Economic Potential Evaluation of a VMS Deposit

Synthetic Case Study at the Iberian Pyrite Belt

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Abstract

One of the major concerns to mining companies nowadays lies on the definition of the limit between ore and waste material in a deposit. This is a complex process which requires additional tools and techniques in order to avoid estimation errors to be significant. Besides, metal prices are very difficult to predict as they are constantly fluctuating. Considering this, Mine Planning aims to deal with uncertainties related to its geological, technological and economical subsystems, trying to work them out all together in order to provide the best solutions in each problem found. These techniques demand deposit block modelling, for which are associated some relevant geological data that will allow to establish an economic value to each block. Thus, an overall economic value can be associated to the deposit. Nevertheless, there will always be some uncertainty related to the prediction made. This uncertainty can be assessed through sensitivity analysis which are economic feasibility studies that are made to investigate the influence of some parameters concerning production.

Having this in consideration, this paper was developed to perform an economical approach to a case study, to understand the chances of these analysis and its contribution to profit prediction based on a previously set block model for modelling the deposit. This model requires block classification according to its metal content, conducted using two different criteria: the Cut-Off Grade Criteria and a second criteria developed during the experiments, named Minimum Loss Criteria. The results achieved are used to access how is the project is prepared to respond in each possible situation, predicting the consequences that may come to the company.

Most of the times, these financial studies play a key role to the success of a mining project.

Keywords: Mine Planning; Economic evaluation; Uncertainties control; Total Profit Function; Block model; Sensitivity Analysis.

1. Introduction

Planning and developing a mining project from the discovery of a new mineral deposit to the production itself, is a very complex and time consuming process. According to Bustillo, R. M. et al (1997), one of the major problems faced by mining companies, especially by Mining Plan teams, is the quantification and qualification of resources and reserves. This leads to a critical issue which a project economic feasibility. It is considered to be one of the most risky activities according to the return of the invested capital. The considered risk comes from different sides: there are geological uncertainties arising from the estimation of reserves and grades; at a geotechnical level, one can consider the mining recovery and dilution factor as a source of some uncertainty too; finally, considering metal markets, this can be an epicentre of uncertainty due to the volatility of the metal prices stablished by centres for industrial metals trading like de Londom Metal Exchange centre (LME) or the American Metal Market (AMM).

In order to diminish this risk associated to those uncertainties, some methods and techniques have been developed to allow data collection about a mine and its surroundings, with the purpose of being a tool to be used to eliminate a problem or at least to reduce its undesired consequences. It is now possible to use computing methods to calculate statistics about some parameter, to produce 3D visualizations of the deposit and estimate its reserves or even to simulate some scenarios to predict the effects of some alteration that the company wants to implement.

In this perspective, there are two science areas rising in the mining industry: Mine Planning and Geostatistics, this one as a tool that allow mathematical and statistical methods to be applied to solve Earth science problems (Soares, A., 2006). Geostatistics estimates values from unknown attributes following the Theory of the Regionalized Variables (Matheron, G., 1971; Huijbregts 1973 and Oliver & Webster 1990).

Nowadays, geostatistical techniques to estimate economical ore reserves demand the construction of a 3D block model generated upon geological information collected normally on prospecting samplings. According to Philips, J., (2008), analysis models of economic decision provide a solid frame to understand complex problems, improving quality on decision making under uncertainties. Based on all data known about the blocks one must collect some other information in order to be able to estimate the economic value for each block being able to estimate the overall profit of the ore deposit (Bustillo, R. M. et al, 1997).

One of the purposes of this work consists of an economic potential prediction of a Volcanogenic Massive Sulphide (VMS) through the development of a synthetic case study based on the Iberian Pyrite Belt geology. This evaluation is carried out by using a block model to assess the overall profit of the deposit by the sum of each block's predicted profit.

To complement this study, four different sensitivity analysis are made to assess the stability of the results obtained to the profit estimation.

