A comparison of discounted cash flow and Monte Carlo discounted cash flow valuation techniques on a gold mining project

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Uncertainty is intrinsic to mining. This implies that mining is an inherently risky business. This associated risk must be taken into account during the mine design and planning process. Similarly, the valuation of mineral projects needs to take into account this associated risk. The discounted cash flow (DCF) is a widely used technique for mineral projects valuation. One of the limitations of the DCF technique is that it is deterministic. This means that the valuation technique makes use of static input variables. Therefore, it does not model the risk associated with mineral projects, apart from applying a discount rate which is a fudge factor. To overcome this limitation, probabilistic valuation approaches are used such as the Monte Carlo DCF (MCDCF) technique. This paper applied and compared the results of the static DCF and MCDCF techniques on an underground mining project with two possible extraction scenarios. The static DCF was used as the basis to determine the economic value of the mining project, while the MCDCF incorporated uncertainty in its input variables and quantified the risk associated with the project using @RISK software. The static DCF resulted in an NPV of US$9.60 million and an IRR of 8.67% for scenario 1 while scenario 2 had an NPV of US$11.35 million and an IRR of 8.95% at a 5% discount rate. The MCDCF resulted in a range of possible net present values (NPVs) and internal rates of return (IRRs). Based on the NPV and IRR decision criteria coupled with their probabilities, it was recommended that the company use the MCDCF to quantify the risk associated with the project for decision making.

Keywords: DCF, MCDCF, NPV, IRR and uncertainty

INTRODUCTION

All mining companies aim to create value from their operations for the benefit of their stakeholders. There are different types of value which include social, intrinsic and economic value (Jenkins, 2004). The focus of this paper was on economic value. Economic value can be created in many ways, including through increased production output and through cost-cutting strategies. The mining industry is unique compared to other industries in that it is susceptible to high risks and uncertainties such as grade, commodity price and other technical and economic factors. The value of a mining project is strongly affected by the uncertainties that are associated with the mining industry. It is therefore imperative that investment decisions in mineral projects are informed by appropriate valuation techniques that incorporate such risks and uncertainties. There are three valuation approaches commonly applied in mineral projects' valuation, namely the market, cost and income approaches. Each of the approaches consist of techniques. However, the focus of the study was on the DCF technique within the income approach. This paper applied and compared the static DCF and MCDCF valuation techniques on a gold mining project case study with two different exploitation scenarios. The aim of the research was to quantify the risk associated with the mining project. For confidentiality reasons, the identity of the case study project and owning company could not be disclosed in this paper.

Discounted cash flow analysis

The DCF is the most widely used technique for mineral project valuation (Macfarlane, 2001). The technique is based on estimating annual cash inflows and outflows over the life of a project. The total cash outflow is then subtracted from the total cash inflow, resulting in the net cash flow for each project year. Based on the risks associated with the project, an appropriate discount rate is applied to discount the annual net cash flows. The sum of the discounted net cash flows gives the net present value (NPV) of the project. NPV is calculated using Equation 1 (Brigham and Gapenski, 1997):

$$NPV = C_0 + \sum_{t=1}^{t=n} \frac{NCF_t}{(1+r)^t} \qquad [1]$$

Where C_0 is the initial capital invested in the project for its development; NCF_t is the yearly projected future net cash flows; *r* is the discount rate which represents the risk associated with the project; *n* is the life of the project; and *t* is the cash flow period. NPV, IRR and payback period (PP) are the main decision criteria of the DCF technique. A project is considered viable if the NPV is positive and IRR is greater than the discount rate. The viability of the project based on the PP decision criterion is dependent on how fast the investors want their initial investment back (Haotian, *et al*., 2022). There are two main variations of the DFC techniques: the static DCF and the MCDCF.

Despite the wide application of the DCF technique in several industries, the technique has several limitations. Torries (1998) and Kelly (1998) both stated that it is difficult to determine the most suitable discount rate to accurately calculate NPV. This is because in reality the determination of the discount rate is dependent on an individual's experience, making the calculation of the discount rate subjective (Park and Matunhire, 2011). Furthermore, the discount rate in the DCF technique accounts for all the risks in the project over its life cycle. Conversely, the risks of a project may change during the project's life (Mun, 2006).

In addition to the limitations of the DCF technique in general, the static DCF in particular assumes that all input variables are deterministic and known with certainty throughout the life of the project on the day of valuation, and the investment decision is made without considering other factors. In reality, input variables are uncertain, stochastic in nature and can vary in the future, which can affect the outcome of the decision criteria of the static DCF. This makes the cash flows uncertain and can ultimately change the investment decision because a profitable project can become unprofitable due to changes of input variables in future (Mun, 2006).

