Using real options to introduce flexibility in mine planning under uncertainty

Nelson Morales, Juan Quiroz and Bastian Rudloff. *Advanced Mining Technology Center, Universidad de Chile*

Today, mine plans are optimized for a fixed set of parameters (prices, costs, resource model, etc.), knowing that they will not be realized and that the plan will have to be changed in the future. Uncertainty (in grades, market, etc.) is included only as a post-analysis though variability of said parameters. While this can be acceptable for a certain set of decisions, it can also happen that relevant decisions must also be adapted (like extraction plans or reserve estimation), or that the operation will incur higher costs to reach the production goals, therefore reducing the value of the project.

We postulate that more robust decisions, higher and more reliable project values are possible by considering uncertainty from the beginning of the mine planning process and therefore introducing flexibility in some decisions of the mining plan. We illustrate these ideas by using real options to introduce such flexibility in order to gain robustness against uncertainty in two case studies.

The first case study considers the uncertainty due to the delay between the moment when equipment purchase orders are placed, and the start of the operation in a long-term mine planning in an open pit. The option consists in determining the optimum number of trucks so that the expected NPV of the project is maximized over a number of scenarios.

The second case study refers to the life of an underground mine that consists of several sectors and uncertainty in prices. In this case, the options considered refer to the optimum timing of the mine sectors (when to start their production, and optimum production rates) so that the value of the project is maximized.

INTRODUCTION

Recently, mine planning has progressed to integrate more and more variables to the planning process and has developed tools to achieve more robust plans in terms of expected value and fulfilment of promises productive, maximize profit and/or the expected return for shareholders. Unfortunately, a significant gap still exists between what is planned (and offered as value) and the result of the implementation of the mine plans in the operation. One of the more important reasons for this is that the whole process is affected by various sources of uncertainty that are not properly accounted for in the mine planning process. These differences are reflected mainly in: (a) income, (b) costs, (c) mineral reserves and (d) investments.

The sources of uncertainty in Mining although numerous, can have varying degree of impact on the business and can be of different nature. For example, uncertainty sources can be classified as external or internal. External uncertainty is defined as one such that its source lies outside the company, the main example here is the market (commodity price, price of key inputs, investment amount, etc.). Internal uncertainty is dictated by the assets of the company and its organization. For example, geological and operational uncertainties fall in this category. On this basis, the three types of uncertainty that govern the mining business are mainly: geological, operational and market. (Mayer Z Kazakidis V, 2007)

The problems created by uncertainties in a mining project, occur precisely because there is no methodology or tool that integrates uncertainty properly into the mine planning process: the standard software tools are oriented towards the optimization of a fixed plan under a predefined set of parameters, therefore the robustness of the plan can only be tested after the plan has been computed and there is no way (using standard methodology) to integrate flexibility into the construction of the plans. Flexibility is understood in this article as (Mayer Z., Kazakidis V 2007) as the ability of a system to sustain performance, preserve a certain cost structure, adapt to changes in internal and external operating conditions, or take advantage of new development opportunities during the life cycle of the mine operational modifications.

This article looks at illustrating how the introduction of flexibility in decision-making for planning permits to address sources of uncertainty. This approach, being general, is shown in this case by applying real options for upgrading and constructing of mine plans under uncertainty, contemplating both market and geological flexibility. Specifically, we consider two case studies.

- The first case study considers the uncertainty due to the delay between the moment when equipment purchase orders are placed, and the start of the operation in a long-term open-pit mine plan. The option consists of determining the optimum number of trucks so that the expected NPV of the project is maximized over a number of scenarios.
- The second case study refers to the life of an underground mine consisting of several sectors and metal price uncertainty. In this case, the options considered refer to the optimum timing of the mine sectors (when to start their production, and optimum production rates) so that the value of the project is maximized.

There are several ways to address uncertainty through flexibility in the planning procedure. In this paper, we work using the framework provided by real options, because they provide not only a theoretical framework (more or less understood by the industry), but also valuation mechanisms that allow to compute flexible solutions in reasonable time (as opposed to, for example, stochastic programming, that rely on dynamic programming approach requiring an exponential number of decisions to be computed, which turns to be very computation intensive.

Real Options in Mining

An option is the right (but not obligation) to perform a certain action in a given time (in the future). This right is established by paying a "price" (for example, an increase in the investments), and produces a net difference in the expected value of a project or asset: the "value" of the option.

Several researchers have tried to apply real options to evaluate different types of flexibilities under different sources of uncertainty. Independently of the characteristics used in the investigations, all these studies conclude that this methodology (real options) produces a profit increase over the use of discounted cash flows when applied to real options.

