The design and implementation of the Top of Block 4 (TOB 4)/Bop resource at Finsch Mine (a division of Central Mines)

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Synopsis

The purpose of this study is to establish whether to mine the Bottom of Pit (BOP)/TOB 4 reserve before the commencement of the Block Cave or whether this should be disregarded and the reserve be extracted at the end of the life of the Cave. The primary goal of this report is to investigate and propose a practical mining method to safely extract the reserve given the set constraints. This report quantifies the additional revenue the TOB 4 will contribute to Finsch's overall NPV thus enhancing Finsch's business case and strategically enhancing the SBP.

Several underground mining options have been investigated. The proposed mining method includes the installation of a series of extraction tunnels below the TOB 4 reserve from 53 level, with a slot access tunnel system. Ground will be loaded by LHDs from the drawpoints and tipped into 50-ton dumptrucks at a transfer point, from there the ground will be transported to 53 level No. 1 groundpass where it will join the existing ground-handling system.

Primary development is scheduled to begin October 2002 and last for a period of approximately 7 months until early April 2003. The production is broken into 4 phases. Phase 1 is scheduled to begin mid-April 2003. The final production phase will be completed by November 2005. The production scheduling has been designed in order to remain ahead of the Block 4 undercut in order to ensure stability and safety.

Due cognisance was taken of the health and safety of all employees concerned during the design of the mining and ground-handling processes for the Bottom of Pit. As far as is reasonably practicable, the BOP was designed and will be constructed and equipped to provide conditions for the safe operation of machinery and a healthy working environment for people underground. Relevant requirements of the Mine Health and Safety Act regulations pertaining to mining operations have been identified and adhered to during all phases of the design process.

Scope

Overview and vision

The need for alternative and additional resources has become apparent over the past months. Finsch Mine has been placed under pressure to increase production and to achieve and exceed the set production targets. There are two possible avenues to explore. The possible sources of extra resources may come from the precursor and the extension of Top of Block 4 ore pile, whereby it is estimated that over 2.4 million tons of kimberlite is situated.

The Top of Block 4 is a result of the open blast hole stoping mining method employed at Finsch Mine. For each blast ring designed on the various mining levels, there are geological parameters of lithology, density and grade. However, once blasted, the ground loses its identity due to both vertical and lateral migration to the bottom of the pit. Over the years, material has accumulated at the bottom of the pit on 510 m level as well as on berms on 430 m level, creating a huge stockpile. While attempts have been made to deplete this stockpile through introduction of remote loading, this has not been adequate to make a significant impact on the size of the stockpile.

A project was initiated and implemented in 2001 to mine the Top of Block 4 reserve before the commencement of the Block 4 Block Cave and not to leave the ore to be extracted at the end of the life of Block 4 in 2012–2014 when the reserve will have a 70% dilution with dolomite.

This ore would represent a significant addition to revenue and contributes to the extension of the life of Finsch Mine. In doing this, we shall endeavour to maintain Finsch Mine as the leader in the De Beers group in terms of management and technology.

Objectives

Motivation for this project comes from several areas. Of primary importance is the need to increase the NET Present Value of the Strategic Business Planning, which would be approximately R140 000 000.

The objective of this project would be to extend the current mining method and to safely and cost effectively extract the Top of Block 4 reserve given the set constraints. In achieving the said objective, the additional revenue from the BOP reserve will contribute to Finsch's overall NPV thus enhancing Finsch's business case and strategically enhancing the SBP.

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Purpose

The purpose of this document is to state the mining method that can be used to mine the Top of Block 4, so as to put in place the current mining method that would optimally, safely and cost effectively satisfy these requirements.

Reasons for the project

At the beginning of 2000, Finsch Mine was asked to explore and produce from other available avenues to increase production as the Block 4 project was behind schedule. This resulted in Finsch Mine initiating the extension of TOB 4 reserve as a project to optimize current mining.

The decision to mine the TOB 4 reserve before the commencement of Block 4 was made for the following reasons, which were highlighted in the Top of Block 4 (BOP) feasibility study conducted in 2000–2001.

