

Chilean artisanal mining: a gambling scenario

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Abstract

One of the most characteristic aspects of artisanal mining is the lack of geological exploration. Going into production without previous exploration is here defined as a *gambling scenario*. The present study intended to quantify the risk associated to such gambling by analyzing the operations of an area of artisanal underground gold mining in central Chile. To quantify the risks and the probable outcomes, a risk analysis technique called Event Tree Analysis has been applied. This technique is based on the analysis of possible multiple outcomes of single events or decisions and the probability of occurrence of each. Results show that chances of negative vs. positive revenue are 83% vs. 17%, with an order of magnitude of difference between worst-case and best-case scenarios.

keywords: artisanal mining, risk assessment, event tree, gambling.

1. Introduction

Artisanal mining (AM) is a type of mining activity that has grown to play a prominent role within the extractive industry around the world. Artisanal mining occupies about 16 million people around the world, producing between 380 and 450 t of gold per year, i.e. between 17% and 20% of the world gold production (Seccatore *et al.*, 2014). Although AM is “generally seen as a source of concern owing to its illegality and the environmental pollution that it causes” (Marin *et al.*, 2016), such aspects are effects of the phenomenon and do not analyze the source issue.

The issue at the base of the very concept of artisanal mining is that the exploratory and modeling phases are generally neglected due to a lack of capital (Hruschka and Echavarría, 2011). In traditional industrial mining, the phases prior to the opening of a mine (from scoping to feasibility studies) require the careful management of risks associated

with the business (Singer and Kouda, 1999). This includes geological exploration, analysis, review and modeling of indicated or measured resources and the study of alternative mining scenarios to exploit such resources. Nevertheless, while being largely diffused in a standardized manner in Large-Scale Mining, with large investments applied and state-of-the-art technologies employed, AM does not employ any kind of exploration, modelling or planning (Seccatore *et al.*, 2013). As analyzed in Seccatore *et al.* (2013), what results is a “gambling” scenario for the operators of AM: with the limited economic resources available, they invest directly in the operation, without previous geological exploration, restricting their operational planning on the available information, experience from previous operations and, often, simply on instinct.

As reported by Hruschka and Echavarría (2011), AM operators “usually skip the exploration phase and [...]

proceed with extraction immediately after discovery.” Such a lack of methodology creates the highest levels of uncertainty. Seccatore *et al.* (2013) and Marin *et al.* (2016) propose a solution to this vicious circle, reducing investment risk to a minimum by financing merely the geological exploration necessary to prove a minimum reserve and initiating a virtuous circle of replication where the revenues from the minimum reserve both produce a gain for the investor and finance future exploration. The present article focuses on the scenario where such a solution is not applied. Here the risk associated with the lack of geological exploration is analyzed from a quantitative, probabilistic point of view. The risk analysis associated with such a gambling scenario shows the probabilities of success and failure of a mining operation that lacks geological prospecting and also shows the associated revenues or losses.

1.1 Artisanal underground mining in the Chilean district of Chancon

Chile has not yet established a unique way to catalog Small Scale Mining. However, the sector can be divided into two segments, small-scale mining (SSM) and a segment called small-scale artisanal mining (AM), where the latter stands out as the most precarious and

informal sector (Cochilco, 2014). The Chilean Copper Commission (Cochilco, 2014) recognizes structural factors that negatively affect the development of SSM in the country, such as: low access to mining property (miners do not own the mineral rights of the mine they are

exploiting, as discussed below) and to financing mechanisms, and low levels of technology, which generate higher production costs. This has caused a stagnation at the productive level, in spite of public initiatives and financial resources dedicated to promote the

small mining sector. The present article analyzes the specific AM reality of Chancón. The district of Chancón is a mining and agricultural district near the city of Rancagua, in the VI region, central Chile. As of 2003, 55 mining operations and 1 processing plant were present in the area (Castro and Sanchez, 2003). In 2016, the number of counted active mines was 75 (RTM, 2016). As of 2018, the count of mines performed by the authors of the present study together with the local Association of Miners ASOMIN can reach 99, but it is a rough estimate, since it is difficult to differentiate fully between operating mines and those operating part-time, those prone to closure, those still developing but not producing yet, or those still