In the case of mining projects, there are 3 factors that affect or determine the optimal investment decisions (Drieza, Kicki and Saluga, 2002; Topal 2008).

- The investments are partially or completely irreversible, this means that capital investment is required to establish the operation, with this initial investment cannot be recovered.
- Uncertainty exists about the future rewards of the investment. Some of these variables can have significant effects on future mines, such as commodity prices, deposit characteristics (geology) and operating costs.
- Finally, the investor has a margin of action in the timing of investment. Indeed, investment in a mine does not happen immediately, there is a delay between the decision of the mine and the investment in the project occurred.

Samis y Poulin (Samis and Poulin, 1996) showed that:

"Project value is influenced by economic uncertainties and physical environment, a dynamic structure of project risks and the ability to use, multiple and mutually exclusive projects."

The NPV is extensively used in mining projects although it is incapable of accounting for these influences on the value of the project. Samis and Poulin evaluate two different articles in copper and gold mines and project value calculated by the discounted cash flow (DCF) and real options valuation (ROV) techniques, concluding that ROV was more flexible and suitable for mining projects compared to DCF.

Most papers that apply ROV use very simple or hypothetical examples of projects in the mining or oil industries, and compared the traditional analysis of cash flows with ROV (McKnight, 2000).

METHODOLOGY

The methodology used in this paper, for the construction of flexible plans over time, is a feedback and iterative methodology which has the following stages:

- Build a long-term plan, under the standard methodology mine planning (base case, for comparison).
- Model and / or simulate the sources of uncertainty though simulation of scenarios.

- Identify potential flexibilities and model them with an optimization model (for example linear programming), considering the restrictions and design options.
- Valuate the options of the simulated scenarios.
- Analyse results and compare with base case.

As mentioned before, we illustrate this methodology in two case studies. We present them next.

Case 1: Sequence Flexibility in open pit mine under geological uncertainty

In this case study we are interested in evaluating the reliability of the selection of the size of the transportation fleet with regards to geological uncertainty. The aim is to model the change (learning) about the geology between the instant in which the equipment purchase orders are placed and the moment in which operations begin.

The inputs for the case study are: the economic and operational parameters and a fixed mine design. Geological uncertainty is modelled through the Kriging method (to construct the base case) and conditional simulations. The optimization model schedules then the extraction in the long-term at the phase-bench level, so different schedules can be constructed for each scenario and transportation equipment investment (option price). The output is a graph from which we can evaluate the reliability of the plans depending on different option prices.

The methodology in this use study is:

- A long-term mine plan is built for the deposit modelled with traditional Kriging method, which is the standard methodology mine planning (base case).
- Geological uncertainty is modelled through N conditional simulations of the same deposit previously modelled with the Kriging method.
- The sequence, established in the mining plan made with Kriging method, was evaluated in the other N conditional simulations deposit yielding the respective NPV.
- To simplify the analysis and reduce computation time, the scenarios are ordered from worst to best NPV, and n classes are constructed, each containing N/n scenarios. The first class corresponds to the N/n with lowest NPV, and the last to the N/n scenarios with higher NPV. Within each class, the scenario with the lower NPV is chosen as a representative.
- For each of these representatives, and based on the updated reserves, the optimal sequence is constructed depending on transportation investment, so the production plan is evaluated in detail including the actual CAPEX and OPEX that apply in each case.
- Finally, we evaluate the robustness achieved by each plan in terms of the investment level on transportation.

This will have a pool of options to choose from depending on geological deposit conditions, the reliability they want to achieve, the option price to pay and the expected value.

Case 2: Optimal project mining under market price uncertainty

This case study deals with a copper mine with several sectors (5) that include underground operations (4) and one open-pit, all coexisting and affected by external resources, like a shared plant and transportation system, as well as constraints associated to precedence and subsidence limitations between the projects.

For this case study, we study the flexibility of advancing and delaying the start of production sectors depending on price uncertainty. Our goal is to study the variability of optimal periods to start each project, how this impacts the production plans (particularly the rates) in each of them and to determine, if possible, simple rules (for example, market conditions) indicating that a project must start before planned.

A total of five sectors are considered, one for open pit (B) and the remaining 4 underground (A, C, D and E). The initial plan is made according to the traditional parameters of the mine planning.

Uncertainty is modelled by constructing price paths for the life of mine. While this limits the impact of the methodology, we did not change the production plans for the underground mines, but allowed some changes only in the production rate for the open pit mine, considering for this all subsidence constraints and updating CAPEX and OPEX accordingly.