Dolomite dilution

During the Block 4 feasibility study, investigations by independent consultants and on-mine personnel suggested that the dolomite sidewalls will ravel back to a stable angle as the sidewalls are exposed by the depletion of the mining blocks. This would cause large volumes of waste to report to the bottom of the pit. From block caving experience, it is highly unlikely that this will remain clean waste ,and through the mining of the Block Cave this waste will be mixing with the kimberlite and will result in low-grade ore. The ore that will be extracted only at the end of the life of Block 4 in 2012–2014 will have a 70% dilution with dolomite. Mining the TOB 4 (BOP) tons before the commencement of the Block Cave will optimize resource management by preventing dolomite dilution of the resource.

Production increase

Mining of the TOB 4 (BOP) tons will allow for an increase in Block 3 production in the short term and contribute to Finsch achieving its production targets.

Block 3/4 interface

Mining of the TOB 4 (BOP) reserve before the commencement of Block 4 will ensure the smooth interfacing of the current blast hole open stoping and Block 4 Block Cave at increased output levels. It will also alleviate pressure and provide some form of flexibility should problems be experienced during cave propagation.

Opportunities

- Improve the NPV of the Strategic Business Planning
- It will alleviate pressure and provide some form of flexibility should problems be experienced during Block 4 Cave propagation.
- Optimize resource management by preventing dolomite dilution of the resource.
- Allow for an increase in tonnage in the short term and contribute to Finsch Mine achieving its set production targets.
- Provide an excellent opportunity to climb up the learning curve and, upon successful completion, the experience could be shared with other operations.
- Fast tracking of machines as they will be used again for the block cave operation.

Project execution

Phased approach

This project should be broken down into a series of phases. This approach allows the total project to be broken down in to manageable stages, and permits focus on each task, ensuring that specific objectives and deliverables are achieved before the next phase commences. It is envisaged that this project be handled in two phases:

- Development phase
- Production phase.

Acronyms, abbreviations and definitions acronyms and abbreviations

TOB 4	Top of Block 4
BOP	Bottom of Pit
NPV	Net Present Value
SBP	Strategic Business Plan
CPHT	Carats per Hundred Tons
BHAG	Big Hairy Audacious Goal
IRR	International Rate of Return
UBS	Underground Bulk System
R&M	Repair and Maintenance

Current mining methods

Underground production at Finsch started in 1991 using the blast hole open stoping method. Block 1, now depleted, was mined utilizing the blast hole open stoping method and Blocks 2 and 3 are presently being mined in this manner and will be depleted in 2006. Production from Block 4 by means of a mechanized block cave was to begin in 2003. Consisting of 282 drawpoints, the block cave will produce approximately 36 million tons over 14 years at an average production rate of 3.6 million tons per annum, yielding some 13.4 million carats.

The extraction level for the block cave will be sited on 630 metre level elevation (63 Level). The undercut level will be sited 20 metres above the extraction level on the 610 metre level elevation (61 Level).

Undercutting was to begin at an accelerated rate in 2002 until such stage as the hydraulic radius has been achieved. Thereafter it will continue at a normal rate until completion in approximately 2014.

Ground-handling will be by means of LHDs tipping directly into dump trucks near the orebody. The dump trucks will tram the ore to a gyratory crusher situated at the shaft, whereafter the ore will be conveyed to the present storage passes on 65 Level.

With the current blast hole open stoping method of mining in Blocks 2 and 3, blasted ground is left behind on the 510 metre level elevation (51 Level), which is inaccessible from the drawpoints on 51 Level. Currently this blasted ground amounts to approximately 2 million tons and will increase as the mining of Blocks 2 and 3 progresses.

In the past strategic business plan the TOB 4 tons were planned to be mined in Block 4, and it was be assumed that the TOB 4 tons will only be mined throughout the final two years of the block cave between 2012 and 2014 at a 70% dolomite dilution.

