MINE DEVELOPMENT – ACCESS TO DEPOSIT

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Abstract

A deposit to be mined by underground methods can be accessed by a number of methods:

- Adit
- Decline or ramp
- Inclined shaft
- Vertical shaft.

Adits are an economical approach when the orebody is above the general floor elevation i.e. suitable in hilly or mountainous terrain. Incline shafts are limited to relatively shallow deposits, and because they are developed on an incline, development lengths for a given depth are the three to five times longer than for a vertical shaft. Vertical shafts are the preferred method for deposits deeper than 300 m but the development rate is slow and construction costs are very high. Declines or ramps offer early access to shallow deposits, which develops the ore body expediently, but are generally developed at a gradient of approximately 12 per cent.

Decline haulages have become an attractive alternative to shaft hoisting, and over recent years the role of decline access has become more widespread throughout South Africa. Traditionally, South Africa has enjoyed the use of shaft systems, largely due to the large knowledge base of mining the Witwatersrand Basin, where vertical and inclined shafts were the norm. South Africa has also had the advantage of cheap electricity, giving shafts a definite economic advantage. However, in recent years the national power utility ESKOM has undergone an expansion programme that has led to tariff increases of nearly 100% over a three-year period.

Based on the changes in electricity tariffs and technological improvements to underground haulage trucks, the economic inputs to access development have changed. This paper reviews mine access for shallow deposits as currently applied in South Africa. Based on current economic inputs, the paper investigates at what point a vertical shaft would be more economical than a decline system utilizing typical South African mining equipment.

Introduction

The question of which access method is applicable to exploit an underground deposit is one that mine engineers and planners are faced with when investigating the viability of most shallow deposits. Basically there are four approaches to gain access to an orebody; namely, adits, incline shafts, vertical shafts, and declines or ramps.

The four methods are briefly discussed in this paper for the sake of continuity, but the details are not included. Wilson *et* al. (2004) provide a comprehensive discussion of access methodologies between vertical, incline, and decline shafts and it is not the intention of the author to repeat the detail of this discussion.

However, with the increased use of mechanized mining methods in the narrow-reef environment of South Africa, the question of when to convert from decline truck haulage to vertical shaft hoisting is pertinent to most shallow greenfield projects in the Bushveld Complex. The economics of vertical shafts *versus* decline ramps is further complicated with the electricity tariff increases since 2010, and simply applying the 'old rule of thumb' to establish the changeover depth may not apply any more, especially as trucks are becoming larger, more powerful, and fuel-efficient. This paper looks at the economics of a shaft *versus* decline system and when it becomes more economically attractive to utilize a vertical shaft rather than a ramp decline system for a shallow deposit.

Initial considerations

Many factor influence the decision of selecting a shaft or decline/ramp to access an underground mine. Some of these factors include the depth of the deposit, geotechnical aspects, production rate, dimensions, availability of capital, and operating costs.

A key consideration is that it is extremely expensive to convert from a ramp to a shaft system, so the mine engineer/planner must consider the entire mineral resource or potential to increase the resource at depth. Figure 1 depicts a typical access strategy for platinum mine where the initial orebody is exploited by means of an incline or decline shaft system, and later accessed by vertical shafts.

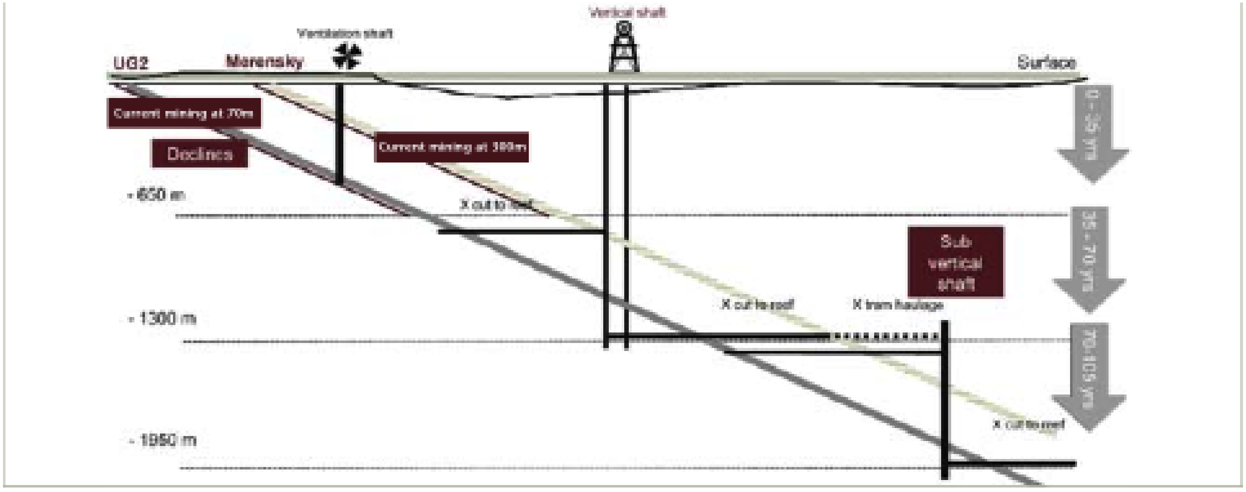

Figure 1-A schematic illustration of decline and vertical shaft system (Anooraq Resource Corporation, 2010)

