Modelling financial risk in open pit mine projects: implications for strategic decision-making

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Transaction Paper

Synopsis

Strategic decisions in the mining industry are made under multiple technical and market uncertainties. Therefore, to reach the best possible decision, based on information available, it is necessary to integrate uncertainty about the input variables and model financial risk of the project's merit measures. However, this provides few useful insights to decision-makers unless accompanied by modelling management responses to uncertainty resolutions. It is widely acknowledged that conventional decision-support methods based on static, no-change, discounted cash flow (DCF) techniques such as net present value (NPV) and internal rate of return (IRR) tend to provide inaccurate value estimates. This could mislead the strategic decision-making process and result in significant value losses.

This paper aims to model financial risk related to uncertainty about market variables such as metal prices and foreign exchange rates. Other sources of risk that are related, for example, to geology and production costs are not considered in this work. The article outlines a flexible financial model that integrates uncertainty about market variables and management flexibility to react to uncertainty resolutions into mine project valuation using a real-options valuation technique based on Monte Carlo simulation. Significance of information generated from this simulation-based flexible valuation model to the strategic decision-making process is tested using an illustrative case study of a Canadian mining project. The project is a typical multi-metal, open pit mine that produces copper and gold. In this case, there are three uncertain market variables, which are: copper and gold prices and US$/CAN$ exchange rate. Financial valuations are carried out using both the conventional static DCF method and a flexible real-options model. In the flexible model, management flexibility to decide whether to go ahead with the next expansion or terminate production operations is integrated. Results show how the flexible financial model can enhance the decision-making process.

Introduction

The purpose of valuation is manyfold. It establishes a measure by which a project can be measured against other possible candidates. It allows for informed decision-making and, it enables the best allocation of limited resources between competing projects.

Discounted cash flow (DCF) analysis is probably the most widely applied technique for valuing mining projects. It performs well as a decision-making tool when the underlying project has low cash flow volatility (Miller and Park, 2002) and when intermediate cash flows can be reinvested at comparable interest rates. Having said that, DCF requires that all decisions are made up front and no changes to these will occur over time.

For investments with highly volatile cash flows, the static DCF analysis can produce misleading valuation results. This is because conventional DCF analysis does not capture the value of management flexibility to revise decisions based on new information. As noted by Moyen *et al.* (1996) and Keswani and Shackleton (2006), the additional value of management flexibility could be of significant importance to strategic investment decisions.

In contrast to conventional DCF analysis, real options valuation (ROV) approach is a promising technique for dealing with high-volatility cash flow investments. In addition to its ability to deal with differences in financial risk between cash flow items (Samis *et al.*, 2006), ROV can integrate the value of management responses to take some future actions. Applications of ROV to valuing mining investments include, for example: Brennan and Schwartz (1985), Moyen *et al.* (1996), Kelly (1998), Slade (2001), Moel and Tufano (2002), McCarthy and Monkhouse (2003), Abdel Sabour and Poulin (2006), Samis *et al.* (2006) and Dimitrakopolis and Abdel Sabour (2007).

This paper examines the significance of the difference between the conventional DCF and the ROV analysis in incorporating financial uncertainty and operating flexibility into the strategic decision-making process. Rigorous mathematical formulations will be avoided. Instead, the main concept of the paper will be illustrated using a case study of what might be a typical Canadian copper-gold open-pit mine. Section 2 outlines briefly the real options valuation methodology. The case study is

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 This paper was first published at Strategic vs Tactical Approaches in Mining 2008, Conference, Canada.

presented in Section 3 along with valuation results of both the conventional and the flexible valuation models. Investigating the impacts on the decision-making process is also discussed in Section 3. Finally, conclusions are drawn.

Advanced financial valuation

One of the most important shortcomings of conventional static valuation techniques based on DCF methods is that management flexibility to take actions in the future in response to uncertainty resolution is ignored. In this respect, the typical approach of static valuation techniques is to generate a long-term production plan before starting production. This plan projects production schedules (ore and waste tonnages and ore grades), capital expenditures, operating costs, revenues, etc. throughout open-pit mine life based on a set of what is called 'long-term metal prices and exchange rates'. However, there is consensus among mining practitioners that there is a high probability that actual metal prices will be significantly different from feasibility-stage expectations.