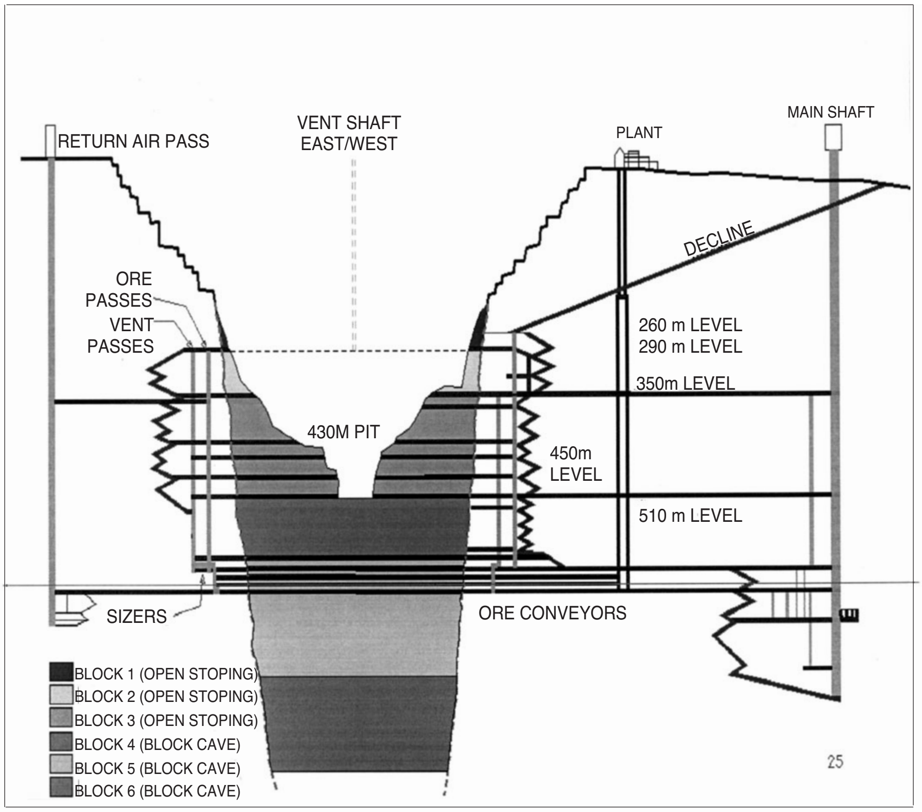


Figure 1—Finsch Mine: diagrammatic section

Resource characteristics

There are approximately 2 685 424 tons of ore currently broken in the pit and this figure is continuously increasing. Approximately 43% of it is lying on 43 Level, while the remaining 57% is on 51 Level elevation. It is assumed that the grade is 43 cpht recoverable. This yields a total proven reserve of 1 103 708 carats.

The certainty regarding this estimate is quite high, since most of the information has been known and accepted for a long time. To achieve the average grade, one must simply calculate a weighted average of those unloaded tons that have been carried forward throughout underground operations at Finsch. The tons are reconciled and calculated monthly by the survey department. There is still room for a limited degree of uncertainty, however, it is low as we can simply assume that the grade is at an inferred level of confidence.

Mining design

Preliminary selection of a mining method

During 2000 Finsch Mine was asked to increase its underground production as part of the De Beers BHAG initiative. This resulted in Finsch looking at additional resources such as the TOB 4 reserve to optimize their current mining. The decision to propose the mining of the TOB 4 reserve before the commencement of Block 4 was made for the following reasons:

During the Block 4 feasibility study, investigations by independent consultants and on-mine personnel suggested that the dolomite sidewalls will fall back to a stable angle as the sidewalls are exposed by the depletion of the mining blocks. This would cause large volumes of waste to report to the bottom of the pit. From block caving experience, it is highly unlikely that this will remain clean waste and through the mining of the Block Cave this waste will mix with the kimberlite and will result in low-grade ore. The ore that will only be extracted at only the end of the life of Block 4 in 2012–2014 and will have a 70% dilution with dolomite.

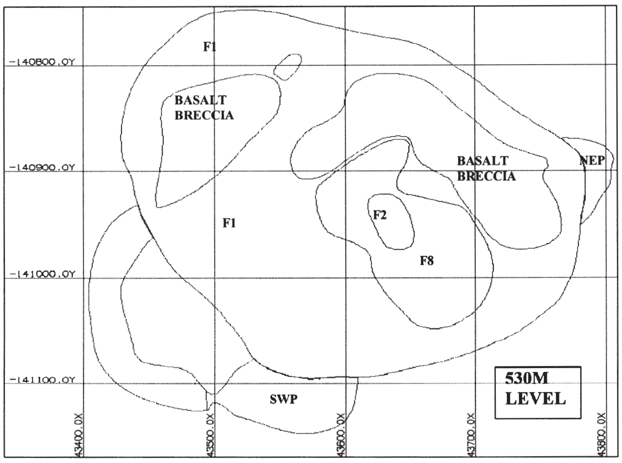


Figure 2

Mining the TOB 4 tons before the commencement of the Block Cave will optimize resource management by preventing dolomite dilution of the resource.