Adits

Adits offer an entrance into an underground mine that is horizontal or near horizontal and provides access for personnel, material, rock, ventilation, and mine drainage. Adits are driven into the side of a hill or mountain and are often developed when the deposit is located inside the mountain and above the adit. Examples of adits used In South Africa are often seen in the mountainous areas of the eastern limb of the Bushveld Complex and the Barberton area, where the deposit dips under the mountain.

Incline shafts

Mining engineers in South Africa quickly realized the benefits of sinking incline shafts on the Witwatersrand, as vertical shafts require considerable lateral development to gain access to the orebody. Incline shafts offered quick access to the orebody and minimized development and capital expenditure, resulting in great savings of time and cost.

The benefits of incline shafts over vertical shafts are summarized as:

- Less development required to access the orebody
- Development kept close to the orebody
- Smaller requirements for shaft headgear and winder installation
- Incline shafts are cheaper to sink than vertical shafts.

Despite these advantages, incline shafts are regarded as labour-intensive, and operationally not as efficient as a vertical shaft. One of the biggest negatives regarding incline shafts is the inability to easily clean broken rock when shaft-sinking and the propensity for tracked equipment to suffer derailments.

Cleaning systems have been introduced to increase the cleaning rate for incline access, including the mechanized mucking system, the LMG-600 shaft loader, and the Salzgitter side dump loader; however, limited success has been achieved, and inclined shaft sinking has thus been on the decrease over recent decades. Figure 2 depicts an incline and vertical shaft system exploiting a shallow to moderately deep orebody.

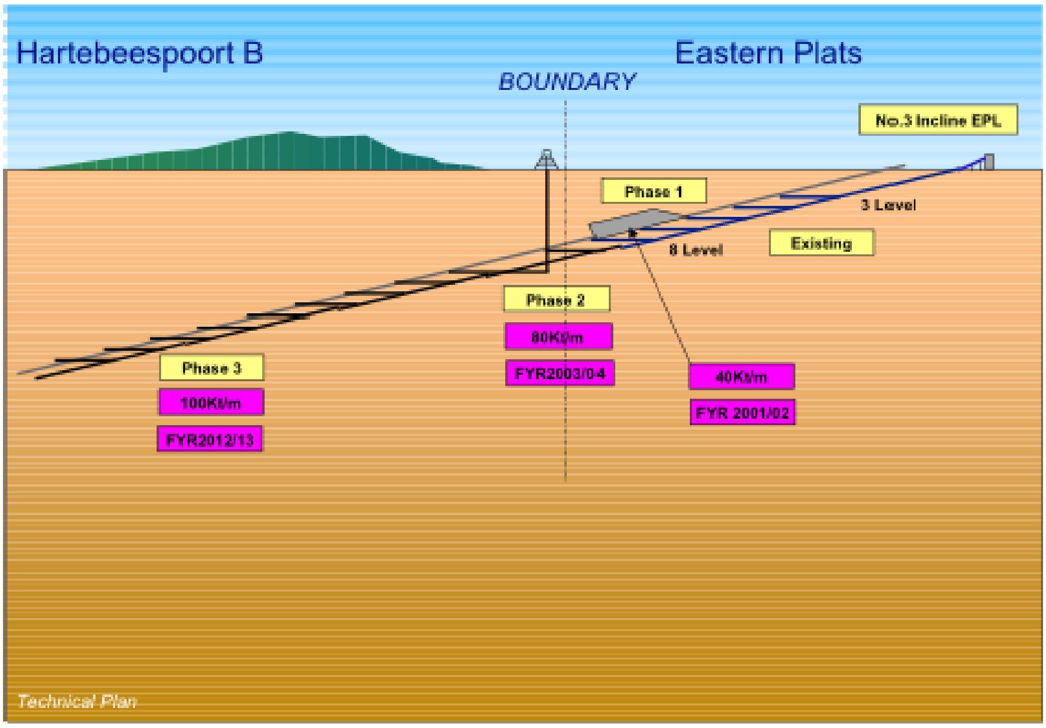

Figure 2-A Schematic illustration of an incline and vertical shaft system (Lonmin Patinum/Anglo American, 2001)

Vertical shaft access

Shafts are vertical excavations sunk in a position so as to access the orebody as effectively as possible, with the size of the shaft excavation generally being determined by the production and ventilation requirements. Depending on a variety of considerations, vertical shafts are typically sunk when orebodies extend deeper than 250 m to 500 m, as shafts then become more economic than a decline ramp system. Shafts are usually placed such that horizontal distances to the ore body are minimized while still allowing for a shaft pillar. Shafts vary in shape and dimension, but are typically circular or elliptical, depending on geotechnical and environmental considerations.