With ROV the value of management flexibility to revise operating policy in the future is included in the current value estimate. It is a dynamic optimization process that compares two values at each point of time and takes the decision that corresponds to the maximum of them. These two values are the stopping value and the continuation value. To continue means keeping the current operating policy unchanged, whereas to stop means switching to an alternative plan with a higher expected value (see Dixit and Pindyck, 1994 and Brennan and Schwartz, 1985 for more details).

Numerical techniques for applying ROV include finite difference (Brennan and Schwartz, 1977; 1978), binomial lattice (Cox *et al.*, 1979), and Monte Carlo simulation (Boyle, 1977 and Longstaff and Schwartz 2001). The last of these has advantages over the others in terms of being able to simultaneously handle multiple sources of uncertainty and deal easily with the complexity and irregularity of real projects cash flows. Therefore, ROV based on Monte Carlo simulation is well suited to analyse mining investments and it is capable of handling cases of multi-metal projects without the need to oversimplify reality. Details on applying this method to mining investments can be found in Abdel Sabour and Poulin (2006) and Dimitrakopolis and Abdel Sabour (2007). This paper takes the simulation-based ROV method further by integrating the following details in the valuation model in an effort to improve the reliability and transparency of ROV even further:

- Production-dependent closure costs
- Developing the expected cash flows based on annual operating costs rather than on an approximated $/tonne basis.
- Integrating real life details such as smelter terms and concentrate transportation conditions directly into the ROV model.

This work aims to provide a practical example investigating if ROV provides additional useful information, over the conventional DCF analysis that would result in improving the strategic decision-making process. In this respect, presentation of the mathematical formulations of the ROV model is avoided. Interested readers are referred to the work cited in the previous paragraph for detailed mathematical derivation of ROV. This work will focus on the practical application of the ROV to the long-term mine planning and strategic decision-making process through the case study presented in the following section.

Case study: decision making at a copper-gold mine

This section provides a case study of a typical Canadian copper-gold mine. Possible mine production data are provided in Table I along with the associated capital and operating

Table I

Mine production and cost data

Year	Waste Million tonnes	Ore Million tonnes	Cu grade %	Au grade g/t	Cu recovery %	Au recovery %	Cu concentrate grade % Cu	Capital costs CAN$ million	Operating costs CAN$ million
-2								200.00	
-1								250.00	
1	35.86	6.12	1.07	0.40	80.95	63.15	23.85	170.00	104.94
2	16.27	7.91	1.03	0.36	81.72	67.68	23.02	70.06	121.32
3	30.53	10.75	1.03	0.37	80.42	67.58	24.37	44.71	156.11
4	56.28	11.81	1.02	0.36	78.59	61.88	22.58	63.75	172.77
5	79.43	13.43	1.01	0.35	83.40	65.76	22.75	60.57	191.46
6	52.73	14.91	1.01	0.35	81.38	62.67	24.73	73.26	192.68
7	31.85	11.51	0.84	0.35	77.71	65.29	23.11	43.71	165.12
8	37.24	11.95	0.81	0.34	76.04	63.32	22.82	55.45	175.76
9	31.87	11.24	0.69	0.37	76.82	68.70	23.59	45.62	167.75
10	43.11	11.90	0.68	0.38	74.70	68.44	24.94	58.50	156.70
11	27.30	12.11	0.66	0.32	78.68	68.79	24.80	42.68	169.26
12	56.46	13.40	0.74	0.33	80.01	64.15	22.51	57.83	185.38
13	64.98	11.92	0.74	0.32	75.62	67.14	22.55	63.29	154.83
14	56.42	12.08	0.83	0.40	76.07	62.83	22.92	74.19	169.49
15	53.45	10.17	0.71	0.39	78.71	65.47	24.70	68.91	159.22
16	67.44	9.60	0.71	0.35	76.45	66.68	24.89	83.44	147.93
17	59.87	8.64	0.68	0.35	82.80	68.30	23.93	74.20	132.22
18	60.04	9.44	0.48	0.38	74.97	67.97	24.69	75.25	146.02
19	50.51	8.86	0.42	0.39	77.15	64.07	23.04	64.30	135.80
20	26.26	9.46	0.56	0.35	78.84	67.42	24.40	0.00	121.61

costs throughout the possible 20-year mine life. Table II provides base case flat metal prices to be used in conventional financial modelling, smelter terms and mine closure cost. The aim of management is to estimate mine value and find the optimum mine life that maximizes project economic performance. This will be carried out using both conventional DCF procedures and ROV to investigate how the decision-making process is affected by modelling financial risk and integrating management flexibility to react to market uncertainty resolution. For the sake of the study, all analyses are performed on a before-tax basis.

