henderson Mine in the USA which incorporates twenty-four 50 ton DC electric locomotives.

Conveyor belts

Mostly either conventional (troughed idlers) or cable-driven. In the first case, the belt runs on troughed idlers which support the laden belt, and return idlers (not troughed) are used to support the empty return belt underneath. The belting itself is powered to provide motion. In the case of a cable-driven conveyor, the belt lies on two cables supported at intervals by jockey wheels. The cables are driven and the belt is thus drawn by the cables. To prevent the belt from simply falling through between the cables on either side, the belt must be laterally reinforced with steel to give it rigidity.

In both cases, the idlers or jockey wheels are supported by steel foot structures and stringers between feet or, for lower capacity (although higher conveying speeds) conveyors, cables can be used on which idlers or jockey wheels are hung.

Endless Rope Haulage

Where numerous groups of cars must be handled to achieve the desired capacity, endless rope haulage is best employed. The endless rope haulage, Figure 4, at one time handled extremely high outputs at speeds of about 1m/s. Two pairs of tracks are essential for high capacity, with full cars travelling in one direction and empties in the other. The system may be labour intensive but with automatic attachment and release of cars, it can be economic.

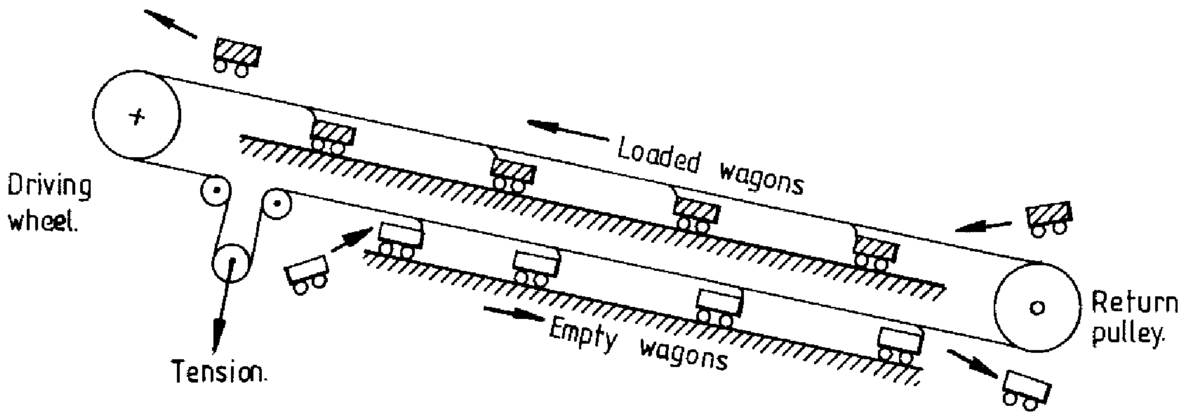

Figure 5: Endless rope haulage system with tail rope tensioning

Endless haulage systems can operate over steep gradients very efficiently. Haulages with two-speed gear-boxes are widely employed to haul supplies and men, the slower speed used for supplies, and the higher for men. Speeds in many cases can match those employed by many underground locomotives.

2.8 CONCLUSIONS FROM MILESTONE

The following conclusions were made of the objectives during the work done:

The production cycle time exceeds the available shift time. To address this, the stoping activities must be split to ensure the completion of the mining cycle daily for an improved stoping operation. This split will ensure that the quality and quantity of work output will be met.

The stoping cycle was discussed in this article but the same principle can be applied to the development cycle. The improvement of the development meters per half-level is important because ore-reserves must be maintained throughout the life of the Mine.

2.9 WAY FORWARD

Create a Blueprint cost and evaluation model.

2.10 LINKAGES TO OTHER MILESTONES

Evaluating production cycle optimisation scenarios for Blueprints.

2.11 RECOMMENDATIONS

The stoping activities as a combination cannot be completed in an eight-hour shift and it is recommended to split the stoping operations, to ensure that the stoping cycle is completed in a shift.

3 DETERMINE THE CYCLE TIME FOR EACH TECHNOLOGY APPLICATION WITHIN EACH PRODUCTION CYCLE ACTIVITIES

The following section covers the conventional drill and blast mining methods and the equipment applied to these methods. The conventional mining method is applied to most narrow reef hard rock mines in South Africa, which is used at any reef dip. The method recovers the mineralisation in stopes and permanent support and/or leaves pillars of ore to support the roof. The products consist of multiple activities, namely stoping and tramming and in most cases, an equipment unit per activity is applied. Table 2 summarise the mining method and Table 3 of the mining equipment.

The conventional mining method delivers reef tons and around 20% waste tons which delivers a minimum amount of waste tons but a lower quality reef ton is delivered to the metallurgical plant for processing.

3.1 MINING SUMMARY

The following section covers the conventional drill and blast mining methods and the equipment applied to these methods.

The conventional mining method is applied to most narrow reef hard rock mines in South Africa, which is used at any reef dip. The method recovers the mineralisation in stopes and permanent support and/or leaves pillars of ore to support the roof. The products consist of multiple activities, namely stoping and tramming and in most cases, an equipment unit per activity is applied. Table 2 summarise the mining method and Table 3 of the mining equipment.

The conventional mining method delivers reef tons and around 20% waste tons which delivers a minimum amount of waste tons but a lower quality reef ton is delivered to the metallurgical plant for processing.

Table 4: Summary of bord-and-pillar mining method

Summary – Conventional mining Method	
Description	The conventional mining method is applied to most narrow reef hard rock mines in South Africa, which is used at any reef dip. The cut width is mining at a range between 90cm and 200cm. The average panel length is 30 meters, which is used for the equipment performance calculations.
Where	Gold and PGM mines
Advantages	▪ Low extraction rate ▪ Depth a constraint ▪ Required skilled labour which is scarce in South Africa at the moment Profitable due to high volumes and less labour intensive
Disadvantages	▪ High dilution ▪ An average safety record due to physical work required ▪ High labour complement ▪ Limited application of equipment in the operation
Successes	• High extraction rate • Low dilution factor.
Failures	• Average mining Safety, and • Low productivity

The conventional mining method is a semi mechanized operation, which proved average safety and produce results, but yields a high dilution factor, in cases of low reef widths. Extraction rates are in the low range of 60 to 70%, depending on the pillar size requirements.

3.2 EQUIPMENT SUMMARY

Table 5: Summary of conventional mining equipment

Summary – Conventional mining Equipment	
Activities	▪ Barring – Pinch bars used for barring ▪ Netting – Installation by hand ▪ Temporary support - Installation by hand ▪ In-stope roof bolts – Hole drilling and installation by hand ▪ Drilling – The number of face blast holes depends on the stoping width and done by handheld drilling machines ▪ Permanent support – Installation by hand ▪ Charging – require the charging unit to charge the blast holes manually ▪ Timing – by hand ▪ Cleaning – Scrapers remove blast rock from the face, tips into ore-passes, and loads on hoppers or belts to shaft station ore-passes from where it is hoisted to surface. ▪ Tramming – Locomotives pull the hoppers to the tipping points
Equipment Description	The mining method requires equipment that can operate at a minimum height of 1.0m. The production mining block of equipment produces 12 870 tonnes (depends on stoping width, panel length, and several panels per half-level) per half-level per month. The equipment consist of the following: • Pinch bar • Camlok props • Nets • In-stope roof-bolt drilling machine • Drilling machines • Explosive chargers
Maintenance	The equipment availability and utilisation is around 70% and no rotating equipment is available, however, when there is an equipment breakdown it would result in a production loss.
Utilisation	For the majority of the equipment, the average utilisation of these units is utilised around 70% of equipment availability. ▪ Drilling – 35 to 55% ▪ Support – 35 to 50% ▪ Cleaning – 60% for winches The equipment is static in a panel, irrespective of the panel is in operation or not.
Successes	In mines where the face time is long, where lowering and traveling time is short between the surface and the underground workings
Failures	Lack of sinking of new shafts which results in shorter face time, which results in an incomplete stoping cycle, due to longer traveling time to the working places.

Table 6: Cycle time (One Panel per Crew) (Meyer, L.D., 2019)

Activity	**Time (min)**	
	Day shift	**Night shift**
Re-entry (Night shift)		90
Travelling in	60	60
Waiting Place	30	30
Re-Entry examination (barring and water down)	30	
Cleaning (Night shift)		360
Installation of temporary support	45	
Installation of nets	25	
Marking of drill holes	25	
Drill in-stope roof-bolts	60	
Installation of roof-bolts	60	
Drilling of holes	240	
Blow-out of holes	20	
Charging of holes	45	
Timing of blast holes	25	
Removal of temporary support	30	

Activity	Time (min) Day shift	Night shift
Removal of nets	15	
Travel out	60	60
Blasting		
Total (hours; minutes)	**12:50**	**9:00**

3.3 Supporting Information

Drilling

Table 7: Drilling time (Drilling Cycle)

Parameters	B1	Pneumatic	Electric	Hydraulic
Penetration Rate (Quartzite) (m/min)	0,30	0,30	0,78	1,3
Hole length (m)	1,05	1,05	1,05	1,05
Time to drill one hole (mins)	3,55	3,55	1,35	0,81
Non-drilling time per hole (min)	2	2	3	2
Total time taken per hole (min)	5,55	5,55	4,35	2,81
Number of holes drilled per hour	11	11	14	21
Number of holes(panel)	141	141	141	141
The time required to complete all holes (hours)	13	13	10	7
Number of drills required	2,90	2,90	2,27	1,47
Actual number of drills required for panel	**3,00**	**3,00**	**3,00**	**2,00**
Holes drilled per machine	47,02	47,00	47,00	70,53
Total drilling time - hrs	4,35	4,35	3,41	3,30
Total drilling time - min	261	261	204	198
Total drilling time (hrs)	4:20:55	4:20:55	3:24:22	3:18:02

Cleaning

Table 8: Cleaning time

Stope Panel		Scraper	Waterjet
Parameter (units)	**Description**	**Value**	**Value**
in-situ volume (m3)		39,0	39,0
Swell factor (%)		0,3	0,3
Volume broken rock (m3)		50,7	50,7
Mass (m)	V x p	108,5	108,5
Density broken rock (t/m3)		2,14	2,14
Scraper capacity (t)		0,75	1,15
Scoop fill factor (%)		0,8	0,8
Mass per trip (t)	m x fill factor	0,6	0,9
Trips required	m/mass per trip	180,8	117,9
Winch rope speed (m/s)		1,0	2,0
Digging time (s)		5,5	5,5
Time to ASG (s)	Face length/rope speed	31,6	31,6
Time modification (%)		0,1	0,1
Time up the face (s)		28,7	14,4
Total trip time (s)		65,8	51,5
Tons per hour (tph)	tons per trip/trip time	32,8	50,0
Face cleaning time (hrs)		**3,3**	**2,2**
Face cleaning time (min)		198,2	130,2

ASG		Scraper	Waterjet
Parameter (units)	**Description**	**Value**	**Value**
In-situ volume (v)	h x w x adv	3,4	3,4

Stope Panel		Scraper	Waterjet
Parameter (units)	**Description**	**Value**	**Value**
Mass (t)		9,5	9,5
Swell factor (%)		0,3	0,3
Volume broken rock (m3)	V	4,5	4,5
Density broken rock (t/m3)	p	2,1	2,1
Rock mass (t)	V x p	9,5	9,5
Gully length (m)		90,0	90,0
Total tons (t)	ASG tons + Panel tons	118,0	118,0
Scraper capacity (t)		2,3	2,3
Fill factor (%)		0,8	0,8
Tons per scraper scoop (t)	scoop capacity x fill factor	1,8	1,8
Rope speed (m/s)		1,0	1,0
Empty scraper trip time time (s)	gully length/rope speed	90,0	90,0
Time allowance (%)		0,1	0,1
Loaded scraper trip time (s)	gully length/rope speed x (1.1)	99,0	99,0
Turning (digging time) - (s)	5sec + time allowance	5,5	5,5
Overall trip time (s)		194,5	194,5
Tons per hour (tph)	[tons per trip/overall trip time] x 3600s/1hr	33,3	33,3
Gully cleaning time (hrs)	**Total tons/tph**	**3,5**	**3,5**
ASG cleaning time (min)		212,6	212,6
Total Cleaning time (gully + face) - (hrs)		**6,8**	**5,7**
Total Cleaning time (gully + face) - (min)		**411**	**343**
Effective face time - (hrs)		**6,1**	**6,1**
Time difference - (hrs)		**-0,7**	**0,4**