The advantages of shafts are that they support high production rates, and are efficient for the transportation of personnel, material, and rock. Disadvantages include the high initial capital expenditure, long lead time to production, and difficulty in transporting large equipment.

Decline shaft/ramp

Decline ramps (Figure 3) are typically developed with gradients between 10 per cent and 15per cent. Ramp systems are less commonly used in South Africa but are commonly used in Australia, where over two-thirds of underground mines are accessed through decline/ramp systems. Declines allow the movement of equipment from one level to another without the need for disassembling, transporting, and reconstructing the equipment, which is often required in a vertical shaft system. Declines must provide adequate turning radius for the largest piece of equipment. Advantages of decline systems are the low cost of development, ease of access for equipment, and the short period to commencing mining operations. Disadvantages included low vertical development rates, increased ventilation requirements due to the use of diesel equipment, and increase in labour to support truck operations. Two basic methods are used to transport ore from the decline system, namely truck haulage or belt conveyor. Truck haulage is suitable for tonnages up to 3000 t/d, while belt conveyors are advocated for large-tonnage operations. Figure 3 demonstrates the user of a decline ramp system and adit.

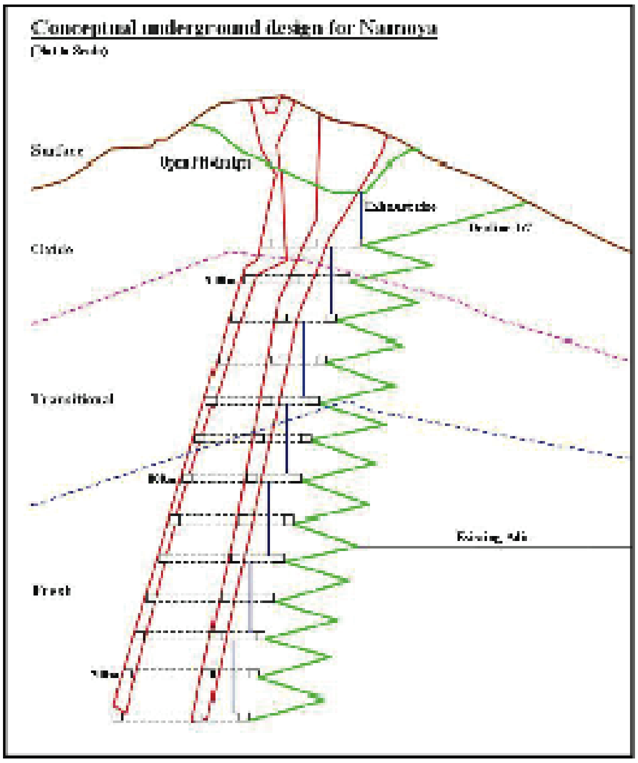

Figure 3-Conceptual design utilizing a decline and adit system (Pittuck and Smith, 2007)

Given the above background regarding methods of access to exploit underground deposits, the question of selecting the appropriate changeover depth between a decline ramp and vertical shaft is explored.

Background

As early as 1973, Northcote and Barnes investigated the optimum changeover depth for Australian conditions and recommended changeover depths of the order of 350 m, a depth still often quoted in South African operations.

McCarthy and Livingstone (1993) suggested that the transition depth from decline to shaft in Western Australian practice had increased from 300 m to 500 m or more, with potential to increase this depth to 1000 m. McCarthy and Livingstone noted that every mine has its own peculiar circumstances, which would influence the determination of the changeover depth. Some factors that they identified and which still hold true today include:

- Funding or capital available for project development
- Mining method and ground conditions
- Requirements for service access via a decline
- Requirement for lateral and vertical ramp coverage of the orebody and the lateral extent of the orebody
- Depth from decline portal to top of orebody
- The planned rate of vertical advance and its relation to the ore distribution and hence production rate
- The ore reserve and development schedule and thus the planned mine life
- The existence of exploration shafts suitable for conversion to production hoisting
- Whether the decline can be advanced sufficiently ahead of current mining areas to enable raisebored hoisting shafts
- The discount rate used in the analysis
- Life of mine
- Haulage distance to shaft.

McCarthy (1999) expanded further on shaft hoisting *versus* decline trucking, focusing on the impact that the production rate and depth had on the ultimate changeover depth. McCarthy commented that advances in trucking technology would challenge current changeover limits. McCarthy highlighted the fact that 50 t capacity diesel trucks had become the benchmark in Australian mines, operating at 1 in 7 gradients at speeds of approximately 9 km/h.

Future trucking improvements would include greater payloads (60 t to 80 t) with more powerful fuel-efficient diesel engines. Thus, future operations should see greater haulage speeds, better availability, and improved ergonomics.

