Project optimization

Otimização de projeto

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Abstract

A mineral deposit can be exploited by underground methods or by open pit methods, defined according to their characteristics, especially in relation to depth and geometry of the ore body and the economic feasibility of the methods. However, there are cases in which the alternative that represents the best return for the project is the application of combined methods, i.e., the open pit followed by underground mining. In these situations, the major difficulty is the definition of the transition point of methods, seeking to maximize the net present value of the project and the use of mineral resources. The premature suspension of activities in the open pit, as well as advancing beyond the optimum depth, can derail the implementation of the combination of methods, so it is important to analyze the project not only individually but also in an integrated way.

Keywords: mine planning; open pit optimization; underground mining; methods transition.

Resumo

Um depósito mineral pode ser explorado por métodos subterrâneos ou por métodos a céu aberto, sendo tal ação definida de acordo com as suas características, principalmente em relação à profundidade e à geometria do corpo de minério e aos aspectos econômicos de viabilidade dos métodos. Contudo existem casos em que a alternativa que representa melhor retorno para o projeto é a aplicação dos métodos combinados, ou seja, a lavra a céu aberto seguida da lavra subterrânea. Nessas situações, a grande dificuldade é a definição do ponto de transição de métodos, de forma a maximizar o valor presente líquido do projeto e o aproveitamento dos recursos minerais. A suspensão prematura das atividades a céu aberto, bem como o avanço além da profundidade ideal, pode inviabilizar a aplicação da combinação de métodos, portanto é importante que o projeto seja analisado não só de forma individual, mas, também, de forma integrada.

Palavras-chave: *planejamento de mina; otimização de cava; lavra subterrânea; transição de métodos.*

1. Introduction

The OP mining methods have many advantages comparing to UG mining methods, such as the level of mechanization, the lower dilution and larger recovery of the deposit, flexibility and others (Bakhtavar *et al*., 2008). These advantages make the application of the OP methods more usual than the UG methods, even when the latter one presents also some favorable aspects, mainly related to reduction of the environmental impact (Chadwick, 2008). Aiming to maximize the resources and/or the economical results of the mining enterprise, several times the characteristics of the ore body suggest the application of combined methods. When it occurs, it is very important to find out the right moment of transition from OP to UG methods, because if this point is not well defined it can implicate in material losses as well as in the impossibility of applying underground mining after extraction by open pit due to the lack of remaining resources (Bakhtavar & Shahriar, 2007; Bakhtavar *et al*., 2008; Visser & Ding, 2007; Camus, 1992).

2. Methodology

In the process of looking for the optimal transition point from OP to UG mining, in scenarios where the combination option gives better results than the individual application of the methods, different pits should be assessed with their remaining resources, in order to determine the combination that presents the higher net present value for the project and maximizes the recovery of mineral resources. The scenarios of mining only by OP or only by UG methods should also be analyzed, to confirm which option generates the best return. Figure 1 shows a schematic example of different combinations of pits with their respective remaining UG resources and necessary development to access the ore body.