Risk and uncertainty in the mining industry

Uncertainty is intrinsic to the mining industry; something which must be considered during mineral projects valuation. Most input parameters into the valuation process are unknown at the time of valuation. There are various sources of uncertainty which are broadly categorised into internal (endogenous) and external (exogenous) sources (Kazakidis and Scoble, 2003). Internal uncertainties are those uncertainties that are dictated by the orebody and the mining method. External uncertainties are those uncertainties that are governed by factors outside of the project, over which the business has no direct control, such as the market in which they operate (Mayer and Kazakidis, 2007). External uncertainties are managed at a strategic level, for example by diversification of portfolios and hedging of mineral commodity price. Internal uncertainties are managed at the source where operations take place. This includes stochastic mine planning, adjusting production schedules, changing mining and processing equipment, and adding additional capacity.

The uncertainty associated with mining makes it a risky business. Risk and uncertainty have major impacts on the valuation of mineral projects and can make a potentially viable project unviable. The fact that input variables are uncertain makes it possible for the risk of a project to be quantified. Risks can be measured on input variables and quantified on output variables by using probabilistic models (Ajak *et al*., 2018).

To overcome some of the limitations of the static DCF, simulations can be done to incorporate uncertainty associated with DCF input parameters. Monte Carlo simulation, alternatively known as probabilistic simulation, is a statistical problem-solving technique adopted to understand the effect of risk and uncertainty in compound situations (Mun, 2006). The technique uses probability distributions to model the uncertainty of input variables and compute all the possible outcomes (Harrison, 2010). Different simulations are run to produce possible outcomes of the problem. This simulation technique is one of the most used methods for modelling uncertain variables. Combining the simulation technique to the DCF technique results in a MCDCF. The underlying principle of the MCDCF is similar to that of the static DCF. The only difference is that a MCDCF considers uncertainty in the calculation of NPV. Probability distributions are fit to uncertain input variables such as mineral commodity prices, grade, operating costs and metallurgical recoveries. The result is a probability distribution of NPV.

Gold mine case study

The case study mine has two production pits; Pit A and Pit B, with a combined expected life of mine (LoM) of nine years. Of the nine years, seven years involve active mining and the remaining two years involve processing stockpiles. Exploration at Pit B has discovered an additional mineral resource of 1.49 million tonnes of gold ore that extends deep underground. The mine plans to exploit this newly discovered mineral resource using an underground mining method from 2026 before its mining lease expires in 2032. The mine is considering the following two scenarios to exploit the mineral resource:

- Scenario 1: The development of the preproduction phase will be conducted by a contractor, thereafter the company will proceed with production.
- Scenario 2: The company will develop the mine and operate throughout the LOM.

The two scenarios resulted in two different production schedules and costs as shown in Tables I and II.

Table I. Economic and technical parameters for scenario 1
(Source: Adapted from Shivute, 2019)

Description	Unit	1	2	3	4	5	6	7	8	Total/average
	Year	2026	2027	2028	2029	2030	2031	2032	2033	
Ore milled	tonnes	0	0	164 269	273 750	273 760	273 699	234 748	207 608	1 427 834
Grade	g/t	0	0	6.13	5.93	5.77	5.26	4.38	5.79	5.52
Unit variable costs	US$/t milled	0	0	114.92	131.35	133.25	135.68	127.13	99.98	123.72
Capex	US$ million	27.31	47.62	18.90	0	0	0	0	0	93.83
Sustaining capital cost	US$ million	0	0	5.65	0.41	0.69	0.35	0	0	7.10

Table II. Economic and technical parameters for scenario 2
(Source: Adapted from Shivute, 2019)

Description	Unit	1	2	3	4	5	6	7	8	9	Total/average
	Year	2026	2027	2028	2029	2030	2031	2032	2033	2034	
Ore milled	tonnes	0	0	18 899	239 148	273 699	273 749	273 751	234 852	113 735	1 427 834
Grade	g/t	0	0	3.85	5.80	5.89	5.86	5.00	5.11	5.57	6
Unit variable costs	US$/t milled	0	0	0	147.76	144.31	117.36	115.32	112.61	87.13	106.23
Capex	US$ million	21.48	25.04	38.4	0	0	0	0	0	0	84.92
Sustaining capital cost	US$ million	0	0	0	8.99	0.47	0.10	0.09	0.02	0	9.67

Parameters in the tables were the input parameters used in the DCF analysis. The other input parameters used were the same for both scenarios. These are gold price (US$1 300/oz), processing recovery (97%), discount rate obtained from the company (5%), royalty and tax rate in the country of case study; 4% and 37%, respectively.

RESULTS

Static DCF Results

Table III shows a summary of the static DCF analysis results for scenarios 1 and 2.