Table 1 Productive Sectors

Sector	Start of Operations
A	In Operation
B	In Operation
C	2027
D	2039
E	2048

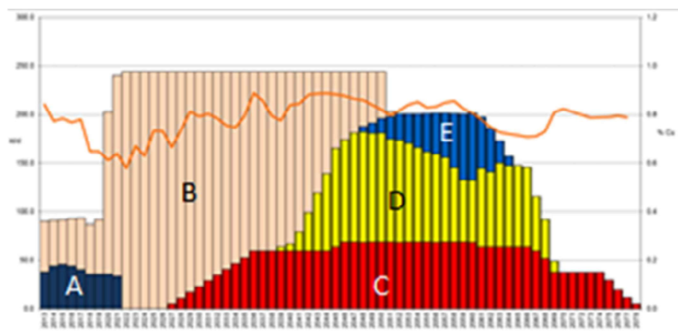

Figura 1 Base Production Mine Plan

As mentioned before, our interest is to study the robustness of planned decisions in terms of price uncertainty and determine, if possible, the types of scenarios (early price behaviour) that may change decisions in the standard plan because they no longer maximize NPV. Options are then generated that allow to change the sequencing (at project level), thus updating the overall production plan.

The above calculation was programmed a PPL linear programming problem.

RESULTS AND DISCUSSION

Case 1: Sequence Flexibility in open pit mine under geological uncertainty

In the actual case study, we used N=100 scenarios and selected n=10 classes. We have 11 sequences: "Krig", for the base case; and sequences 1 to 10, each one optimal for its corresponding representative of the class.

The decision to incorporate flexibility in the sequences of the plan is based on the increased productivity which allows switching between sequences that may be carried out under these conditions. For this, the methodology considers the sequence 8 as the starting sequence as it is one that provides the highest expected value. Additional sequences are considered as the investment (price of the option) in transportation increases. Thus 10 options were obtained, each with options and option prices values generated (change in the respective CAPEX). Table 2 presents every option in order of increasing price, and the sequences that are feasible at each investment level. As expected, as the price of the option increases this allows for a greater productivity based on more equipment haulage, transport and perforation, which can be decided among a larger number of extraction sequences. Thus all options were evaluated and the obtained results are shown in Figure 2.

Table 2 Available Sequence to run for each of the available options

	Option									
	1	2	3	4	5	6	7	8	9	10
Op. Price [MUS$]	0.0	0.3	4.2	5.0	9.4	12.6	42.2	47.8	66.5	69.3
Feasible Sequences	Krig.	Krig.	Krig.	Krig.	Krig.	Krig.	Krig.	Krig.	Krig.	Krig.
	8	8	3	3	3	3	1	1	1	1
		9	8	6	6	4	3	3	2	2
			9	8	8	6	4	4	3	3
				9	9	8	6	5	4	4
					10	9	8	6	5	5
						10	9	8	6	6
							10	9	8	7
								10	9	8
									10	9
										10

Finally, Table 3 summarizes the information regarding each option. We observe that, while this set of data reliability (measured as the probability of having a positive NPV) does not have substantial changes, the expected NPV values and the standard deviation observed in each case are interesting to note.

Table 3 Detailed results by option: Expected VAN, Price, Standard Deviation, and Reliabil y

	Option 1	Option 2	Option 3	Option 4	Option 5
Option Price [MUS$]	0.0	0.3	4.2	5.0	9.4
E(NPV) [MUS$]	338.4	342.5	345.5	348.8	345.2
Option Value [MUS$]	0.8	4.9	7.9	11.2	7.6
Reliability	0.977	0.975	0.979	0.979	0.978
Stan. Dev [MUS$]	169	174	170	171	172
Discount Investment [MUS$]	3015.4	3015.8	3020.2	3021.1	3026.5
	Option 6	**Option 7**	**Option 8**	**Option 9**	**Option 10**
Option Price [MUS$]	12.6	42.2	47.8	66.5	69.3
E(NPV) [MUS$]	342.5	317.5	324.2	306.6	307.2
Option Value [MUS$]	4.9	-20.2	-13.4	-31.0	-30.5
Reliability	0.977	0.973	0.981	0.976	0.975
Stan. Dev [MUS$]	172	164	156	155	157
Discount Investment [MUS$]	3030.1	3064.1	3070.3	3092.2	3095.5

Based on the presented results, the option required to improve the expected VPN is the number 4. The implementation of the sequences related to this option needs an extra investment of 5 [MUS$], related to the CAPEX of a biggest movement in the mine. With the results obtained we observed that the option value and reliability decreases when the option price, related to the movement required, increase. This effects is based on the economic result of those realizations of the block model that present a negative value after the incorporation of more Capex, result that can't we compared with the benefits incorporated with the flexibility of new sequences capacity.