Table 9: Cleaning time using a water jet (Van Rooyen, 2018)

Parameter	Time (hrs: minutes)	Value
Panel Length		20 metres
Cleaning	2:37	

Charging

Table 10: Charging time (Khusasletho)

Heading	Amount	Time (minutes)
Number of holes per panel (Include ASG)	166	
Insert fuses	166	20
Loading of explosives	166	35
Timing	30 metres	10
Total		**75**

Support

3.3.1.1 Temporary support and netting

Table 11: Installation time of temporary support and netting (Meyer L.D., 2019)

Activity	Time (minutes)
Barring and water down	30
Clean the foot-wall for one jack or stick	2
Install a jack or stick	3
Number of jacks per 30-metre panel (1,5 metres apart)	20
Install the jacks or sticks	60
Total (simultaneous cleaning and installation)	**70**

3.3.1.2 In-stope roof-bolts

Table 12: Installation time of in-stope roof-bolting (Meyer L.D., 2019)

Activity	Time (minutes)
Drill a hole	3
Install a roof-bolt	2
Number of jacks per 30-metre panel (1,5 metres apart)	20
Drill the roof-bolts	60
Install the roof-bolts	60
Total (simultaneous drilling and installation)	**70**

3.4 CONCLUSIONS FROM MILESTONE

The following conclusions were made of the objectives during the work done:

- All parameters that need to be considered in the shift cycle for a different type of shift cycle activities was discussed.
- The shift cycle is discussed in this article but the same principle can be applied to the development shift cycle. The improvement of the development meters per half-level is important because ore-reserves must be maintained throughout the life of the Mine.

3.5 WAY FORWARD

Determine the baseline cost measures for each technology application within each production cycle activity as provided in Section 4.

3.6 LINKAGES TO OTHER MILESTONES

Evaluating shift cycle optimisation scenarios for Blueprints.

3.7 RECOMMENDATIONS

The stoping activities as a combination cannot be completed in an eight-hour shift and it is recommended to split the stoping operations, to ensure that the stoping cycle is completed in a shift.

4 DETERMINE THE BASELINE COST MEASURES FOR EACH TECHNOLOGY APPLICATION WITHIN EACH PRODUCTION CYCLE ACTIVITY

This section is work done within the milestone deliverable 5 of the project deliverables, which aim is to capture the baseline cost measures for each technology application within each production cycle activity.

The methodology is to capture the baseline cost measures for each technology application within each production cycle.

4.1 BASELINE COSTING MODEL

The stoping activities and cost breakdowns are provided in tables 13 to 18.

Labour

Table 13: Parameters (Khusasalethu, 2019)

Shifts per month	**23**	
Option	**Base 1**	33%
		The baseline for Current Drill Time
	Parameter	**Baseline 1**
Mine	Mining method	sequential grid breast mining method
	Operating levels	4
	Number of Shifts	23
	Monthly Tons	120000
	Monthly m²	26978
	m² per crew	230
	Total Stoping Crews (Based on tons)	118
	Total Stoping Crews (Plan)	49
	Number of equipped panels	49
Production	Raiseline spacing (m)	200
	Stope block width (m)	170
	Crews/half-level	6
	Production per crew (t)	1082
	Production Grade (g/t)	5,20
	Production ton density (t/m3)	2,78
	Tonnes/shift	141,39
Panel	Monthly production per panel (m2)	230
	Monthly production per raise (m2)	1377
	Density (t/m3)	2,78
	Production per crew (t/month)	1021
	Stope reef grade (g/t)	5,29
	Stoping width (m)	1,6
	Panel length (m)	30
	Face Length (m)	28,7
	Advance per month (m)	7,65
	Advance per blast (m)	0,85
	Number of drill machines per panel face	5
	Hole Diameter (m)	0,038
	Burden (m)	0,6
	Number of holes drilled in a shift	141
	Effective hole length (m)	1,05
	Drilled metres in a panel per shift (m)	148,12
	Drilled metres per machine per advance	29,62

ASG	Gully width (m)	1,3
	Gully Height (m)	2,2
	Gully Volume per month (m3)	22
	Gully tonnes per month (t)	61
	Gully Grade (g/t)	3,78
	Number drilled holes in the gully	19
	Hole length in ASG (m)	1,5
	ASG advance per blast	1,2
	Total m drilled in ASG	28,5
	Total metres drilled in ASG monthly	218,025
	Number of drill machines in the ASG	1
Panel and ASG	The total number of drill machines required	6
	Drilled metres per day	176,62
	Drill time (min)	260,92
	Actual Drill Time (Hrs / shift)	4,35
	Allowable Hrs / Shift	4:30
	Available Drill Time (Min)	270,00
	% Improvement	0%
Drilling	Drilled metres per month per panel	1133
	Drill metres / reef t	1,11
	Drill metres per month per ASG	218
	Drill metres / reef t	3,58

Table 14 Labour Cost

Labour	Parameter	Baseline 1
	Capital Cost / Drilling Equipment per Machine	10 072,00
	Gold price (R/kg)	961 990
	Recovery	0,75
	RDO salary ®	15000
	Miner salary	18000
	Team leader	16000
	Miner assistance	10000
	Support	1000
	Winches	10000
	Other team members	10000
	Cost per tonne	495
	Cost per tonne (excl Drilling)	385,99
	Labour Cost R/t	202,67
	Drilling	108,63
	Blasting	18,38
	Charging	18,38
	Support	6,54
	Cleaning	12,54
	Tramming	7,96
	Sundries	119,5
	STOPING CREW (Includes leave provisions)	
Labour	RDOs	6,78
	Miner	1,13
	Team leader	1,13
	Miner assistance	1,13
	Support	2,26
	Winches	4,52
	Total number of crew members	17,0
	Labour Cost R/t	**202,67**

Drilling

Table 15: Drilling Time (Khusasaletho, 2019)

Item	Parameter (unit)		B1
Lubrication	Consumption of grease (l/day/drill)		0,5
	Cost of lubrication (R/l)		20,00
	Lubrication cost per drill machine (R)		10,00
	Lubrication cost per panel per day		60,00
	Lubrication cost per month/ panel	**R**	**459,00**
	Lubrication cost per ton (R/t)	**R**	**0,42**
Drill Bit	ROTARY TYPE DRILL BITS AND STEMS R32 COUPLING (R)		319,61
	Total number of metres drilled per machine per month (m)		226,62
	Life of a drill bit (m)		113,00
	The number of the time's drill bit will be replaced per month per machine		2,01
	Cost of drill bit per month in panel(R)		3204,90
	Total metres drilled in ASG per month (m)		218,03
	Number of the time drill bit will be replaced monthly		1,93
	Cost of drill bit per month in ASG (R)		616,66
	Total monthly drill bit cost in panel	**R**	**3 821,56**
	Total monthly drill bit cost per ton (R/t)	**R**	**3,53**
Drill Steel	Cost of drill steel		783,76
	Life of a drill steel (m)		197,00
	Total number of metres drilled per machine per month		226,62
	Number of times drill steel will be replaced per month per panel machine		1,15
	Drill bit cost per month for panel (R)		4 508
	Total number of metres drilled per machine per month in ASG		218,03
	Number of times drill steel will be replaced per month per asg machine		1,11
	Drill bit cost per month for ASG (R)		867
	Panel drill steel cost	**R**	**5 375,46**
	Panel drill steel cost/ton (R/t)	**R**	**4,97**
Energy	Energy required kWh		63,10
	The time machine is in operation (hours)		4,35
	Drilling energy per machine		274,41
	Panel drilling energy per shift		1 372,03
	Time spent drilling in ASG		2,64
	ASG drilling energy per shift (kWh)		166,32
	Mega-flex cost per KW (R)		0,99
	Total energy cost per shift (R)		1 522,96
	Total energy cost per month	**R**	**11 650,67**
	Total energy cost per month (R/t)	**R**	**10,77**
Pumping Energy	Pumping energy kWh/m		0,14
	Total pumping energy/shift (kWh)		24,73
	Total energy pumping energy costs/ shift ®		24,48
	Total energy pumping energy costs/ month	**R**	**187,27**
	Total energy pumping energy costs/ month (R/t)	**R**	**0,17**
Total Energy	**Total energy costs**	**R**	**11 837,94**
	Cost/tonne energy cost (R/t)	**R**	**10,94**
Water Usage	Water usage (l/s)		0,13
	Total drilling time per drill machine in panel face area (s)		15655
	Water usage per shift (Kl)/drill machine		2,04
	Rate of water (Rand water) (R/kl)		12,35
	Water costs/ machine per shift (R)		25,13
	Total water costs per shift in panel face area (R)		150,81
	Total drilling water costs per month	**R**	**1 153,69**
	Water Cost/tonne (R/t)	**R**	**1,07**

Item	Parameter (unit)		B1
Maintenance of the drill machine	Maintenance cost (R/m2)		3,52
	Centares achieved per blast (m2)		30,00
	Drill machine maintenance cost (panel) (R)		633,60
	Total maintenance cost per month	**R**	**4 847,04**
	Cost/tonne maintenance cost (R/t)	**R**	**4,48**
RDOs	The total number of RDOS required		6
	RDO cost per month (R)		**90 000**
Total monthly cost		**R**	**117 494,70**
Panel Monthly drilling cost per tonne (R/t)		**R**	**108,63**

Cleaning

Winches and Waterjets

Table 16: Cleaning time with winches and waterjet (Khusasaletho, 2019)

Parameter (units)	Description	Scraper Value	Waterjet Value
Ropes and S natchblocks	Cost of rope	783,76	0,00
	Life of a rope (m)	197,00	197,00
	Total number of metres cleaned per month	660,10	298,60
	Number of times rope will be replaced per month per panel machine	1,30	0,00
	Rope cost per month for panel (R)	1222666	0,00
	Total number of ropes per month in ASG	1,00	6,10
	Number of times rope will be replaced per month per ASG winch	0,01	0,03
	Drill bit cost per month for ASG (R)	3,98	0,00
	Panel rope cost	**R1 222 666**	**0,00**
	Panel rope ton (R/t)	**R10**	**R0**
Energy	Energy required kWh	63,10	500,00
	Time machine is in operation (hours)	0,02	0,02
	Cleaning energy per machine	1,19	9,42
	Panel cleaning energy per shift	21 391	169 500,00
	Time spent cleaning in ASG	2,64	2,64
	ASG cleaning energy per shift (kWh)	166,32	1 317,89
	Total energy cost per shift (R)	21 557	170 817,89
	Total energy cost per month	**R16 168**	**R128 113**
	Total energy cost per ton(R/t)	**R0,13**	**R1,01**
Pumping Energy	Pumping energy kWh/m	0,14	0,34
	Total pumping energy/shift (kWh)	0,16	0,38
	Number of panels	118	118
	Total energy pumping energy costs/ shift	2,60	15,36
	Total energy pumping energy costs/ month (R/t)	**R1,95**	**R11,52**
Water	Water usage (l/s)	0,03	0,33
	Total cleaning time per panel face area (s)	411	343
	Water usage per shift (Kl)/machine	0,01	0,11
	Rate of water (Rand water) (R/kl)	12,35	12,35
	Water costs/ machine per shift	0,15	1,40
	Total water costs per shift in panel face area	0,91	17,52
	Total cleaning water costs per month	**R1,01**	**R19,45**
	Water Cost/tonne (R/t)	**R0,84**	**R16,21**
Cost/Ton		**R12,54**	**R28,73**

Charging

Anfex and Pump-able Explosives

Table 17: Anfex and pumpable explosives (Khusasaletho, 2019)

Parameters	Value	Time (minutes)
Charge weight per hole (kg)	0.65	
Number of holes per panel	160	
Explosives per panel (kg)	104	
Insert Detonators	160	20
Charging	160	40
Total time	**160**	**60**

Table 18: Charging Cost (Baseline)