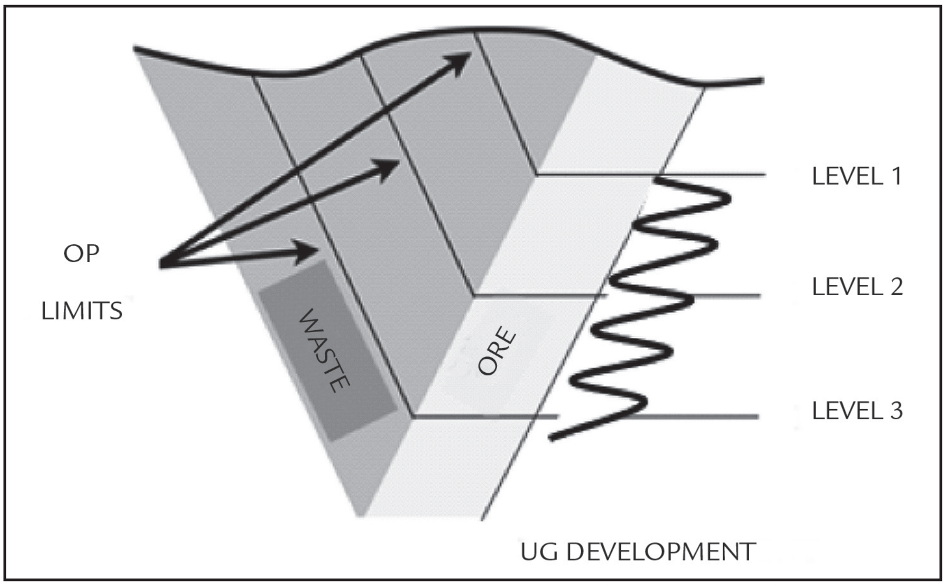

Figure 1
Combination of different scenarios (De Carli, 2013)

Figure 2 shows the flowchart of the sequence of steps suggested in this study to determine the optimal transition point of methods.

These steps will be applied to a gold deposit as case study, which has a mineral body with characteristics for the application of combined methods.

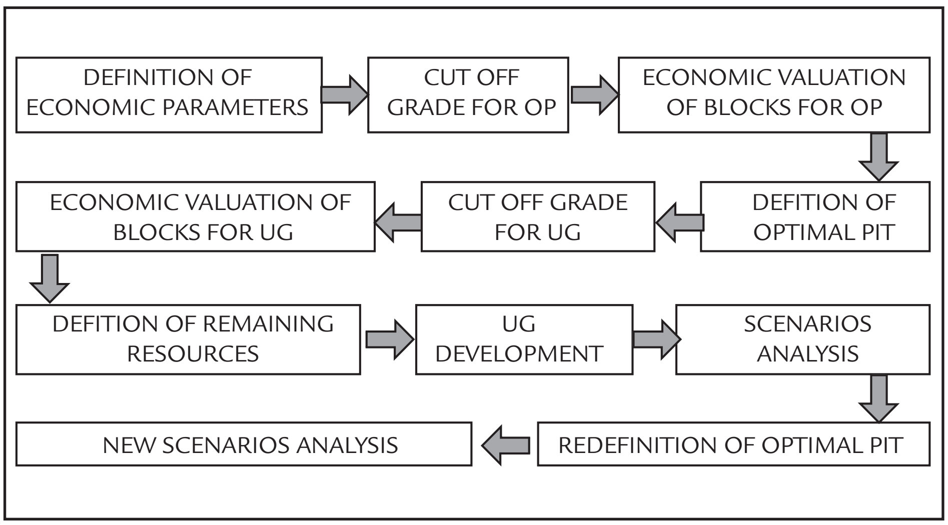

Figure 2
Flowchart of the sequence of steps used in the methodology

The *Studio 3* and *NPV Scheduler* softwares were applied to assist in the search of required results in most of the steps.

As shown in Figure 2, the first step is determining the economic parameters. Once these parameters are defined, it is possible to find the minimum ore grade that pays for all costs involved in the production, called Breakeven Cut Off Grade (BCOG), according to the equation (Rendu, 2008):

$$BCOG = \frac{C_M + C_P + C_{G\&A}}{R(P - C_R)}$$

Where: C_M – Mining cost for ore (OP)
C_P – Processing cost
$C_{G\&A}$ – General and administrative costs
R - Recovery
P – Selling price
C_R – Refining cost

Also, it is necessary to find the Marginal Cut-Off Grade (MCOG), considering that the extraction capacity is not restricted in a mine, according to the equation:

$$MCOG = \frac{Inc + C_p + C_{G\&A}}{R(P - C_R)}$$

Where: *Inc* – Incremental cost of transport

Each block of the model receives an economic value, according to its classification (Halatchev, 1999), applying the profit function (PF):

$$PF\,(ORE) = (AU * R * (P - C_R) - (CM + CP + C_{G\&A})$$

$$PF\,(\,MARGINAL) = (AU * R * (P - C_R)) - (\,INC + CP + C_{G\&A})$$

$$PF\,(WASTE) = -\,(C_{MW})$$

Where: C_{MW} – Mining cost for waste (OP)

To generate the optimal pit, the software Studio 3 is applied. The mine life and the NPV can be found determining the block extraction sequence inside the pit.