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2. Geological Framework

As previously mentioned, this work approaches the proposed development through a synthetic case study due to confidentiality issues. The considered case study is a volcanogenic massive sulphide deposit (VMS or VHMS), typically from the Iberian Pyrite Belt (IPB), located in the SW of the Iberian Peninsula. The IPB major consists of pyrite around 90% while the remaining 10% mainly consists of chalcopyrite, sphalerite and galena. Galley et al., (2007), say that The VHMS deposits may be classified into five groups, according to its lithological type (Barrie & Hannington (1999), modified by Franklin et al. (2005)):

- Back-arc Mafic: Troodos Island (Cyprus);
- Bimodal-Mafic: Noranda and Kidd Creek (Canada);
- Pelitic-Mafic: Besshi (Japan) and Windy Craggy (Canada);
- Bimodal-Felsic: Hellyer (Australia) and Skellefte (Sweden);
- Felsic-Siliciclastic: Iberian Pyrite Belt (Portugal and Spain) and Bathurst (Canada)

In the IBP, there are some of the most important VMS deposits worldwide. This nomenclature considers not only the huge volumes of reserves but also its high grades in copper, tin, zinc and other non-ferrous metals. Some of those VMS deposit are considered *Supergiant* deposits, with more than 250 Mton of ore (Franklin et al., 2005), like the Neves-Corvo mine in Portugal, discovered in 1977. Albouy et al. (1981) and Leca (1983 and 1985) suggest an ore classification based on metal contents, dividing ores into:

- Fissural and stockwork ore (chalcopyrite, pyrite, cassiterite and stannite)
- Breccia ore (mainly chalcopyrite and pyrite, with rare associations of sphalerite and galena).
- Massive ores (mainly chalcopyrite, pyrite, sphalerite and galena):
  - Massive copper ore (MC)
  - Massive zinc ore (MZ)
  - Massive tin ore (MT)
  - Massive pyrite as waste material (ME).

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3. Case Study

In order to perform the studies suggested, it is required to find out which is the relevant data needed to perform those studies. Therefore, this chapter is intended to create a data base for that purpose. The data base created gathers block model information, technical information, production costs structure and market issues.

Block Model

The block model is composed by 135.252 blocks with $12x12x7m$ and average density $d = 4{,}5t/m^3$, performing 4.536 tonnes per block. The average copper grade in the deposit is $\bar{t}_{Cu} = 5{,}20\%\ Cu$, while the average zinc grade is $\bar{t}_{Zn} = 0{,}76\%\ Zn$. Some basic statistics were made in order to better understand the results obtained for the grades estimation. The results are shown in table 1.

Table 1 – Basic statistics for copper and zinc grades at the block model

Statistics	Grade (%)	
	Copper	Zinc
Minimum	0,54	0,03
Average	5,2	0,76
Maximum	9,12	8,2
Standard Deviation	2,76	0,24
Median	3,32	0,74

Total Benefit Function

In order to develop the deposit economic evaluation, the total benefit function (B_T) has been chosen. The general function for the benefit is written on equation (3.1) and states that the total benefit predict to one deposit is defined by the sum of the benefit predicted for each block i.

$$B_T = \sum_{i=1}^{n} B_i \tag{3.1}$$

This function is develop through a simplistic equation where to the net revenues for each block (R_i) are subtracted the diluted production costs (DPC_M) for that same block (3.2).

$$B_i = R_i - DPC_M \tag{3.2}$$

Mine and Processing Plant

In here, one must define the mining methods to be used in the project in order to define both mining recovery to consider material losses during extraction and the dilution factor to consider costs associated to the inclusion of waste material in the exploitation. In this case study, a 95% mining recovery and a

10% dilution were adopted based on a Technical Report about Neves-Corvo Mine, made by Wardell Armstrong International Limited (WAI) in 2007.

In the study there are two possible treatment facilities working at the same time. The ore recoveries from each plant have their own characteristic curve function of the metal grades at the plant feed. Both characteristic curves are shown in figures 1 and 2. The copper and the zinc plant recoveries are shown in equations (3.3) and (3.4) respectively. For reasons of confidentiality, values for Pb grades, As grades and Sb grades cannot be revealed.

$$\eta_{Cu}(\%) = 95{,}75 - 26{,}39 \times \frac{t_{Pb}}{t_{Cu}} - 7{,}29 \times \frac{t_{Zn}}{t_{Cu}} - 0{,}00128 \times \frac{t_{As}}{t_{Cu}} - 0{,}0461 \times \frac{t_{Sb}}{t_{Cu}} \qquad (3.3)$$