open but not currently active because they are in the middle of a change of ownership. The main product of these mines is gold; accessory sub-products include copper, silver, lead. All these mines operate underground, by means of drilling and blasting. Figures 1 to 4 document key operations of this process and indicate the low level of technology employed. It must be highlighted that these pictures have been taken in the mine considered the “cutting-edge” mine of the sector; the other mines in the vicinity operate with much more rudimentary techniques. A majority of the miners in Chancón are tenants (RTM, 2016), who have to discount part of their revenues to the owners of the mineral rights, as discussed below

in this document. Different from artisanal miners (called *pirquineros*) in the northern part of Chile, who process their own ore in artisanal plants (called *trapiches*, as referred in Castro, 2003 and Castro and Sanchez, 2003), none of the mines in Chancón process the mineral by themselves. In Chancón, the ore extracted by each mine is sold to a central plant managed by the national mining company ENAMI. This plant is a clean, modern one that does not employ polluting substances such as mercury to process the ore. The ENAMI plant receives the ore from each mine by truck, analyzes an average gold grade, and pays the mine accordingly. The trust of ENAMI’s grade analysis is a key issue in this process.



Figure 1 - Rock drilling (downwards).
Source: Universidad Adolfo Ibañez



Figure 2 - Rock drilling (upwards).
Source: Universidad Adolfo Ibañez



Figure 3 - Miner, wearing primed cartridges around his neck for transportation. Source: Universidad Adolfo Ibañez



Figure 4 - Blast face, loaded and primed with fire cap and safety fuse, ready to be ignited. Source: Universidad Adolfo Ibañez

As typical of artisanal mining, the miners of Chancón do not invest in mineral exploration. Mines are “discovered”

(RTM, 2016), exploited as long as they are profitable, and abandoned when they no longer are. Often a mine abandoned by a

miner who did not find it profitable was recovered by a new miner, who continued the excavation and found mineralized ore

just a few meters beyond the point where the previous miner abandoned the operation. Furthermore, small-scale miners are those

most sensitive to mineral commodity prices, and, when they are low, their production is immediately affected (MCH, 2016). The

present article intends to analyze and quantify the risk associated with a productive framework such as the one described above.

2. Event tree analysis

An Event Tree Analysis (ETA), often called Fault Tree Analysis (FTA) when dealing with mechanical or industrial systems, is a method to assess risk in a quantitative way. ETA allows to “assess likelihood in a probabilistic context” (Ferdous et al., 2009) of an event based on the causes that led to it. Moving forward and bottom-up from a starting point, an ETA analyzes the possible outcomes of

events and their probability of occurrence. The logic mechanism is that from a specific event two or more events may follow (hence the “tree” definition: forking paths growing like branches on a tree), up to the possible final outcomes of the system being analyzed. Risk assessment tools such as ETAs and FTAs receive sometimes critiques in high-profile risk analysis, due to their imposition of a cause-effect

mechanism: “In a fault tree or an event tree, it is assumed that if a sequence of events occurs, a specified accident is the result” (Jensen and Aven, 2018). Nevertheless, due to the rudimentary reliability of the statistics regarding event occurrence gathered during the present study, a solid and simple method is considered preferable, and simplifications such as the above-mentioned are acceptable.

2.1 Gathering of information

Information regarding the probability of occurrence of the events within the ETA was gathered through the following methods:

- Mining and geological events: data was gathered by interview with

local miners and analysis of historical production data of the local mines

- Market price events: probability of variations of the gold price and of the exchange rate US\$ to Chilean Peso were gathered via the SONAMI (Chil-

ean National Mining Society) website (Sonami, 2018)

- Sale events: data were gathered by analysis of historical sales data of the local mines.

2.2 Eta of the mining process

The ETA of the typical mining process in the Chancón region is

shown in Figures 5 to 10, broken into parts to make it more easily readable.

The events of the ETA are described in Table 1.