Table III. Summarised static DCF analysis results for scenarios 1 and 2
(Source: Adapted from Shivute, 2019)

	Scenario 1	Scenario 2
NPV (US$ million)	9.60	11.35
IRR (%)	8.67%	8.95%

As shown in Table III, both scenarios have positive NPVs and IRRs greater than the 5% discount rate. Therefore, based on the NPV and IRR decision criteria the project is viable for both scenarios. Furthermore, scenario 1 has a PP of 5.21 years. For a mining project with a six-year LoM, a PP of 5.21 years would likely make the project unviable. However, the major decision criteria of the DCF that have more weight on deciding on the viability of a project are NPV and IRR (Awomewe and Ogundele, 2008). The cash flow of scenario 2 resulted in a PP of 5.49 years, which is approximately equal to the LoM. Although the project is viable at face value, that is, based on deterministic NPV and IRR results, it is possible that the project may have a low probability of being viable. To assess the risk and enable properly informed investment decision making, a MCDCF analysis was conducted.

Monte Carlo DCF Analysis

The inputs of the static DCF analysis were simulated using @RISK software to create a MCDCF. The variables that were simulated are: gold price, gold grade, production rate and unit variable cost. The other input parameters were assumed to be deterministic, as for the static DCF. The gold price used in the static DCF of US$1300/oz was used in the simulation as the annual average gold price provided by the company. The historical gold price from January 2010 to December 2018 was used to determine the probability distribution of the gold price using @RISK software. The assumption was that the gold price over the LoM will have a similar behaviour to the previous eight years' trend. The analysed eight-year historical gold price data found that the gold price followed a triangular distribution. Using @RISK, the minimum, maximum and mode of the historical gold price was found to be US$1038/oz, US$1898/oz and US$1198/oz, respectively. The mode was computed manually using Microsoft Excel because @RISK does not compute a mode.

The probability distribution of gold grade was determined from the current operating surface mine's historical grades using @RISK. The analysis found that the gold grade followed a positively skewed lognormal distribution. This is the probability distribution used to simulate the gold grade in this study. This supports the finding by Kennedy (1990) that the grade of precious metals, including gold grade, tends to follow a lognormal distribution. The standard deviation and the average gold grade were calculated from the stope in-situ mineral resource provided by the company. Both production rate and unit variable costs were assumed to follow a normal probability distribution. The standard deviation and average unit variables costs were calculated from the projections provided by the company used in the static DCF. The resultant average ore milled was calculated to be 237 972 tonnes with a standard deviation of 41 235 tonnes for scenario 1. Scenario 2 had an average of 203 977 tonnes and a standard deviation of 56 602 tonnes of ore milled.

Monte Carlo DCF results

One hundred thousand iterations of each input parameter were conducted simultaneously with other parameters in one simulation to create probability distributions of NPV and IRR of the project. The outcome of the simulation quantified the risk associated with the project. Figure 1 shows the range of possible NPV for scenario 1.

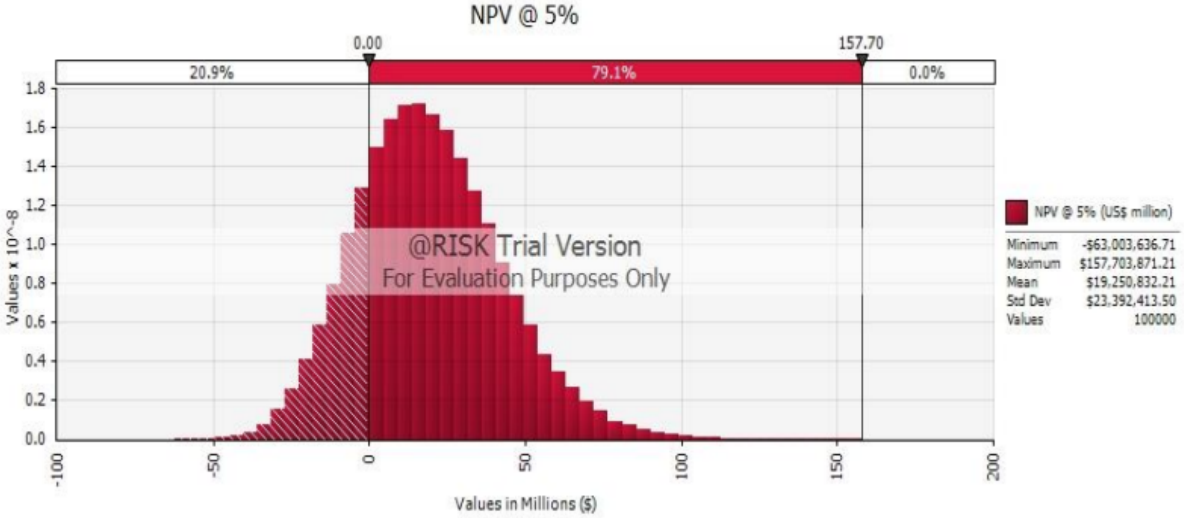

Figure 1. Probability distribution of a negative NPV for scenario 1 (Source: Shivute, 2019).