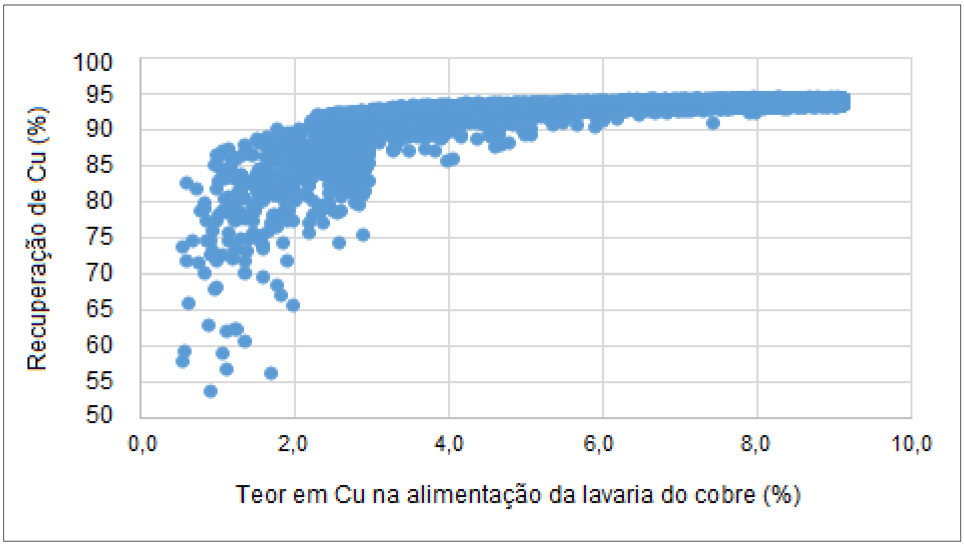

Figure 1 - Characteristic curve for copper plant

$$\eta_{Zn}(\%) = 12{,}99 \times \ln(t_{zn}) + 52{,}7 \qquad (3.4)$$

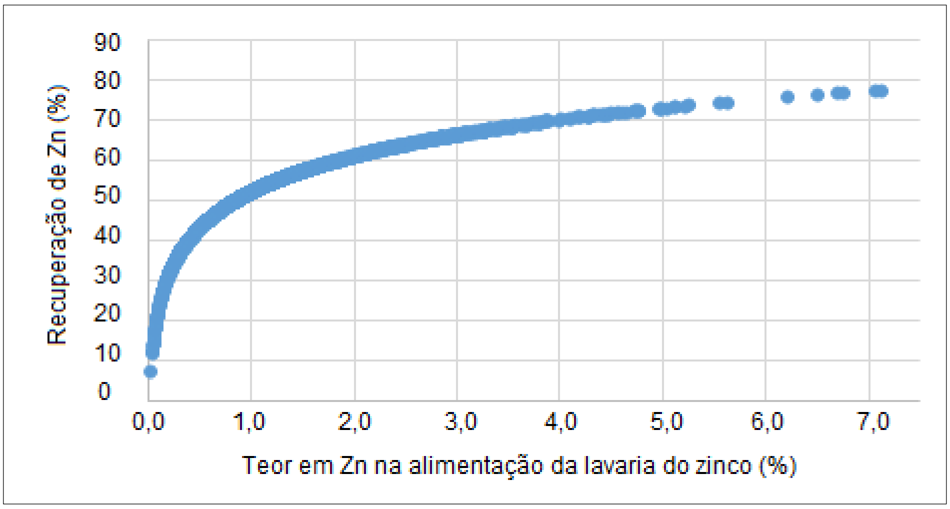

Figure 2 - Characteristic curve for zinc plant

Revenues / Incomings

The net revenues expected for each block considers the metal content of the block and its selling price at the metal market. The metal prices (USD/lb) are settled by proper companies like the London Metal Exchange (LME) or the American Metal Market (AMM). As this case study is based on Neves-Corvo's geology, the prices consulted must be converted to €/t through the adequate exchange rate conversion. The prices as they are shown in the markets, must also be multiplied by a depreciative factor that takes into consideration transportation and refining costs, in order to achieve the actual net revenue that the owner of a mining property shall receive from the sale of the metal content. That factor is the NSR which stands for Net Smelter Return. For copper, this value is around 80% while for zinc it goes from 50% to 55%. For this case study, were chosen $\boldsymbol{NSR_{Cu}} = \mathbf{80}\%$ and $\boldsymbol{NSR_{Zn}} = \mathbf{55}\%$. Metal prices are values that are very difficult to predict, particularly at a long range period of time, as they are very volatile and sensible to world's demand. In figure 3, it is possible to check copper and zinc prices historical data. The exchange rate was also defined the same way as the metal prices.

