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Considerations in the choice of primary access and transportation options in platinum mines

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This paper reviews issues to be considered in choosing primary access and transportation options for platinum and other mines. It proposes appropriate criteria and a methodology for deciding on the optimum primary access option for any particular orebody. Also included are generic parameters that can be used to facilitate the process of choosing the optimal access option.

Introduction

This paper focuses on the issues pertaining to methods that can be considered for orebody primary access. Although generic observations are made, the focus is on narrow reef deposits typically found in platinum mining in South Africa.

The South African platinum industry has grown rapidly, particularly during the past decade. This period has seen the development of new mines and extensions to existing mines. There is also an increasing realization that productivity, in its broadest sense, must continue to improve if South African mines wish to remain globally competitive and attractive to investors. This realization has motivated the introduction of various forms of mechanization, the most significant being trackless equipment and conveyor belts for rock handling.

A historic review of access options and mining machinery

Ever since mining began, miners have driven adits and shafts into the earth. Vertical shafts are known to have existed in the 15th century or even earlier. Many inclined shafts (in excess of 300 m are shown on plans) were sunk during the first 20 years of mining in the Witwatersrand Basin. These were seen as the most obvious way of following the narrow steeply-dipping tabular gold reefs. Soon their capacity and length constraints became apparent and vertical shafts from surface became the norm. As mining progressed even deeper, and while the extent of the orebody was still in doubt, inclined shafts were again introduced as sub-incline shafts. Later sub-vertical shafts were widely applied in preference to sub-incline shafts. Recently, however, sub-inclines are again finding favour as a means of accessing orebodies below existing shaft infrastructure.

This evolution is instructive in a number of ways. Vertical shafts have consistently delivered lower operating cost and safety performance, while inclined shafts have sometimes been typically resorted to when it is perceived that orebodies are reaching the end of their economic lives. It is, however, thought provoking to recall the following statement made by Jeppe in the 1940s: 'In every decade since 1890 there has been at least one respected mining man who has predicted the end of economic mining on the Witwatersrand within that decade'.

Massive orebodies have generally been mined by adit and vertical shaft before the advent of modern trackless mobile equipment in the mid to late 20th century; these innovations having contributed significantly to the development and economic exploitation of smaller resources.

Success in massive mines with trackless technology has caused narrow reef miners to re-examine the potential of applying trackless methods. In particular, the years 2001 to 2003 have seen at least ten new shallow narrow reef platinum producers come into production in South Africa's Bushveld complex, with at least another eight due to come on stream before the end of 2005 (economics permitting). Apparent on-reef dip declines at 9º to 10º are normally used and are equipped with a combination of conveyor belt for primary and secondary rock transport and trackless equipment on the face. The combination of trackless mining with conveyor belt primary rock transport works well in some mines but not in others. Ultra low profile (ULP) machines are currently being trialled and time will tell if they are robust and safe enough for hard rock mining conditions. The use of normal low profile equipment still dominates, even although dilution remains a serious concern when using this equipment.

Also, as consistent rock sizing is very difficult to achieve with trackless mining, high rates of conveyor damage and high maintenance costs are commonplace. Current thinking is that, even for narrow reef mining, trucks should be used to 300 m below surface, after which either a permanent conveyor or short vertical shaft should be installed for exploitation of the lower levels. At 600 m, vertical shafts are indicated, as is a move away from diesel-powered trackless equipment, as mine cooling becomes an issue.

The current thrust of development includes the use of electric power to drive trackless equipment and the development of ULP machines for use in hard rock mines.

Access options

Access infrastructure provides for a variety of functions. The more important include:

- Access to the orebody
- Rock removal
- Men and material travelling ways

- Ventilation ways (downcast and upcast)
- Services infrastructure (power, communication, water, backfill, mud removal, etc.).

In brief, the purpose of access tunnels is to provide a conduit or logistics pipeline to serve the workings of the mine. While there is a large variety of access options and combination of options that can provide a suitable conduit, there are three generic types of primary access systems used to access underground orebodies. These are ramps and declines, inclined shafts, and vertical shafts, and are discussed further as follows:

Ramps and declines

This category includes conventional trackless access ramps that can be straight or spiral in plan view. Also included in this category are straight lengths or those that may have transition curves designed for the installation of conveyor belts.

Decline with truck hoisting

Trucking ramps are ideal for early start, low capital applications and for conditions that require early production in situations where the orebody is close to surface. They allow 'pay-as-you-go' benefits to the limit of their relatively limited throughput potential. A significant advantage of these systems is that they can be stopped at any time with a minimal of outstanding liabilities and redundant plant; they can typically be developed almost entirely with leased plant or by a mining contractor.