	B1
Parameter (units)	**Value**
Charge Weight/Hole (kg)	0.65
Number of holes/Panel	160
Explosives/Panel (kg)	104
Explosives Cost/kg	R14.05
Explosives Cost/Panel (R)	**R1 461.80**
Shock tubes (R/m)	R5.23
Shocktubes cost per panel (R)	R923.72
Stemming cost per panel (R)	R213.71
Accessories Cost/Panel (R)	**R1 137.43**
Blasting Cost/panel (R)	**R2 599.23**
Monthly blasting cost/panel (R)	**R19 884.10**
Monthly blasting cost R/t	R18.38

Support

Table 19: Support cycle time (Khusasaletho, 2019)

Item	Parameter (unit)	Baseline 1
Sticks	Number of sticks in a row	19,00
	Number of rows installed per blast	0,50
	Number of sticks installed per advance	9,50
	Amount spent on sticks per blast	**2090,00**
	Cost per Ton	**1,93**
Props	Number of props in a row	0,00
	Number of rows installed per blast	0,50
	Number of props installed per advance	0,00
	Amount spent on props per blast	**0,00**
	Cost per Ton	**0,00**

Item	Parameter (unit)	Baseline 1
Bolts	Number of bolts in a row	22,00
	Number of rows installed per blast	1,00
	Number of bolts installed per advance	22,00
	The unit cost of bolts	55,80
	Amount spent on bolts per blast	**1227,60**
	Cost per Ton	**1,13**
Resin	Number of resin capsules required per blast	44,00
	Cost of resin box (16 capsules)	286,47
	Cost of each resin capsule	17,90
	Amount spent on resin per blast	**393,90**
	Cost per Ton	**0,36**
Grout packs	Grout bag cost	635,49
	Grout pack bags required in 1 grout pack support	3,00
	Grout bag cost per pack	1906,47
	Cost of grout (R/m3)	1014,80
	The volume of grout required for 1 pack	0,64
	Cost of grout per grout pack support	649,47
	The total cost of 1 grout pack	2555,94
	Timber support required	249,27
	Cost of grout per grout pack support including timber	2805,21
	Number of grout packs required per row	6,00
	Number of rows of packs required per blast	0,20
	Total number of packs required per blast	1,20
	Cost of packs per blast	**R3 366**
	Cost per Ton	**R3**
	Total support cost (R/blast)	**R7 078**
Total support cost per month		**R346 810**
Panel Monthly support cost per tonne (R/t)		**R6,54**

4.2 CONCLUSION FROM MILESTONE

All parameters that need to be considered in the production cycle for the different types of production cycle activities were discussed.

The cost measures were captured for use in the BluePrint Cost Model.

4.3 WAY FORWARD

Establish a BluePrint Cost Model per technology for each activity which is provided in Section 5.

4.4 RECOMMENDATIONS

The stoping activities as a combination cannot be completed in an eight-hour shift and it is recommended to split the stoping operations, to ensure that the stoping cycle is completed in a shift.

5 CAPTURE BASELINE COST MEASURES FOR EACH TECHNOLOGY APPLICATION WITHIN EACH PRODUCTION CYCLE

5.1 BASELINE COST MEASURE FOR EACH TECHNOLOGY APPLICATION

The following technology applications were used for the baseline cost measurements:

Layout

- Mining method: the method that is selected to extract the valuable material from the ground in the most economical way possible.
- Operating levels: production levels.
- Total Stoping Crews: the total number of crews for stoping.
- Raiseline spacing (m): the optimal range of raise spacing is between 180 m and 220 m.
- Crews/half-level: the number of stoping crews required per half-level.
- Production per crew (t): the number of tonnes that a crew produces in a shift.
- Production Grade (g/t): the amount of metal contained in a tonne of ore, expressed as grams per tonne of ore.
- Tonnes/shift: the tonnes produced in a single shift.
- Monthly production per panel (m^2): the tonnes produced per panel in a month.
- Monthly production per raise (m^2): the tonnes produced per raise in a month.
- Production per crew (t/month): the tonnes produced by a single crew in a month.
- Stoping width (m): the width dimension of a stope.
- Panel length (m): the length of a single panel.
- Advance per blast (m): the metres advanced per blast.
- Advance per month (m): the sum of the metres advanced from all the blasts in a month.
- Hole diameter (m): the diameter of the holes that are drilled.
- Burden (m): the distance from a single row to the face of the excavation, or between rows in the usual case where rows are fired in sequence.
- Drilled metres in a panel per shift (m): the metres drilled in a panel in a single blast.
- Gully width (m): the width dimension of the gully.
- Gully height (m): the height dimension of the gully.
- Several drilled holes in gully: the number of holes that have been drilled in the gully.
- Total metres drilled in ASG: calculated as the total number of holes x hole length in ASG (m).
- Drilled metres per day: the sum of drilled metres in a panel per shift with the total metres drilled in ASG.

- Drill time per machine (min): calculated as the holes drilled per machine x time taken to drill one hole.
- Actual drill time (hrs/shift): calculated as the drill time per machine / 60.
- Available drill time (hrs): the time that is available for drilling operations.
- Drilled metres per month per panel: calculated as drilled metres in panel per shift (m) x monthly advance.
- Drill metres/reef t: calculated as drilled metres per month per panel (m) / production per crew (t/month).
- Drill metres per month per ASG: calculated as total metres drilled in ASG (m) x monthly advance.
- Recovery: the percentage of minable reserves extracted in the mining process.
- Cost per tonne: calculated as the sum of the monthly labour salaries, drilling, blasting, support, and cleaning costs multiplied by 1,5.

Production indicators

- Monthly production tonnes: the number of tonnes that a mining operation produces in a month.
- Total number of crew members: number of people working at the face (miner, team leader, rock drill operators, and other crew members).
- Monthly labour costs (R/t): the capital that is allocated towards paying a mining operation's workforce.
- Drilling costs/tonne (R/t): the cost of drilling per tonne produced.

Time study drilling

- Penetration Rate (m/min): the rate at which the drill bit penetrates the rock mass to begin the rock breaking process. This is affected by many variables, including hydraulics, weight-on-bit, rotational speed, and bit wear.
- Hole length (m): the length of the blast hole.
- Time to drill one hole (min): the time that it takes to drill a blast hole.
- Non-drilling time per hole (min): the time spent on a hole that does not relate to the drilling process.
- Total time is taken per hole (min): the sum of the time taken to drill a hole with the non-drilling time.
- Several holes drilled per hour: a factor that can be used to evaluate the efficiency of a drill rig.
- The time required to complete all holes (hrs): the time required to drill all the required holes on a panel.
- Holes drilled per machine: the number of holes that a drill rig drills.
- Total drilling time (hrs): the total time spent on drilling all the required holes.

Drilling cost

- Rotary type drill bits and stems R32 coupling (R): the type of drill bit that is being used.
- A total number of metres drilled per machine per month (m): the sum of all the hole lengths drilled by a machine in a month.
- Drill bit: the rotary cutting tool that is used to penetrate the rock mass and create holes in a variety of materials.
- Life of a drill bit (m): the total distance that can be drilled before the bit wears out.
- Several times drill bit will be replaced per month per machine: the total number of metres drilled per machine per month/life of a drill bit.
- Total metres drilled in ASG per month (m): the monthly advance.
- Cost of drill bit per month in ASG (R): the sum of the amount spent on drill bits in a month.
- Drill steel: high-grade steel used in tools and dies that is made by fusing low-carbon steel with charcoal or cast iron.
- Cost of drill steel (R): the amount spent when purchasing drill steel.
- Life of drill steel (m): the total distance that can be drilled before the steel wears out.
- Drilling energy per machine: Energy required (kWh) x time machine is in operation (hrs).
- Mega-flex cost per kW (R): an electricity tariff with a value of 0.99 R/kW for this project.
- Total energy costs per month (R): the sum of the total monthly energy cost with the total pumping energy costs.
- Water usage (ℓ/s): the amount of water that is used by a mining operation.
- Water usage per shift (kℓ)/drill machine: the amount of water that each drill rig uses for flushing of holes in a shift.
- Rate of water (Rand water) (R/kℓ): valued at 12.35.
- Water costs/machine per shift (R): the costs associated with the water usage for each machine in a single shift.
- Maintenance cost (R/m2): the capital that is allocated to the maintenance of the machines.
- Centares achieved per blast (m2): the face length mined (m) x advance per blast (m).
- Total number of RDOS required: the required number of rock drill operators.

Charging cost

- Charge Weight/hole (kg): the required weight of an explosive in a hole.
- Number of holes/panel: number of drilled holes per panel.
- Explosives/panel (kg): the number of explosives in a hole multiplied by the number of drilled holes in a panel.
- Explosives cost/kg: the cost of an explosive per kilogram.

- Explosives cost/panel (R): total cost of explosives in a panel.
- Shock tubes (R/m): the cost of a shock tube per meter.
- Shock tubes cost/panel (R): total cost of shock tubes in a panel.
- Stemming cost/panel (R): total cost of stemming in a panel
- Accessories cost/panel (R): total cost of other tools and materials used in hole charging per panel.
- Blasting cost/panel (R): total cost of blasting per panel.
- Monthly blasting cost/panel (R): the total monthly cost of blasting per panel.
- Monthly blasting cost (R/t): the total monthly cost of blasting per tonne produced.
- Tamping (R/bag): total cost of tamping per bag.

Support cost

- Number of sticks installed per advance: number of sticks in a row multiplied by the number of rows installed per blast.
- Amount spent on sticks per blast: time spent installing sticks per blast.
- Number of bolts in a row: number of bolts installed in each row.
- Number of rows installed per blast: total number of rows installed per blast.
- Number of bolts installed per advance: number of bolts in a row multiplied by the number of rows installed per blast.
- The unit cost of bolts: the total cost of bolts.
- Amount spent on bolts per blast: time spent installing bolts per blast.
- Cost of resin box (16 capsules): total cost of a resin box (16 capsules).
- Amount spent on resin per blast: time spent installing bolts per blast.
- Grout bag cost: the cost of a grout bag.
- Grout bag cost per pack: the cost of a grout bag per pack.
- Cost of grout (R/m3): the cost of grout per volume.
- Total number of packs required per blast: number of grout packs required per row multiplied by the number of rows of packs required per blast.
- Cost of packs per blast: cost of grout per grout pack support including timber multiplied by the total number of packs required per blast.
- Total support cost (R/blast): total cost of required support per blast.
- Total support cost per month: the total monthly cost of required support.
- Panel monthly support cost per tonne (R/t): total panel monthly cost of required support per tonne produced.

Cleaning cost

- In-situ volume (m3): volume of the mining block (face length × advance per blast × stoping width).
- Swell factor (%): the amount of volume increase from in-situ volume to lose volume of the rock due to voids created to the material after blasting.
- The volume of broken rock (m3): the total volume of broken rock (in-situ volume × (1 + swell factor %)).
- Mass (t): volume of broken rock multiplied by the density of the broken rock.
- Density broken rock (t/m3): tonnages per unit volume.
- Scraper capacity (t): the maximum amount of tonnages a scraper can carry.
- Scoop fill factor (%): percentage of an available volume in a scoop that is used.
- Mass per trip (t): scraper capacity (t) multiplied by scoop fill factor (%).
- Trips required: calculated as mass (t) / mass per trip (t)
- Winch rope speed (m/s): the speed at which the winch rope travel.
- Digging time (s): calculated as 5 × (1 + percentage time modification).
- Time to ASG (s): Face length/ Rope speed multiplied by (1 + percentage time modification).
- Time modification (%): Alterations made in time, in this case, 10%.
- Time up the face (s): calculated as face length/winch rope speed.
- Total trip time (s): calculated as time up the face (s) + time to ASG (s) + digging time (s).
- Tonnes per hour (tph): calculated as (mass per trip (t) / total trip time (s)) × 3600.
- Face cleaning time (hrs): calculated as mass (t) / tonnes per hour.
- Face cleaning time (min): calculated as face cleaning time (hrs) × 60.