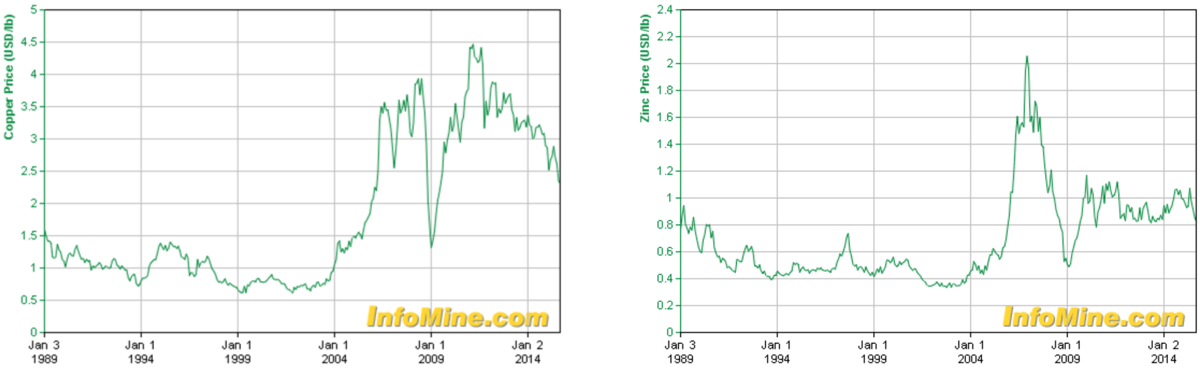

Figure 3 - Historical Copper (left) and Zinc (right) prices in the last 26 years (USD/lb)
Source: www.infomine.com

Considering this problem, the prices taken into account for this case study were determined by comparison of the monthly average prices for the last 5 years. In this perspective, copper and zinc net prices are shown in table 2.

Table 2 – Net Selling prices (USD/lb) and (€/t) for copper and zinc metals
Source: http://www.investing.com/commodities (01/07/2015)

Metal	Selling Price (USD/lb)	Exchange Rate (€/USD)	Selling Price (€/t)	NSR (%)	Net Selling Price (€/t)
Copper	3,44	0,7624	5778,00	80	4622,40
Zinc	0,95	0,7674	1600,43	55	880,24

Production Costs

The production costs were adjusted from a similar project, being divided into costs associated with mine activities (C_M) and costs from the treatment facilities (C_{L_M}), which depends on the ore type defined for the block as it is explained on equation (3.3). All the values shown in the next tables already take into account the 10% dilution factor.

$$C_{L_m} = \begin{cases} C_{L_{Cu}} = 8{,}80\ €/t & \text{If the block is MC ore type} \\ C_{L_{Zn}} = 13{,}20\ €/t & \text{If the block is MZ ore type} \\ 0 & \text{If the block is ME ore type} \end{cases} \tag{3.3}$$

So, the DPC_M are a function of M, which defines the ore type considered to each block. All the costs considered are stated in table 3.

Table 3 – Diluted Production Costs defined for this case study (€/ton)

Ore type	Mining Costs (€/ton)	Treatment Costs (€/ton)	Total DPC costs (€/ton)
MC	33	8,8	41,8
MZ	33	13,2	46,2
ME	33	-	33

Block Classification

Block classification was made by two different criteria:

1) The Cut-Off Grade Criteria (COGC) states that blocks are classified considering its metal grades in a comparison to the COG defined by the mining plan activities. This criteria is schematically shown in figure 4. The COG defined for each metal are $COG_{Cu} = 1{,}16\%\ Cu$ and $COG_{Zn} = 7{,}47\%\ Zn$.

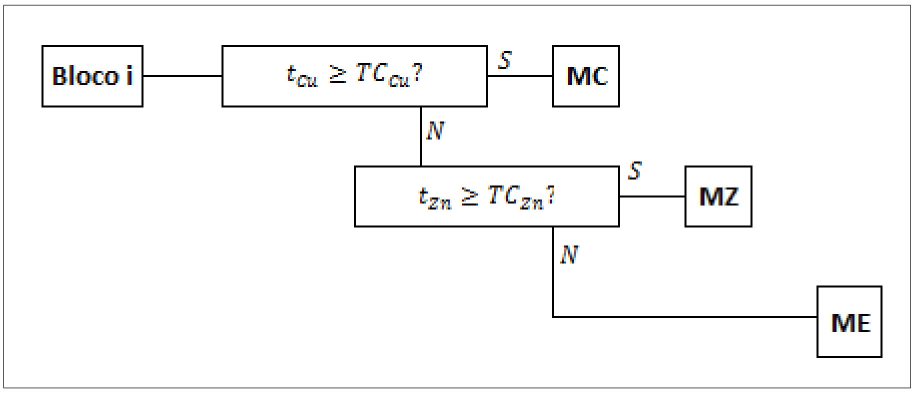

Figure 4 - Schematically representation of the Cut-Off Grade Criteria

2) The Minimum Loss Criteria (MLC) is a criteria that has been developed during this work in order to confirm the results obtained by the first criteria. It says that a block is considered to be MC ore type if the predicted revenue is the highest among all the possible revenues that block can manage to achieve if it is sent to any other treatment plant rather than ist own (copper plant). The same process is done to assess if the block is MZ or ME type. A simple scheme is shown in figure 5.