Conventional static DCF analysis

Conventional financial analysis starts with building a spread sheet financial model to estimate economic merit measures such as payback period, IRR, cumulative NCF and NPV. Then sensitivity analysis is performed to investigate effects of changing project key variables on one or more of the measures of economic merit. This is carried out by changing one variable at a time while holding the others constant.

Monte Carlo simulation is also a viable tool that allows investigating the effects of all key variables simultaneously instead of one by one as in the conventional sensitivity analysis. However, it is not regularly used in real life mine project studies.

Conventional NPV for this project, based on data of Tables I–II, is found to be CAN$ 34 million. According to the NPV decision rule, a positive NPV indicates a go-ahead sign for the project. However, since the goal is to maximize NPV, it is worthwhile looking at the annual NCFs and the cumulative NCF to investigate the economic performance of the project with time. Figure 1 shows the annual NCFs and the cumulative NCF throughout pit life. As in most mining projects, NCFs are negative during the early project years due to the preproduction capital expenditures and then they start to be positive once production begins. Accordingly, cumulative NCF starts at a negative value and starts to increase with mine life. As shown in Figure 1, starting from year 16 annual NCFs are negative and the curve representing cumulative NCF starts to decline. Therefore, from the conven-

Table II

Base case assumptions*

Base case market variables	Discount rate	%	8.00
	Cu price	US$/lb	1.70
	Au price	US$/oz	650
	Exchange rate	US$/CAN$	0.9
Smelter terms	Moisture content	%	7.00
	Concentrate losses	%	0.50
	Freight	US$/wmt	40.00
	Marketing & Other	US$/dmt	3.00
	Insurance premium	%	0.20
	Treatment charge	US$/dmt	70.00
	Refining charge	US$/pay lb	0.070
	Pay factor	%	97.00
	Unit deduction	%	2.00
	PP percentage	%	0.00%
Gold pay	Pay factor	%	98.0%
	Unit deduction	g/t	1.5
	Refining charge	US$/oz	6.00
Closure cost		CAN$/t mined	0.10

*Base case metal prices and exchange rate are provided for explanation purposes only. These assumed figures do not necessarily reflect AMEC's or any other party's expectations

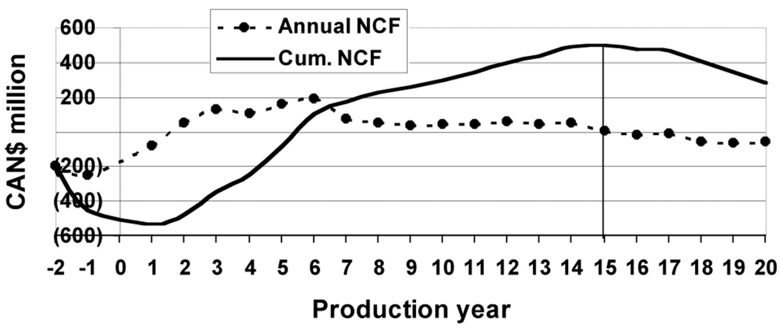


Figure 1—Cumulative NCF and annual NCF for the open pit

tional NPV point of view, it is optimum to terminate mining operations in year 15 rather than in year 20 to avoid negative cash flows over the last 5 production years. Table III shows a comparison between the economic merits of the project in the cases of 15-year and 20-year open pit. It is obvious that the 15-year pit is much better than the 20-year pit. Based on these results, the optimum management decision that maximizes the NPV of the project is not to extend the pit beyond year 15 production. This decision has many consequences related to capital budgeting: design and location of surface facilities, for instance. The latter is of significant importance since it could result in irreversible use of land outside ultimate pit limits. As a future consequence, it may be too costly to move installed surface facilities in order to give access to underlying mineralization. On the other hand, installing surface facilities in an arbitrary location remote from the pit could result in unnecessary increase in costs, especially when financial analysis shows that the area of pit beyond year 15 is not likely to be mined since its net cash flows are negative.

