Analysis of options of production and access ways in underground mines

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Abstract

This article aims to review the issues to be considered in choosing primary access and transportation options for underground mines. The main accesses to underground orebodies are declines or vertical shafts. They serve both as a way to transport ore or waste, and move people, equipment or supplies. In underground mines, the ore transport option significantly affects the productivity and profitability of the company. Then, choice of access is a way to reduce costs and improve production. This study is primarily based on some case studies of Brazilian, South African, Australian and Turkish mines, among others. Literature review shows that the depth at which shaft hoisting becomes a more economically attractive alternative to decline truck haulage is changing from being previously 350 m to present 1000 m, depending on the mining country and cultural underground mine development. For some of them the depth of 1000 m would be the threshold for use of the access by decline. The main criteria in determining access are depth, rate of production and mine life. In South Africa, mines reach depths greater than 3000 m and shaft access is more common. In Australia there are mines that use a ramp (decline) to a depth greater than 1000 m. In Brazil, underground mines are still shallow (depth up to 800 m) and feature short mine life and, most of them have chosen access by decline. Results of this study corroborate the statement that decline is ideal for shallow mines and low production rates and that shaft is for deep mines, high production rate and long mine life.

Keywords: underground mining, access ways, shaft, decline, deep mine.

1. Introduction

In Brazil, the most productive underground mines extract up to 1.000.000 tons/year (MINÉRIOS & MINERALES, 2013), representing less than 2% (30 mines) of all the mines (open pit and underground) in the country as KOPPE (2006). According to DNPM (2009) 47 are exclusively underground mines, while 17 are concomitant with open pit mining.

The choice of the main underground access for production is made in the planning phase and requires careful assessment. It is not an easy task, since it requires examination of a number of factors such as: location, topography, geology, rock geomechanical behavior, mining method, run time, production rate, and mine-life operational costs, among others.

Figure 1 shows the main access ways (ramp and shaft) and ore body in a hypothetical mine, which in this case has a big dip. The costs involved, coupled with the need for increased production and the life of underground mines, require that the choice of main access to ore bodies, increasingly deeper, be efficient, fast, economical and safe (FUJIMURA et al, 2001). The choice for not optimizing these causes disadvantages throughout the mine life and can lead to greater costs (MOSER, 1996). The decision should be taken once, since subsequent changes are expensive and involve losses (HARTMAN & MUTMANSKY, 2002). Among the main accesses to underground ore bodies include decline and vertical shaft. These pathways are used as much for ore transportation as for that of people, equipment, and supplies.

When a new ore body is found to have a certain depth, there are three basic options according to COSTA (1984):

Option 1 – deepening existing structures (shaft or other main access);

Option 2 – construction a ramp or inner shaft connected to an existing access;

Option 3 – construction of a new shaft from the surface to access the deep ore zone.

Figure 2 represents option 2. Figure 3 displays option 3, which shows two crushing, loading stations, and a new shaft. In this option, the body is deeper, which can justify the construction of the shaft and a new crushing and loading station.