Table 1

Event no.	Event	Description	Associated probability
1	Blast a new tunnel face	Abandon current tunnel, open a new one	None (it is a decision)
2	Keep blasting along the same tunnel	Blast along the existing tunnel	None (it is a decision)
3	No blast	Zero-option (no action taken, wait for market conditions to change)	None (it is a decision)
4	Indication of mineral presence	Presence of galena, quartz and chalcopryrite, or quartz vein in sight	65%
5	No indication of mineral presence	Presence of green-coloured rocks (considered as waste)	35%
6	Scenario: Excellent (p6: previous scenario was 6)	gradeAu > 7 g/t 38% gross income is discounted to the owner of the mineral right	20%
7	Scenario: Good (p7: previous scenario was 7)	6 g/t < gradeAu < 7 g/t 33% gross income is discounted to the owner of the mineral right	35%
8	Scenario: Average (p8: previous scenario was 8)	5 g/t < gradeAu < 5 g/t 27% gross income is discounted to the owner of the mineral right	25%
9	Scenario: Bad (p9: previous scenario was 9)	4.5 g/t < gradeAu < 5 g/t 22% gross income is discounted to the owner of the mineral right	15%
10	False positive (misleading mineral indication)	gradeAu = 4.5 g/t is considered the break-even cutoff grade. Lower grades do not allow pay-back for the investment to blast	5%
11	Recent rise in Au market price	Au price recently increased on the national market	53%
12	Recent fall in Au market price	Au price recently decreased on the national market	47%
13	Sell ore	Sell the ore to the National Mining Company	None (it is a decision)
14	Keep ore in stock	Keep the ore in stock waiting for better market conditions	None (it is a decision)
15	Sell ROM as construction material	Do not consider the ROM as ore, and sell it to a crushing company to be used as construction material	90% chance to have a successful sale, 10% chance not to be able to make the sale

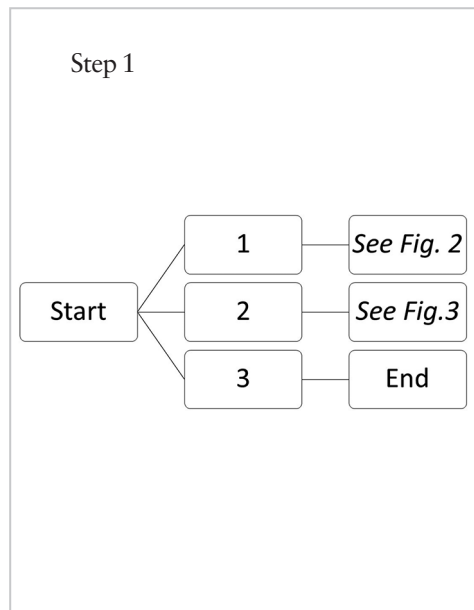


Figure 5 - Step 1 of the ETA.

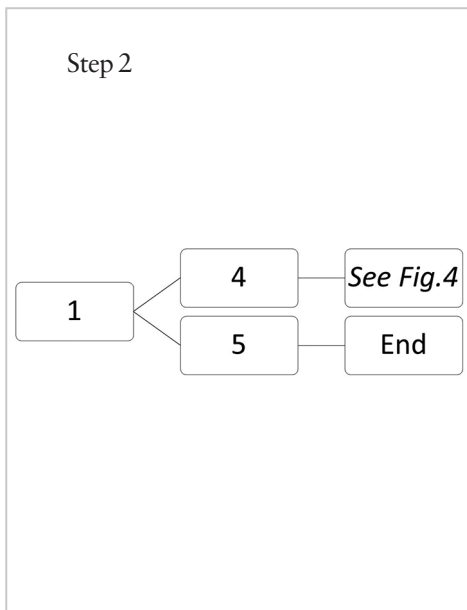


Figure 6 - Step 2 of the ETA.