Sensitivity analysis is carried out for the two cases of 15-year and 20-year pit. What can be inferred from Figure 2 (a) and (b) is that project NPV is more sensitive to variations in copper price and exchange rate than it is to gold price; and it is slightly more sensitive to operating costs than capital costs. Regarding the decision to have a 20-year or 15-year pit, this kind of sensitivity analysis provides no more information or insight than the conventional single value estimate presented above. Therefore, the decision is still the same as with the conventional point estimate: design a 15-year open pit.

Table III

Comparison between the 15-year and the 20-year life pit

Economic merit measure		20-year pit	15-year pit
Cumulative NCF	CAN$ million	283	482
NPV (8% discount rate)	CAN$ million	34	74
Internal rate of return (IRR)	CAN$ million	9.5%	10.7%
Payback period	Years	5.5	5.5

A more advanced tool to integrate risk is to run Monte Carlo simulation on one or more economic merit measure. In this study, probability distributions for the NPV calculated at 8% discount rate will be generated assuming, for simplicity and also as commonly used, that copper and gold prices, exchange rate, capital expenses and operating expenses follow symmetric triangular distributions. The advantages of Monte Carlo simulation over the conventional sensitivity analysis in Figure 2 are that it generates distributions for the selected merit measures and allows for studying the effect of all key variables simultaneously. As shown in Figure 3, since the distributions of input variables are symmetrical with 0 correlation coefficients, the expected NPV of the two cases (20-year and 15-year life pits) are CAN$ 34 million and CAN$ 74 million, respectively, approximately the same as the single value estimate. The 10th and 90th percentiles (in CAN$ million) for the 20-year option are -640 and 736, and those for the 15-year life case are -546 and 721. In summary,

