Comparison between traditional project appraisal methods and uncertainty analysis applied to mining planning

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Abstract

Long-term mining planning is a complex process which involves a large number of variables and uncertainties. Traditional discount cash flow (DCF) is usually used in the evaluation of mining projects. DCF includes net present value (NPV), internal rate of return (IRR), and profitability index (PI). A sensitivity analysis is usually carried out to evaluate the impact of the main variables on the project. Another way to measure uncertainties is through the Monte Carlo simulation (MCS). The objective of this study is to evaluate and compare the DCF methods and measure uncertainties through sensitivity analysis and MCS in the evaluation of mine sequencing. A case study of a phosphate mine project was used to chart the comparative study. In the results, NPV and uncertainty analysis through MCS were more consistent.

keywords: mining planning; discount cash flow, Monte Carlo simulation, uncertainties.

1. Introduction

Mining activities have contributed to the development of society for thousands of years and the high standard of living today is dependent on minerals. However, the success of the mineral business from a production perspective has not always been accompanied by the success from an economic perspective. According to IBRAM (Brazilian Mining Institute 2017/2018), mining exported 403 million tons of mineral goods, and generated a foreign exchange of FOB US$ 28.3 billion. This value represented 13% of Brazil's total exports and 30.5% of the trade balance. The mineral extractive industry also has fundamental participation in the gross domestic product (GDP) and represents 1.4% of total Brazil's GDP, according to IBGE (Brazilian Institute of Geography and Statistics), employing around 180,000 workers directly.

The need to adopt technical criteria for choosing investment projects stems from the fact that the capital resource of a company is limited. Regardless, the company cannot take advantage of all the available investment opportunities. Therefore, it is necessary to develop ways to choose, among many options, those which maximize the value of the company for their shareholders and creditors, rejecting the others.

A vast majority of companies adopt deterministic methods to evaluate mining projects, just as they do in other areas. It includes NPV, IRR, and PI. Some ventures also use Simple Payback and Discounted Payback. According to Trigeorgis (1993) and Drieza *et al.* (2002), traditional techniques are appropriate for the evaluation of risk-free assets.

Among deterministic models, NPV

is the most usual and accurate. The value of any investment is a function of four variables: 1) how much will be invested; 2) how much will be generated from cash flow; 3) when cash flow should occur; 4) what is the risk associated with this cash flow. Thus, NPV calculation observes the following methodology:

I) cash flow design (using basic financial mathematics) to be generated by the project throughout its economic life;

II) discount rate determination which reflects the time value of money, the cost of capital and the risk of the project;

III) calculation of the present value of that cash flow by using the discount rate determined, that is, the equivalent amount for this series of cash flows, called the present value of the project;

IV) calculation of the net value to be received by the company for this project by deducting the initial investment required for its implementation. This value is the NPV of the project;

V) as the objective of the company is to create value, the following decision criterion should be used: invest whenever NPV is positive. This means that the value of the project is higher than its cost.

Fontes *et al.* (2018) consider that most projects in which the company invests start-up capital in exchange for a series of future cash flows, NPV decreases as the discount rate of these flows increase and may become harmful, if the rate is high enough. According to Topal (2008), this discount rate or attractiveness is crucial to the viability of the project. Moyen *et al.* (1996) mention that business analysts typically use a real rate of return of about 15%. Mun (2016) points out that in essence the higher the risk, the higher the return.

Brealey *et al.* (2011) state that the IRR of a project is defined as the discount rate which makes NPV zero. If the IRR is greater than the opportunity cost of the capital under consideration (loss of remuneration for alternative applications of shareholder resources), the project will have a positive NPV; otherwise, NPV will be negative. Therefore, IRR represents the highest opportunity cost that a project can afford. The decision criterion in this case is the following: a project will be acceptable if its IRR is greater than its opportunity cost of capital, whereas the NPV criterion provides a monetary value that represents the value creation which will occur with the implementation of the project. Hence, IRR provides a rate that can be interpreted as the expected rate of return of the project.