Tramming cost

- Tramming distance & speed
- Locomotive capacity
- Hopper capacity
- Hopper fill
- Tramming time
- Labour complement
- Operating cost
- Maintenance cost
- Labour cost

5.2 RESEARCH FINDINGS

Base Line – Blue Print Working Cost Model – production cycle

Table 20 indicates the production parameters.

Table 20: Blueprint – Base Line Working Cost Model – Production cycle

Financial evaluation of Scenario:	**Base 1**	**PNEUMATIC**		
Baseline conditions form the foundation of the project. Based on the current crew advance rates of 7,2m at the mine, the efficiency of 40% is maintained for the current technology (pneumatic drilling, stick support, charging, and tramming).				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	19 080 123	636 004
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	74 436	
Gold Oz		Oz	2 393 168	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	7 365	385,99
Drilling cost	Real	R/t	2 073	108,63
Total working cost (excl Royalties)	Real	R mil	9 437	494,61
Cost per kilogram (excl Royalties)	Real	R/kg		126 784
Working Revenue	Real	R000	71 607	
Working profit/(loss)	Real	R000	62 169	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	3 580	
Financial Evaluation (Real terms)				
Revenue	R000		71 607	
Working costs	R000		9 437	
Working profit/(Loss)	R000		62 169	
Royalties	R000			
Ongoing capital	R000		566	
Project capital	R000		0	
Pre-Tax Net Cash Flow	R000		58 023	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		39 512	
Discounted Cash Flow	6,00%			

Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	29 732	22 842	18 232
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine or Equipment	20 144	10 072	10 072
No of additional Machines or equipment	0	0	0
Total Cost of drills and equipment	R0,00	R0,00	R0,00
Inflate Cost	R0,00	R0,00	R0,00
Total Capital	**R0,00**	**R0,00**	**R0,00**

*** JHH is the capital cost required to get extra drilling machines for the second panel for a crew

Scenario 1 – Blue Print Working Cost Model – Production cycle

Table 21 indicates Scenario 1 – Blue Print Working Cost Model – Production cycle.

Table 21 Scenario 1 – Blue Print Working Cost Model– Production cycle

Financial evaluation of Scenario:	**S1**	**PNEUMATIC**		
Blast every second day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	28 682 538	956 085
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	111 897	
Gold Oz		Oz	3 597 573	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	9 103	317,37
Drilling cost	Real	R/t	2 317	80,77
Total working cost (excl Royalties)	Real	R mil	11 420	398,14
Cost per kilogram (excl Royalties)	Real	R/kg		102 055
Working Revenue	Real	R000	107 644	
Working profit/(loss)	Real	R000	96 224	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	5 382	
Financial Evaluation (Real terms)				
Revenue	R000		107 644	
Working costs	R000		11 420	
Working profit/(Loss)	R000		96 224	
Royalties	R000			
Ongoing capital	R000		685	
Project capital	R000		0	
Pre-Tax Net Cash Flow	R000		90 157	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		61 333	
Discounted Cash Flow	6,00%			
Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	46 198	35 493	28 330
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine	5 510 072	10 072	5 500 000
No of additional Machines	0	0	0
Total Cost of equipment	R0,00	R0,00	R0,00
Inflate Cost 2018	R0,00	R0,00	R0,00
Total Capital	**R0,00**	**R0,00**	**R0,00**

Scenario 2 – Blue Print Working Cost Model – Production cycle

Table 22 indicates the Scenario 1 – Blue Print Working Cost Model – Production cycle

Table 22 Scenario 2 – Blue Print Working Cost Model– Production cycle

Financial evaluation of Scenario:	**2**	**Pneumatic**		
Cycle mining (one crew two panels) - one blast per day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	40 155 553	1 338 518
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	156 656	
Gold Oz		Oz	5 036 602	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	11 837	294,78
Drilling cost	Real	R/t	2 484	61,85
Total working cost (excl Royalties)	Real	R mil	14 321	356,63
Cost per kilogram (excl Royalties)	Real	R/kg		91 415
Working Revenue	Real	R000	150 701	
Working profit/(loss)	Real	R000	136 381	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	7 535	
Financial Evaluation (Real terms)				
Revenue	R000		150 701	
Working costs	R000		14 321	
Working profit/(Loss)	R000		136 381	
Royalties	R000			
Ongoing capital	R000		859	
Project capital	R000		493,53	1,05
Pre-Tax Net Cash Flow	R000		127 493	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		87 904	
Discounted Cash Flow	6,00%			
Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	65 112	49 926	39 769
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine	5 510 072	10 072	5 500 000
No of additional Machines	49	49	0
Total Cost of drill equipment	R493 528,00	R493 528,00	R0,00
Inflate Cost 2018	R554 528,06	R554 528,06	R0,00
Total Capital	**R1 048 056,06**	**R1 048 056,06**	**R0,00**

Scenario 3 – Blue Print Working Cost Model – Production cycle

Table 23 indicates the Scenario 3 – Blue Print Working Cost Model – Production cycle

Table 23 Scenario 3 – Blue Print Working Cost Model– Production cycle

Financial evaluation of Scenario:	**3**	**Electric**		
Cycle mining (one crew two panels) - one blast per day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	40 155 553	1 338 518
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	156 607	
Gold Oz		Oz	5 035 021	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	11 837	294,78
Drilling cost	Real	R/t	2 555	63,62
Total working cost (excl Royalties)	Real	R mil	14 392	358,40
Cost per kilogram (excl Royalties)	Real	R/kg		91 896
Working Revenue	Real	R000	150 654	
Working profit/(loss)	Real	R000	136 262	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	7 533	
Financial Evaluation (Real terms)				
Revenue	R000		150 654	
Working costs	R000		14 392	
Working profit/(Loss)	R000		136 262	
Royalties	R000			
Ongoing capital	R000		863	
Project capital	R000		987,06	2,10
Pre-Tax Net Cash Flow	R000		126 879	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		87 330	
Discounted Cash Flow	6,00%			
Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	64 581	49 420	39 282
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine	5 510 072	10 072	5 500 000
No of additional Machines	98	98	0
Total Cost of drill equipment	R987 056,00	R987 056,00	R0,00
Inflate Cost 2018	R1 109 056,12	R1 109 056,12	R0,00
Total Capital	**R2 096 112,12**	**R2 096 112,12**	**R0,00**

Scenario 4 – Blue Print Working Cost Model – Production cycle

Table 24 indicates the Scenario 4 – Blue Print Working Cost Model – Production cycle

Table 24 Scenario 4 – Blue Print Working Cost Model– Production cycle

Financial evaluation of Scenario:	**4**	**Hydraulic**		
Cycle mining (one crew two panels) - one blast per day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	40 155 553	1 338 518
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	156 656	
Gold Oz		Oz	5 036 602	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	11 837	294,78
Drilling cost	Real	R/t	2 598	64,69
Total working cost (excl Royalties)	Real	R mil	14 435	359,47
Cost per kilogram (excl Royalties)	Real	R/kg		92 143
Working Revenue	Real	R000	150 701	
Working profit/(loss)	Real	R000	136 267	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	7 535	
Financial Evaluation (Real terms)				
Revenue	R000		150 701	
Working costs	R000		14 435	
Working profit/(Loss)	R000		136 267	
Royalties	R000			
Ongoing capital	R000		866	
Project capital	R000		987,06	2,10
Pre-Tax Net Cash Flow	R000		126 878	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		87 330	
Discounted Cash Flow	6,00%			

Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	64 580	49 420	39 282
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine	5 510 072	10 072	5 500 000
No of additional Machines	98	98	0
Total Cost of drill equipment	R987 056,00	R987 056,00	R0,00
Inflate Cost 2018	R1 109 056,12	R1 109 056,12	R0,00
Total Capital	**R2 096 112,12**	**R2 096 112,12**	**R0,00**

Scenario 5 – Blue Print Working Cost Model – Production cycle

Table 25 indicates the Scenario 5 – Blue Print Working Cost Model – Production cycle

Table 25 Scenario 5 – Blue Print Working Cost Model– Production cycle

Financial evaluation of Scenario:	**5**	**Pneumatic**		
Cycle mining (one crew two panels) - one blast per day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	45 892 060	1 529 735
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	179 035	
Gold Oz		Oz	5 756 116	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	11 585	252,44
Drilling cost	Real	R/t	2 368	51,61
Total working cost (excl Royalties)	Real	R mil	13 953	304,05
Cost per kilogram (excl Royalties)	Real	R/kg		77 936
Working Revenue	Real	R000	172 230	
Working profit/(loss)	Real	R000	158 277	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	8 612	
Financial Evaluation (Real terms)				
Revenue	R000		172 230	
Working costs	R000		13 953	
Working profit/(Loss)	R000		158 277	
Royalties	R000			
Ongoing capital	R000		837	
Project capital	R000		0	
Pre-Tax Net Cash Flow	R000		148 828	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		101 154	
Discounted Cash Flow	6,00%			
Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	76 262	58 591	46 766
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine	5 510 072	10 072	5 500 000
No of additional Machines	49	49	0
Total Cost of drill equipment	R493 528,00	R493 528,00	R0,00
Inflate Cost 2018	R554 528,06	R554 528,06	R0,00
Total Capital	**R1 048 056,06**	**R1 048 056,06**	**R0,00**

Scenario 6 – Blue Print Working Cost Model – Production cycle

Table 26 indicates the Scenario 6 – Blue Print Working Cost Model – Production cycle

Table 26 Scenario 6 – Blue Print Working Cost Model– Production cycle

Financial evaluation of Scenario:	**6**	**Electric**		
Cycle mining (one crew two panels) - one blast per day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	45 892 060	1 529 735
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	179 035	
Gold Oz		Oz	5 756 116	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	11 585	252,44
Drilling cost	Real	R/t	2 368	51,60
Total working cost (excl Royalties)	Real	R mil	13 953	304,04
Cost per kilogram (excl Royalties)	Real	R/kg		77 933
Working Revenue	Real	R000	172 230	
Working profit/(loss)	Real	R000	158 277	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	8 612	
Financial Evaluation (Real terms)				
Revenue	R000		172 230	
Working costs	R000		13 953	
Working profit/(Loss)	R000		158 277	
Royalties	R000			
Ongoing capital	R000		837	
Project capital	R000		493,528	
Pre-Tax Net Cash Flow	R000		148 335	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		102 250	
Discounted Cash Flow	6,00%			

Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	75 792	58 132	46 318
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine	5 510 072	10 072	5 500 000
No of additional Machines	49	49	0
Total Cost of drill equipment	R493 528,00	R493 528,00	R0,00
Inflate Cost 2018	R554 528,06	R554 528,06	R0,00
Total Capital	**R1 048 056,06**	**R1 048 056,06**	**R0,00**

Scenario 7 – Blue Print Working Cost Model – Production cycle

Table 27 indicates the Scenario 7 – Blue Print Working Cost Model – Production cycle

Table 27 Scenario 7 – Blue Print Working Cost Model– Production cycle

Financial evaluation of Scenario:	**7**	**Hydraulic**		
Cycle mining (one crew two panels) - one blast per day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	45 892 060	1 529 735
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	179 035	
Gold Oz		Oz	5 756 116	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	11 585	252,44
Drilling cost	Real	R/t	2 367	51,58
Total working cost (excl Royalties)	Real	R mil	13 952	304,01
Cost per kilogram (excl Royalties)	Real	R/kg		77 928
Working Revenue	Real	R000	172 230	
Working profit/(loss)	Real	R000	158 278	
Royalty ((EBIT/Gross sales*12.5)				
((EBIT/Gross sales*12.5)*100				
Royalty		R mil	8 612	
Financial Evaluation (Real terms)				
Revenue	R000		172 230	
Working costs	R000		13 952	
Working profit/(Loss)	R000		158 278	
Royalties	R000			
Ongoing capital	R000		837	
Project capital	R000		493,528	
Pre-Tax Net Cash Flow	R000		148 336	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		102 251	
Discounted Cash Flow	6,00%			

Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	75 793	58 132	46 318
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		

CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**
Cost / Machine	5 510 072	10 072	5 500 000
No of additional Machines	49	49	0
Total Cost of drill equipment	R493 528,00	R493 528,00	R0,00
Inflate Cost 2018	R554 528,06	R554 528,06	R0,00
Total Capital	**R1 048 056,06**	**R1 048 056,06**	**R0,00**

Baseline and Scenarios Combined Results

The graphs in Figure 6 indicates the square metres, tons, cost per ton per activity, and the revenue, cost, cash flow, and NPV for the baseline and scenarios 1 to 7.