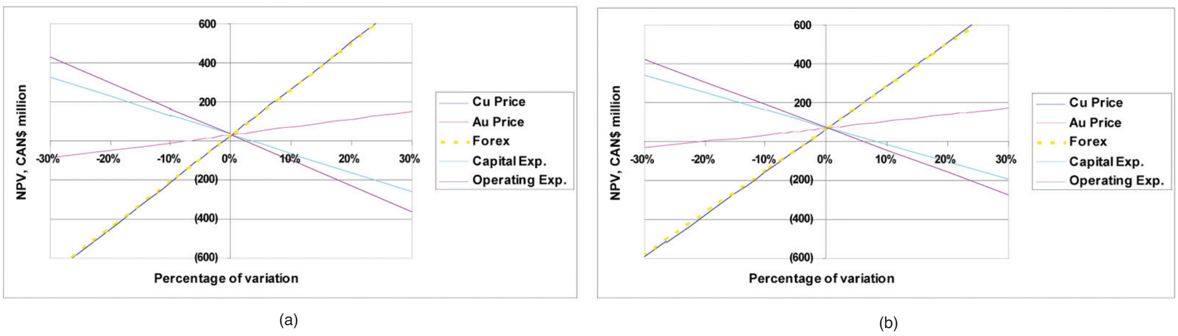


Figure 2—Sensitivity analysis: (a) 20-year pit (b) 15-year pit

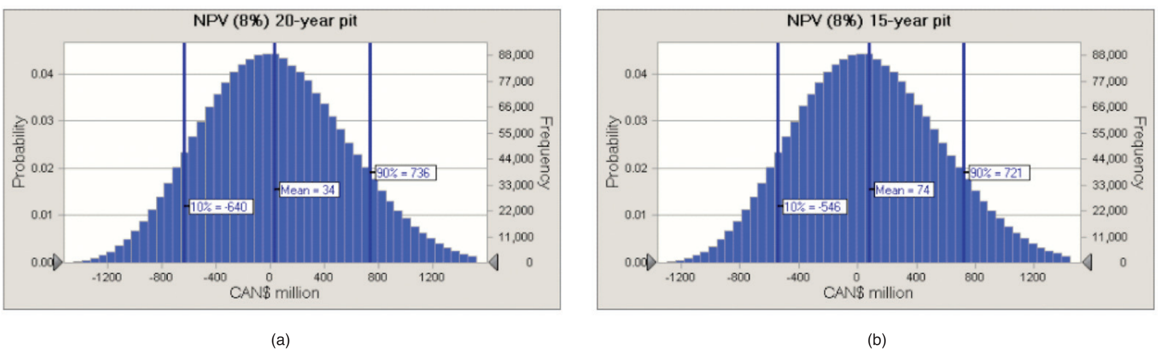


Figure 3—Monte Carlo simulation results: (a) 20-year pit (b) 15-year pit

the 15-year life option gives an expected NPV higher than the 20-year option with a less spread distribution. Therefore, based on the results of Monte Carlo, the 15-year life option is better than the 20-year life option. This is exactly the same conclusion drawn based on both the conventional single point estimate and the sensitivity analysis. The new contribution of simulation is that it gives more insight into the risk associated with the expected NPV. However, it does not contribute significantly to the strategic decision-making process.

Real options valuation

Data required to run the real options valuation model are approximately the same as the conventional DCF analysis presented above. The only new issue here is that uncertainty about market variables need to be introduced. This is usually carried out using stochastic models such as geometric Brownian motion and mean-reversion, for example. Conventional DCF valuations are usually based on deterministic future market, which indicates that future metal prices and exchange rate are perfectly known and will be equal to what is called 'long-term' expectations. As listed in Table II and shown in Figure 4, in conventional DCF analysis, copper price, gold price and exchange rate throughout project life are assumed to be flat at US$ 1.70/lb, US$ 650/oz and US$/CAN$ 0.90, respectively. To keep things simple and to focus only on the difference in mechanism between static DCF and ROV, the same assumption about future metal prices and exchange rate is used in ROV. The only difference is that standard deviations of 20%, 15% and 10% for copper price, gold price and exchange rate, respectively, are used. This is reflected in Figure 4 by the envelopes representing P10 and P90, for future copper price as an example. In static DCF analysis, since future realizations are assumed to be known with certainty, standard deviations are equal to 0 and all of the expected price, P10 and P90 are represented by one line.

To keep things simple, correlations between metal prices, exchange rate and stock market are ignored. In this case, there is no risk-discounting and the same discount rate of 8% used in conventional DCF analysis will also be used in ROV. This is carried out by setting all correlation coefficients to 0 in the ROV model. Computationally, considering correlation is straightforward and is easily carried out at no, or negligible, extra cost. However, over focusing on correlation and risk discounting seems to be distracting readers and adds extra complexity to the understandability of ROV by mining practitioners. Rolling out correlation eliminates many of the apparent complexities and allows focusing on the most significant issue, which is the operating flexibility to modify decisions in the future.

Different types of flexibility could be recognized in mining. These include: investment timing, expansion, temporary shutdown/resumption of operations and early closure, among others. To maintain simplicity, only the management flexibility to close the mine early in response to adverse market conditions is considered.

At some time intervals, usually at the end of each year, it is assumed management will revisit mine production policy and decide whether to go ahead with the predefined next year production plan or close the mine at this time. In the terminology of open pit mining, this operating option can be considered as an option to modify ultimate pit limits**.

Since closure cost is directly related to cumulative tonnes mined, as shown in Figure 5, there will also be a trade-off between closing the mine in period t and paying a lower closure cost, or wait until period t+1 and paying a higher closure cost. In the end, the decision whether to close the mine early or continue until next period will depend, among other factors, on capital expenditures, metal prices and production costs in addition to the difference between the closure costs of periods t and t+1.

In ROV, paths (or sequences of values) are simulated for each of the market variables being considered and cash flows are evaluated for each path. Based on the simulated realizations of market variables and their corresponding cash flows, the valuation model internally determines the optimal choice at each period and revises cash flows accordingly.