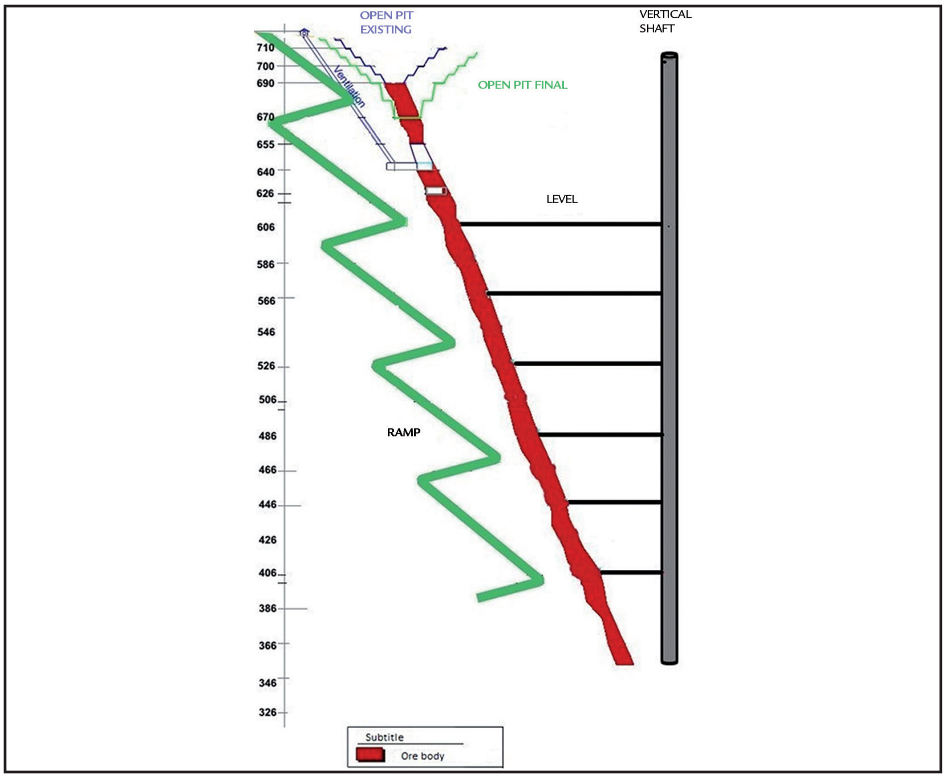

Figure 1
Ore body and access ways (COSTA, 2015).

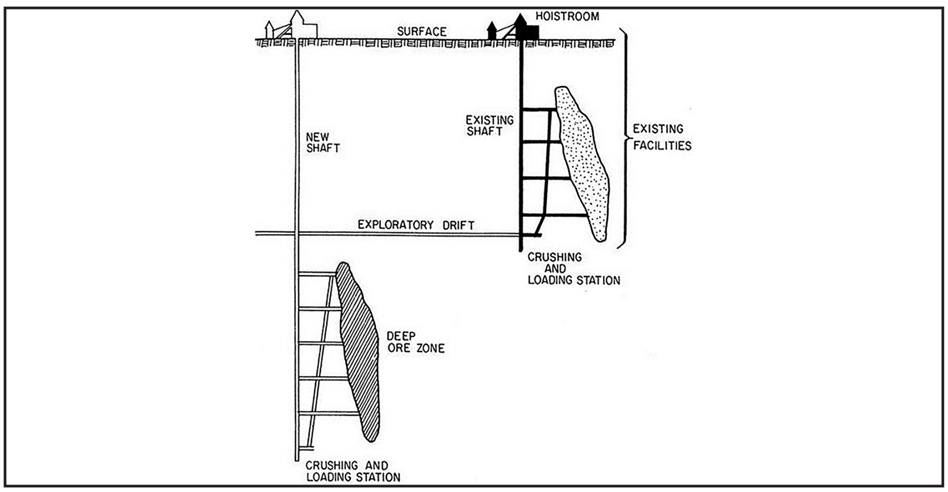

Figure 2
Access to new ore body
using option 2 (COSTA, 1984).

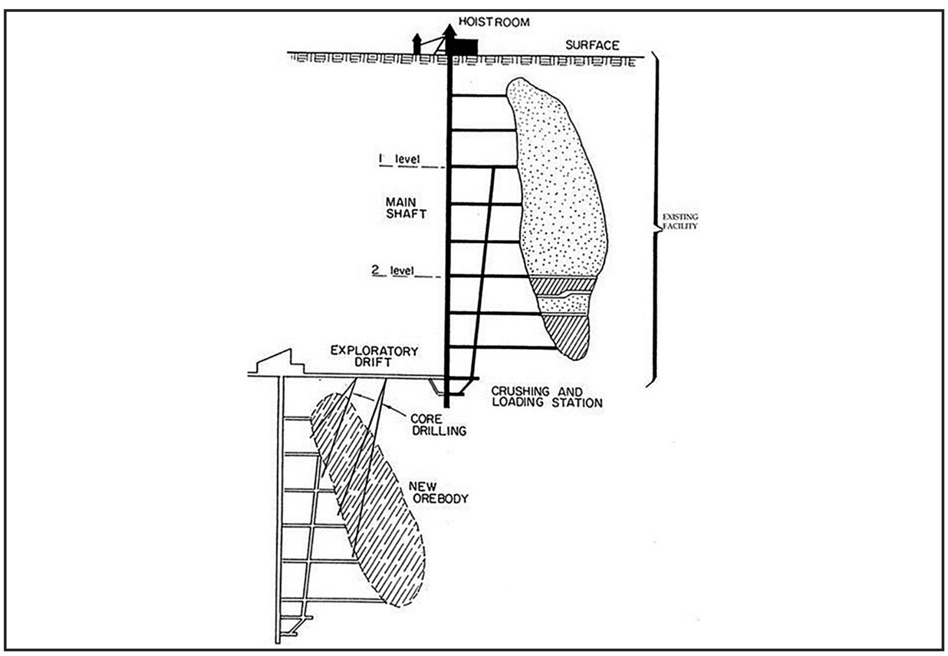

Figure 3
Access to new ore
body using option 3 (COSTA, 1984).