Brealey *et al.* (2011) also demonstrate that PI is a relative measure between the present value of cash flows (NPV) and the initial investment (I): PI = (NPV + I) / I. If PI > 1 for each investment unit, the present value of future cash flows is greater than 1. Thus, the investment will be recovered, remunerated at least at the required rate and there will be an increase in wealth. It is equivalent to saying that NPV > 0. If PI = 1 for each investment unit, the present value of the future cash flows equals 1. That is, the investment will be recovered, remunerated precisely at the required rate if NPV = 0. If PI < 1 for each investment unit, the present value of future cash flows will be less than 1. Thus, the investment will not be recovered; that is, it will not be remunerated at the required rate, destroying value i.e. NPV < 0. When the company has limited investment capital and wishes to diversify its portfolio, sometimes the option is to invest in projects which depend on each other. In this case, it is not possible to classify projects by NPV, which is the most appropriate PI method for categorizing projects.

The simple payback method takes into account the payback time of the invested capital. The investors establish a maximum term for the investment recovery, which works as the standard for the feasibility analysis of the project. The amount applied is periodically added to the net cash flows generated in order to obtain the recovery time of the initial investment. This occurs in the period in which the sum of future cash flows is equal to the initial investment. Discounted payback considers a rate of attractiveness or discount on the cost of capital of the company by estimating the value of money over time.

In the sensitivity analysis or project scenarios, evaluated through deterministic models, the impact of only one variable at a time, such as the project rate of return, price, cost and so on, is assessed. By using MCS, it is possible to investigate the impact of more than one variable at a time, correlating between variables and then simulating n scenarios. The results of the simulation are probabilistic curves where the probability of occurrence of the expected value is present, as well as the possibility of the project being unfeasible. According to Mun (2016), uncertainties become risks if they affect the outcomes and the scenarios of the system.

The objective of this study is to highlight and compare the evaluation of a mining planning project for a mineral occurrence near a phosphate undertaking already underway using NPV, IRR, payback and PI methods, while measuring the uncertainties through sensitivity analysis and MCS. The following economic uncertainties can be considered: phosphate rock price, production costs, dollar exchange rate and inflation in such mine sequencing. Simulation software for risk analysis was used.

2. Materials and methods

In 2010, a new mine was developed to start operation in the subsequent years for a phosphate project in Alto Paranaíba, Minas Gerais. A mineral occurrence near the area of venture was found. The company estimated US$ 47.02 million of investment to exploit the ore. This investment analysis did not consider the cost of capital (CAPEX) to purchase equipment, as the company is outsourced. In the preliminary planning, the previous sequencing has the duration of 4 years along which the company wishes to recover the investment. In order to delineate the final pit, the geological model, the topography of the region was used as well as a profit function based on the historical prices of the phosphate rock in the market (2007-2017) and the estimated production costs of mining operations already underway. In the mine sequencing, the feed mass of 3.2 million tons/year for the beneficiation plant was considered with the respective cutoff grade and stripping ratio (SR) for each mining advance. The average transport distances for ore and waste in the calculation of mining costs were considered. A summary of the mine sequencing data is shown in Table 1. The price of a ton of phosphate rock adopted with a concentrated content of 35% of P_2O_5 in the market was US$ 29.78 million with the dollar exchange rate / Brazilian currency US$ 1.00 = R$ 3.19 for a scenario based on the study year 2017. The costs involved were estimated, considering only the direct costs of mining and mineral processing.

Table 1 - Mine sequencing data.