Table IV provides the expected cumulative NCF, NPV, IRR and payback period of the open pit mine as estimated by the ROV model. For comparison, results of the conventional static financial analysis presented above are also included. It is obvious from Table IV, that cumulative NCF estimated by ROV is about 4 times those of conventional analysis, NPV of ROV is 11 times that of conventional DCF and IRR of ROV is

**Thanks to Professor Roussos Dimitrakopoulos, director of COSMO-Stochastic Mine Planning LAb., McGill Univeristy, who noted that the early closure option is in reality an option to modify ultimate pit limits

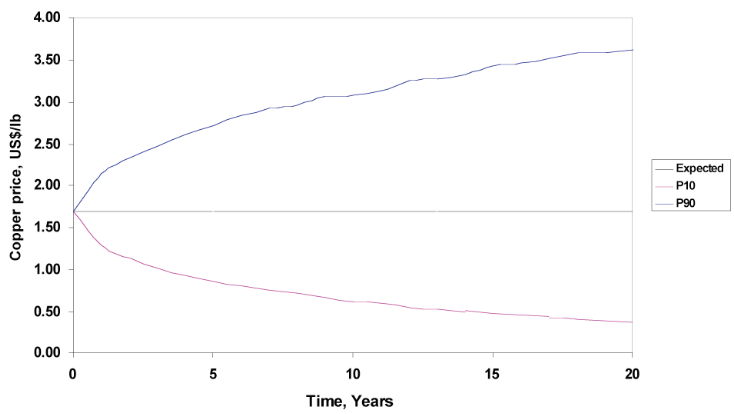


Figure 4—Expected, P10 and P90 copper price

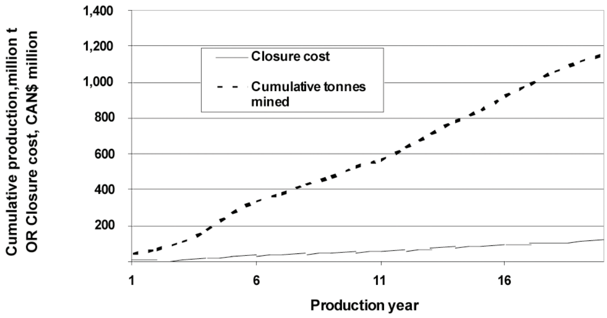
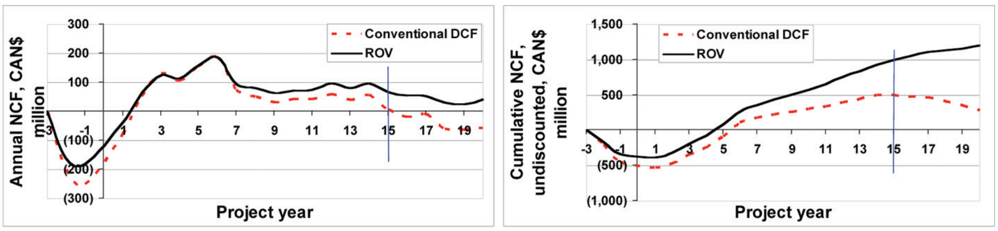


Figure 5—Mine closure cost



(a) (b)

Figure 6—(a) Annual NCF and (b) cumulative NCF of ROV and conventional DCF

Table IV

ROV results vs. results of static financial analysis

Economic merit measure		Conventional DCF analysis	ROV
Cumulative NCF	CAN$ million	283	1,202
NPV (8% discount rate)	CAN$ million	34	381
Internal rate of return (IRR)	CAN$ million	9.5%	20.5%
Payback period	Years	5.5	4.5

about 2 times that estimated by the static DCF. To remind readers, the inputs to the ROV model are the same as the inputs to the conventional DCF analysis, metal prices are the same, and the discount rate and discounting system are the same. The only difference is that the ROV model integrates financial risk and accounts for the possibility to close mine early while the static DCF analysis does not consider such operating flexibility. Therefore, the significant difference in valuation results of Table IV is owed completely to the integration of management flexibility to react to market uncertainty.

Now, we return to the important question that needs an answer: should management consider a 15-year or 20-year pit? The answer of the conventional DCF was that a 15-year pit is much better than a 20-year pit. To investigate the answer of ROV, annual NCF and cumulative NCF throughout project lifetime are depicted in Figure 6. For the sake of comparing results, the curves of conventional DCF analysis are also included. Looking at Figure 6(a), it is clear that, while NCFs of conventional DCF analysis turn negative after year 15, those of ROV are positive. Therefore, as depicted in Figure 6(b), the cumulative NCF curve of conventional DCF analysis declines after year 15, while that of the ROV keeps rising until end of mine life. This indicates that, whereas conventional DCF recommends a 15-year life pit, ROV recommends a 20-year life pit.