Vertical shafts in Brazil are still unusual since most the Brazilian underground mines still do not reach great depths, present low production rates and the mine life is uncertain in the long term. In South Africa, the gold mines usually present a predictable geology favoring greater depths. Access by shaft is recommended in this situation. In addition, production rates are relatively high, and the mine life is long. This kind of access is recommended at depths greater than 500 m with production rates greater than 5,000 ton/day for mines with more than a 12- year production life (MCCARTH, 1993). In Australia, the access by decline provides almost double productivity compared to Canada, where shaft is preferable, considering similar technology (MCCARTHY, 2002). According CHADWICK (2000) and HALL (2005), the use of decline can achieve depths larger than 1,000 m with very competitive costs with the shaft alternative. Australia is leading in developing decline to great depths.

Other important variables are, for example, the production rate and the orebody geometry. Tabular orebodies favor the use of decline rather than shaft. The production rate was the fundamental criterion for defining the type of access chosen in the case of the shaft for increased production. Due to the production rate, the required amount of material would be impossible to be transported by truck, since it would require the addition of various equipments which could cause underground traffic, ventilation and security problems. With increasing depth of the distances, DMT by trucks becomes larger and therefore longer cycles are needed to transport the same amount of material. The operating cost of the ramp is greater than the shaft as the depth increases (COSTA, 2015).

Table II shows that the most productive and foreign deep mine use the shaft instead of decline. Another important point to be made is in relation to the life of these projects. They all have long life, which justifies the implementation of the access by shaft. Thus, there will be enough time for the return of investments used in the application of the shaft.

2. Methodology

This study is based on technical visits to Brazilian underground mines located in the Quadrilátero Ferrífero region, Minas Gerais state, on-the-spot discussions with mining engineers followed by an extensive literature review and a questionnaire submitted to expert technical personnel.

A survey of data contained in papers dealing with South Africa and Australian mines was primarily conducted, which was followed by a survey considering the main Brazilian underground mines Afterwards the following steps were followed in order to acquire enough data for evaluation:

- preparing of a questionnaire;
- visiting underground mines for data collection;
- assembling the database of mines relating to the research project;
- reviewing of literature;
- selecting of the main factors dealing with the choice of main mine access;
- comparison of data collected with surveys conducted in Brazil and other main mining countries.

3. Results

In Brazil, most of the mines (80%) feature low depths (up to 800 m), production rate and the mine life span are relatively short, and there is little ore body in-depth information. These variables are crucial in the definition of access.

Table I – Production and depth of Brazilian mines (COSTA, 2015)

C Company	Mine	Main Mining Method	Mineral	Production rate (ton/day)	Depth (m)	Expected End of Mine Life	Main Access
Anglo Gold (ex-Morro Velho)	Cuiabá	Cut and fill	Au	3.600	840 (shaft) 1.200 (mine) Forecast to reach 1.600 m	2026	shaft /decline
Anglo Gold	Córrego do Sítio I	Cut and fill	Au	1.325	356	2030	Decline
Anglo Gold	Córrego do sítio II	shrinkage Stoping Open stopes.	Au	750	1.450	2029	Shaft
Anglo Gold	Crixas	Open stopes	Au	3.794	300 800 (expectation)	2021	Decline
Votorantim	Morro Agudo	Cut and fill	Zn	2.682	750	2018	Shaft and decline
Votorantim	Vazante	Sublevel Stoping	Zn	3962	320	2025	Decline
Anglo Gold (ex-Morro Velho)	Lamego	Cut and fill	Au	1.148	400	2026	Decline
Jaguar Mining	Turmalina	Cut and fill	Au	1.300	200	2028	Decline
Yamana	Fazenda Brasileiro	Sublevel Stoping	Au	2.840	820	2018	Shaft
Yamana	Jacobina	Sublevel Stoping	Au	4.316	400	2029	Decline
Vale	Taquari Vassouras	Room and Pillar	K	1.347	750	2017	Shaft
Mineração Vale do Curaçá	Caraíba	Cut and fill, VRM	Cu	3.000	1.100	2016	Shaft

For the data regarding the production and life span of Brazilian mines, it is possible to perceive a large discrepancy compared to the rates of production and the life of some foreign mines. In the Brazilian mines, the production rates, the life and the depth are low compared to other mining countries. As a result, in Brazilian underground mines ramps are more frequent than shafts as shown in Tables I and II.

