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Economic feasibility of responsible small-scale gold mining

Tatiane Marin [a, b, *], Jacopo Seccatore [b, c], Giorgio De Tomi [a, b], Marcello Veiga [d]

[a] *Mining and Petroleum Engineering Department, University of São Paulo, Brazil*
[b] *Research Center for Responsible Mining, University of São Paulo, Brazil*
[c] *Instituto de Geociências, Universidade de São Paulo, Brazil*
[d] *Norman B Keevil Institute of Mining Engineering, University of British Columbia, Canada*

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ABSTRACT

Artisanal mining (AM) activities are generally seen as a source of concern owing to their illegality and the environmental pollution that they cause, but in recent years it has been demonstrated that gold mining can be performed on a small-scale mining (SSM) in a responsible way outside of the artisanal dimension. A previous study by the same authors demonstrated how mineral resources and reserves can be managed to achieve a sustainable form of SSM, based on the concepts of proving a “minimum reserve” and working with “replication” of the operation on subsequent small reserves. It was shown that SSM can be viable with 1/100 of the reserves necessary to prove the feasibility of a large-scale mining business. However, that work made some simplifications in terms of value of money over time and taxation.

The present work continues by undertaking a realistic analysis of economic feasibility through a cash flow analysis (CFA) on various scenarios of investment strategy for the SSM business, considering the “minimum reserve” approach along with the traditional mining business strategy. The results show that the “minimum reserve” approach is always more attractive from an economic point of view, in terms of value of the project, rate of return of investment, and payback time. Finally, the most suitable profile for investors in the SSM business is discussed, and it is shown how small-scale investors and large corporations can fit into this approach.

1. Introduction

It is estimated that about 16 million artisanal miners produce between 380 and 450 t of gold per year (Seccatore et al., 2014b). Artisanal mining (AM) activities are generally seen as a source of concern owing to their illegality and the environmental pollution that they cause (Veiga, 1997; Veiga et al., 2006, 2009, 2014; Hintona et al., 2003; Shandro et al., 2009; Spiegel and Veiga, 2010; Velasquez-Lopez, 2010). Nonetheless, gold mining can be performed on a small-scale in a responsible way, outside of the artisanal dimension (Seccatore et al., 2014a, 2015). In Seccatore et al. (2015), small-scale mining (SSM) is defined only by the limits of its scale or production, while artisanal-scale mining (ASM) is defined as “a subset of SSM, falling in the same production range, but possessing moreover the characteristics of rudimentary mechanization, inefficient reclamation, unhealthy and unsafe work conditions and exploitation of labor.” When ASM is performed responsibly (losing its negative aspects), it simply becomes SSM, with the only special feature being its scale. SSM has the potential to be an active, positive stakeholder in the mineral resources market. It is able to operate in deposits that are often neglected by industrial mining, and it “allows the mining of otherwise uneconomic resources, since it is mobile, flexible, and requires little capital” (Andrew, 2003).

The main challenge for AM is obtaining the necessary capital investment to upgrade to become responsible SSM (Hentschel et al., 2002; Hruschka and Echavarría, 2011). Because of the high-risk nature of such investment, resulting from the absence of any guarantee of return and financial success, the SSM scenario has, in general, little attraction for investors. For artisanal miners, this creates a situation similar to a “gambling” scenario: with the limited economic resources available, they invest directly in operations without previous geological exploration, restricting their operational planning to that based on the available information, on experience from previous operations, and, often, simply on instinct.

* Corresponding author. Mining and Petroleum Engineering Department, University of São Paulo, Brazil.
E-mail address: tatiane.marin@gmail.com (T. Marin).

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This lack of methodology creates very high levels of uncertainty and hence leads to a lack of credibility and a negative image for investors.

To overcome this impasse, Seccatore et al. (2014a) conceived a new approach for mineral reserves in the context of SSM. In this new approach, there is no requirement for a large investment for a large-scale campaign of mineral exploration; instead, only a "minimum reserve" is needed as proof for the project start-up. The minimum proof reserve is the one that pays back the capital expenditure (CAPEX) and operational expenditure (OPEX) of the mining business, plus the desired profit and the cost of future geological exploration. This requires little investment and reduces the investment at risk to a minimum. A proportion of the profits from the production of this first minimum reserve are designated to pay for the exploration of the next minimum reserve. Therefore, only the initial investment is at risk. Future exploration to confirm the feasibility of the operation is paid for with the revenues generated by the operation itself. The results of Seccatore et al. applied to a real case, showed that the reserves required to prove the feasibility of a small-scale operation are of the order of 1/100 of that required for large-scale mining.

The large mineral companies invest a lot of time and money on exploration before starting to produce. The differential of this proposal is to produce as fast as possible to pay off the initial investment.