In general, production rates of 3000 tons per day are possible through single ends, although this can be difficult to achieve reliably. Nominally a function of adding extra trucks, there is a point beyond which congestion and difficulties in control make adding extra equipment not possible.

A decline ramp is designed to accommodate trackless equipment and is normally developed at 7º to 9º. In general, the lower the gradient the lower the operating costs. Truck tramming offers flexibility in dealing in both variable tonnage duties and complex ramp layouts. Operating costs are relatively high, but the recent introduction of electric-powered trucks can reduce costs.

Decline with conveyor belt

For conventional belt conveying applications, inclinations should not exceed 10º to the horizontal unless all the ore is well sized. This implies reliable crushing or screening of some sort. It must be borne in mind that conveyor suppliers will often claim that equipment can be used up to a 14º inclination. The practical significance of this is, however, that any round or oversize rocks will start to roll on an empty belt at this angle, rendering travel next to the belt unacceptably dangerous. Also, while the nominal gradient of an excavation may be say, 12º, there will invariably be places where the belt experiences a localized increase in gradient. That becomes the limiting point for the system.

Belts are well suited to high, constant tonnage applications of well-graded ore. This requires crushing or sizing and sufficient storage or surge capacity downstream of the crusher, but before the belt. Installations up to 12000 tons per hour are operational in Chilean copper mines. At least one application at 18000 tons per hour is planned. Conveyors may also be used to transport rock downgrade, but at less than half the gradients noted above. Such applications are design and maintenance intensive and have experienced catastrophic failures.

Non steel-core belts lengths are normally restricted to about 500 m on dips of 9º because of belt tension. These belts are the lowest capital cost alternative. However, as many belts are often required in series, the overall throughput potential reduces as belts are added because, even if only one belt fails, the whole system stops.

An alternative is to use the more expensive steel-core belts that allow much longer single belt lengths to be considered. The length is a function of the belt chosen and the gradient of application. All of the above belts can be installed slightly curved, but only with very constant feed conditions. This cannot be recommended for underground hard rock application. The same applies to the 'JAPAN' pipe conveyor, a patented concept that wraps the belt up into a tube for transition around corners. These belts have found application in the food, beverage and fishing industry for ice application.

Another alternative is a cable belt. This device is essentially a Koepe winder driving cables, with a rubber belt resting on the cables. Within limits, belt design is not restricted by gradient as large steel wire ropes are used to absorb the tension. Gradients of 18º are known to be operational and applications of up to 42 km have worked well. Once again, in underground operations, cognisance must be taken of the size and shape of rocks being conveyed.

Declines equipped with conveyor belts are most inefficient from a ventilation perspective. A combined relative velocity between the air and the belt of no more than 5 m/s must be maintained to prevent excessive dust pick-up. This means that the excavation cannot serve as a main airway and because of the fire hazards associated with rubber belts, they should only be installed in a return airway. This restriction can be lifted by applying additional engineering controls at the design stage, but is not considered by the authors to be best practice. Installing conveyors in intake airways is not favoured in many countries due to fire risk and increased dust loading.

In summary, where high tonnage duties are required, conveyor belts offer low running costs if high utilization can be achieved. However, they often suffer from low availability due to inappropriate system design and incompatibility between the primary rock breaking operations and the requirements of effective belt conveying. Large rocks have to be avoided and it is ideal, but often not very practical, to install surge capacity between belts in series to improve overall availability.

Decline with vertical rock hoist

The most efficient means of removing rock from a mine is through vertical hoisting. Power is only required to overcome gravity, as friction is very low. However, rock has to be dropped to loading boxes at shaft bottom thus negating some of the energy benefits of moving rock from shallower depths. Installing a shaft also takes time and is highly capital intensive unless some form of bottom access is available. This option has the advantage of the flexibility of trackless access while providing for cheaper and higher capacity production rates.

Inclined shafts

This term refers to straight excavations that are equipped with some sort of fixed transportation system. This could include conveyor belts, fixed end winding plant, monorails or endless rope haulages.

Inclined shafts have found favour in the past in applications where the orebody dips or plunges regularly or where relatively small reserves exist immediately below existing levels. This is because they may be configured to 'hug' the orebody and therefore result in the least amount of secondary development on the levels, at least in theory. One of the biggest risks that is associated with this approach is the degree of prior confidence in the structural geology of the orebody to be accessed. It is often the case that the line of the incline has not been drilled or that exploration drilling has not been done at sufficient intervals to support a decision to use an incline shaft for primary access. Once committed, the inclines must go in straight and, in the event of a discontinuity being encountered that throws the orebody into the footwall, must be stopped and re-established in a different form. This can be catastrophic for a mine in terms of capital cost, operating expenditure and production timing.