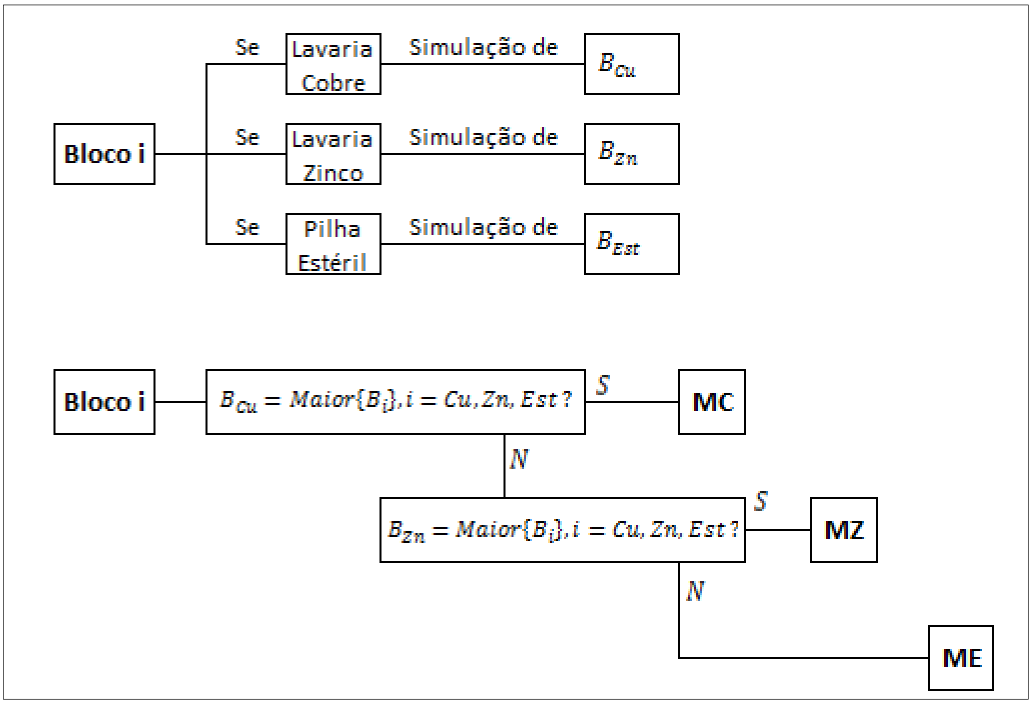

Figure 5 - Schematically representation of the Minimum Loss Criteria

4. Total Benefit Prediction

The results for block classification in its ore type through both criteria is presented on table 4.

Table 4 – Number of blocks by ore type, function of block classification through each criteria mentioned

Ore Type	COG Criteria	ML Criteria
MC	135.202	135.246
MZ	0	6
ME	50	0
Overall	135.252	135.252

The results for the predicted benefit calculated by each block classification criteria used is shown in table 5.

Table 5 - Predicted Benefit results according to the criteria used in block classification

Benefit Function	COG Criteria	ML Criteria
Total deposit Benefict (M€)	105.218,92	105.223,89
Average Benefit by block (m€)	777,95	777,98

5. Sensitivity Analysis

Sensitivity Analysis are performed within the feasibility studies in a mining project, aiming to study the influence of some variables related to the metal production in the financial result predicted. In this work, sensitivity analysis were conducted upon four different parameters, all of them performed base on the benefit predicted by the Minimum Loss Criteria, which was considered to be the base scenario for later comparisons.

Copper and zinc grades in the deposit

In this analysis, both grades were tested separately. Copper grades were varied in$\pm 5\%$ and $\pm 10\%$, while zinc grades were varied in $\pm 15\%$ and $\pm 30\%$). While experimenting the effects of grades for one metal all the other parameters, including the other metal grades were not changed. The results are shown in tables 6 and 7 for copper and zinc analysis respectively.