Wilson (2004) documented the issue of shafts *versus* declines for the South African platinum industry. The situation prevailing in South Africa, in contrast to the Australian experience, indicated that decline systems were advocated between 350 m to 500 m and enabled early project start-up. Wilson highlighted that increasing operating costs detracted from the decline option, and thus as orebodies progressed deeper shafts became more economically sensible, offering reduce operating costs but higher capital requirements and a longer project development schedule. However, this work related to an economic environment where electricity was still very cheap in South Africa.

Tatiya (2005) in a mining textbook describes the modes of accessing a deposit, shown in Table I. Tatiya recommend declines not exceeding 250 m and further describes the general attributes for the various options.

Matunhire (2007) compared vertical, decline, and incline shafts (Table II), citing that vertical shafts should be considered when the orebody is steeply dipping or deep, being most economic at depths exceeding 500 m. Decline shafts were seen to be advantageous for shallow flat-dipping orebodies requiring low initial capital. Incline shafts were also found to be suitable for shallow flat-dipping deposits but had several disadvantages, namely derailments, shaft spillage and maintenance, and limited hoisting capacity.

Decline ramp *versus* vertical shaft – a South Africa reality check

Based on the argument in the previous section, between 250 m and 500 m appears to be the recommended limit to decline ramp systems, although Australia is exploring the use of deeper declines. In the current South African economic climate of increased electrical tariffs, fuel prices, and labour increases one must question if the previous findings are still valid.

Since 2004, specifically with the power shortages associated with 2007 and 2008, there has been a dramatic shift in the South African electricity tariff. In 2010, South African electricity costs increased dramatically and will continue to increase in the order of 30 per cent per annum for the next two years, thus changing the economic dynamics. The following describes the findings of the analysis conducted based on a medium-sized operation applying mechanized trackless mining methods and operating to a depth of 800 m.

Table I-Modes of accessing a deposit (after Tatiya, 2005)

Parameters	Decline/ramp	Incline shaft	Vertical shaft
Opening inclination limit	Up to 8°	Up to 20°	>20° degrees to vertical
Depth limitations	Not exceeding 250 m	Not exceeding 150 m	Depth exceeding ~100 m
Usual rock type through which an entry driven	Mostly in waste rock or black rock	Mostly in waste rock or in orebody	Mostly in waste rock or black rock
Principal purpose	Early access to the shallow deposit to develop and produce ore at the earliest using trackless equipment	Early access to the shallow deposit to develop and produce ore at the earliest. Also equipped with mine services and serves as personnel access	Access to any deposit and produce ore on a regular basis. Usually serve as permanent mine entry
Position w.r.t. deposit	Preferably in F/W side of deposit	Along deposit or in F/W side in waste rock.	For flat deposits in overlying strata but for steep deposits in F/W
Driving rate	Fast	Faster	Slow
Construction cost	High	Low	Highest

Table II: Shaft comparison (After Matunhire, 2007)

Shaft	Selection criteria	Advantages	Disadvantages
Vertical	Steeply dipping or body Deep orebody	Quick access to deep ore bodies Efficient at depths exceeding 500m Cheaper per meter as depth increases Early return on investment	High skilled labour required High labour costs High initial capital costs High maintenance costs Requires headgear Limited hoisting capacity Requires constant power supply
Decline	Flat-dipping orebody Shallow ore body	Can be mined in the strike or dip direction Easy access to shallow ore body Low initial capital costs Low operating costs Construction skills and equipment readily available High hoisting capacity with conveyor belts	Longer distance to ore body Only economical to 500m Excessive travelling time to ore body Trackless hauling is slow and congested Heat pickup from rock over length Slower return on capital invested Water handling can be problematic
Inclined	Flat dipping ore body Shallow ore body	Limited development to ore body Short ore pass system required	Derailments Shaft maintenance and repair time consuming Spillage cleaning is time consuming Limited hoisting capacity

In South Africa, the question of accessing an orebody by decline or vertical shaft remains a topical subject. The evaluation of alternative methods of accessing the orebody is one of the first steps of developing a mine plan. The selection of the proper size, configuration, arrangement and type of opening required to develop a new underground orebody or expand an existing mine is a complex and often difficult engineering problem. Each deposit has it own characteristics and requirements and requires an accurate evaluation of all factors that may affect the mine design to access the orebody. The basic design parameters that should be considered are as follows:

- Lowest capital expenditure
- Lowest operating cost
- Safe and reliable operating system
- Flexible and efficient system
- Supports the mine planning
- Provides fast access to the ore body to promote early cash flow.

Some of the design criteria that need to be considered are:

- Geology and mineral resources
- Hydrology
- Depth of orebody
- Flexibility for changes to mine plan, mining method, or expansion of project
- Production tonnage requirements
- Geotechnical inputs
- Ventilation requirements
- Capital and operating costs
- Schedule completion i.e. commencement of cash flow
- Availability of skills and labour requirements
- Safety
- Productivity and management of system.