For the UG scenario, the BCOG is calculated with the same equation utilized in the OP scenario, but applying the economic parameters for UG mining:

$$BCOG = \frac{C_M + C_P + C_{G\&A}}{R(P - C_R)}$$

Where: C_M – Mining cost for ore (UG)
C_P – Processing cost
$C_{G\&A}$ – General and administrative costs
R - Recovery
P – Sale price
C_R – Refining cost

Evaluated is the total of resources from topography, in the case of applying only UG methods, and also the remaining resources after pit exhaustion, in the case of applying combined methods.

To create the UG development, it is necessary to generate the grade shells, which are envelopes intended to make a separation of ore and waste contained in the ore body, based on cut-off grade, to cover only the material that should be mined. The grade shells, as well as the ramps of development, can be created by software Studio 3. In this study, only the main access ramps were considered. In case the UG methods present the best economic results for the project, it is important to detail the UG development.

This study analyzes a deposit considering just its measured and indicated resources, and three scenarios were generated: mining by OP, by UG and by combined methods.

The results were compared to find the best economic return to the project. Also, the results were compared to optimal transition depth obtained by OSR and ASR (Bakhtavar et al., 2008), a method that suggests that, to respect the viability of an OP project, the Overall Stripping Ratio should be always below the maximum Allowable Stripping Ratio.

3. Results

The economic parameters applied to the study case are shown in Table 1.

Mining cost- Ore	US$ 2.9/t
Mining cost- Waste	US$ 1.4/t
Processing cost+ G&A	US$ 7.22/t treated
Refining cost	US$ 11.00/oz Au (US$ 0,35/g Au)
Processing recovery	93%
Mining recovery	98%
Sale price Au	US$ 1,200.00/oz Au (US$ 38.60/g Au)

Table 1
Economic parameters.

Based on the economic parameters mentioned, the Breakeven Cut Off Grade (BCOG) and the Marginal Cut Off Grade (MCOG) were calculated. The results are in Table 2.

BCOG	MCOG
0.285 g/t	0.245 g/t

Table 2
BCOG and MCOG for OP.

The next step is the determination of the economic value of each block, applying the PF. As long as they are economically evaluated, the optimal pit can be defined by running the pit optimization software (NPV Scheduler), considering some premises related to geotechnical and production aspects according Table 3.

Slope angle	Annual production	Annual discount rate
Region 1: 45°/Region 2: 25°	1,500,000 t	7%
Region 3: 36°/Region 4: 47°		

Table 3
Input data to generate optimal pits.

The pits were generated up to 150% of its initial gold price, creating new pits at every 5% increment.

The pit of 100% of the gold price represents the maximum net present value for the open pit scenario (traditionally considered the ultimate pit).

Table 4 shows the results of OP for the case study.

Ore mass (t)	Avg grade au (g/t)	Total au (oz)	Mine life (years)	NPV (US$)
17,863,681	0.77	440,511	12	141,468,850

Table 4
Results of final pit (100%).

The Overall Stripping Ratio (OSR) in the deposit must be smaller than the Allowable Stripping Ratio (ASR) to respect the viability of the method, which means, the application of OP is more economical than the application of UG, since this relationship is respected.

The ASR is characterized by the maximum stripping ratio practiced in an open pit mine.

This relationship can be determined by applying the equations:

$$ASR = \frac{Cug - Cop}{Cw}$$

Where: Cug – Prime cost of 1 ton of the mined mineral via UG (US$)
Cop – Prime cost of 1 ton of the mined mineral via OP (US$)
Cw – Total costs of 1 ton of ground removal via OP (US$)

$$OSR = \frac{To}{Tw}$$

Where: To – Tonnes of ore (US$)
Tw – Tonnes of waste (US$)

The OSR was compared to the ASR, applying the equation above, and it was lower than ASR, respecting the viability of the method, as shown in Table 5.

Overall Stripping Ratio (OSR)	Allowable Stripping Ratio (ASR)
5.3	26.5

Table 5
Comparison of OSR and ASR.