Table II – Production and depth of some foreign mines (COSTA, 2015).

Company	Mine	Location	Production rate (ton/day)	Principal Mining Methods	Mineral	depth (m)	Expected Mine's Life (from 2003)	Main	Comments
LKAB	Kiruna	Sweden	52.000	78% Sublevel Caving 22% Sublevel Stoping	Fe	915	30+	Shaft	Expansion for 37 M t/y
Leviathan Resources ltd	Stawell	Australia	up to 1.000	-	Au	1.350	-	Decline	Advanced technology in control of trucks and loaders
MIM Holding	Mount Isa	Australia	31.000	70% Sublevel Caving 30% Sublevel Stoping	Zn	1098	70+	Shaft	electric trucks, LHDs controlled from a distance
Western Mining	Olympic Dam	Australia	20.000	Blasthole	Cu	610	Expansion	Shaft	New shaft planned for expansion
Lepanto	Far Southest	Philippines	17.000	Blasthole	Au	1524	Under construction	Shaft	Study of viability
RTZ	Palabora	South Africa	60.000	Block Caving	Cu	1219	Under construction	Shaft	High production for 80.000 t/a
Codelco	El Teniente	Chile	100.000	Block Caving	Cu	610	+50	Decline/ Shaft	LHD controlled by remote control

5. Discussion

From the database presented, one can realize that the Brazilian mines generally use the decline as the main access for production and personnel. Only five mines (7,8%) utilize shaft for hoisting ore production (Córrego do Sítio I, Fazenda Brasileiro, Cuiabá, Caraíba and Taquari - Vassouras). One of the main reasons is the shallow orebodies, unknowingness of the ore reserve, high oscillations on commodities price, production rate, short life span of the mine and operating costs.

The research main purpose was to determine the existence of a plan to change decline for shaft due the increase of the mine depth and the production rate. None the mines had in the long term a plan to change from decline to shaft. However, it is important to note that each mine is unique and therefore, makes it difficult to establish a rule that suits all the mines.

Two examples of Brazilian underground mines should be mentioned. At the Córrego do Sítio II Mine, from Anglo Gold Ashanti, they chose to deepen a previous production and personnel shaft from level 23 up to level 30, a difference of 360 m between these levels, instead of continuing access by decline. The option for this choice was geological and economical. Geological reasons include the geometry and the orebody inclination, since the mine has the potential to achieve greater depths extending the ore resource. The economical reason was due to the significant increase of operational costs, labor, ventilation and safety regarding the decline option. At Taquari Vassouras Mine (potassium), shaft was chosen due to the high production rate required and geomechanical aspects, which were unfavorable for decline. The depth in this case was not the determining factor in the choice for shaft.

Some Brazilian mines have opted for shaft associated with declines. The option shaft and internal ramp with partial transportation by truck to the loading station occurs in Morro Agudo, active mine and in the São Bento Mine, already exhausted. Another example of combined transport is the Santa Helena Mine (limestone), where trucks are used for ore transportation to an underground crusher and then the ore transport to surface by conveyor belt. In Cuiabá Mine (gold), the shaft provides access to odd levels, but there is a decline to give flexibility to the removal of equipment that require more detailed maintenance surface.

The main difference between the Brazilian and African mines is the fact that in South Africa the use of shaft refers to the 15th century. This country has, therefore, a long tradition and knowledge in projecting, developing and working with shaft. The dip of the ore bodies (sub-vertical) and the fact that most of the mines have potential to reach great depths are favorable for shaft choice. The production rates of underground South African mines are high, the geotechnical aspects of the rocks are not favorable to use the decline and the ore body is well delimited.

In Australia, however, the factors affecting the choice between decline or shaft are another. The country is recognized worldwide by using decline to great depths with high rates of production, with the ore transport by trucks. There are mines that operate with that medium at depths greater than 1,000 m. The use of the shaft has been replaced increasingly through access by decline, and less than one third of mines in activity use shaft (CHADWICK, 2000).