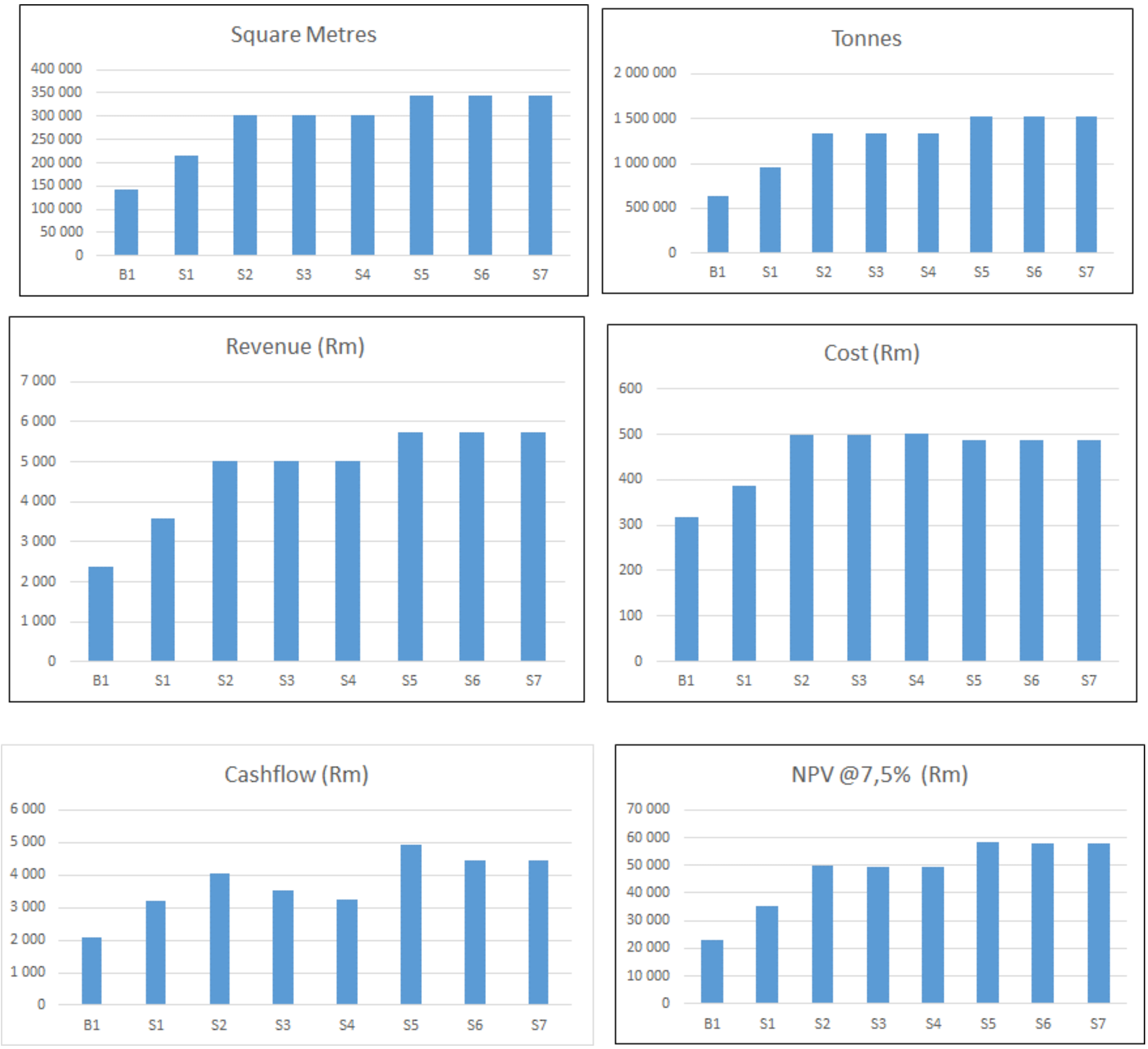

Figure 6 Summary of baseline and Scenarios 1 – 7

5.3 CONCLUSIONS FROM MILESTONE

The following conclusions were made of the objectives during the work done:

- This exercise was done on a fixed number of panels to be mined, but when shaft capacities are taken into the consideration, the results may be different, because the panels to be mined will be different.
- The labour cost is the highest contributing factor to the cost, from MDP labour cost is the highest.
- The stoping cycle was discussed in this article but the same principle can be applied to the development cycle. The improvement of the development meters per half-level is important because ore-reserves must be maintained throughout the life of the Mine.

- Scenarios 2 (one blast) and 5 (two blasts) yields the best NPV's
- The capital outlay for electric, hydraulic drills, waterjet cleaning, and endless rope haulage are high and if those technologies are implemented, the NPV yields a negative amount.

5.4 WAY FORWARD

Compare BPCM against results of baseline models' comparisons against tested and measured results

5.5 LINKAGES TO OTHER MILESTONES

Evaluating shift cycle optimisation scenarios for Blueprints.

5.6 RECOMMENDATIONS

The stoping activities as a combination cannot be completed in an eight-hour shift and it is recommended to adopt a new shift system, to ensure that the stoping cycle is completed in a shift.

6 ESTABLISH A BPCM PER TECHNOLOGY FOR EACH ACTIVITY

6.1 TEST MODEL AGAINST ACTUAL APPLICATIONS

Labour

Table 28 Production input parameters

PRODUCTION INPUT PARAMETERS

Shifts per month	**23**	
Option	**Base 1**	33%
		The baseline for Current Drill Time
	Parameter	**Baseline 1**
Mine	Mining method	sequential grid breast mining method
	Operating levels	4
	Number of Shifts	23
	Monthly Tons	120000
	Monthly m²	26978
	m² per crew	230
	Total Stoping Crews (Based on tons)	118
	Total Stoping Crews (Plan)	49
	Number of equipped panels	49
Production	Raise-line spacing (m)	200
	Stope block width (m)	170
	Crews/half-level	6
	Production per crew (t)	1082
	Production Grade (g/t)	5,20
	Production ton density (t/m3)	2,78
	Tonnes/shift	141,39
Panel	Monthly production per panel (m2)	230
	Monthly production per raise (m2)	1377
	Density (t/m3)	2,78
	Production per crew (t/month)	1021
	Stope reef grade (g/t)	5,29
	Stoping width (m)	1,6
	Panel length (m)	30
	Face Length (m)	28,7
	Advance per month (m)	7,65
	Advance per blast (m)	0,85
	Number of drill machines per panel face	5
	Hole Diameter (m)	0,038
	Burden (m)	0,6
	Number of holes drilled in a shift	141
	Effective hole length (m)	1,05
	Drilled metres in a panel per shift (m)	148,12
	Drilled metres per machine per advance	29,62
ASG	Gully width (m)	1,3
	Gully Height (m)	2,2
	Gully Volume per month (m3)	22
	Gully tonnes per month (t)	61
	Gully Grade (g/t)	3,78
	Number drilled holes in the gully	19
	Hole length in ASG (m)	1,5
	ASG advance per blast	1,2
	Total m drilled in ASG	28,5
	Total metres drilled in ASG monthly	218,025

	Number of drill machines in the ASG	1
Panel and ASG	The total number of drill machines required	6
	Drilled metres per day	176,62
	Drill time (min)	260,92
	Actual Drill Time (Hrs / shift)	4,35
	Allowable Hrs / Shift	4:30
	Available Drill Time (Min)	270,00
	% Improvement	0%
Drilling	Drilled metres per month per panel	1133
	Drill metres / reef t	1,11
	Drill metres per month per ASG	218
	Drill metres / reef t	3,58

Table 29: Baseline Labour costs (Khusasaletho, 2019)

Labour	Parameter	Baseline 1
	Capital Cost / Drilling Equipment per Machine	10 072,00
	Gold price (R/kg)	961 990
	Recovery	0,75
	RDO salary ®	15000
	Miner salary	18000
	Team leader	16000
	Miner assistance	10000
	Support	1000
	Winches	10000
	Other team members	10000
	Cost per tonne	495
	Cost per tonne (excl Drilling)	385,99
	Labour Cost R/t	202,67
	Drilling	108,63
	Blasting	18,38
	Charging	18,38
	Support	6,54
	Cleaning	12,54
	Tramming	7,96
	Sundries	119,5

	STOPING CREW (Includes leave provisions)	
Labour	RDOs	6,78
	Miner	1,13
	Team leader	1,13
	Miner assistance	1,13
	Support	2,26
	Winches	4,52
	Total number of crew members	17,0
	Labour Cost R/t	**202,67**

Drilling

Table 30: Baseline Drilling Costs (Khusasaletho, 2019)

Item	Parameter (unit)	B1
Lubrication	Consumption of grease (l/day/drill)	0,5
	Cost of lubrication (R/l)	20,00
	Lubrication cost per drill machine (R)	10,00
	Lubrication cost per panel per day	60,00

Item	Parameter (unit)		B1
	Lubrication cost per month/ panel		**459,00**
	Lubrication cost per ton		**0,42**
Drill Bit	ROTARY TYPE DRILL BITS AND STEMS R32 COUPLING (R)		319,61
	Total number of metres drilled per machine per month (m)		226,62
	Life of a drill bit (m)		113,00
	The number of the time's drill bit will be replaced per month per machine		2,01
	Cost of drill bit per month in panel(R)		3204,90
	Total metres drilled in ASG per month (m)		218,03
	Number of the time drill bit will be replaced monthly		1,93
	Cost of drill bit per month in ASG (R)		616,66
	Total monthly drill bit cost in panel	**R**	**3 821,56**
	Total monthly drill bit cost per ton (R)	**R**	**3,53**
Drill Steel	Cost of drill steel		783,76
	Life of a drill steel (m)		197,00
	Total number of metres drilled per machine per month		226,62
	Number of times drill steel will be replaced per month per panel machine		1,15
	Drill bit cost per month for panel (R)		4 508
	Total number of metres drilled per machine per month in ASG		218,03
	Number of times drill steel will be replaced per month per asg machine		1,11
	Drill bit cost per month for ASG (R)		867
	Panel drill steel cost	**R**	**5 375,46**
	Panel drill steel cost/ton (R)	**R**	**4,97**
Energy	Energy required kWh		63,10
	The time machine is in operation (hours)		4,35
	Drilling energy per machine		274,41
	Panel drilling energy per shift		1 372,03
	Time spent drilling in ASG		2,64
	ASG drilling energy per shift (kWh)		166,32
	megaflex cost per KW (R)		0,99
	Total energy cost per shift (R)		1 522,96
	Total energy cost per month	**R**	**11 650,67**
	Total energy cost per month	**R**	**10,77**
Pumping Energy	Pumping energy kWh/m		0,14
	Total pumping energy/shift (kWh)		24,73
	Total energy pumping energy costs/ shift		24,48
	Total energy pumping energy costs/ month		**187,27**
	Total energy pumping energy costs/ month		**0,17**
Total Energy	**Total energy costs**	**R**	**11 837,94**
	Cost/tonne energy cost (R/t)	**R**	**10,94**
Water Usage	Water usage (l/s)		0,13
	Total drilling time per drill machine in panel face area (s)		15655
	Water usage per shift (Kl)/drill machine		2,04
	Rate of water (Rand water) (R/kl)		12,35
	Water costs/ machine per shift (R)		25,13
	Total water costs per shift in panel face area (R)		150,81
	Total drilling water costs per month	**R**	**1 153,69**
	Water Cost/tonne (R/t)	**R**	**1,07**
Maintenance of the drill machine	Maintenance cost (R/m2)		3,52
	Centares achieved per blast (m2)		30,00
	Drill machine maintenance cost (panel) (R)		633,60
	Total maintenance cost per month	**R**	**4 847,04**
	Cost/tonne maintenance cost (R/t)	**R**	**4,48**
	The total number of RDOS required		6
	RDO cost per month (R)		**90 000**
Total monthly cost (R)			**R 117 494,70**
Panel Monthly drilling cost per tonne (R/t)		**R**	**108,63**