Case 2: Optimal underground project under market price uncertainty

After running the optimization model over 1,000 different price scenarios, we observe that the impact of the discount rate makes changes in the timing for sectors D and E negligible, hence we are reduced to 4 different scenarios: the base case, starting sector C one year before planned (Option 1), 2 years before planned (Option 2), and 3 years before planned (Option 3). For each of these options, the open-pit (sector B) can be adapted so capacity and subsidence constraints are satisfied.

Table 4 compares these 4 options presenting the expected NPV value, the probability that Option K=1,2,3 performs better than the base case (NoOpt), and the ROV. We observe then that, with probability 99.4%, it is convenient to run Option 3, therefore starting sector C 3 years before than planned.

Table 4 NPV for each Option

Option	E(NPV)	% Price Path : With OP > No OP	ROV
NoOpt	23,557	-	-
1	23,518	0	-39
2	23,558	52	1
3	23,612	99.4	55

Then in Table 5 we compare Options 2 and 3 (Option 1 is left out, because it performs worse than NoOpt) against the base case and considering a fixed expected long-term price of 2.7 U.S. $/lb, which was used in the base case. We then compute the probability of having a price lower or higher that this price (column Option 2/3) and compute the expected NPVs, whether the Option is performed (wOpt) or not (woOpt). So, for example, we have that with 72% of probability, the price will be over the long-term one and in that case, the gain of taking Option 3 is MUS$61, hence we can set the "criteria": If by 2024 the price is over 2.7 USD/lb, then the Option 3 must be taken, as this increases the expected NPV in MUS$61.

Table 5 Analysis NPV of year in which to make the decision

Option 3	E(NPV) MUS$.		Difference MUS$.	Option 2	E(NPV) MUS$.		Difference MUS$.
	wOpt	woOpt			wOpt	woOpt	
72%	24,867	24,806	61	42%	25,502	25,193	309
28%	20,187	20,145	42	58%	22,363	22,372	-9

CONCLUSIONS

We have presented some applications of real options to study the impact of flexibility in mine planning, either in terms of expected NPV, variability or reliability of the plans obtained. We illustrate this application in two case studies. The application performed in this case is different than in other studies in the sense that it is more adapted to the mining industry.

The results show that, indeed, it is possible to generate coverings while maintaining or even increasing the value of the project by introducing some flexibility in some of the outcomes of the planning process. In the first case study, this flexibility is gained in the scheduling of the production, by considering different options regarding the size of the mining capacity, and it is used to increase expected value while maintaining reliability. In the second case study, the flexibility is put into the timing of a mine sector, and a criteria are developed (based on price) to determine whether it is convenient to start a certain project earlier than expected; even in a very constrained scenarios.

In both case studies, the data and option scenarios were limited in terms of the impact produced. We believe this impact will increase when more powerful options are considered. For example, in the case of the second study, a lot more flexibility can be gained if the production plans of all the projects are allowed to change (not only the final pit). This requires a deeper analysis and a higher level of detail, in terms of investments and costs for example, that we plan to do as future work.

A main result of this paper is that the methodology of real options is very versatile, extendable, and applicable to mining; but (as it is known), the actual impact of this strongly depends of other parameters like the level of variability and the value of the project. For example, for very long-term scenarios (like Case 2), the actual impact is not clear considering the effect of the discount rate over a time horizon longer than 50 years.

REFERENCES

Mayer Z, Kazakidis V. (2007) 'Decision making in flexible mine production system design using real options', *Journal of Construction Engineering and Management*, vol. 133, no. 2, p. 169–180.

Drieza, J A, Kicki, J and Saluga, P. (2002) 'Real Options in mine Project budgeting-Polish mining industry example', in Risk Analysis III.

Topal, E, (2008) 'Evaluation of a mining project using discounted cash flow analysis, decision tree analysis, MonteCarlo simulation and real options using an example', *Mining and Mineral Engineering*, 1:62–67.

Samis, M R and Poulin, R. (1996) 'Valuing management flexibility by derivative asset valuation', *98th Annual General Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum*, Canadian Institute of Mining, Metallurgy and Petroleum: Montréal.

McKnight,R T. (2000) 'Valuing mineral opportunities as options, Mining', Millenium Content Management Corp, Toronto,Canada.