Mining of the TOB 4 tons will allow for a ramp-up in Block 3 production in the short term and contribute to Finsch achieving its growth targets.

Mining of the TOB 4 reserve before the commencement of Block 4 will ensure the smooth interfacing of the current blast hole open stoping and Block 4 Block Cave at increased output levels. It will also alleviate pressure and provide some form of flexibility should problems be experienced during cave propagation.

The decision resulted in various alternative mining methods being investigated through a technical study making use of in-house experience and taking cognisance of all constraints. The following options were investigated in the technical study:

- Remote LHDs
- Scraper
- Remote dozer in combination with remote LHDs
- Underground mining option.

These options were strategically investigated and the underground mining option was selected for the following principle reasons:

- Safest method of all investigated, as no person needs to enter the pit during the whole mining operation
- Yields the highest NPV, IRR and the shortest payback period of all options
- Utilizes existing infrastructure
- Lower capital expenditure
- Ensure minimum interference with the current mining operations of Blocks 2 and 3
- Internal and external failures currently experienced may increase to such an extent that the continued mining of Block 3 by blast hole open stoping method would become unfeasible. An underground mining layout situated below 51 Level would be a contingency to eventually recover Block 3 reserves
- Underground mining method will enable waste separation to enable continued mining of Blocks 2 and 3 should the anticipated 2 m ton dolomite failure take place.

If one looks at the available time to mine the TOB 4 reserve, the ore must be mined out with Blocks 2 and 3 and before the commencement of Block 4. As the block cave is initiated, the bottom of pit will become unstable and increase the safety and financial risks of mining. An underground method is the only option, which will enable the mining in the available time.

Underground mining method

Two underground mining methods have been considered for implementation in the mining of the BOP reserve. The methods considered were:

- Modified blast hole open stoping
- Drawbell installation.

With both underground mining methods it is planned to use the existing 530 metre level elevation (53 Level) access, which is situated 20 metres below the current pit floor on 510 metre level elevation (51 Level). By doing so, one would drastically reduce access development to get in below the TOB 4 reserve. With minimum development, 53 Level also allows access to the existing ground handling infrastructure and allows for the ventilation requirements.

Option 1: Modified blast hole open stoping

- This method will consist of five extraction tunnels, which will be blasted from north to south underneath the BOP reserve on 53 metre level elevation with access on the northern end of the pit. On the southern side of the pit the five tunnels will be connected by means of an east-west running tunnel (slot), with a raise-bored hole from the centre of this tunnel running from 53 Level to hole into 51 Level pit floor. One 89 mm hole is to be drilled in the centre of the cut, and will be charged up with a 46 mm plastic pipe filled with emulsion (UBS), all holes in the cut to be drilled at an angle of 90°
- All holes to be drilled to a length of 20 m
- Slot cut to be drilled on indicated 400 × 400 grid.

Once a slot has been created, one would retreat back in a normal blast hole open stoping fashion as currently used on Blocks 2 and 3. Long hole rings would be drilled at 3 metre burden and blasted. As blasting progresses and the tunnels

