Use of Value at Risk to assess economic risk of open pit slope designs

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Introduction

Excavation and haulage of rocks constitute two major costs in open pit mine operations. A simple way to reduce these costs is to steepen the design slope angle to reduce the amount of excavated material. However, the steepening of slope increases the risk of failure and may result in an increased cost of failure. Major costs associated with slope failures include cleanup cost, disruption to the mine operation and damage to mining equipment. Mining engineers face the challenging act of balancing the cost of failure and slope formation cost.

The expected cost of failure, defined as the probability of failure multiplied by the consequences of failure is often used to report slope risk. However, using the expected cost of failure may not provide sufficient information on the costly events that the company is most concerned with. The concept of Value at Risk (VaR) is introduced in this paper to assess economic risk of pit slope designs. This approach was originally employed to assess risks in the financial sectors and this paper demonstrates how the method can be extended to manage risk of open pit slopes. VaR concentrates on the tail end of a distribution curve, and may therefore be more suitable for assessing infrequent events such as slope failures.

The open pit of Telfer Gold Mine, owned by Newcrest Mining and located in Western Australia, is being used as a case study to illustrate ways VaR can be used to assess the economic risk and return associated with different design slope angles.

Economic considerations for pit slope designs

The minimum total cost approach, which incorporates the cost of failure and slope formation cost to determine the total cost, has been addressed by several authors. It identifies the slope design concept that leads to the lowest total cost. Under this method, the expected cost of failure is calculated by multiplying the probability of failure with the consequence of failure. Given that most slopes have a low probability of failure, engineers may find it more valuable focusing on the rarer events. This is explained in Figure 1, which shows the histogram of a probabilistic slope stability analysis with 1000 runs. The probability of failure in this slope is 8.4%. 91.6% of the runs result in a stable slope, and therefore have zero failure cost. The expected cost of failure can be determined by following the steps listed:

1. Multiply the cost associated with a certain failure volume by its probability of occurring;
2. Repeat step 1 for all possible failure volumes determined by slope stability analysis; and
3. Add up the results.

Cost of Failure ($/m)	Probability
4249	0.007
3657	0.056
3046	0.021
0	0.916

Table 1. Summary of data from Figure 1.

Table 1 summarises the data from Figure 1. Using these data, the expected cost of failure can be calculated:

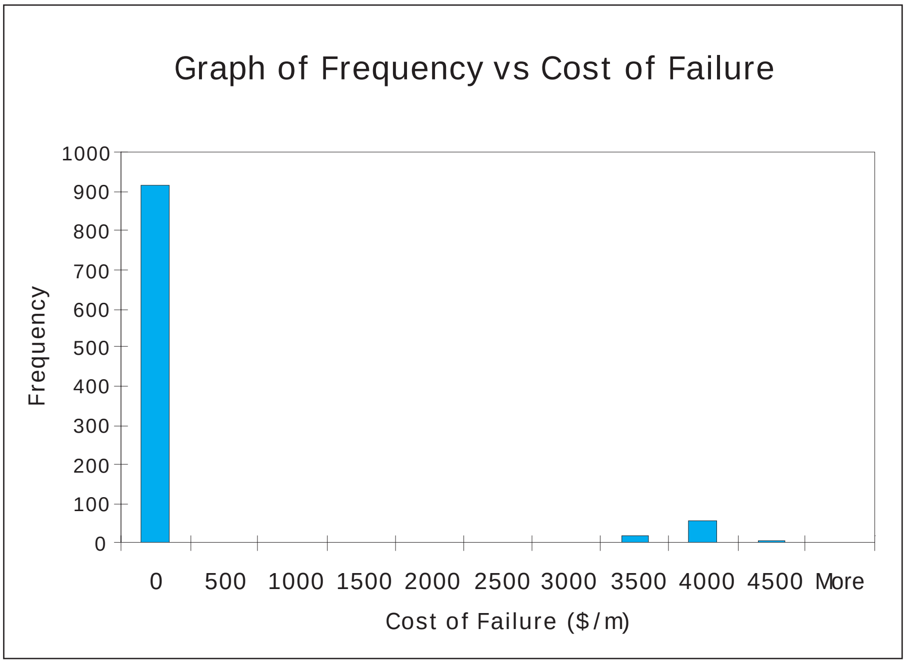

Fig. 1. Histogram of a probabilistic slope stability analysis with 1000 runs.

$$\$4249 \times 0.007 + \$3657 \times 0.056 + \$3046 \times 0.021 + \$0 \times 0.916 = \$299$$

The value $299, by itself, is of limited use because the cost of failure is averaged out among all the runs and provides decision makers with little indication of the actual slope failure cost.