Table 6 – Resulting Total Benefits (M€) from the variance of copper grades (%)

Copper Block Grades	Total Benefit (M€)
-10%	91.810
-5%	98.517
Base	**105.224**
5%	111.931
10%	118.637

Table 7 – Resulting Total Benefits (M€) from the variance of zinc grades (%)

Zinc Block Grades	Total Benefit (M€)
-30%	105.670
-15%	105.447
Base	**105.224**
15%	105.001
30%	104.778

Copper and Zinc Plant Recoveries

In this section, plant recoveries were simulated by changes of $\pm 2{,}5\%$ and $\pm 5\%$. Once again, both parameters have been tested individually. The results achieved are expressed in tables 8 and 9.

Table 8 – Resulting Total Benefits (M€) from the variance of copper plant recovery (%)

Copper Plant Recovery	Total Benefit (M€)
+5%	111.767,27
+2,5%	108.495,58
Base	**105.223,89**
-2,5%	101.952,21
-5%	98.680,52

Table 9 – Resulting Total Benefits (M€) from the variance of zinc plant recovery (%)

Zinc Plant Recovery	Total Benefit (M€)
+5%	105.223,94
+2,5%	105.223,92
Base	**105.223,89**
-2,5%	105.223,87
-5%	104.223,85

Copper and Zinc Metal Prices

This analysis might have a huge impact on mine planning. It will permit that the company predicts what may happen if metal prices suddenly crash. Copper and zinc prices were varied from 0 to $\pm 20\%$ in intervals of 5%. The results for this analysis are inserted in tables 10 and 11.

Table 10 – Resulting Total Benefits (M€) from the variance of copper's net price (%)

Copper Net Price	Total Benefit (M€)
-20%	79.050,43
-15%	85.593,79
-10%	92.137,15
-5%	98.680,52
Base	**105.223,89**
+5%	111.767,27
+10%	118.310,65
+15%	124.854,03
+20%	131.397,42

Table 11 – Resulting Total Benefits (M€) from the variance of zinc's net price (%)

Zinc Net Price	Total Benefit (M€)
-20%	105.223,75
-15%	105.223,77
-10%	105.223,81
-5%	105.223,85
Base	**105.223,89**
+5%	105.223,94
+10%	105.224,00
+15%	105.224,05
+20%	105.224,11

Diluted Production Costs

The final sensitivity analysis was performed over the total operating costs, the DPC. The analysis were made for $\pm 5\%$ and $\pm 10\%$ parameters changes. The results are expressed in table 12.

Table 12 - Resulting Total Benefits (M€) from the variance of the DPC (%)

Diluted Production Costs	Total Benefit (M€)
10%	102.659
5%	103.942
Base	**105.224**
-5%	106.506
-10%	107.788

After performing all sensitivity analyses proposed, the several Total Benefits characteristic curves were condensed in figure 6.

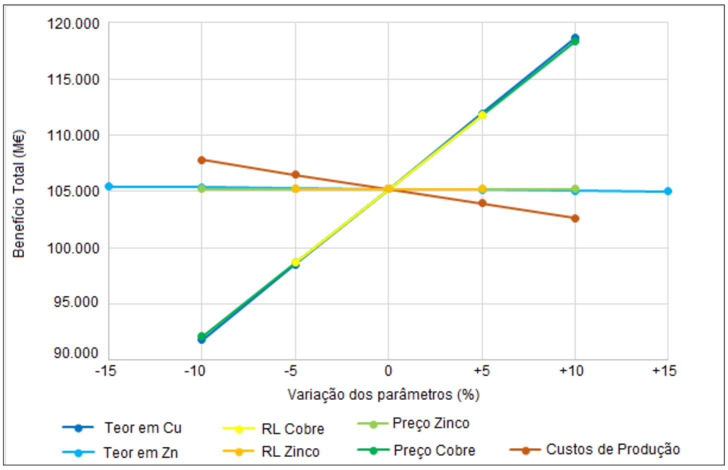

Figure 6 - Total Benefit behaviour according to the sensitivity analysis made

6. Conclusions

Mining projects are becoming more and more dependent on geostatistical models due to the more geological and geotechnical complexity of the projects. With it, also the risk increases and that's why planning engineers must perform very detailed financial studies in order to reduce the uncertainties.

Considering the purposes at the beginning of this work, it is clear that the total benefit function performed very well as the financial result chosen to evaluate this copper-zinc deposit. It is visible the advantages of the sensitivity analysis offering simulated scenarios where the company can observe what happens if some condition is suddenly imposed.

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