Nevertheless, the work by Seccatore et al. was preliminary, and, to simplify the discussion, it was kept "taxless" and "timeless": the original proposition considered neither cash costs over time nor taxes and financial costs. The present work continues from where the previous study left off, in undertaking a realistic analysis of economic feasibility. This requires the use of a method for evaluating mineral projects. The state of the art in the evaluation of mineral projects includes sophisticated techniques such as decision tree analysis, Monte Carlo simulation, and real options analysis (Slade, 2001; Topal, 2008). Nonetheless, the most widely used method is still cash flow analysis (CFA), because of its simplicity (Samis et al., 2012). The mining sector is conservative, and traditional options are often more readily accepted. Also, from a didactic point of view, CFA is more suitable for expressing the point we wish to make in this paper.

The aim of this study is to analyze the economic feasibility of a mining project, adopting the approach of the minimum reserve, taking into account the influence of the time value of money and considering different strategies of geological exploration to prove the replication of the reserve.

2. Methodology

This work is based on the concepts of minimum reserve and replication, introduced and thoroughly described in Seccatore et al. (2014a). The *minimum reserve* is the volume of mineral whose exploitation allows for the payment of the initial investment (i.e., CAPEX), the operating costs, the cost of mineral exploration needed to extend the proven reserve, plus the desired profit. *Replication* is the exploitation in cycles of several volumes of minimum reserves.

To include these items and undertake an economic analysis of the minimum reserve approach, we use a method called *discounted cash flow (DCF)*. *Cash flow (CF)* is the flow of funds into a business, and DCF is "the method used to evaluate [in a business] future flow of money in terms of what it is worth today" (Reider and Heyler, 2003). DCF is standard in both literature and practice of economic evaluation and decision-making. At this stage of research, we chose to use classic DCF to evaluate the minimum reserve, despite the model is deterministic.

A business must be profitable to exist. Profit is determined by a rate of return on the initial investment that is attractive to those who invest in the business. The future profit figures have a determinable value at the beginning of the business. This value is the net present value (NPV). It is the sum of the cash values of the various periods of the project at a discounted rate of return. The NPV is determined by the following equation:

$$NPV(T,r) = \sum_{t=0}^{T} \frac{C_t}{(1-r)^t} \tag{1}$$

where T is the total number of periods, t is the analysis interval of the CF (generally considered as one year), C_t is the CF in the period t, and r is the discount rate.

The minimum reserve of a production cycle may be defined as the one that generates an NPV equal to zero throughout its production. This concept is expressed by the following equation:

$$\sum_{t=I_n}^{Texp_n} \frac{EXP_{n_t}}{(1-r)^t} + \sum_{t=Texp_n}^{Tdev_n} \frac{DEV_{n_t}}{(1-r)^t} + \sum_{t=Texpn}^{Tcap_n} \frac{CAP_{n_t}}{(1-r)^t} + \sum_{t=Tdev_n}^{Tpro_n} \frac{PRO_{n_t}}{(1-r)^t} + \sum_{t=I_{n+1}}^{Texp_{n+1}} \frac{EXP_{n+1_t}}{(1-r)^t} + \sum_{t=Texp_{n+1}}^{Tdev_{n+1}} \frac{DEV_{n+1_t}}{(1-r)^t} = 0 \tag{2}$$

where n is the productive cycle, PRO is the profit obtained with the production of the mineral reserve (it has a positive value), EXP is the investment in mineral exploration with a feasibility study to determine the next minimum reserve (it has a negative value), DEV is the investment in development to mine the next minimum reserve (it has a negative value), CAP is the investment in new equipment and operation improvement, I_n is the beginning of operation of the next minimum reserve, and I_{n+1} is the beginning of the exploration for the next-plus-one cycle, *Texp* is exploration period, *Tdev* is development period, and *Tcap* is investment period.

The right-hand side of this equation is zero because it is considered that the net income generated by the production cycle of a minimum reserve should pay for the initial investment, development, and exploitation of the current cycle and the exploration and development of the next cycle. To simplify the mathematical discussion and show that the minimum reserve is the one that pays for its exploitation, the second term on the left-hand side is taken to be zero. However, this does not mean that the project has no value or that the business does not generate revenues: the profits are simply embedded in the discount rate.

In this view, the minimum reserve volume is not fixed; rather, it depends on the mineral exploration strategy. The beginning of the exploration of the next cycle (I_{n+1}) is a key factor in this proposal, because it defines the CF. The beginning and the duration of exploration may vary according to the investor's strategy, the only restriction being that $\text{Tdev}_n < \text{Tpro}_{n-1}$, i.e., that the development of the next volume must be ready before the end of the exploitation of the current one to ensure continuity of production.

In this study, we analyze different mining scenarios to simulate different strategies of the investors. A period of analysis of 10 years was chosen because it is a suitable range for CFA. This time was applied to the four scenarios analyzed. These scenarios are shown conceptually in Fig. 1 and can be summarized as follows:

A. *Traditional model*. This scenario is the nearest to the approach adopted by traditional mining companies. In this case, it has to be proved that the necessary reserves exist for the whole