The next scenario evaluated is the UG option alone. The BCOG of the deposit was calculated applying the same equation used in the first scenario, however changing the OP mining costs for UG mining costs, and the result found was a BCOG of 1.33 g/t.

From the calculation of the BCOG, generated are the grade shells and the UG development (main ramps and crosses) to access them. Only when this step is concluded, is it possible to estimate the remaining resources, from the original topography and also from the final pit, considering the application of combined methods and the preliminary UG development necessary to access the main grade shells.

The resources for application of only UG methods are presented in Table 6.

Table 6
Resources for application of only UG methods.

Ore mass (t)	Avg grade au (g/t)	Total au (oz)	Mine life (years)	NPV (US$)
3,862,975	2.32	287,890	9	6,818,213

In the case where combined methods were being applied, the remaining resources from the final pit were estimated, and are shown in Table 7.

Table 7
Underground remaining resources from the final pit.

Ore mass (t)	Avg grade au (g/t)	Total au (oz)	Mine life (years)	NPV (US$)
1,149,913	2.67	98,711	4	10,168,800

To find the total results of the combined methods, it is necessary to add the results of OP showed in Table 4 with the results of remaining resources showed in Table 7. They can be found in Table 8.

Table 8
Results of combined methods.

Ore mass (t)	Avg grade au (g/t)	Total au (oz)	Mine life (years)	NPV (US$)
19,013,594	0.88	539,223	16	151,574,176

In the case study, the combination of methods will be examined in more detail, since this scenario is the best option and a small variation of transition depth represents a considerable variation of final NPV. Along with the combination of optimum pit generated in scenario 1, with underground mining, the results of intermediate pits combined with extraction of the remaining resources by UG methods will also be generated.

This approach is the main proposal in the methodology, since the analysis of what is determined as "optimal pit" may not necessarily be the most profitable scenario for the project in an integrated way.

The pits 60%, 70%, 80%, 90% and 100% of the price of gold were evaluated with their respective remaining resources, considering the difference in total development for each case. The results are shown in Table 9.

Table 9
Results of different combinations of OP and UG.

	Pit 100%+UG	Pit 90%+UG	Pit 80%+UG	Pit 70%+UG	Pit 60%+UG
Ore mass (t)	19,013,594	18,402,229	17,862,103	17,259,284	14,766,371
Grade Au (g/t)	0.88	0.90	0.91	0.93	1.01
Total Au (oz)	539,223	530,382	522,304	515,777	477,580
Mine Life (years)	16	16	15	15	13
NPV (US$)	151,574,176	151,903,449	153,308,887	152,404,996	146,168,595

Table 10
Comparative analyze of results.

	Only OP	Only UG	Pit 80%+UG
Ore mass (t)	17,863,681	3,862,975	17,862,103
Grade Au (g/t)	0.77	2.32	0.91
Total Au (oz)	440,511	287,890	522,304
Mine Life (years)	12	9	15
NPV (US$)	141,468,850	6,818,213	153,308,887

4. Conclusions

The analysis of the deposit using the suggested methodology incurred some situations related to the geometry of the bodies and the connectivity of the mineralized zone between superficial and deep areas. Due to the characteristics of the deposit, different transition depths were analyzed. The results prove that, in some cases, what is considered optimum for OP is not necessarily so for the project in an integrated way. The best NPV was not found with the combination of the pit considered optimal in a scenario of OP, but with the combination of the pit that represents 80% of the gold price with the succeeded mining by underground methods of its respective remaining resources. Besides providing the highest NPV, this scenario also has the best use of resources and consequently an extended mine life, increasing the time that the enterprise will spend on that site, which is important for environmental issues, depreciation, social development, among others.

The proposed methodology determines that the depth of transition should be analyzed through the use of a cyclical calculation of COGs integrating the use of mining softwares, considering the difference between the blocks of ore and waste in each one of the mining methods, since the operational costs involved in open pit and underground mining are not the same. This differentiation provides to the economic models and the decision making process greater precision in the definition of transition depths and scenario interaction.

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