Cleaning

6.1.1.1 Winches

Table 31: Baseline Winch cleaning costs (Khusasaletho, 2019)

Parameter	Value (R/t)	Remarks
Ropes	R 6.90	
Ancillary	R 4.80	
Energy	R 10.94	
Total	**R 22.64**	

6.1.1.2 Waterjets

Table 32: Baseline Waterjet costs (VanRooyen, 2019)

Water jet cleaning	Cost (R/t)	Remarks
Water	1.07	
Energy	6.94	
Total	**8.01**	

Charging

Anfex and Pump-able explosives

Table 33: Baseline Charging costs (Khusasaletho, 2019)

Explosive Cost	**Value**
Charge Weight/Hole (kg)	0.65
Number of holes/Panel	160
Explosives/Panel (kg)	104
Explosives Cost/kg	R14.05
Explosives Cost/Panel (R)	**R1 461.80**
Accessory Cost	
Shock tubes (R/m)	R5.23
Shocktubes cost per panel (R)	R923.72
Stemming cost per panel (R)	R213.71
Accessories Cost/Panel (R)	**R1 137.43**
Charging Cost	
Blasting Cost/panel (R)	**R2 599.23**
Monthly blasting cost/panel (R)	**R19 884.10**
Monthly blasting cost R/t	R18.38

Support

Table 34: Baseline Support costs (Khusasaletho, 2019)

Item	Parameter (unit)	Baseline 1
Sticks	Number of sticks in a row	19,00
	Number of rows installed per blast	0,50
	Number of sticks installed per advance	9,50
	Amount spent on sticks per blast	**R 2090,00**
	Cost per Ton	**R 1,93**
Props	Number of props in a row	0,00
	Number of rows installed per blast	0,50
	Number of props installed per advance	0,00

Item	Parameter (unit)	Baseline 1
	Amount spent on props per blast	**R 0,00**
	Cost per Ton	**R 0,00**
Bolts	Number of bolts in a row	22,00
	Number of rows installed per blast	1,00
	Number of bolts installed per advance	22,00
	The unit cost of bolts	55,80
	Amount spent on bolts per blast	**R 1 227,60**
	Cost per Ton	**R 1,13**
Resin	Number of resin capsules required per blast	44,00
	Cost of resin box (16 capsules)	286,47
	Cost of each resin capsule	17,90
	Amount spent on resin per blast	**R 393,90**
	Cost per Ton	**R 0,36**
Grout packs	Grout bag cost	635,49
	Grout pack bags required in 1 grout pack support	3,00
	Grout bag cost per pack	1906,47
	Cost of grout (R/m3)	1014,80
	The volume of grout required for 1 pack	0,64
	Cost of grout per grout pack support	649,47
	The total cost of 1 grout pack	2555,94
	Timber support required	249,27
	Cost of grout per grout pack support including timber	2805,21
	Number of grout packs required per row	6,00
	Number of rows of packs required per blast	0,20
	Total number of packs required per blast	1,20
	Cost of packs per blast	**R 3 366**
	Cost per Ton	**R 3**
	Total support cost (R/blast)	**R 7 078**
Total support cost per month		**R 346 810**
Panel Monthly support cost per tonne (R/t)		**R 6,54**

7 COMPARE BPCM AGAINST RESULTS OF BASELINE MODELS

7.1 STOPING ACTIVITIES

Table 355, summarizes the alternative stoping activities. By splitting the stoping activities the required daily stoping cycle can be completed in a shift.

Table 35: Alternative stoping activities (Meyer L.D., 2020)

	S1 - One panel per crew		S2 - Two panels per crew		S3 - One panel per crew and 2 blasts – first panel		S3 - One panel per crew and 2 blasts – second panel	
	Day Shift	Night Shift	Day Shift	Night Shift	Day Shift	Night Shift	Day Shift	Night Shift
Activity	**Time (min)**	**Time (min)**	**Time (min)**	**Time (min)**	**Time (min)**	**Time (min)**	**Time (min)**	**Time (min)**
Re-entry (Night shift)		60		60		60		60
Travelling in	60	60	60	60	60	60	60	60
Waiting Place	30	30	30	30	30	30	30	30
Re-Entry examination (barring and water down)	30	30	5	30	5	30	5	30
Cleaning (Night shift)		408		342		342		342
Installation of temporary support	45							
Installation of nets	25		25		25		25	
Installation of permanent support								
Marking of drill holes	25			25		25		25
Drill in-stope roof-bolts	60		60		60		60	
Installation of roof-bolts	60		60		60		60	
Drilling of blast holes	261		261		204		198	
Blow-out of holes	20		20		20		20	
Charging of holes	25		25		25		25	
Timing of blast holes	15		15		15		15	
Removal of temporary support	30							
Removal of nets	15		15		15		15	
Travel out	60	60	60	60	60	60	60	60
Total (hours; minutes)	**12,68**	**10,80**	**10,60**	**10,12**	**9,65**	**10,12**	**9,55**	**10,12**

Table 36: Production Indicators (Khusasaletho, 2019)

Parameter		B1	S1	S2	S3	S4	S5	S6	S7
PRODUCTION PER PANEL / MONTH									
Panel Productivity	Square Metres produced monthly	229,5	345,0	483,0	483,0	483,0	552,0	552,0	552,0
	Labour Productivity (m2/man)	13,54	20,35	22,50	22,50	22,50	36,80	36,80	36,80
	Volume produced monthly	389	585	819	819	819	936	936	936
	Monthly production/crew (t)	1082	1626	2276	2276	2276	2602	2602	2602
	Ore produced (kg)	4,22	6,34	8,88	8,88	8,88	10,15	10,15	10,15
	Ore (oz)	135,67	203,94	285,52	285,52	285,43	326,31	326,31	326,21
Panel Cost Labour & Drilling Cost	RDOs	6,78	6,78	6,78	6,78	6,78	6	6	6
	Miner	1,13	1,13	1,13	1,13	1,13	1	1	1
	Team leader	1,13	1,13	1,13	1,13	1,13	1	1	1
	Miner assistance	1,13	1,13	1,13	1,13	1,13	1	1	1
	Support	2,26	2,26	4,52	4,52	4,52	2	2	2
	Winches	4,52	4,52	6,78	6,78	6,78	4	4	4
	Total number of crew members	17	17	21	21	21	15	15	15
	Productivity per employee (m2/man)	13,54	20,35	22,50	22,50	22,50	36,80	36,80	36,80
	Total monthly labour cost ®	28656	19063	16424	16424	10543	10543	10543	0
	Monthly labour cost (R/t)	202,67	134,82	116,16	116,16	116,16	74,57	74,57	74,57
	Drilling Cost/tonne (R/t)	108,63	80,77	61,85	63,62	64,69	51,61	51,60	51,58
	Blasting Cost/tonne (R/t)	18,38	18,38	18,38	18,38	18,38	18,38	18,38	18,38
	Charging Cost/tonne (R/t)	18,38	18,38	18,38	18,38	18,38	18,38	18,38	18,38
	Support Cost/tonne (R/t)	6,54	8,44	6,03	6,03	6,03	5,28	5,28	5,28
	Cleaning Cost/tonne (R/t)	12,54	12,54	12,54	12,54	12,54	12,54	12,54	12,54
	Tramming Cost/tonne (R/t)	7,96	5,30	3,78	3,78	3,78	3,78	3,78	3,78
	Sundry Cost/tonne (R/t)	119,50	119,50	119,50	119,50	119,50	119,50	119,50	119,50
	Total monthly Cost (R/t)	**494,61**	**398,14**	**356,63**	**358,40**	**359,47**	**304,05**	**304,04**	**304,01**
PRODUCTION TOTAL MINE / MONTH		**B1**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Production	Monthly Production Tonnes	53 000	79 674	111 543	111 543	111 543	127 478	127 478	127 478
	m^2	11 916	17 912	25 077	25 077	25 077	28 660	28 660	28 660
	Crews	49	49	49	49	49	49	49	49
	Ca per crew	243,17	365,56	511,78	511,78	511,78	584,89	584,89	584,89
	Kg / month	275,69	414,43	580,21	580,21	580,02	663,09	663,09	662,89
	Oz / Month	8 863,58	13 324,34	18 654,08	18 654,08	18 648,23	21 318,95	21 318,95	21 312,26

Time study drilling

Table 37 indicates the drilling parameters.

Table 37 Time study drilling

	PARAMETERS	B1	Pneumatic	Electric	Hydraulic
Drilling Cycle	Penetration Rate (Quartzite) (m/min)	0,30	0,30	0,78	1,3
	Hole length (m)	1,05	1,05	1,05	1,05
	Time to drill one hole (mins)	3,55	3,55	1,35	0,81
	Non-drilling time per hole (min)	2	2	3	2
	Total time taken per hole (min)	5,55	5,55	4,35	2,81
	Number of holes drilled per hour	11	11	14	21
	Number of holes(panel)	141	141	141	141
	The time required to complete all holes (hours)	13	13	10	7
	Number of drills required	2,90	2,90	2,27	1,47
	Actual number of drills required for panel	**3,00**	**3,00**	**3,00**	**2,00**
	Holes drilled per machine	47,02	47,00	47,00	70,53
	Total drilling time - hrs	4,35	4,35	3,41	3,30
	Total drilling time - min	261	261	204	198
	Total drilling time (hrs)	4:20:55 AM	4:20:55 AM	3:24:22 AM	3:18:02 AM

Drilling cost

Table 38 indicates the drilling cost per ton.

Table 38 Drilling cost

Item	Parameter (unit)	B1	S1	S2	S3	S4	S5	S6	S7
Lubrication	Consumption of grease (l/day/drill)	0,5	0,5	0,5	0,1	0,20	0,5	0,1	0,2
	Cost of lubrication (R/l)	20,00	20,00	20,00	20,00	20,00	20,00	20,00	20,00
	Lubrication cost per drill machine (R)	10,00	10,00	10,00	2,00	4,00	10,00	2,00	4,00
	Lubrication cost per panel per day	60,00	60,00	60,00	12,00	24,00	60,00	12,00	24,00
	Lubrication cost per month/ panel	**459,00**	**690,00**	**966,00**	**193,20**	**386,40**	**11,04**	**2,21**	**4,42**
	Lubrication cost per ton	**0,42**	**0,42**	**0,42**	**0,08**	**0,17**	**0,00**	**0,00**	**0,00**
Drill Bit	ROTARY TYPE DRILL BITS AND STEMS R32 COUPLING (R)	319,61	319,61	519,61	320,61	320,61	320,61	320,61	320,61
	Total number of metres drilled per machine per month (m)	226,62	340,67	476,94	476,94	476,94	5,45	5,45	5,45
	Life of a drill bit (m)	113,00	113,00	113,00	113,00	113	113,00	113,00	113,00
	Number of times drill bit will be replaced per month per machine	2,01	3,01	4,22	4,22	4,22	0,05	0,05	0,05
	Cost of drill bit per month in panel(R)	3204,90	4817,82	10965,69	6766,06	6766,06	77,33	77,33	77,33
	Total metres drilled in ASG per month (m)	218,03	327,75	524,40	458,85	458,85	524,40	524,40	524,40
	Number of time drill bit will be replaced monthly	1,93	2,90	4,64	4,06	4,64	4,64	4,64	4,64
	Cost of drill bit per month in ASG (R)	616,66	927,01	2411,36	1301,88	1487,86	1487,86	1487,86	1487,86
	Total monthly drill bit cost in panel (R)	**3 821,56**	**5 744,83**	**13 377,05**	**8 067,93**	**8 253,91**	**1 565,18**	**1 565,18**	**1 565,18**
	Total monthly drill bit cost per ton (R)	**3,53**	**3,53**	**5,88**	**3,54**	**3,63**	**0,60**	**0,60**	**0,60**
Drill Steel	Cost of drill steel	783,76	783,76	1183,76	1083,12	1083,12	1083,12	1083,12	1083,12
	Life of a drill steel (m)	197,00	197,00	197,00	197,00	197	197,00	197,00	197,00
	Total number of metres drilled per machine per month	226,62	340,67	476,94	476,94	476,94	545,08	545,08	545,08
	Number of times drill steel will be replaced per month per panel machine	1,15	1,73	2,42	2,42	2,77	2,77	2,77	2,77
	Drill bit cost per month for panel (R)	4 508	6 777	14 330	13 111	14 984	14 984	14 984	14 984
	Total number of metres drilled per machine per month in ASG	218,03	327,75	524,40	458,85	524,4	524,40	524,40	524,40
	Number of times drill steel will be replaced per month per asg machine	1,11	1,66	2,66	2,33	2,66	2,66	2,66	2,66
	Drill bit cost per month for ASG (R)	867	1 304	3 151	2 523	2883	2 883	2 883	2 883
	Panel drill steel cost (R)	**5 375**	**8 081**	**17 080**	**15 634**	**17 868**	**17 867**	**17 868**	**17 868**