The difference in decision between the ROV and the conventional DCF analysis is due to the difference in dealing with financial uncertainty and management responses to resolution of such uncertainty. The conventional DCF analysis assumes that production will continue as planned regardless of changes in future markets. In contrast, ROV enables modelling financial risk and integrating the value of management flexibility to modify original plans. While the conventional DCF assumes that there is a 100% probability that the mine will be open throughout its planned life, ROV accounts for the fact that the mine could be closed early as a result of adverse financial conditions. Therefore, as shown in Figure 7, the probability that the mine will be open is less than 100% and the probability declines as the mine matures.

Based on the results of conventional DCF analysis, the 15-year life pit is the optimum option that maximizes the NPV of the project. This is because NCFs during production years 16 to 20 are negative. Therefore, based on the value-maximization rule, the probability that the mine will be open after year 15 is exactly 0%, as shown in Figure 7. In contrast, ROV results show significant probabilities that the mine will be open during these periods. Figure 8 compares NCFs throughout years 15 to 20 estimated by both techniques. Based on the expectations of ROV, there is a possibility that the NCFs during years 16–20 will be positive. In today's money, conventional DCF estimate of total NCF during years 15 to 20 is negative CAN$ 44 million, while ROV expectation is positive CAN$ 45 million. Therefore, based on ROV, strategic mine planning should consider this CAN$ 45 million expected value of extending the pit beyond year 15 when planning the mine as well as when designing and locating processing plant, stockpiling and dumping options, and all other surface facilities.

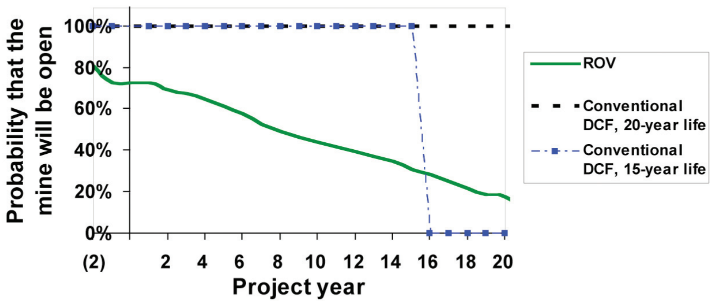


Figure 7—Probability that the mine will be open

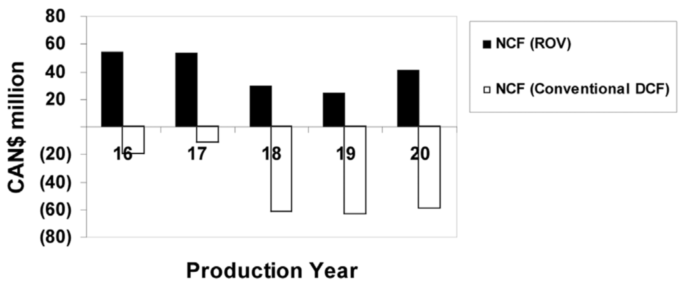


Figure 8—NCF throughout production years 15 to 20

Conclusions

It is a fact that strategic decisions and long-term mine planning are carried out under multiple sources of uncertainty. This paper focused on financial uncertainty related to metal prices and exchange rates. Efficiency of conventional DCF analysis in supporting strategic decision-making process was compared to that of ROV using the data of a hypothetical Canadian copper-gold open pit mine project. The results showed that static, single point estimate, DCF analysis based on deterministic future metal prices and exchange rates did not provide significant information to the strategic long-term mine planning process. Also, conventional sensitivity analysis and even Monte Carlo simulation did not provide new insight to the strategic decision-making and, in this respect, did not have sensible advantage over the static DCF analysis based on one scenario. This is mainly because although conventional risk analysis based on Monte Carlo simulation considers uncertainty in input variables and produces distributions for economic merit measures, it ignores management responses to changes in market variables. In contrast, ROV showed an advantage over conventional financial analysis in terms of better modelling of financial risk and capturing of strategic value. This was shown quantitatively in the provided case study. While conventional analysis recommended a shorter open pit life due to negative last years cash flows, ROV indicated that there is a strategic value for those last years. Accordingly, this value should be considered in long-term strategic open pit mine planning.

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