Production data (mine)					
Mine sequencing	**Rock**	**Ore**	**Waste**	**SR**	**P_2O_5**
	tonnes	tonnes	tonnes		percentage
1	4,250,000	3,237,500	1,012,500	0.31	11.05
2	9,762,500	6,287,500	3,475,000	0.55	9.63
3	2,325,000	1,975,000	350,000	0.18	9.64
4	3,775,000	1,925,000	1,850,000	0.96	9.77
Total	20,112,500	13,425,000	6,687,500	-	-
Average	-	-	-	0.50	9.99

After performing the traditional mining planning routine, the data for the four years of mine sequencing were placed in a spreadsheet for evaluation via DCF and risk analysis. The project appraisal can be based on NPV, IRR, and PI, as well as the investment return. After the investment analysis, it is possible to verify the uncertainties through sensitivity analysis and MCS. Thus, economic uncertainties, such as phosphate rock price, cost of production, dollar exchange rate and inflation can be assessed.

In MCS, it was possible to establish the type of curve which best represents the behavior of each variable according to the data. In the emulation, the triangular probability distribution was adopted for all variables in this study. The selected distribution allows for the choice of the most probable, the smallest and the highest acceptable value based on the historical data showing their randomness. For the use of other probability distributions, a longer period of historical data is necessary and some hypothesis tests should be made to prove that the adopted curve actually represents the behavior of the variable. Therefore, the SMC was standardized to evaluate 5000 attempts for each scenario.

3. Results and discussion

Figure 1 displays the estimated operational cash flow in millions of dollars without depreciation and income taxes for the enterprise. In order to make visualization easier, the figures were simplified and reduced to power base 10. The value found with the discount rate of 16%, suggested by the company, was US$ 1.60 million in the evaluation through NPV. As a result, the project was able to pay back the investment within four years and still make a profit of US$ 1.60 million. The NPV method has the following advantages: I) it recognizes the value of money over time; II) it is not affected by accounting techniques; III) it reflects the increase of the shareholder's wealth; IV) it can be added to another NPV; V) it only depends on cash flows and opportunity cost. The main disadvantage is to merge all the sources of uncertainties into a single discount rate.

The IRR of the enterprise was 18%, which is above the desired remuneration by the shareholders (16%). The company expects to obtain profit with the project soon. It is important to emphasize that, in a set of projects, the one with the highest IRR does not necessarily have the highest NPV. So, it is necessary to be careful about using IRR when classifying projects according to their profitability or choosing between mutually exclusive projects, especially when there are large differences in investment scale or cash flow patterns. In long-term projects, there may be several capital opportunity costs. As IRR is the same for the whole project, it is not always so clear what opportunity cost it should be compared to. It is questionable whether a flat rate for all periods is representative of a cash flow measured by different opportunity costs. The IRR method assumes that the company has other equally profitable projects on which it can invest the intermediate cash flows generated by the current project. In so doing, IRR credits the current project with the benefits of the others. In practice, however, no future project will be analyzed at a rate higher than the company's capital cost. Thus, the correct reinvestment rate is the company's own capital cost, which makes the basic premise of the IRR incorrect.

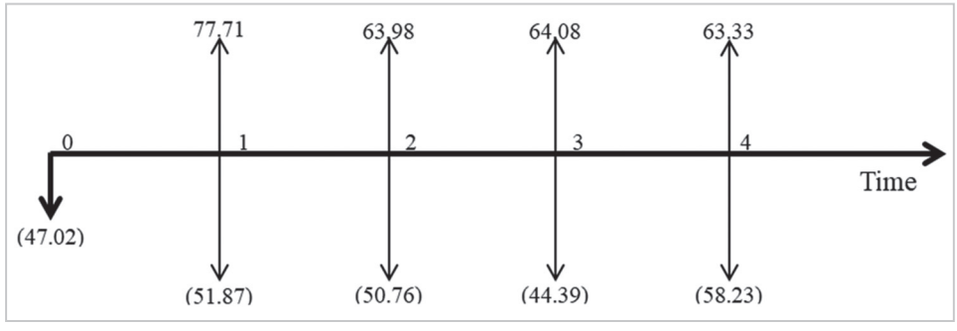

Figure 1 - Projected cash flow in millions of dollars.