The NPV ranges from a minimum of US$-63 million to a maximum of US$157.70 million. From these results, the company can see two extreme possible outcomes of the NPV that scenario 1 can have. Furthermore, from the resultant range of US$220.70 million, the company will have an idea of the risk associated with the project. This is because the wider the range the higher the risk associated with the project and vice versa. Scenario 1 has a probability of 0.21 that the project will have a negative NPV. With this additional information about the risk associated with the NPV for scenario 1, the company can make an informed investment decision as compared to the static DCF results. For a more comprehensive understanding of the risk, Figure 2 shows the probability distribution of the project having a NPV less and greater than the NPV obtained from the static DCF (US$9.60 million).

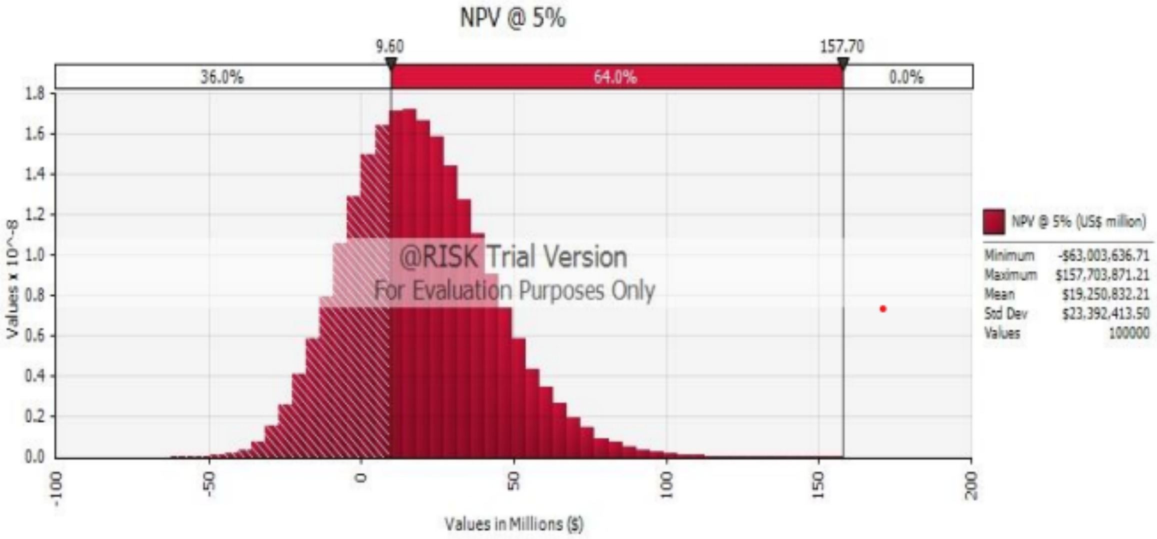

Figure 2. Probability distribution of an NPV less and greater than US$9.60 million for Scenario 1 (Source: Shivute, 2019).

Figure 2 shows that there is a probability of 0.64 that the project will have a NPV of US$9.60 million and greater if the company were to implement Scenario 1. The Figure also shows that there is a 0.36 probability that the project will have a NPV less than US$9.60 million. The company is now able to make a decision based on the NPV criteria that are strongly supported by probability. The range of possible IRR for scenario 1 is shown in Figure 3.

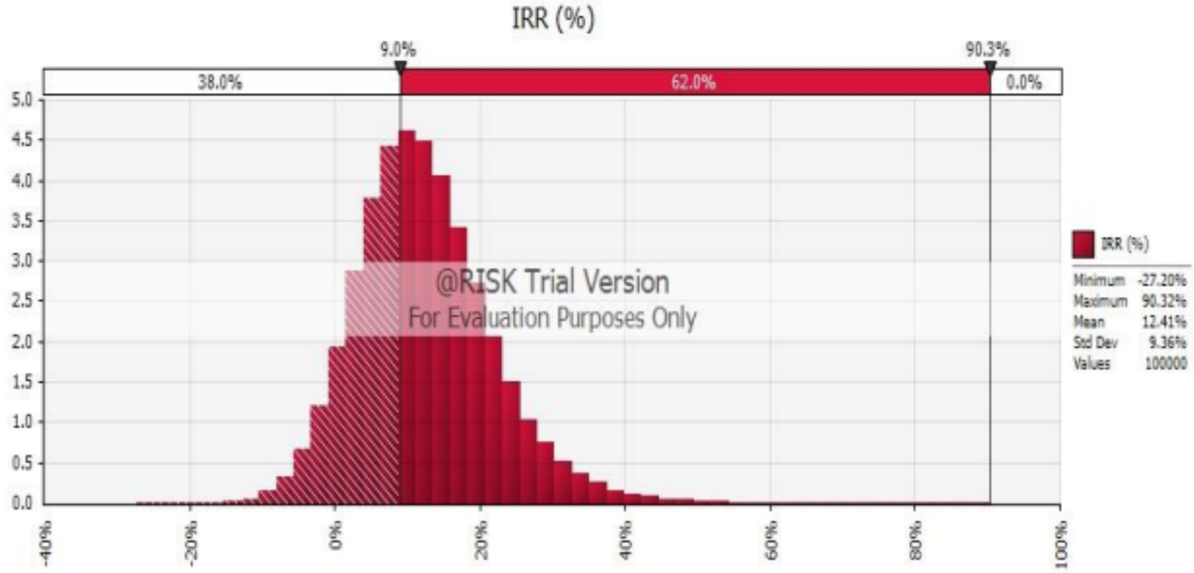

Figure 3. Probability distribution of an IRR of less and greater than 9% for scenario 1 (Source: Shivute, 2019).