The design of a mine's access is an important aspect of the overall mine design. Each individual deposit must be carefully reviewed. The selection of decline or shaft access may not be straightforward as the economics of the access options change with depth and tonnage, and often the decision is influenced by mitigating factors such as the availability of capital or the ability of the project to become cash positive as soon as possible. If all the design criteria are not considered in the initial phase of the project then the mine's access can potentially become a bottleneck. For example, the opening must be of sufficient size to handle ventilation and planned equipment. Therefore, it is advisable to design for a certain amount of flexibility in the mine's access as insurance against unexpected changes in the design. It may become impractical to increase production throughput due to the size of the shaft or decline.

Decline access is attractive for shallow orebodies or for continuation of operations from open pit to underground, whereby access is gained through a decline portal situation within the pit. However as mining progresses deeper and tonnage requirements increase, shaft hoisting becomes more appealing. The following access options have been considered for the purpose of this paper and notable exclude incline shafts and conveyor declines, as well as the consideration of capital expenditure to develop the various shaft systems.

- Trackless declines utilizing trackless mechanized (diesel) equipment. This mining method is well proven worldwide and is often used for shallow orebodies.
- Vertical shafts servicing standard track haulages. This is a common access method for many South African mines.

Decline haulage

A decline system from surface has been assumed consisting of a spiral ramps or declines inclined at 8° to 9° (1:7) and developed to a height of 5.0 m and 5.0 m width. Vertical distances of 100 m to 800 m have been considered in the comparison between decline and vertical shaft costs. Operating costs are based on a production rate of 80 000 t/month and are based on a deposit located near surface (50 m) extending 800 m below surface.

Operating costs for the haulage are based on initially estimating the speed of haulage equipment over the various segments of the haul route. Based on equipment manufacturers' recommendations and approximate speeds used for other South African operations utilizing truck hauling, the following speeds and operational times were used in this study:

• Up a 14% gradient loaded	6.0 km/h
• Level loaded	12 km/h
• Level empty	15 km/h
• Down a 14% gradient empty	15 km/h
• Loading of truck	11 minutes
• Spot and manoeuvre	3 minutes
• Tip	1 minute

It is important to note that the above times are used as a guide and can vary widely between operations. Of interest is the gradient of the decline and the condition of the haul road. Operationally, 1:7 (14 per cent or 8 degrees) is now the norm, which provides for the steepest practical gradient while still including curves and allowing for safe stoppage of machines on the down slope.

Construction and maintenance of the haul road is also important to enable the above haulage speeds. A screened road base material is required to maintain a good working road surface, which is to be applied to at least 300 mm in thickness, with a cross-fall to allow for adequate drainage.

Services can also affect the smooth operation of the decline haulage if placed in apposition, where they may foul with the loaded truck (see Figure 4). Drains should be established on the service side of the decline, opposite to any muck bays and on the inside of all curves. All services installed in the main declines are to be located on the shoulder above truck tray height and above the drain. This is critical for the positioning of any dewatering or water lines that are to be installed in the declines.

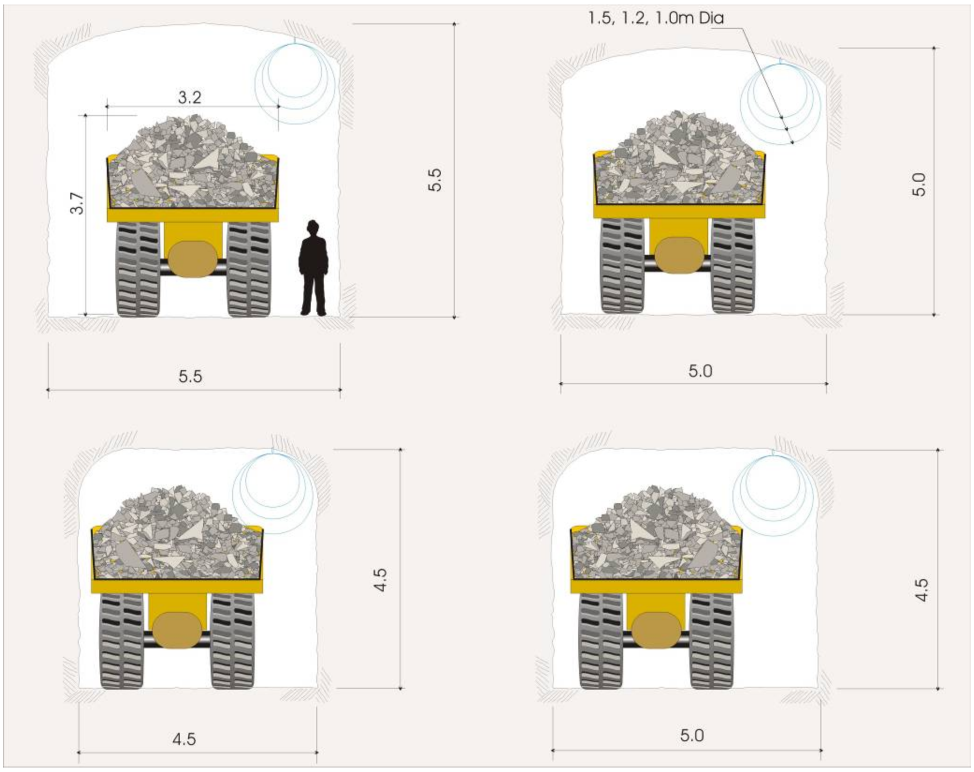

Figure 4-Truck profiles for various haulage sizes

Three haulage trucks were considered in the evaluation, namely 30 t, 40 t, and 50 t trucks. Operating costs are based on actual costs for a 30 t haulage truck operating in a South African mine. Operating cost for the 40 t and 50t trucks are based on manufacturers' databases with adjustments made to maintenance costs to reflect actual on-mine costs.