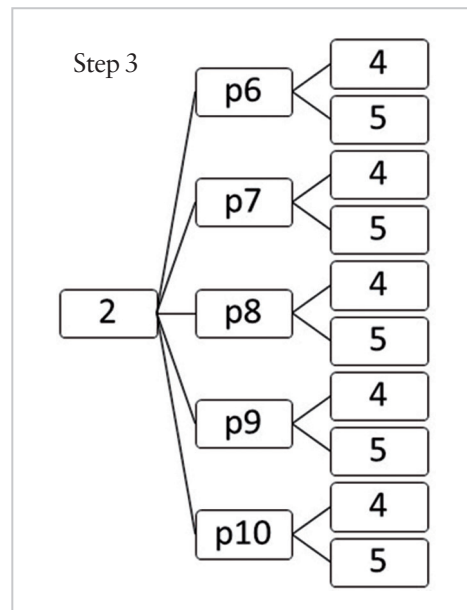


Figure 7 - Step 3 of the ETA.

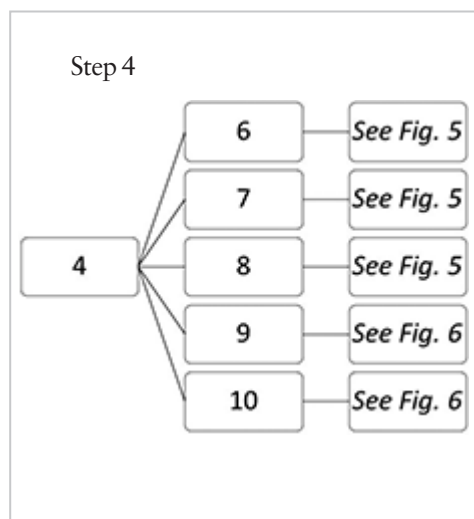


Figure 8 - Step 4 of the ETA.

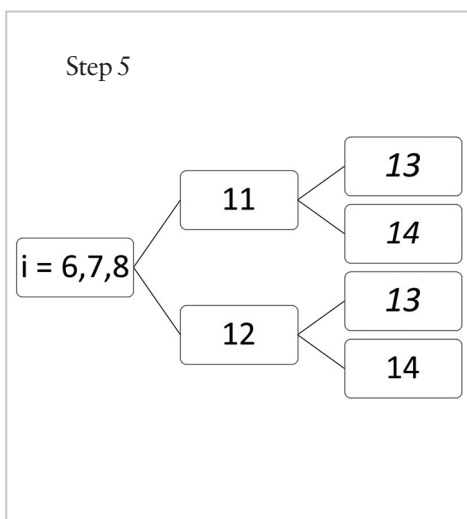


Figure 9 - Step 5 of the ETA.

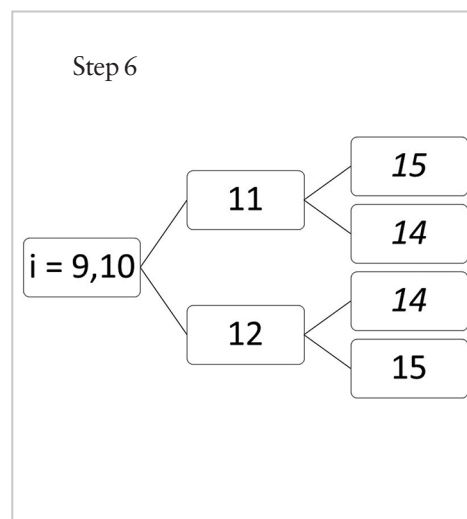


Figure 10 - Step 6 of the ETA.

It can be summarized as follows, observing Figures 5 to 10 for reference to event numbers:

i. The process starts with the opportunity of blasting a tunnel face (start), where one can open a new tunnel (1), keep blasting along the existing one (2) or do not blast at all (3).

ii. If one decides to blast a new face (1), indication of probable Au presence by accessory minerals can either be (4) observed or not (5). It must be highlighted that this visual, artisanal observation of geological features is highly ineffective, as the results show. From option 4 follows the collection of the blasted material, that can appear under five scenarios (6 to 10); from option 5 follows the correction of the decision, and no blast is performed.