The IRR ranges from a minimum of -27.2% to a maximum of 90.3% for scenario 1. The resultant range was calculated to be 117.5%. From this range, the company can see two extreme IRRs in scenario 1, the worst and best case. As for scenario 1 IRR, the wider the range the higher the risk associated with the project and vice versa. Additionally, Figure 3 shows the risk that the project will have an IRR less and greater than the IRR generated by the static DCF. The results in Figure 2 show that there is a probability of 0.62 that the project will have an IRR of 9% and greater, the same IRR generated by the static DCF. Figure 3 also shows that there is a 0.38 probability that the project will have an IRR less than 9%. Given this risk, the company can make an informed investment decision based on the IRR decision criteria. Figure 4 shows the probability of scenario 1 having an IRR greater and less than the 5% discount rate.

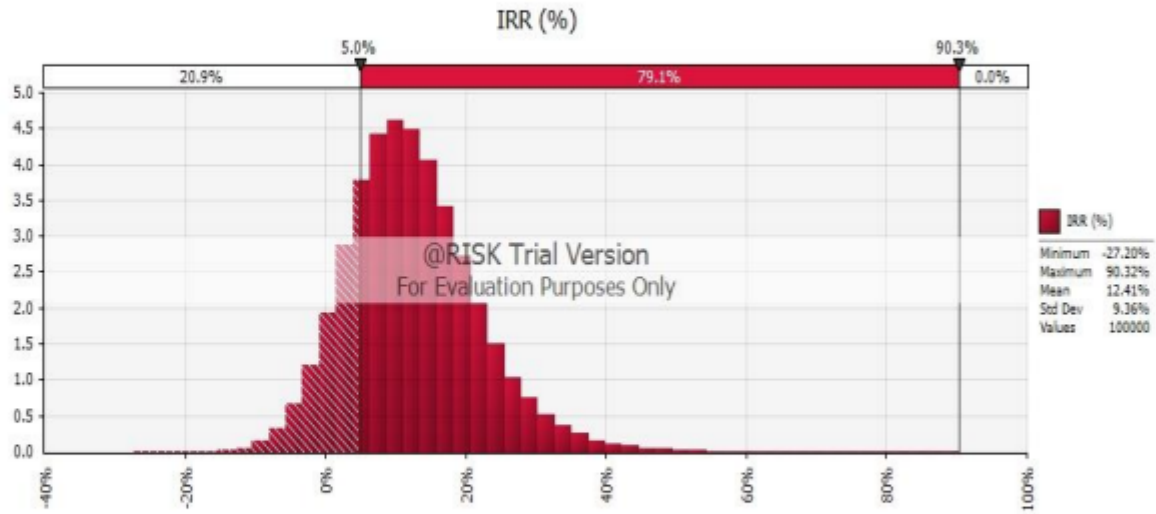

Figure 4. Probability distribution of an IRR less and greater than 5% for scenario 1 (Source: Shivute, 2019).

Figure 4 shows that there is a probability of 0.79 that the project will have an IRR of at least 5% (discount rate) and a 0.21 probability that the project will have an IRR of less than 5% for scenario 1. According to the DCF valuation criteria with the respective probabilities of the NPV and IRR, scenario 1 is still viable. However, depending on the company's risk appetite it may change its investment decision regarding scenario 1. The following results were obtained when scenario 2 was analysed in @RISK software. Figure 5 shows the range of possible NPV for scenario 2.