Table III reflects the operating and cost parameters for a 30 t haulage truck. Table IV and Table V depict the general operating parameters for all three types of haulage truck.

Table III-Operating parameters and cost For 30 t haulage truck

Description	Criteria	Cost per hour (Rand)
Life expectancy	20000 h	
Average tons per shift	1160	
Average hours per year	4000	
Service items and labour		175
Tyres	2050 hours per tyre	94
Fuel	R12 per litre	366
Lubricant	20% of fuel	72
Major repairs		516
Insurance		28
Labour		135
Total		**1414**

Operating costs for the various sizes of haulage trucks were derived based on the following cycle times as shown in Tables VI–VIII.

Table V-Operating parameters - haulage truck

Description	Unit
Equipment utilization	83%
Equipment availability	72%
Payload	27/36/45
Days per month	23
Days per year	276
Hours per year	6667
Operating hours	4000

Table VI-30 t haulage trucks

Depth, m	Number of trucks	Operating cost (R/t)
100	3	26
200	4	36
300	5	46
400	6	57
500	7	67
600	8	77
700	9	88
800	10	98

Table VII-40 t haulage trucks

Depth, m	Number of trucks	Operating cost (R/t)
100	2	22
200	3	31
300	4	40
400	4	49
500	5	58
600	6	67
700	7	76
800	8	85

Table VIII-50 t haulage truck

Depth, m	Number of trucks	Operating cost (R/t)
100	2	21
200	2	29
300	3	37
400	3	45
500	4	54
600	5	62
700	5	70
800	6	78

Figure 5 reflects the production capacity per working shift for 30 t, 40 t, and 50t capacity trucks operating from various depths ranging from 100 m to 800 m. Production per truck reaches over 700 t per shift while using a 50 t haulage truck, while the more commonly used 30 t truck approaches 450 t per shift for a depth of 100 m. As the depth increases productivity between the various sized trucks narrows, ranging from 193 t per shift to as little as 116 t per shift at a depth of 800 m.

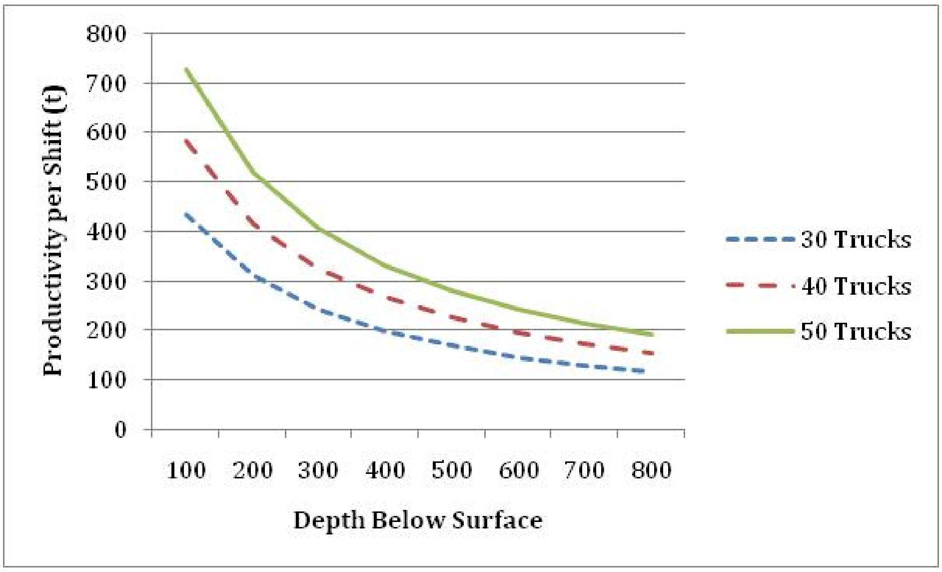

Figure 5-Truck production capacity per shift versus depth

Shaft system

Shaft operating costs (Table IX) are based on rates provided by a South African shaft-sinking company based a production rate of 80 000 t/month. The size, speed, and cycle time of the skip based on a 20 t skip travelling at 15 m/s was used as a basis for estimating the shaft operating costs. Table IX indicates shaft costs based on various depths and accounts for electricity, rope costs, maintenance and labour, shaft steelwork, and general contingency. As can be seen, operating cost are decreased some 10 per cent when the overall tonnage profile is increased to 120 000 t/month. The reader should note that the outcome of this study is based a production profile of 80 000 t/month.