The PI calculation result was 1.03, which means the company is creating value. The PI analysis is very simple and may be helpful in circumstances where the company needs to decide between two mutually exclusive projects where IRR can present conflicting results with NPV.

In simple payback analysis, the project returns the initial investment in the

3rd year and makes a profit of US$ 11.70 million. However, the evaluation through simple payback presents some problems: I) It does not take into account the value of money in time; II) It does not estimate the cash flow distribution within the period of investment recovery; III) It does not consider the cash flows after the recovery period. This can lead to the rejection of long-term projects and so make more profit; IV) It cannot be compared to a profitability standard such as capital cost.

Discounted payback analysis does not solve all the problems presented, but it introduces the discount rate and the idea of the value of money over time. Thus, the payback period discounted is the time to recover the investment at the chosen interest rate, which in this case study was 16%. This method is close to NPV, and the results show that the initial investment is repaid in the 4th year and is still generating a profit of US$ 2.35 million. Discounted payback can be more useful when used: I) to tie up similar NPV situations where faster cash recovery becomes relevant; II) as a second filter analysis, as a measure of liquidity risk or, generalizing, as a degree of risk of the project. Over time, the uncertainties associated with the project, such as revenue forecasts and corresponding costs, tend to increase and consequently the associated risk; III) in the analysis of projects without major financial significance for the investors.

A sensitivity analysis was conducted in the NPV assessment for the oscillation of ± 10% of the main variables involved in the study (market price of phosphate rock, dollar exchange rate, production cost and inflation). However, each variable was analyzed separately, and the others were kept unchanged based on the input scenario. Figure 2 displays the results of the sensitivity analysis. According to this Figure, NPV results in the sensitivity analysis for the dollar exchange rate in the oscillation of more or less than 10% were US$ 20.82 and -US$ 17.62 million, respectively. For the same positive and negative variation for the phosphate price, the value was US$ 20.77 and -US$ 17.56 million, respectively. The NPV result for the variation of ± 10% for the cost of production was -US$ 5.43 and US$ 8.63 million, for more and less, respectively. Considering inflation, the result was -US$ 2.54; with a 10% increase, the value was -US$ 2.90, and with a 10% decrease, the NPV value was -US$ 2.13 million.

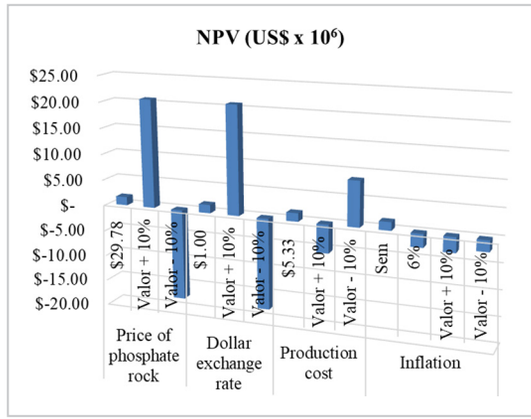

Figure 2 - Sensitivity analysis of the main variables.

In the Monte Carlo simulation, it was possible to make a probability assessment because the number of emulated scenarios allows for a statistical analysis. The Risk Simulator software provides a tool, called Tornado, which permits to analyze the main variables influencing the project. This tool performs a sensitivity analysis routine internally for the declared variables and lists based on that analysis which has the greatest impact on the investment valuation. It is noteworthy that this tool is present in most risk assessment software and aims at saving time. The Tornado result showed that the two main variables influencing the project were the dollar exchange rate and the phosphate rock market price. Therefore, the evaluation of the project was made only by considering these two variables through a triangular probability distribution.