iii. If one decides to blast an existing tunnel (2), the outcomes of the

previous blast influence the results (p6 to p10). For each outcome, then the logic process starts again from point 4;

iv. Scenarios 6 to 10 define the mineral content of the blasted material (ROM, Run of Mine), as described in detail in Table 1. The “false positive” scenario (10) indicates that the mineral indications of possible presence of Au were misinterpreted as favorable.

v. Depending on the outcome of the options 6 to 10, and on gold market conditions (11, 12), the miners can choose whether to sell the ore to the ENAMI (Chilean National Mining Company, different from SONAMI, that will pay the miners for its content and process it separately in a clean, modern processing facility. This is option 13 in the ETA), keep the ore in stock waiting for better market conditions (14), or, in case of a negative outcome in

terms of mineral grade, sell the ROM as construction material (15) to a local crushing plant to try and recover some of the costs of the blast.

vi. One must highlight that is an outcome from events 3 and 5 leads to the decision of not performing the blast, therefore not having any gain but also no cost, keeping a break-even condition.

The process described above clearly shows the gambling features of this form of mining: miners exclusively rely on a visual analysis of geological features, and then they have to hope that their supposition was correct; even in case of a correct supposition, the outcome is uncertain and can vary between excellent or bad conditions. The only uncertainties in common with any other kind of mining are related to mineral price and monetary exchange rates.

3. Results

The results of the final outcomes of the ETA analysis are summarized in Table 2. The chances of making a loss, i.e. losing all or part of the money invested in a single blast, are 83% against a 17% chance of

a possible profit or at least a break-even. Once again, as highlighted above, break-evens consider also the options where there is considered the no-action solution (no blasting, or zero-solution). Both analyz-

ing the average of positive versus negative outcomes or observing the worst-case vs. best-case, the possible losses exceed the possible outcomes by an order or magnitude.

Table 2

Total events	139	
Loss events	115	(83%)
Profit or break-even events	24	(17%)
Average loss	-US\$ 307	
Average profit	US\$ 39	
Worst case scenario loss (initial investment or blast cost)	-US\$ 614	
Best case scenario profit	US\$ 78	

4. Discussion

Lack of geological investigation is one of the key aspects that define ASM (Veiga *et al.*, 2006; Hruschka and Echarriá, 2011; Seccatore *et al.*, 2013). The results presented above show the financial risks associated with getting into production without previous exploration. Geological uncertainty, such as the one contemplated in high-profile geostatistical analysis (such as described in Li *et al.*, 2004), is not even discussed here as it is embedded in the coarser uncertainty derived from an absence of prospection whatsoever. As described above, the only

form of geological control is a visual analysis on a face that is the result of a previous mining activity, meaning that production is used as the only, if limited, means of exploration.

Also, the gambling condition observed is a bad one: in addition to highly unfavorable probabilistic conditions, in case of a positive outcome the possible winnings are way lower than the possible losses. Just for a comparison, in a game of French, single-zero roulette, 84 to 16 are the chances recognized to a “line” bet, but the payout for such

play is 5 to 1 (Barboianu, 2008), while in the artisanal mining gambling it is 1.13 to 1.

The chances of making a profit out of this kind of mining activity is so low that local mines in the Chancón region continuously open and close depending on the aleatory outcome of the business; those that are kept open, change continuously from owner to owner, sometimes more than once per year, when the old one either lost all their money or thinks they made enough and the new one has capital to gamble.

5. Conclusions

The present study intended to quantify the risk associated with the lack of geological exploration in artisanal underground gold mining. Production without geological exploration is here defined as a *gambling scenario*. To quantify the associated risk, and the probable outcomes in terms of financial profit or

loss, an Event Tree analysis has been applied, based on the analysis of possible multiple outcomes of single events or decisions and the probability of occurrence of each. Results show that chances of negative vs. positive revenue are 83% vs. 17%, with an order of magnitude of difference between worst-case and

best-case scenarios. In the area used as basis for this study, this is reflected in the continuous change of property of the mines, depending on the aleatory success or failure of the business. The present study allows to quantify the imperative need to introduce mineral exploration also in small-scale mining.

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