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Easy profit maximization method for open-pit mining

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ABSTRACT

A methodology applicable at any phase of a surface mining project for evaluating its current technical and economic feasibility is presented.

It requires the typically available quantitative data on the ore-body, with its three-dimensional block model developed upon accurate interpolations. Thus it allows estimations of exploitable reserves in function of various cut-off grades, such as the average grade of mineable ore, the tonnages of ore and waste rock, stripping ratios and profit estimates for different production levels.

If cost evaluations of essential mine operations are available (such as ore mining, waste removal, ore concentration, transportation, indirect project costs and expected concentrate selling prices), the methodology will provide clear indications on the economic feasibility of mining, including the best available options at any moment. Simple expressions are developed on the basis of a profit mathematical function and an application example is presented with data available from an existing iron ore deposit.

1. Basic concepts

Mining is essentially governed by the knowledge obtained from three scientific disciplines: geology, mining engineering and economics.

Only through an intensive program of research and field studies can a successful mining project be implemented. This program must be carefully coordinated through a succession of pre-designed stages. Since the ultimate goal to achieve is obtaining an economic benefit upon the invested capital, that benefit is justified due to the uncertainty and risk that are involved in all those stages.

Initial studies are geological in nature, based on pre-existing information (publications, technical reports, satellite images, etc.) and usually complemented with data from exploration activities on the ground, involving studies of geology, geophysics and geochemistry. Representative sample acquisition follows from field investigation including open-pits, shallow trenches, as well as drilling campaigns. These samples are then sent to specialized laboratories for the physico-chemical characterization of minerals, allowing the creation of a database that, after appropriate computational processing, may describe the main characteristics of the deposit. Analyses of technical and economic feasibility of the project are thus required, initially with reduced available data and subsequently with the greater volumes of information in order to provide reliable evaluations of project feasibility.

Questions on the possibility of ensuring future revenues from the sale of the final product to the market, which should be higher than the investments required in all steps of the previous study, must be answered. Moreover, it is expected that these revenues will cover the necessary capital for the mining project with yields that should be higher than those of alternative financial applications.

In essence, there is always a strong interaction between the four variables represented in Fig. 1.

It is obviously necessary to involve components of engineering and economics to answer these questions.

Gama (1986) listed the following tasks required to develop this approach:

(1) Determine the geometric shape of the mineralization, by defining the spatial orientation of the ore to extract (including the distribution of its contents along the mineralized volume) as well as the barren rocky material that must be removed.
(2) Design the mining method appropriate for extracting the deposit, including the mechanical equipment to be used in operations of excavation, loading and transportation of both ore and waste.

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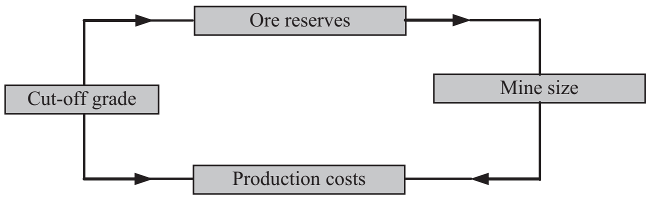

Fig. 1. The four main variables influencing the economic feasibility of a mining project, according to Gentry and O'Neil (1984).

(3) The techniques of washing/processing that will be recommended for the product concentration, in conditions of supplying the consumer market.
(4) The general costs necessary to implement the project, from investments in exploration and recognition of the deposit, to feasibility studies and engineering design of the mine, not to mention the corresponding indirect costs of production (offices, business administration, social services, etc.)
(5) The funds to be spent as payments of taxes, miscellaneous fees and compliance with environmental protection rules will apply.

There are several criteria to quantify all the variables listed above, being more used that proposed by Plewman (1970), Barnes (1980), and Hustrulid and Kuchta (2006).