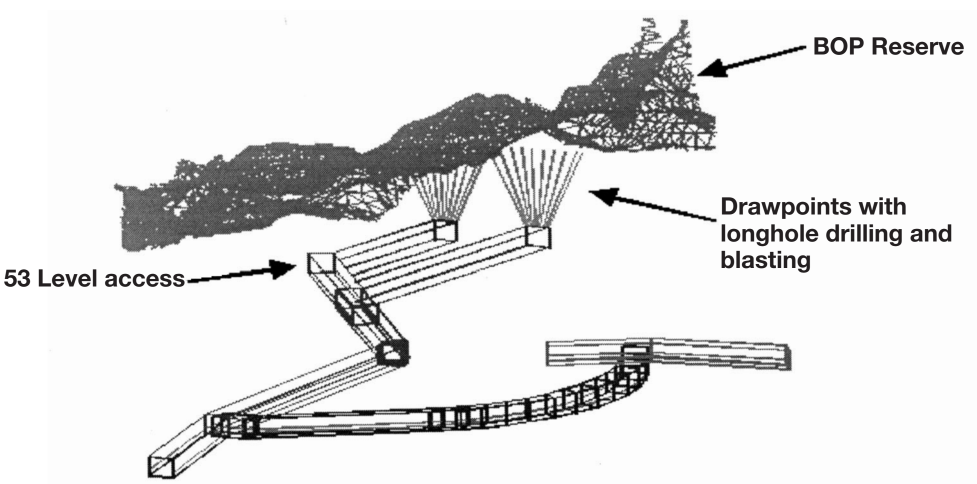


Figure 3—Schematic representation of modified blast hole open stoping

are retreated underneath the blasted ground (muck pile), ground from the TOB 4 would flow into the drawpoints and be loaded.

The following is a SWOT analysis of Option 1

- *Strengths*
  - Method is simple to implement
  - On-mine experience in mining method
  - No drawbell construction needed
  - Primary drilling and blasting to be done as part of mining process.
- *Weaknesses*
  - Long-hole drilling and charging equipment and machinery will be required throughout the production process
  - Slot cutting would be required
  - Selective mining will not be possible
  - Future use of drawpoint for extraction in case of ore or waste failures would be impossible
  - All broken ground would not flow directly into drawpoints and there would be a need for a remote controlled LHD to ensure effective extraction of all broken ground.
- *Opportunities*
  - No drawbell and drawpoint development would reduce the number of tunnels to be developed.
- *Threats*
  - A risk exists of having drilling, charging and LHD units buried by falls of loose ground during production loading, drilling and charging. It will be difficult to retrieve buried production units
  - In the event of dolomite failure, ground would flow freely into drawpoints, causing a safety hazard
  - Low production rates threaten project completion.

Option 2: Drawbell installation

This method will consist of an extraction level being developed on 530 metre level elevation running from north to south underneath the BOP reserve with access on the northern and southern sides of the pit. A series of drawpoints would then be developed with drawbells from the 53 metre level elevation to hole into the broken ground on the 51 metre level elevation, the current pit bottom. The ground would then be extracted through the drawbells as in a normal block cave operation, except for the fact that the ground on the pit bottom is already broken at will not be caving but flowing into the drawpoints being loaded.

The following is a SWOT analysis of Option 2

- *Strengths*
  - Selective mining will be possible
  - No remote loading would be required at all, as broken ground would be directed into drawpoints by the drawbells. In the event of a failure, it would lessen the safety risk of people and equipment being trapped by the failed ground.
- *Weaknesses*
  - More development would be required as in option 1
  - May anticipate problems with development of drawbells into loose ground
  - No primary drilling and blasting as part of mining process.
- *Opportunities*
  - Act as a learning curve for Block 4 drawbell development and construction
  - Allow for the refinement of secondary rock-breaking systems in a block cave ahead of Block 4 block cave operation
  - Drawpoints would be available for the extraction of failed material in the future, even after the BOP reserves are depleted
  - Drawbells can be designed in such a manner as to facilitate the flow of ground across the major apices
  - Drawpoint construction techniques will be perfected prior to being utilized in Block 4
- *Threats*
  - Due to more tunnel development and drawbell development, the timing of the project to be completed before cave initiation could become critical.