Item	Parameter (unit)	B1	S1	S2	S3	S4	S5	S6	S7
	Panel drill steel cost/ton (R)	**4,97**	**4,97**	**7,68**	**6,87**	**7,85**	**6,87**	**6,87**	**6,87**
Energy	Energy required kWh	63,10	63,10	1,8	20	20	20	20	20
	Time machine is in operation (hours)	4,35	4,35	3,41	3,41	3,30	4,35	3,41	3,30
	Drilling energy per machine	274,41	274,41	6,13	68,12	66,01	86,97	68,12	66,01
	Panel drilling energy per shift	1 372,03	1 372,03	30,65	340,61	330,06	434,87	340,61	0,00
	Time spent drilling in ASG	2,64	2,64	2,64	2,64	2,64	2,64	2,64	2,64
	ASG drilling energy per shift (kWh)	166,32	166,32	4,74	52,72	52,72	52,72	52,72	52,72
	Mega-flex cost per KW (R)	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99
	Total energy cost per shift (R)	1 522,96	1 522,96	35,05	389,39	378,95	482,71	389,39	52,19
	Total energy cost per month	**11 651**	**17 514**	**564**	**6 269**	**6 101**	**8 882**	**7 165**	**960**
	Total energy cost per month	**10,77**	**10,77**	**0,25**	**2,75**	**2,68**	**3,41**	**2,75**	**0,37**
Pumping Energy	Pumping energy kWh/m	0,14	0,14	0,07	1,07	1,07	1,07	1,07	1,07
	Total pumping energy/shift (kWh)	24,73	24,73	12,36	188,98	188,98	188,98	188,98	188,98
	Total energy pumping energy costs/ shift ®	24,48	24,48	12,24	187,09	187,09	187,09	187,09	187,09
	Total energy pumping energy costs/ month ®	**187,27**	**281,51**	**197,06**	**3012,19**	**3012,19**	**34,43**	**34,43**	**34,43**
	Total energy pumping energy costs/ month ®	**0,17**	**0,17**	**0,09**	**1,32**	**1,32**	**0,01**	**0,01**	**0,01**
Total Energy	**Total energy costs (R)**	**1 183**	**17 796**	**761**	**9 281**	**9 113**	**89,16**	**71,99**	**9,95**
	Cost/tonne energy cost (R/t)	**10,94**	**10,94**	**0,33**	**4,08**	**4,00**	**0,00**	**0,00**	**0,00**
Water Usage	Water usage (l/s)	0,13	0,13	0,13	0,13	0,13	2,30	2,30	2,30
	Total drilling time per drill machine in panel face area (s)	15 655	15 655	12 262	12 262	11 882	15 655	12 262	11 882
	Water usage per shift (Kl)/drill machine	2,04	2,04	1,59	1,59	27,33	36,01	28,20	27,33
	Rate of water (Rand water) (R/kl)	12,35	12,35	12,35	12,35	12,35	12,35	12,35	12,35
	Water costs/ machine per shift (R)	25,13	25,13	19,69	25,13	25,13	25,13	25,13	25,13
	Total water costs per shift in panel face area (R)	150,81	150,81	118,12	150,78	150,78	150,78	150,78	150,78
	Total drilling water costs per month (R)	**1153,69**	**1734,31**	**1901,71**	**2427,56**	**2427,56**	**2774,35**	**2774,35**	**2774,35**
	Water Cost/tonne (R/t)	**1,07**	**1,07**	**0,84**	**1,07**	**1,07**	**0,01**	**0,01**	**0,01**
Maintenance of the drill machine	Maintenance cost (R/m2)	3,52	3,52	5,63	6,63	**663%**	6,63	6,63	6,63
	Centares achieved per blast (m2)	30,00	30,00	30,00	30,00	30,00	3000,00	3000,00	3000,00
	Drill machine maintenance cost (panel) (R)	633,60	633,60	1013,40	1193,40	1193,40	119340,00	119340,00	119340,00
	Total maintenance cost per month (R)	**4 847,04**	**7 286,40**	**16 315,74**	**19 213,74**	**19 213,74**	**21 958,56**	**21 958,56**	**21 958,56**
	Cost/tonne maintenance cost (R/t)	**4,48**	**4,48**	**7,17**	**8,44**	**8,44**	**8,44**	**8,44**	**8,44**
	Total number of RDOS required	6	6	6	6	6	6	6	6
	RDO cost per month (R)	**90 000**	**90 000**	**90 000**	**90 000**	**90 000**	**90 000**	**90 000**	**90 000**
Total monthly cost (R)		**117 495**	**131 332**	**140 802**	**144 818**	**147 262**	**134 266**	**134 240**	**134 180**
Panel Monthly drilling cost per tonne (R/t)		**108,63**	**80,77**	**61,85**	**63,62**	**64,69**	**51,61**	**51,60**	**51,58**

Charging cost

Table 39 indicates the charging parameters and cost per ton.

Table 39 Charging cost

	B1	S1	S2	S3
Parameter (units)	**Value**	**Value**	**Value**	**Value**
Charge Weight/Hole (kg)	0,65	0,65	0,65	0,65
Number of holes/Panel	160	160	160	160
Explosives/Panel (kg)	104	104	104	104
Explosives Cost/kg	R14,05	R14,05	R14,05	R14,05
Explosives Cost/Panel (R)	**1 461,80**	**1 461,80**	**1 461,80**	**1 461,80**
Shock tubes (R/m)	R5,23	R5,23	R5,23	R5,23
Shocktubes cost per panel	R923,72	R923,72	R923,72	R923,72
Stemming cost per panel	R213,71	R213,71	R213,71	R213,71
Accessories Cost/Panel	**R1 137,43**	**R1 137,43**	**R1 137,43**	**R1 137,43**
Blasting Cost/panel	**R2 599,23**	**R2 599,23**	**R2 599,23**	**R2 599,23**
Monthly blasting cost/panel	**R19 884**	**R19 884**	**R29 891**	**R41 848**
Monthly blasting cost R/t	R18,38	R18,38	R18,38	R18,38

Support cost

Table 40 indicates the support parameters and cost per ton.

Table 40 Support cost

Item	Parameter (unit)	Baseline 1	S1	S2	S3	S4	S5	S6	S7
Sticks	Number of sticks in a row	19,00	19,00	19,00	19,00	19,00	19,00	19,00	19,00
	Number of rows installed per blast	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
	Number of sticks installed per advance	9,50	9,50	9,50	9,50	9,50	9,50	9,50	9,50
	Amount spent on sticks per blast	**2090,00**	**2090,00**	**2090,00**	**2090,00**	**2090,00**	**2090,00**	**2090,00**	**2090,00**
	Cost per Ton	**1,93**	**1,29**	**0,92**	**0,92**	**0,92**	**0,80**	**0,80**	**0,80**
Props	Number of props in a row	0,00	19,00	19,00	19,00	19,00	19,00	19,00	19,00
	Number of rows installed per blast	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
	Number of props installed per advance	0,00	9,50	9,50	9,50	9,50	9,50	9,50	9,50
	Amount spent on props perblast	**0,00**	**6650,00**	**6650,00**	**6650,00**	**6650,00**	**6650,00**	**6650,00**	**6650,00**
	Cost per Ton	**0,00**	**4,09**	**2,92**	**2,92**	**2,92**	**2,56**	**2,56**	**2,56**
Bolts	Number of bolts in a row	22,00	22,00	22,00	22,00	22,00	22,00	22,00	22,00
	Number of rows installed per blast	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	Number of bolts installed per advance	22,00	22,00	22,00	22,00	22,00	22,00	22,00	22,00
	Unit cost of bolts	55,80	55,80	55,80	55,80	55,80	55,80	55,80	55,80
	Amount spent on bolts perblast	**1227,60**	**1227,60**	**1227,60**	**1227,60**	**1227,60**	**1227,60**	**1227,60**	**1227,60**
	Cost per Ton	**1,13**	**0,75**	**0,54**	**0,54**	**0,54**	**0,47**	**0,47**	**0,47**
Resin	Number of resin capsules required per blast	44,00	44,00	44,00	44,00	44,00	44,00	44,00	44,00
	Cost of resin box (16 capsules)	286,47	286,47	286,47	286,47	286,47	286,47	286,47	286,47
	Cost of each resin capsule	17,90	17,90	17,90	17,90	17,90	17,90	17,90	17,90
	Amount spent on resin per blast	**393,90**	**393,90**	**393,90**	**393,90**	**393,90**	**393,90**	**393,90**	**393,90**
	Cost per Ton	**0,36**	**0,24**	**0,17**	**0,17**	**0,17**	**0,15**	**0,15**	**0,15**
Grout packs	Grout bag cost	635,49	635,49	635,49	635,49	635,49	635,49	635,49	635,49
	Grout pack bags required in 1 grout pack support	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00
	Grout bag cost per pack	1906,47	1906,47	1906,47	1906,47	1906,47	1906,47	1906,47	1906,47
	Cost of grout (R/m3)	1014,80	1014,80	1014,80	1014,80	1014,80	1014,80	1014,80	1014,80
	Volume of grout required for 1 pack	0,64	0,64	0,64	0,64	0,64	0,64	0,64	0,64
	Cost of grout per grout pack support	649,47	649,47	649,47	649,47	649,47	649,47	649,47	649,47
	Total cost of 1 grout pack	2555,94	2555,94	2555,94	2555,94	2555,94	2555,94	2555,94	2555,94
	Timber suport required	249,27	249,27	249,27	249,27	249,27	249,27	249,27	249,27

	Cost of grout per grout pack support inluding timber	2805,21	2805,21	2805,21	2805,21	2805,21	2805,21	2805,21	2805,21
	Number of grour packs required per rowl	6,00	6,00	6,00	6,00	6,00	6,00	6,00	6,00
	Number of rows of packs required per blast	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20
	Total number of packs required per blast	1,20	1,20	1,20	1,20	1,20	1,20	1,20	1,20
	Cost of packs per blast	**R3 366**	**R3 366**	**R3 366**	**R3 366**	**R3 366**	**R3 366**	**R3 366**	**R3 366**
	Cost per Ton	**R3**	**R2**	**R1**	**R1**	**R1**	**R1**	**R1**	**R1**
	Total support cost (R/blast)	**R7 078**	**R7 078**	**R7 078**	**R7 078**	**R7 078**	**R7 078**	**R7 078**	**R7 078**
Total support cost per month		**R346 810**	**R346 810**	**R346 810**	**R346 810**	**R346 810**	**R346 810**	**R346 810**	**R346 810**
Panel Monthly support cost per tonne (R/t)		**R6,54**	**R8,44**	**R6,03**	**R6,03**	**R6,03**	**R5,28**	**R5,28**	**R5,28**

Cleaning cost

Table 41 indicates the cleaning parameters and cost per ton.