The most fervent proponents of inclined shafts are those expecting early returns. The most fervent detractors appear to be those who have to construct and maintain them. In a recent research exercise, one of the world's oldest and most experienced shaft sinking companies was asked about which system was the most difficult to establish—the answer: 'If its to be at an angle, do it with an LHD, otherwise make it vertical'. There is a significant amount of safety awareness built into this statement. In vertical shafts, crews always stand and work vertically and bottom crews have a multi-deck cover (the sinking stage) above their heads to protect them from any falling objects. In the steeper inclines (greater than 18º), it is difficult to work comfortably and no effective brattice has yet been designed to adequately protect face workers from rolling objects.

Incline shaft with conveyor

For an incline shaft system of up to 14º, a conveyor belt can be installed. Provision for man transport, normally a chairlift, and a material hoist can be made for dips of up to 30º.

Incline shaft with rock hoisting

Winding applications are limited in terms of gradient to between 10º and 45º with open rail guidance systems, and to 55º with captured rail systems. Man riding should not be practised at gradients greater than 45º unless vertical. At low gradients, acceleration rates must be low and speeds limited to 4 m/s. For gradients above 18º, speeds of up to 8 m/s are possible. Higher speeds require captured rail systems. Because of the inclination, skip factors are much lower than with vertical shaft systems and loading arrangements are prone to spillage. It is difficult to work in excavations much steeper than 18º because of the angle at which people must stand.

Inclined shafts using winding plant have not, in the past, exhibited good safety performance. There are a number of contributory factors to this, including the fact that rope wear rates are high, ropes are subject to mechanical damage by falling objects and during handling, persons come into contact with conveyances on the levels, and spillage sometimes causes conveyances to derail. Pay-as-you-go is often motivated with low capacity inclined shafts; these work if the mining rate required is low. For example, most inclined shafts operated at tonnages of less than 30 kt/month. The application of modern designs to inclines including the mandatory use of captured rail and conveyance braking systems are likely to improve safety quite dramatically.

At least one perspective project in South Africa has chosen to investigate the use of endless rope haulage as the main means of rock transport. This technology is basically an inclined Koepe winder installation and is capable of being extended down in sections to follow mine development. The technology promises the simplicity and low operating costs of hoisting without the traditional drawbacks of inclined shafts.

Incline shaft with vertical rock hoisting

This is often used as a compromise to minimize development requirements while offering high production rates.

Vertical shafts

Vertical shafts are the most efficient and cost-effective systems to operate at depths greater than 300 m. This is because they follow the shortest path, they follow a defined path of travel and can therefore be automated, there is almost no friction involved with conveyance operation, they impact minimally on the environment from an energy perspective and, in the case of vertical shafts, heat generated by the winding plant is discharged on surface. The use of open top skips allows tolerance of larger lump sizes when compared with conveyor belts, and conveyances can be used to transport rock, men or material.

Vertical shafts are particularly attractive in mines where additional cooling is required as they provide the most direct route, and therefore the least heat load on the mine. They are very efficient with respect to the amount of air transported into and out of the mine, from both a tolerable velocity perspective and length of travel and consequent ventilation system resistance.

Vertical shafts can be established by raise boring, raise boring and sliping, blind boring or blind sinking techniques. They are easy and safe to sink, line and equip, it is relatively easy to negotiate poor ground conditions and simple to recover in the event of water ingress.

The major disadvantage of vertical shafts is the time required to establish them. The suggested crossover depth between vertical shafts and other primary access of 300 m remains hotly debated by proponents of alternative access systems and the decision must be reviewed in accordance with the specific project criteria. A 1 000 m shaft will typically take four years to bring into production and no pay-as-you-go advantage (see comment below) is possible during this period.

Some shafts have had mid-shaft loading arrangements installed to exploit early advantage or to expedite development. This invariably delays the shaft considerably as full bratticing must be installed above the mid-shaft loading position to secure the safety of those working below. In reality, and in the experience of the authors, it is seldom, if indeed ever, that the planned advantages of installing mid-shaft loading have been achieved in practice.

A relatively high capital injection is generally required up front and lead time on start-up is of order 6–12 months depending on the amount of work done prior to the decision to implement. Vertical shafts are also limited in respect of payload and size of equipment that can be transported, but these limits can generally be adequately addressed at the design stage. Single hoists that will transport 30000 tons per day from 800 m are in operation.

Issues to be considered and criteria for decision making

Ideally, the following issues should be well understood before an optimal primary access method can be identified:

- The business objectives of the project
- The financial drivers or constraints
- The structure of the orebody and the degree of confidence in this information
- The mining methods and equipment that will be use
- The required production rate and production cycle of activities.