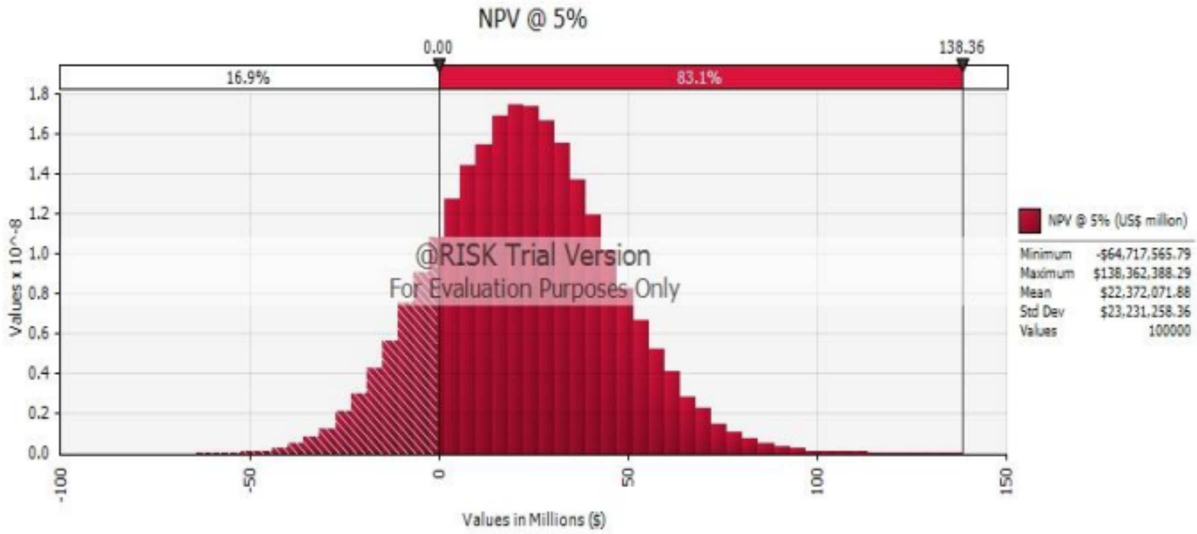

Figure 5. Probability distribution of a negative NPV for scenario 2 (Source: Shivute, 2019).

Figure 5 shows that the NPV ranges from a minimum of US$-64.72 million to a maximum of US$138.36 million. The range for scenario 2 was calculated to be U$203.08 million. This is a slightly lower range than that of scenario 1, which means scenario 2 is less risky than scenario 1. Figure 5 also shows that there is a probability of 0.17 that the project will have a negative NPV for scenario 2. It also shows that the project has a probability of 0.83 of having a positive NPV for scenario 2. For a more comprehensive understanding of the risk, Figure 6 shows the probability distribution of the project having a NPV less and greater than the NPV obtained from the static DCF.

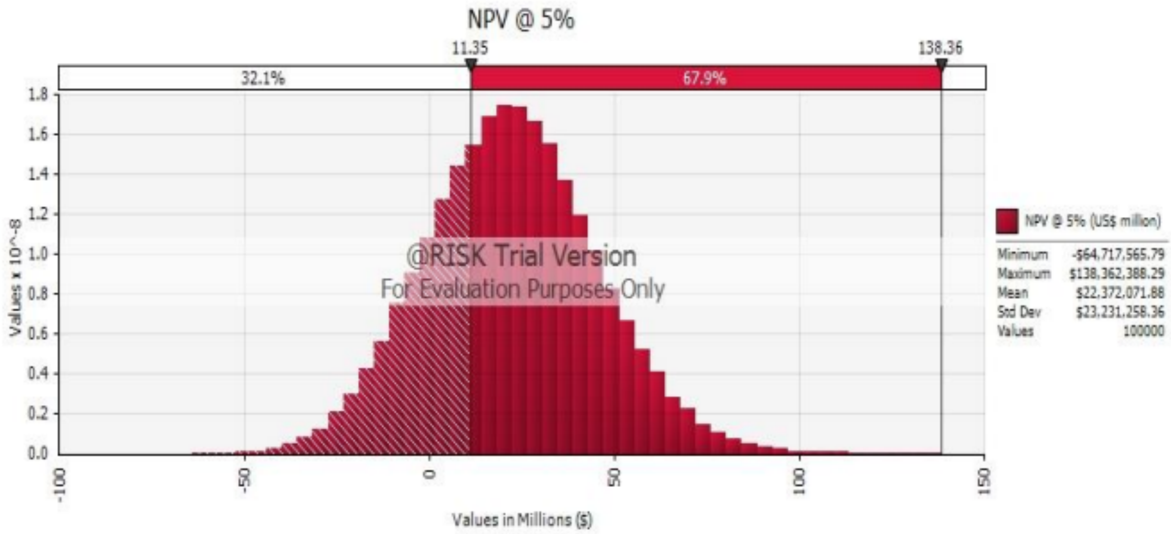

Figure 6. Probability distribution of an NPV less and greater than US$11.35 million for Scenario 2 (Source: Shivute, 2019).

It also shows that there is a probability of 0.68 that the project will have a NPV of US$11.35 million and greater if the company were to implement scenario 2. It also shows that there is a 0.32 probability that the project will have a NPV less than US$11.35 million. Scenario 2 is still viable but depending on the risk appetite of the company a different investment decision can be made. With this additional information about scenario 2, the company can make an informed investment decision as compared to the static DCF results based on the risk associated with the NPV. The range of possible IRRs for scenario 2 is shown in Figure 7. The figure also shows the probability distribution of the project having an IRR less than and greater than the one obtained from the static DCF.