In order to define the parameters of the triangular distribution, a historical dollar exchange rate for the last ten years was used, whereby, the dollar exchange rate had the following parameters: most probable: US$ 1.00, minimum: US$ 0.88 and maximum value: US$ 1.13. For the price of phosphate rock, the following parameters were used: most probable: US$ 29.78, minimum: US$ 25.08 and maximum value: US$ 36.05. The base year of the study was 2017. Figure 3 shows the results of the simulations for the variable price of phosphate in the market and the dollar exchange rate.

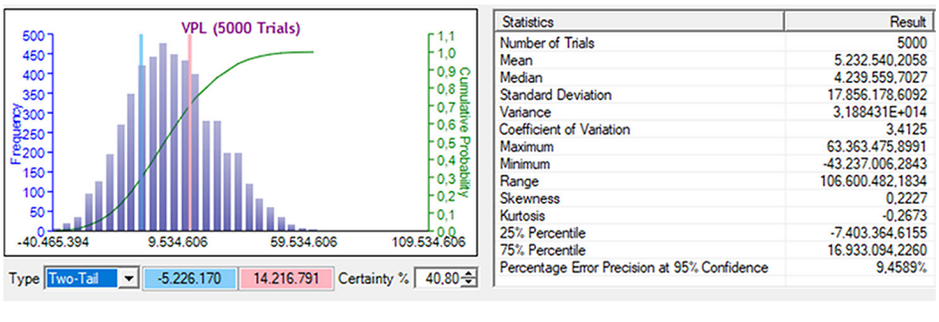

Figure 3 - Result of the simulation for the variable price of phosphate and the dollar exchange rate.

In the simulation result for a 95% confidence interval of the dollar exchange rate, the probability of NPV being negative was 42.36%, with an average NPV of US$ 1.97 million. In the simulation of the price of phosphate rock, the possibility of NPV being negative was 38.14%, with an NPV average of US$ 4.91 million. Moreover, for both variables, the dollar exchange rate and phosphate price, the probability of NPV being negative was 40.80% and the average NPV of US$ 5.24 million for the same confidence interval.

However, the analysis of the project via NPV was carried out and the results refer to only one value, in this case, US$ 5.11 million. In the sensitivity analysis, the main variables suffered a ± 10% oscillation generating the values presented in Figure 2. It is notable that the oscillation of the variable values is made one at a time. When MCS is used, the NPV analysis is repeated as many times as desired, in this case, 5000 emulations. Thus, it is possible to analyze the uncertainties of NPV through statistical analysis and also to define a confidence interval. And, perhaps most interesting, it is possible to analyze more than one variable at a time, i.e. the correlation of variations. In the example, the average NPV result through price simulation is US$ 15.68 million, with a 38.14% probability of obtaining a lower value than this for a 95% confidence interval. By analyzing the dollar price and the exchange rate variable together, the NPV was US$ 16.72 million with a 40.80% probability of being lower than this for the same confidence interval.

4. Conclusions

Discounted cash flow methods are still the most used in investment project analysis. This methodology leads to satisfactory results when the investment has low levels of uncertainties. Nevertheless, in the mining business in general, this level is very high due to a large number of variables, and it involves a long period.

Some of the main discounted cash flow methods with their main advantages and disadvantages were presented in this study. Typically, more than one method of analysis is used to evaluate a project, one may complement the other. Sensitivity analysis is subjective in the choice of variables and in the percentage of variation of such variables. Besides, only one variable is analyzed at a time. Therefore, sensitivity analysis contributes to the assessment of the project, but it does not consider many scenarios. Two aspects stood out during the analysis: first, the dollar exchange rate has a greater influence than the cost of production and this analysis is usually neglected by the companies. Second, when considering inflation in the sensitivity analysis, it has a reasonable impact; however, its variation is not so significant.

MCS turned out to be very useful because it permits the analysis of a much larger range of scenarios, it accepts the correlation of variables, and it allows for a better assessment of the result uncertainties. Moreover, the results are more consistent when it comes to risk assessment in projects.

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