Once overall guidance has been obtained from the project criteria, it is necessary to proceed to a more detailed analysis of design input requirements. The following issues need to be considered when deciding on primary access methods:

- Orebody dimensions
  - -Dip
  - -Width
  - -Depth
  - -Extent
  - -Consistency of grade
  - -Frequency and degree of geological disturbance
- Existing infrastructure
- Mining method and equipment suite
- Number and position of reefs
- Required production rate
- Geothermal gradient
- Hydrogeology
- Ventilation requirements and air contaminant control
- Level intervals (combination of dip and mining method)
- Required speed of construction
- Capital availability
- Technology availability.

The shape, nature and knowledge of the extent of the orebody, the mining method to be used, the choice of mining equipment and regulatory restrictions all have an influence on the choice of access method. Finally, and most importantly, it is the strategy by which an owner wishes to exploit an orebody over time that has the greatest influence.

The classic financial measurements, such as NPV, IRR or payback periods, are often not enough to assess the relative benefits of primary access options. Although these financial criteria remain important, other non-financial criteria must also be considered. As examples, these could include:

- Safety
- Flexibility
- Time to production start-up
- Risk
- Labour numbers required
- Ease of implementation
- Availability of capital and overall cash flow.

The use of non-financial criteria is often ignored in project evaluation due to a subjective rather than an objective assessment often being required. The solution is firstly to adopt a team approach with many experts from both the technical and the client project teams being involved, and secondly using this team approach to identify the criteria and to decide on the weighting of each criteria. Once the criteria (including the traditional financial criteria) have been decided on and the weighting agreed to, it is relatively easy to compare each option. The methodology to achieve this is detailed in the following section.

Methodology

It should not simply be assumed that the most effective access option for shallow trackless mines is a ramp with a conveyor system, or that a vertical shaft system is the most effective for deeper level mining. For example, a recent study[1] indicated that it might be economical to truck-hoist to surface over a vertical distance of up to 1000 m because of the recent innovation of electric-powered trucks that has significantly reduced operating costs. Such adoption of new technology can occur in unexpected areas and can have a major influence on the relative merits of alternative access options.

What is required is an acceptable methodology that needs to be followed to arrive at the optimum primary access option. Where a number of different access options exist, a four-step approach should be adopted to assist in this multi-criteria decision-making process:

- *Step 1*—Identify selection criteria, based on an understanding of the mine's business imperatives and constraints. Selection criteria would typically include issues such as safety, production risk, capital cost, operating cost, time to first production, and the like as covered above. Criteria should be quantified and benchmarking may be useful to achieve this. For example, simply stating a safety criterion to be: 'as safe as possible' is far less meaningful than stating the safety criterion as, say: 'safer than mine type A, but not necessarily as safe as mine type B'
- *Step 2*—Weight the criteria, taking account of their relative importance for the particular mine under consideration
- *Step 3*—Identify all technically feasible options that could be considered
- *Step 4*—Undertake a preliminary selection in order to determine those options that are worthy of more detailed consideration
- Step 5—Undertake sufficient design and costing of the options that remain in consideration following Step 4, in order to allow their relative merits to be evaluated in terms of the selection criteria and their weightings as derived during Steps 1 and 2. In some cases, the differences between the options under consideration may be relatively large, in which case it may be possible to identify the most suitable option after little additional study. In other cases, however, it may be necessary to undertake relatively detailed design and costing before the most suitable option can be identified.

The process of identifying and evaluating alternative access options is best undertaken, at least during Steps 1 to 4 above, during structured multi-disciplinary workshops interspersed with breakaway sessions (that may last for several days or longer, depending on the complexity of the evaluation process) to consider particular issues and gather relevant information. Care should be taken not to regard primary access as being the professional domain of any one technical discipline. Also, ideas from a variety of different mining companies in various parts of the world should be considered, particularly during Step 3: mining companies all too often favour one particular access method in all their mines, presumably on the implicit (but erroneous) assumption that what works well in one instance will also work well in all others.

Conclusions

Generic guidelines related to primary access options are

Guidelines			
	Ramps	Inclined shafts	Vertical
Orebody depth	<300–500 m	Plunge dependent	>300–500 m
Key driver	Early start	Reduces secondary development	Low operating cost
Biggest detractor	Increasing operating cost with depth	High risk if structural geology not known	High initial capital; long production lead time

presented in the Table above. These are general principles only, and should not be used to determine the optimal solution for any particular mine, without applying the process described above.

Extreme caution is advised to those not experienced in the choice and design of access systems in applying the abovementioned guidance parameters without proper iterative and detailed study of the particular circumstances and without following the methodology outlined in this paper. A well-designed, properly structured and professionally facilitated approach to selecting the optimal access option for any particular mine will pay ongoing dividends throughout the life of the orebody.

References

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