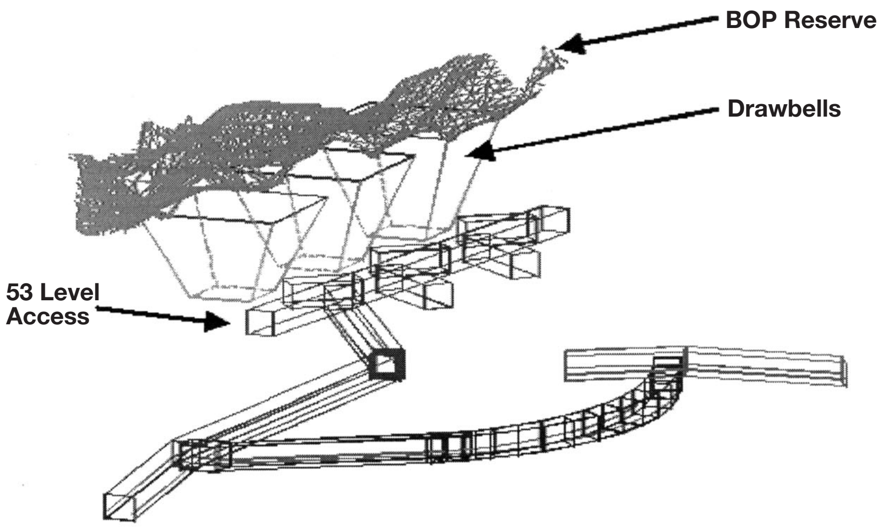


Figure 4—Schematic representation of drawbell installation

Conclusions

In order to clarify the underground mining methods, selection, the two methods were ranked. The ranking is in ascending order, with the lowest being the best option. (See Table I below). All the parameters were weighted equally, as a priority could not be established. It was decided to consider all the factors that are related to a particular option.

Based on the results of the SWOT analysis and the ranking of the two underground options, the modified blast open hole stoping method was selected as the most suitable for mining the BOP reserve at Finsch Mine for the following reasons:

- On-mine experience available—same method as the current one that is being used for Blocks 2 and 3 Improved safety
- High extraction ratio
- Optimum production rates
- Reduced drill and blast for TOB 4 ground
- Low operating costs for production
- Optimizing Finsch Mine NPV.
- *Breakdown of Mining method*
  - Drilling of long-hole rings to liberate loose ground
  - Use of remote or conventional LHD
  - Emulsion Explosives used (AEL UBS)
  - Electronic detonators (AEL Smartdet).

Production

Strategy

Development of the slot tunnel and the other five extraction tunnels is to take place simultaneously in the same districts. The same equipment that will be used to tram the blasted ground from development will be used to load the ground from the extraction tunnels. Therefore, production will not officially begin until the development process has been completed. Some production will take place as we develop the extraction tunnels as this will be in the kimberlite area. It is expected that once the slot has been blasted, some of the TOB 4 tons will report to the drawpoints of this tunnels.

The above strategy has been chosen since there is only a limited amount of space on 53 Level and it would be counter-productive to mine reduced quantities over a longer period. Development is planned to be completed at the end of March 2003, therefore a fleet capacity must be selected that will be able to load the given tons before 100% of the Block 4 undercut and 10% of the above columns have occurred (2005–2006). Thus there is approximately 5 years to complete all of the production phases. Obviously, dragging the project out over this period would have negative implications on the NPV. Therefore is it intended to mine out the TOB 4 reserve over a maximum period of 3 years (November 2005) in order to buffer Block 4 start-up with a significant amount of TOB 4 production and to maximize the NPV.

Production, phase 1, is to begin with extraction tunnel 1, 2, 3, 4 and 5 on the southern side of the pit. The expected yield from these tunnels is 268 421 tons, so production on these tunnels must be completed by November 2005, as they are located directly above the zone of cave initiation. This gives approximately 36 months for completion.

Fleet requirements

In order to select the required fleet, one must consider the capacity required, size constraints, congestion, compatibility with the current infrastructure, and fleet and loading position sequences, as well as efficiency. The selected fleet is usually a balance between congestion and efficiency.

LHDs and haul truck selection

In selecting a fleet to mine the BOP ore pile, it becomes apparent that haul trucks will be necessary, as the tramming distances are too large for LHDs to mine alone. Due to the layout of east and west accesses, it is possible to have independent simultaneous loading. This allows an LHD to be positioned in each access tunnel. The next step required was to create a loop so that the traffic flow of the haul trucks would run smoothly. The exact location of the x-cut necessary to complete the loop had to be investigated. Another area of research required was to select the size and number of trucks necessary.

Two trucks would give a close match with respect to cycle time; however, the LHDs will be idling for short periods.