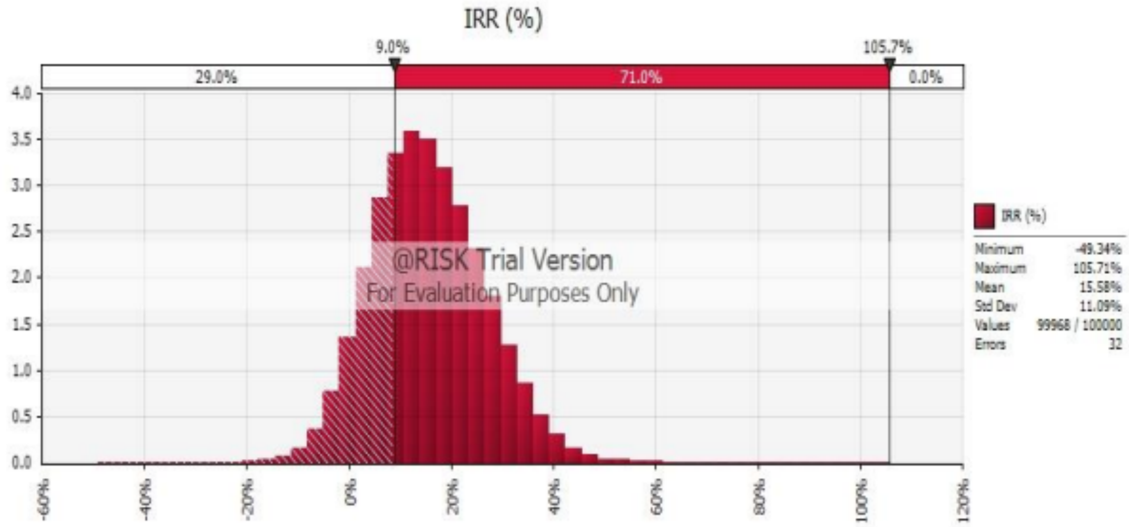

Figure 7. Probability distribution of an IRR less and greater than 9% for scenario 2 (Source: Shivute, 2019).

Figure 7 shows that the IRR ranges from -49.3%% to 105.7%, with a calculated range of 155%. A negative IRR would result from the amount of cash flow generated over the life the project being less than the initial investment. Scenario 2 has a wider range of IRR when compared to scenario 1, which means it is more risky than scenario 1 based on IRR. Furthermore, there is a probability of 0.71 that the project will have an IRR of 9% and greater. The figure also shows that there is a 0.29 probability that the project will have an IRR of less than 9%. Figure 8 shows the probability of scenario 2 having an IRR less than and greater than 5%.

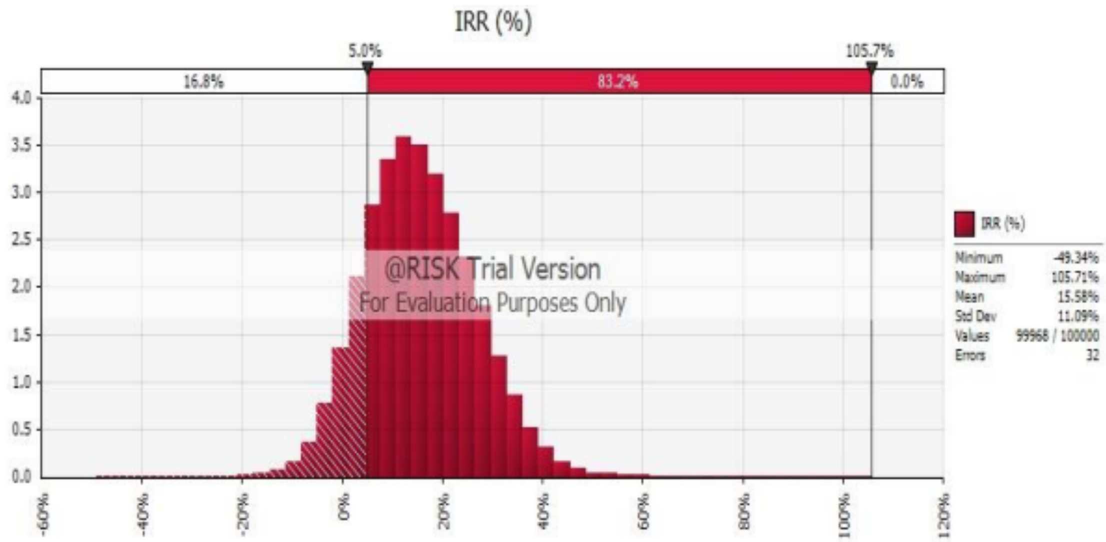

Figure 8. Probability distribution of an IRR less and greater than 5% for scenario 2 (Source: Shivute, 2019).