Table IX-ShaftcCosts (R/t)

Depth (m)	Elect-ricity	Rope	Level Maint-enance	Mainte-nance accessories	Guides and buntons	Labour	Contin-gency	Total at 80 kt/m	Total at 120 kt/m
150	0.87	1.01	0.66	1.80	1.01	30.14	2.28	37.77	34.12
300	1.75	1.01	1.33	3.55	1.30	31.05	2.58	42.57	38.46
450	2.62	1.01	2.53	5.31	1.58	31.95	2.90	47.90	43.28
600	3.50	1.01	4.52	7.07	1.87	32.86	3.28	54.11	48.89
750	4.37	1.01	6.38	8.05	2.16	33.17	3.64	58.75	53.99
900	5.25	1.01	7.31	10.61	2.45	34.67	3.95	65.25	58.96

Results

Figures 6–8 indicate the various breakeven points for various size trucks for a production rate of 80 000 t/ month. An additional graph (Figure 9) illustrating a 50 t haul truck at a production rate of 120 000 t/ month is displayed for comparison purposes.

The changeover point, as shown in Figure 6, for a 30 t haul truck and 80 kt/month shaft is just under 200 m. This indicates that trucks are a cheaper option up to 200 m, while the shaft option is economically viable beyond 200 m.

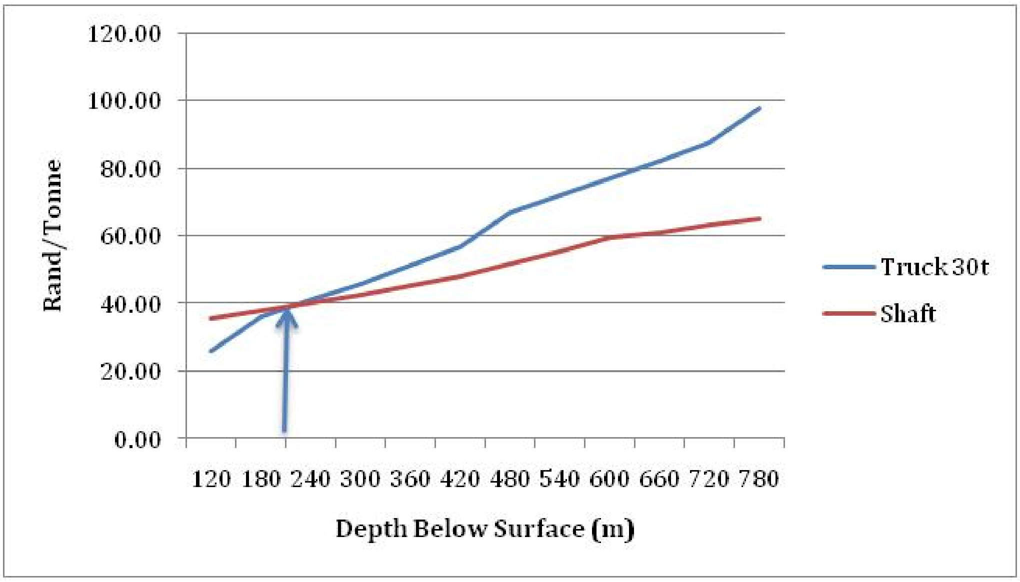

Figure 6-Break-even analysis for 30 t trucks and 80 kt/month shaft

Figure 7 indicates that the changeover point between a 40 t haul truck and a 80 kt/month shaft is just under 360 m. Trucks are a cheaper option up to 360 m while the shaft option is economically viable beyond 360 m.

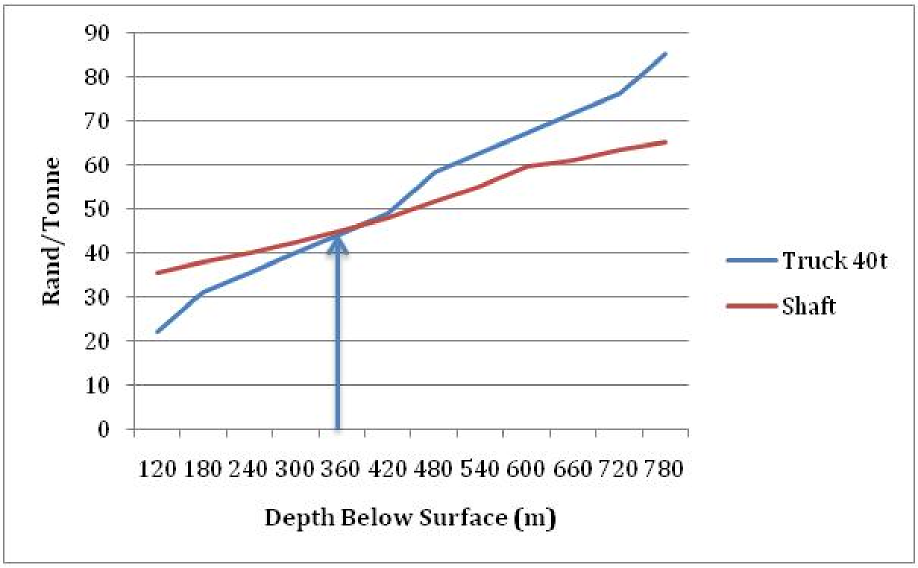

Figure 7-Break-even analysis for 40 t trucks and 80 kt/month shaft

The changeover point between a 50 t haul truck and vertical shaft producing 80 kt/month, as shown in Figure 8, is just under 450 m, trucks are a cheaper option up to 450 m while the shaft option is economically viable beyond 450 m.