Table I

Ranking of underground mining options

Parameter	Underground mining method	
	Modified blast hole open stoping	Drawbell installation
Safety (risk to men and machinery)	1	2
Geotechnical	2	1
Capital cost	1	2
Operating cost	1	2
Total development metres	1	2
Primary drilling & blasting (as part of production)	1	2
Selective Mining	2	1
Use of current infrastructure	1	2
Future use of drawpoints (before cave initiation)	2	1
Remote LHD's	2	1
Time required before start of production (timing)	1	2
Simplicity of operation	1	2
Production rates (Production output with same amount of production machines)	1	2
Secondary breaking/ blasting	1	2
Explosive consumption	2	1
Total	**20**	**25**
Overall ranking	**1**	**2**

Using three haul trucks maximizes the use of LHDs and enhances the fleet's capacity; however in this case, one truck in each cycle will remain idle for most of the cycle.

Toro 1400s were chosen as the optimal LHD. Their use has been justified for the development and therefore it is recommended that they be maintained on 53 Level until the project completion date. Matching the LHDs with the trucks, it is recommended that Toro 50 Ds are purchased. Since the effective bucket capacity of a 14-ton loader is 12 tons, it is anticipated that it will take approximately 4 cycles to fill the truck, whereas a 40-ton truck would only take 3 cycles to fill. Thus, considering economies of scale, it is better to haul more ore per cycle and maximize LHD utilization than to maximize haul truck utilization and haul less ore per cycle. The decision to use 50-ton haul trucks also coincides with the Block 4 plan. It is therefore intended to move the Toro 50s down to Block 4 after the project termination date. But at a later stage it was decided to change from the Toro 50D to 530Ds.

Robust machine and Commando rigs

Since it is expected that many large boulders will be reporting to the 53 Level drawpoints, it is recommended that we make use of the Robust and the Commando rigs currently situated in Block 3 in order to aid with the secondary breaking on 53 Level. The opportunity also exists to bring forward capital from Block 4 for the purchase of a Robust machine to be used in the BOP project and after completion of the project to be used in the block 4 operation. (Capital for a Robust machine has been provided for in the Block 4 capital).

High hang-up rig

As many high hang-ups are expected in the drawpoints, it is recommended that capital be brought forward from Block 4 in order for the rig to be used for the BOP project. This would benefit both parties, since the BOP project could make any necessary adjustments and this would give an excellent opportunity for those people involved with Block 4 to gain experience with the equipment.

Resources

The resources required for production are similar to those required for the development. It will be broken down into three sections, namely, human resources or manpower complement, then the vehicle fleet, and finally the auxiliary resources such as R&M workshops, the refuelling bays, explosive magazines and electrical substation.

Human resources

The number of machines that need to be manned determines the manpower requirement.

The complement is as follows:

Job Description	People equired per shift	Shifts per day	Total required
Shift boss	1	3	3
Miner	1	3	3
LHD operators	2	3	6
Truck operators	3	3	9
Rock breaker operator	1	3	3
Charging a ssistant	1	3	3
Total	9	3	27

Financial evaluation

Exchange rate	7.50	7.50	7.50
Diamond price	45	45	45
Year	One	Two	Three
Tons	650000	750000	800000
Grade	45	48	42
Carats	295,500.00	360,000.00	336,000.00
Revenue	98,718,750	121,500,000	113,400,000
Capex	12,000,000	10,000,000	6000000
Opex	32,500,000	38,250,000	41,616,000
Profit	R54,218,750	R73,250,000	R65,784,000
NPV (15% Dis. rate)			R145,788,310.59
Discount rate	15%		