Figure 8 shows that there is a probability of 0.83 of having an IRR of 5% (the discount rate) and greater if the company will opt for scenario 2. The figure also shows that there is a 0.17 probability that the project will have an IRR of less than 5%. According to the DCF valuation criteria with the respective probabilities of the NPV and IRR, scenario 2 is still viable.

A summary of the results of the MCDCF analysis for scenarios 1 and 2 is shown in Table IV.

Table IV. Summary of MCDCF analysis results
(Source: Shivute, 2019)

	Scenario 1		Scenario 2	
Measure	**US$ million**	**Probability**	**US$ million**	**Probability**
NPV	< 9.60	0.36	< 11.35	0.32
NPV	< 0	0.21	< 0	0.17
NPV range	220.70	1	203.08	1
Measure	**%**	**Probability**	**%**	**Probability**
IRR	< 9	0.38	< 9	0.29
IRR	< 5	0.21	< 5	0.17
IRR range	117.50	1	155.00	1

According to the DCF decision criteria of NPV and IRR, both scenarios are viable. The results from the MCDCF show that scenario 2 is a better option according to the DCF decision criteria because it has a lower:

- Probability, and hence lower risk of both NPV and IRR being less than the NPV and IRR obtained from the static DCF;
- Risk of NPV being negative;
- Risk of IRR being less than the discount rate; and
- Range of NPV.

However, the overall investment decision will depend on the risk appetite of the company.

CONCLUSION

Valuation techniques under the income approach are only as accurate as the economic and technical input data available to conduct the valuation of mineral projects. Results from the study indicated that scenario 2 is the better option because it resulted in a higher NPV from the static DCF and MDCF. Additionally, it has a lower risk of both NPV and IRR being less than the NPV and IRR obtained from the static DCF. Therefore, the company should consider implementing scenario 2. It is however recommended that the company should invest in increasing the confidence level of the project by conducting a feasibility study that will provide more information to accurately determine the economic value of the project at a greater confidence level.

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References

Awomewe, A. and Ogundele, O. (2008). The importance of the Payback method in Capital budgeting decision. MBA Thesis, Blekinge Institute of Technology, Karlskrona.

Ajak, A., Lilford, E. and Topal, E. (2018). Real Option Identification Framework for Mine Operational Decision-Making. *Natural Resources Research*, 1573(8981), pp. 1-22.

Brigham, E. F. and Gapenski, L. C. (1997). *Financial Management - Theory and Practice. 8th ed*. The Dryden Press, Orlando.

Haotian, D., Ningfan, L., Yuhan, W. and Xinrui, Z. (2022). The Analysis of Three Main Investment Criteria: NPV IRR and Payback Period. *The 7th International Conference on Financial Innovation and Economic Development*, Zhuhai.

Harrison, R. L. (2010). Introduction to Monte Carlo simulation. *AIP Conf Proc*, 1204(1), pp.17-21.

Jenkins, H. (2004). Corporate social responsibility and the mining industry: conflicts and constructs. *Corporate social responsibility and environmental management*, 11(1), pp. 23-34.

Kazakidis, V. and Scoble, M. (2003). Planning for flexibility in underground mine. *Mining Engineering*, 55(8), pp. 33-39.

Kelly, S. (1998). A Binomial Lattice Approach for Valuing a Mining Property IPO. The*Quarterly Review of Economics and Finance*, 38(Special Issue), pp. 693-709.

Kennedy, B. A. (1990). *Surface Mining. 2nd ed*. Society for Mining, Metallurgy and Exploration, Baltimore.

Kvalevag, T. (2009). How do discounted cash flow analysis and real options differ as basis for decision making about oil and gas field developments?, MSc Thesis, Copenhagen Business School, Copenhagen.

Macfarlane, A. S. (2001). A Code for the valuation of mineral properties and projects in South Africa. *The Journal of the Southern African Institute of Mining and Metallurgy*, 102(1), pp. 37-48.

Mayer, Z. and Kazakidis, V. (2007). Decision making in flexible mine production system design using real options. *Journal of Construction Engineering and Management*, 133(2), pp. 169-180.

Mun, J. (2006). Real Options and Monte Carlo Simulation versus Traditional DCF Valuation in Layman's Terms. In: K. Leggio, D. Bodde & M. Taylor, (eds). *Managing Enterprise Risk: What the electric industry experience implies for contermporary*. Elsevier Global Energy Policy and Economic Series, pp. 75-106.

Park, S. and Matunhire, I. (2011). Investigation of factors influencing the determination of discount rate in economic evaluation of mineral development projects. *The Journal of the Southern African Institute of Mining and Metallurgy*, 111(11), pp. 773-779.

Torries, T. (1998). General description of the evaluation process. In: *Evaluating Mineral Projects: Applications and Misconceptions.* Society for Mining, Metallurgy and Exploration, pp. 3-4.

Shivute, A.P. (2019). A comparison of Real Options and Discounted Cash Flow valuation techniques on a gold mining project. *MSc Research Report*, University of the Witwatersrand, Johannesburg.

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