Table 41 Cleaning cost

Stope Panel		**Scraper**	**Waterjet Cleaning**
Parameter (units)	**Description**	**Value**	**Value**
in-situ volume (m3)		39,0	39,0
Swell factor (%)		0,3	0,3
Volume broken rock (m3)		50,7	50,7
Mass (m)	V x p	108,5	108,5
Density broken rock (t/m3)		2,14	2,14
Scraper capacity (t)		0,75	1,15
Scoop fill factor (%)		0,8	0,8
Mass per trip (t)	m x fill factor	0,6	0,9
Trips required	m/mass per trip	180,8	117,9
Winch rope speed (m/s)		1,0	2,0
Digging time (s)		5,5	5,5
Time to ASG (s)	Face length/rope speed	31,6	31,6
Time modification (%)		0,1	0,1
Time up the face (s)		28,7	14,4
Total trip time (s)		65,8	51,5
Tons per hour (tph)	tons per trip/trip time	32,8	50,0
Face cleaning time (hrs)		**3,3**	**2,2**
Face cleaning time (min)		198,2	130,2
ASG			
In-situ volume (v)	h x w x adv	3,4	3,4
Mass (t)		9,5	9,5
Swell factor (%)		0,3	0,3
Volume broken rock (m3)	V	4,5	4,5
Density broken rock (t/m3)	p	2,1	2,1
Rock mass (t)	V x p	9,5	9,5
Gully length (m)		90,0	90,0
Total tons (t)	ASG tons + Panel tons	118,0	118,0
Scraper capacity (t)		2,3	2,3
Fill factor (%)		0,8	0,8
Tons per scraper scoop (t)	scoop capacity x fill factor	1,8	1,8
Rope speed (m/s)		1,0	1,0
Empty scraper trip time (s)	gully length/rope speed	90,0	90,0
Time allowance (%)		0,1	0,1
Loaded scraper trip time (s)	gully length/rope speed x (1.1)	99,0	99,0
Turning (digging time) - (s)	5sec + time allowance	5,5	5,5
Overall trip time (s)		194,5	194,5
Tons per hour (tph)	[tons per trip/overall trip time] x 3600s/1hr	33,3	33,3
Gully cleaning time (hrs)	**total tons/tph**	**3,5**	**3,5**
ASG cleaning time (min)		212,6	212,6
Total Cleaning time (gully + face) - (hrs)		**6,8**	**5,7**
Total Cleaning time (gully + face) - (min)		**411**	**343**
Effective face time - (hrs)		**6,1**	**6,1**
Time difference - (hrs)		**-0,7**	**0,4**
Ropes and Snatchblocks	Cost of rope	783,76	0,00
	Life of a rope (m)	197,00	197,00
	Total number of metres cleaned per month	660,10	298,60
	Number of times rope will be replaced per month per panel machine	1,30	0,00
	Rope cost per month for panel (R)	1 222 666	0,00
	Total number of ropes per month in ASG	1,00	6,10
	Number of times rope will be replaced per month per ASG winch	0,01	0,03
	Drill bit cost per month for ASG (R)	3,98	0,00

	Panel rope cost (R)	**R1 222 666**	**0,00**
	Panel rope cost / ton (R/t)	**R10**	**R0**
Energy	Energy required kWh	63,10	500,00
	Time machine is in operation (hours)	0,02	0,02
	Cleaning energy per machine	1,19	9,42
	Panel cleaning energy per shift	21 391	169 500,00
	Time spent cleaning in ASG	2,64	2,64
	ASG cleaning energy per shift (kWh)	166,32	1 317,89
	Total energy cost per shift (R)	21 557	170 817,89
	Total energy cost per month	**R16 168**	**R128 113**
	Total energy cost per ton	**R0,13**	**R1,01**
Pumping Energy	Pumping energy kWh/m	0,14	0,34
	Total pumping energy/shift (kWh)	0,16	0,38
	Number of panels	118	118
	Total energy pumping energy costs/ shift	2,60	15,36
	Total energy pumping energy costs/ month	**R1,95**	**R11,52**
Water	Water usage (l/s)	0,03	0,33
	Total cleaning time per panel face area (s)	411	343
	Water usage per shift (Kl)/machine	0,01	0,11
	Rate of water (Rand water) (R/kl)	12,35	12,35
	Water costs/ machine per shift (R)	0,15	1,40
	Total water costs per shift in panel face area (R)	0,91	17,52
	Total cleaning water costs per month (R)	**R1,01**	**R19,45**
	Water Cost/tonne (R/t)	**R0,84**	**R16,21**
Cost/Ton		**R12,54**	**R28,73**

Tramming cost

Table 42 indicates the tramming parameters and cost per ton.

Table 42 Tramming cost

	REEF	**WASTE**
Max current tramming distance (ONE WAY)	1500	1500
Relative density of reef (mined width)	4	3,1
Hopper factor - (Tons per Hopper)	3,5	3,5
Average tramming speed kph	6	6
Hoppers per loco - AVERAGE	10	10
Loco amounts - MIXED	3	1
Hopper loading time - mins	2	6
Hopper discharge time - mins	1	1
Trip length (m)	3000	3000
Trip time (hours)	1,00	1,67
Tramming shift length (hours)	8,5	8,5
Tramming shifts per day	2	1,5
Equipment utilisation	70%	70%
Average tramming time per DAY - hours	8,33	6,2
Trips per day per loco	8,33	3,7
Total trips per day	24,99	3,7
Total hopper per day	249,9	37,5
Total tons per day	874,7	131,2
Required tramming rates (tons per day)	848	85
	Loco - S1	**Endless Rope**
Capital per half-level	**R 2 000 000**	**R 7 500 000**
Loco amounts - MIXED	16	1
Number -Labour	35	15
Labour Costs	352000	150000
Operating cost	40000	30000
Maintenance cost	30000	100000
Total Costs	422000	280000
Cost per ton	**7,96**	**23,20**

7.2 FINANCIAL EVALUATIONS

Table 43 and Figure 7 indicates the summary of the different scenarios.

Table 43 Financial Evaluations

Financial evaluation of Scenario:	**5**	**Pneumatic**		
Cycle mining (one crew two panels) - one blast per day				
			Totals	**Inputs**
Gold Price	Real	R/kg		961 990
Production				
Tons Milled		T	45 892 060	1 529 735
Recovery Grade	0,75	g/t		3,90
Kilograms produced		Kgs	179 035	
Gold Oz		Oz	5 756 116	
Cost				
Operating cost (Base Excl. Drilling cost)	Real	R/t	11 585	252,44
Drilling cost	Real	R/t	2 368	51,61
Total working cost (excl Royalties)	Real	R mil	13 953	304,05
Cost per kilogram (excl Royalties)	Real	R/kg		77 936
Working Revenue	Real	R000	172 230	
Working profit/(loss)	Real	R000	158 277	
Royalty ((EBIT/Gross sales*12.5) ((EBIT/Gross sales*12.5)*100				
Royalty		R mil	8 612	
Financial Evaluation (Real terms)				
Revenue	R000		172 230	
Working costs	R000		13 953	
Working profit/(Loss)	R000		158 277	
Royalties	R000			
Ongoing capital	R000		837	
Project capital	R000		0	
Pre-Tax Net Cash Flow	R000		148 828	
Pre-Tax Cumulative Cash Flow				
Tax Calculation:				
Taxable Income	R000			34,00
X Ratio (taxable income/total revenue)				170,00
Y Tax Rate	%			
Tax Payable	R000			
After-Tax Net Cash Flow	R000		101 154	
Discounted Cash Flow	6,00%			
Financial Analysis				
Discount Rate	Real	5,0%	7,5%	10,0%
Pre-Tax NPV - R000	Real	76 262	58 591	46 766
Pre-Tax IRR	Real	#NUM!	#NUM!	#NUM!
Payback	Years	0		
CAPITAL REQUIREMENT	**Total**	**JHH**	**Tramming**	
Cost / Machine	5 510 072	10 072	5 500 000	
No of additional Machines	49	49	0	
Total Cost of drill equipment	R493 528,00	R493 528,00	R0,00	
Inflate Cost 2018	R554 528,06	R554 528,06	R0,00	
Total Capital	**R1 048 056,06**	**R1 048 056,06**	**R0,00**	

The graphs in Figure 6 indicates the square metres, tons, cost per ton per activity, and the revenue, cost, cash flow, and NPV for the baseline and scenarios 1 to 7.

The best result is scenario 5.

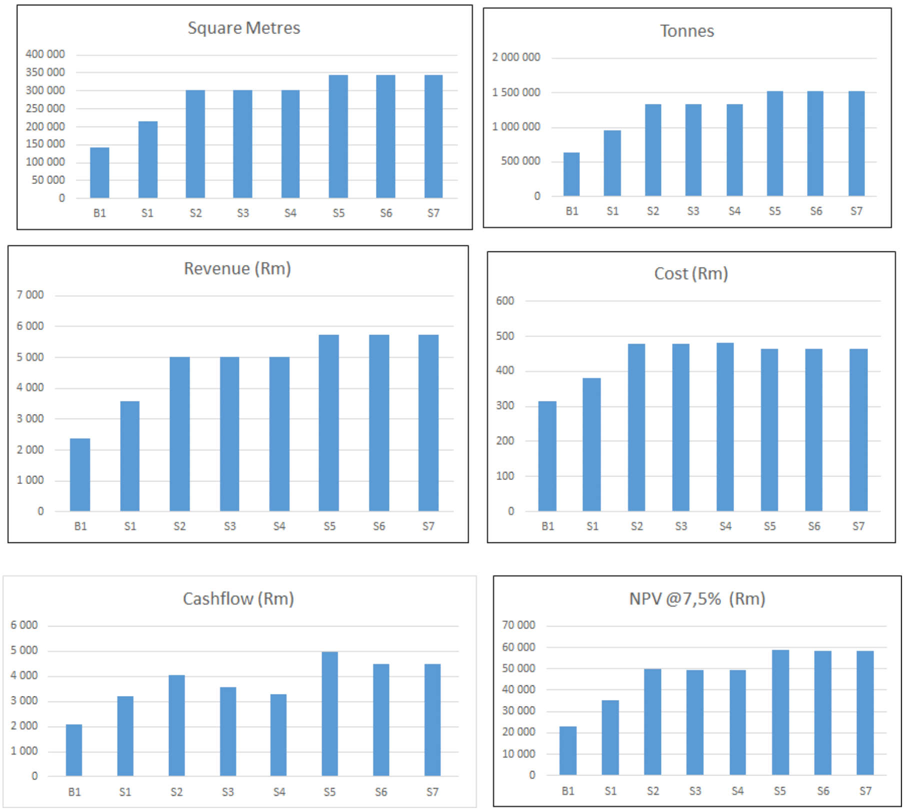

Figure 7 Summary of the baseline and scenarios

7.3 CONCLUSIONS FROM MILESTONE

The following conclusions were made of the objectives during the work done:

This exercise was done on a fixed number of panels to be mined, but when shaft capacities are taken into the consideration, the results may be different, because the panels to be mined will be different.

The labour cost is the highest contributing factor to the cost, from MDP labour cost is the highest.

The stoping cycle was discussed in this article but the same principle can be applied to the development cycle. The improvement of the development meters per half-level is important because ore-reserves must be maintained throughout the life of the Mine.

The stoping cycle was discussed in this article but the same principle can be applied to the development cycle. The improvement of the development meters per half-level is important because ore-reserves must be maintained throughout the life of the Mine.

7.4 RECOMMENDATIONS

The stoping activities as a combination cannot be completed in an eight-hour shift and it is recommended to adopt a new shift system, to ensure that the stoping cycle is completed in a shift.

8 SUMMARY OF OVERALL PROJECT

8.1 FINDINGS FOR THE PROJECT

The long travelling time, waiting place procures, making safe, installation of temporary support, and nets still take up a lot of time in the stoping cycle and the cycle still cannot be completed in an eight-hour shift. The introduction of new technology does not bring the total shift time significantly, due to the abovementioned factors.

8.2 CONCLUSIONS

The following conclusions were made of the objectives during the work done:

To reduce the stoping cycle on the panel; the stoping activities must be split to ensure the completion of the mining cycle daily for an improved stoping operation. This split will ensure that the quality and quantity of work output will be met.

The stoping cycle was discussed in this article but the same principle can be applied to the development cycle. The improvement of the development meters per half-level is important because ore-reserves must be maintained throughout the life of the Mine.

8.3 RECOMMENDATIONS

The stoping activities as a combination cannot be completed in an eight-hour shift and it is recommended to split the stoping crew to work on 2 panels, to ensure that the stoping cycle is completed in a shift.

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APPENDIX 1

BLUEPRINT COST MODEL

Production cycle Blue Prints cost (updated).xlsx