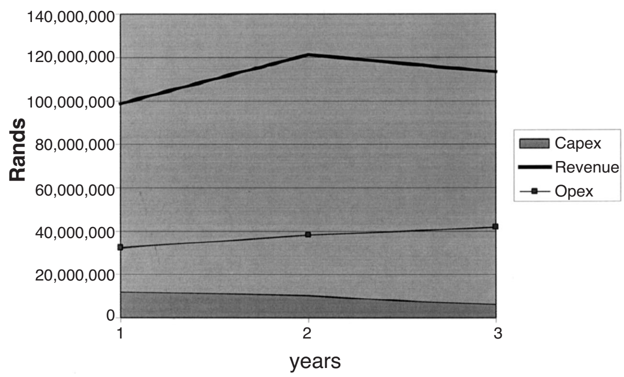
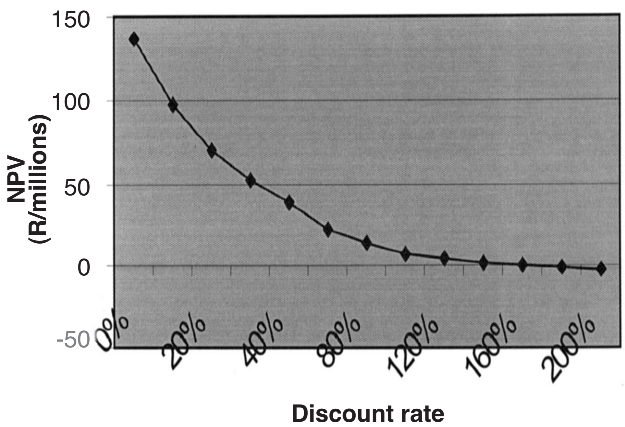


Figure 5—Revenue graph

Inputs for determination of IRR	
Function	**Amount in rands / $**
CAPEX	R28,100,100
OPEX	R50 per ton
Plant recovery factor	95%
Exchange rate	R7.50
Diamond price	$45 per carat
Average grade	45 cpht

OPEX increase at 5% per annum—wear and tear only



Note: The financial figures and grade are indicated only and do not represent the realistic figures which are confidential

Figure 6—NPV vs Discount rate

Conclusion

Challenges

Safety

Due cognisance must be taken of the health and safety aspects of all employees concerned in the design of a mining method extension for the TOB 4. As far as reasonably practicable, the extension of TOB 4 must be designed, constructed, and equipped to provide conditions for the safe operation of machinery and a healthy working environment for people underground. Relevant requirements of the Mine Health and Safety Act and regulations pertaining to mining operations must be identified, and adhered to, during all phases of the design process.

During the design process, potential risks relating to current and future mining operations must be identified, analysed, and assessed as far as reasonably practicable, and must be dealt with.

Time

If one looks at the available time to mine the TOB 4 ok reserve, the ore must be mined out with Blocks 2 and 3 and before the commencement of Block 4. As the block cave is initiated, the Top of Block 4 (Bottom of Pit) will become unstable and increase the safety and financial risks of mining. This time constraint must be taken into consideration when designing and extending the current mining method for the TOB 4 as to ensure timeous completion of the project.

Autonomous operation

In designing a mining method for the TOB 4 due cognisance was and must be taken to ensure the absolute minimum interference with the current mining operations of Blocks 2, 3, and 4.

Existing infrastructure

- The mining method to mine the TOB 4 reserve must make use of the existing mine infrastructure
- Shaft and ground-handling infrastructure
- Development and production equipment
- Ventilation layouts
- Dust extraction system
- Water handling and settling infrastructure
- Refuelling and workshop facilities
- Electrical reticulation system
- Breakdown and preventative maintenance infrastructure.

Dolomite failure

As far as practically possible, the mining method must be able to separate waste to enable continued mining of Blocks 2 and 3 should the anticipated 2 million ton dolomite failure take place.

Extraction ratio

A minimum extraction rate of 75% would be required in mining the total TOB 4 reserve.

Risk

The original Bottom of the Pit (Top of Block 4) feasibility study identified the following risks, which are applicable to the extension of Top of Block 4 resource mining method.

There are geotechnical implications for an extraction level directly below the pit floor. Ground conditions 10–20 metres below the pit bottom may have been altered due to weathering or may be saturated with water. This would result in very slow development rates due to increased ground support.

The impending dolomite failure is a significant concern as ground toppling down onto the pit bottom would not only make the area below the TOB 4 (BOP) reserve unstable but will also cause dilution to the reserve.

Because the reserve consists of recompacted blasted ground, the angle of repose of the material is unknown. The percentage extraction that would be achieved will be very sensitive to this angle.

Other risks include:

- Flooding of infrastructure below the TOB 4 reserve by rainwater
- Unknown fragmentation size of the TOB 4 material
- Mining into Block 4 ore reserves
- Cost overruns
- Time overruns
- Schedule slips
- Production loss.

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