It consists in defining the hourly profit function L (\$/h) by the following relation:

$$L = PTUV - P(M + ER + B) - F \tag{1}$$

where P (t/h) is the hourly production of the mine, which is sent to the mill; T (%) is the average grade of ore that is mined; U (%) is the metal recovery rate obtained in the concentration plant; V (\$/t) is the sales price per ton of metal (or useful substance) out of the plant; M (\$/t) is the cost of mining per ton of excavated ore; E (\$/t) is the cost of removal per ton of waste material; R (t/t) is the instantaneous waste/ore stripping ratio; B (\$/t) is the cost of processing per ton of ore that enters the plant; and F (\$/h) is the hourly incidence of fixed costs, capital, taxes and other indirect charges.

Fig. 2 schematically represents those variables.

The profit function can also be formulated in unit values (per ton or cubic meter of ore), by assigning a unit profit function L' (\$/h), which is given by

$$L' = TUV - M - ER - B - \frac{F}{P} \tag{2}$$

In all these variables, there are two geological characteristics, which have great importance: the stripping ratio R and the grade of ore T. It is therefore essential to determine what their extreme values are which may lead to a zero profit.

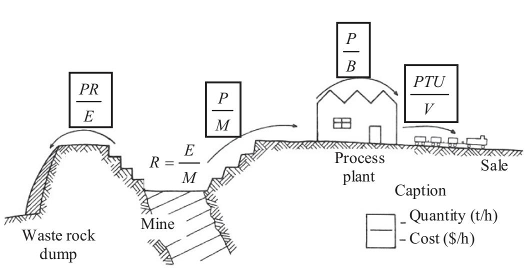

Fig. 2. Flowchart of production in an open-pit mine, with its main attributes.

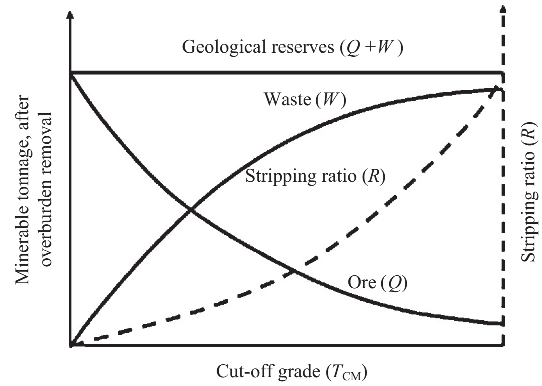

Fig. 3. Typical variations of exploitable reserves (Q + W) and stripping ratio (R) as a function of the cut-off grade (T_{CM}).

Thus, the *minimum allowable cut-off grade* is provided by the expression:

$$T_{CM} = \frac{M + ER + B + F/P}{UV} \tag{3}$$

meaning the grade content that separates the exploitable material (ore) from the one which is sent to the heap (waste).

In the same way, *the maximum allowable stripping ratio* is given by

$$R_{max} = \frac{TUV - M - B - F/P}{E} \tag{4}$$

representing the largest amount of overburden material that can be removed in order to extract one ton of ore with an average grade T, above the level of T_{CM}.

In practice, the operating conditions of any mine should be set away from those where profit can either be zero or negative, so that T_{CM} and R_{max} are limit values not to be exceeded, considering that the other variables are unchanged.

It is worth noting the instant relationships that must exist between the quantities of ore, waste rock and the actual cut-off grade. Fig. 3 shows this typical variation, by means of introducing the concept of geological reserve Q + W, which is defined as the sum of the quantities of ore and waste, as well as showing a typical variation of the stripping ratio with cut-off grade.

Another relevant concept is the *allowable stripping ratio* R_{ad}, which is defined upon the consideration of a minimum profit (L_{min}) that must always exist, and it is given by

$$R_{ad} = \frac{TUV - M - B - F/P - L_{min}}{E} \tag{5}$$

Therefore, the economic control of mining should be conducted in a continuous way and it must be based on the assessment of the levels of the ore grade T and stripping ratio R, which should satisfy the following conditions:

$$T > T_{CM} \tag{6a}$$

$$R < R_{ad} < R_{max} \tag{6b}$$

2. Correlations between ore body model and profit function

The ability to formulate three-dimensional block models for any mineral deposit can be used to evaluate the conditions of its exploitability.

For this purpose, it is important to correlate mathematically the relevant variables in the profit function and its dependence on the cut-off grade T_C. In particular, there are three variables that can be