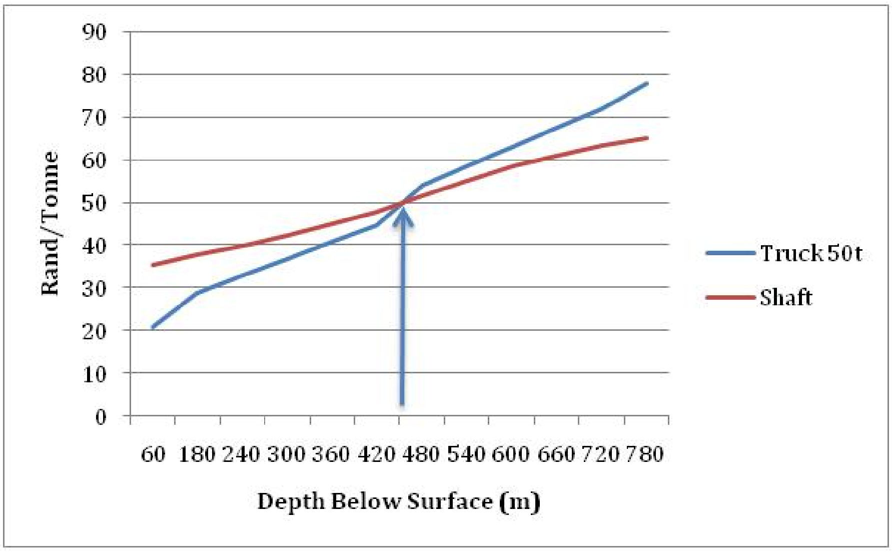

Figure 8-Break-even Analysis for 50 t trucks and 80 kt/month shaft

For comparison purposes, Figure 9 shows the changeover point between a 50 t haul truck and 120 kt/month shaft decreases from just approximately 450 m to 400 m, indicating that as tonnage is increased the shaft operating cost will decrease, in this example, by some 10 per cent.

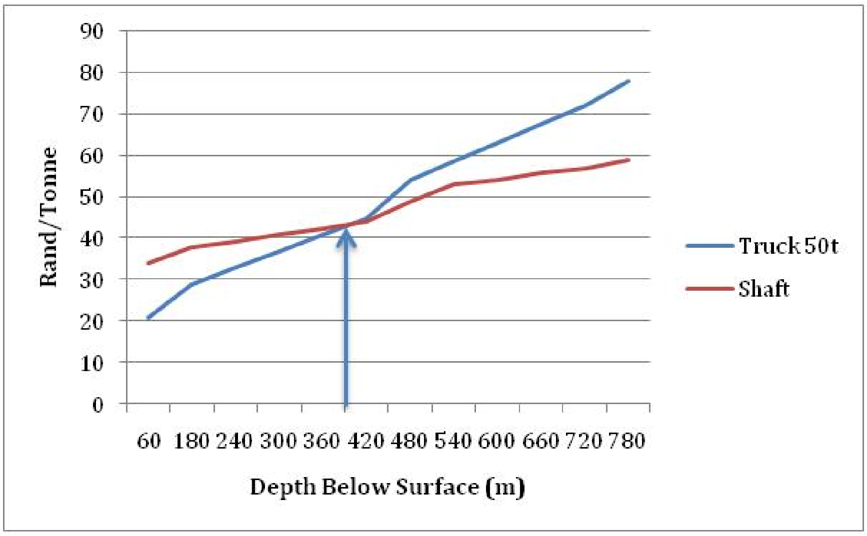

Figure 9-Break-even analysis for 50 t trucks and 120 kt/month shaft

Results

This exercise indicates that the old rule of thumb in South Africa, that the economic changeover point between truck haulage and vertical shafts is 300 m to 350 m, remains valid for the smaller haul trucks, but the changeover depth increases to 450 m for the larger 50 t haul trucks. Noticeably, as tonnage and depth increase, the shaft hoisting systems becomes more attractive. As with any new project it is advisable for the mine engineer to validate the changeover depth for their own specific project as operating costs, will vary from operation to operation.

In conclusion, the decline system offers an alternative to vertical shafts from 200 m to 450 m, depending upon the size of the haul truck and the tonnage profile. This is especially true when there are capital constraints to developing the project, when an early cash flow is required or mineral resources are limited to a depth of 450 m.

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