Shaft opening and assembling requires high capital investments, and the need for a mine life span higher than 12 years for recovery of investments, as some author's advise. Added to this, there is the time spent for shaft construction and assembling with postpone the mine production.

The deep mines are generally of medium to high diving bodies, high as the mines of Kiruna, Palabora, Olympic Dam and El Teniente. The mining methods adopted by them (sublevel caving, block caving and sublevel stoping) are indicated for mines with potential to reach great depths and high dives, as shown in Table II.

The depth for choosing decline with trucks has been increasing over the years. Back in 1973 the mines were about 350 m (South Africa), and nowadays there are mines that exceed 1,000 m (Australia). Despite the Australian and South African difference about the depth for changing from decline to shaft, they agree that the production rate is a fundamental criterion. This will determine whether ore will be transported by decline using trucks or hoisted by shaft. Therefore, shaft will be used when the amount of ore is not advantageous to be transported by trucks. The increased rate of production would require additional trucks that could cause queues and higher costs of ventilation to minimize the pollutants emitted by the trucks and increase of diesel consumption. The life span of a mine is another important factor. If it is too short, there will not be enough time for the return on investments of shaft construction and assembling.

The type of haulage equipment influences the choice between decline (ramp) or shaft. It is important to note that the improvement of diesel trucks and the insertion of electric trucks, in recent years, allowed exploitation of resources in-depths, with operating costs very competitive with shaft hoisting. Studies carried out in South Africa by Rupprecht (2012) demonstrate the depth of transition (ramp for shaft) increases as the size of the equipment evolves. Varying capacity of 30 t to 40 t trucks to the depth transition went from 200 m to 360 m in comparison with the shaft production rate of 80.000 ton/month. From this analysis, the author has shown that the "golden rule," which says that the point of economic transition truck transport to vertical shaft is between 300 m and 350 m, remains valid only for small trucks. The transition depth varies from operation to operation and as the size of the equipment increases.

The same author shows that the depth of transition for a 50 ton truck and a shaft with production rate of 120.000 ton/month decreases the depth of 450 m to 400 m. Shaft operating costs decreased 10% by increasing the amount of transported (80.000 ton/month to 120.000 ton/month). Completing this way, both increased production and depth make access more attractive by shaft.

Over the years the depth of decline transition to shaft increased from 350 m to depths exceeding 1,000 m in some mines due to the improvement of the trucks and reduces operating expenses.

6. Conclusions

This study shows that the main access decision-making involves a series of criteria. The analysis of these criteria allows the mining planning process to assert that the use of decline is usually recommended for mines with low production rate and shallow depth (up to 800 m). However, some mines, especially in Australia, use decline to depths greater than 1,000 m and with relatively high rates of production.

There are few Brazilian mines that exceed the depth of 1,000 m (Cuiabá, Córrego do Sítio II and Caraíba ones). The others have chosen to access the decline due to six reasons: low production rate, short mine lifespan, ore body close to surface, low cost of implementation, fast return on investment and unavailability of capital. However, one must be careful to not only consider the depth as a criterion. The deployment of a shaft costs too much and requires potential and availability of resources to justify this option of access.

As the mine progresses in depth, the greater knowledge of the geometry of the ore body, the better knowledge of in-depth deposit, the distances to be overcome until the surface, the access option, determined at the beginning of the life of the mine, may be amended or maintained. The application of shaft requires at first the availability of resources, knowledge established, and high ore resource.

It can be concluded that in mines near the surface, the transport by decline is recommended due to the low investment, quick return of investment, and it presents generally the largest NPV (net present value).

It is noticed that it is difficult to establish a general rule to define the main access because each mine has its peculiarities. For mines of great depths is practically unfeasible to use decline due to the operating cost that it represents. In this case, the use of shaft becomes more appropriate. However, the major disadvantage of shaft is the high initial investment required and the relatively long time for the deployment of this infrastructure. For this reason, the main underground mine projects require usually long maturation, about 7 to 8 years before the withdrawal of the first ton of ore.

As seen, the depth of the orebody, the target production, the cost, the life expectancy of the projects, as well as body shape, type and size of the transport equipment, the experience, the orebody behavior knowledge ore, the existence of new reserves are factors in the complex network of decision elements, which makes this an important step in the underground mining project.

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