Furthermore, due to the low probability of failure, the expected cost of slope failure is often small compared to the expected cost of other risk sources in the mine. This makes it challenging to emphasise the importance of geotechnical risk to top management.

This paper uses VaR principles as an extension to the minimum total cost approach. The new approach focuses on the extreme values and provides decision makers with an alternative tool for risk assessment. Compared to the expected cost of failure, VaR provides top management with a better understanding of the potential failure cost.

Assessing economic risk using Value at Risk (VaR)

VaR is extensively used in financial sectors as a means to assess financial risk. Risk usually refers to the standard deviation of returns or the potential loss. In this study, VaR concentrates on potential loss.

In simple terms, VaR is the maximum likely financial loss incurred over a specified period of time at a given confidence level. Figure 2 shows a typical VaR diagram. In this example, the VaR at 95% confidence level is -17100. This means that the loss is expected to exceed $17,100 in only 5% of the time. This method can be used to assess risk associated with the position of an asset, a portfolio of assets or an entire company.

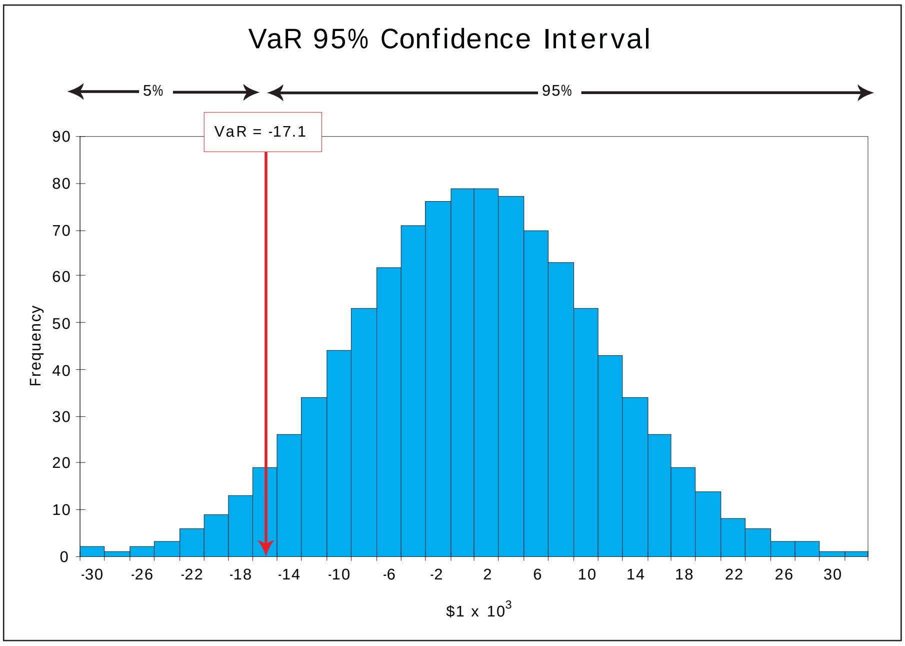

Fig. 2. A typical diagram of VaR with 95% confidence level.

Background

In an effort to minimise financial loss caused by inadequate monitoring of risk, VaR has been used by banks and financial institutions to manage market risks. The method is particularly effective in assessing risk of investments with huge loss potential. VaR is now widely used in the banking sector and is recognised as an accepted risk model for the regulation of risk in banks.

Period of time

In financial sectors, the specified period of time refers to the duration the firm intends to assess. It varies depending on the aim of the task but is usually confined to a relatively short time, for example one to ten days.

Confidence level

The chosen confidence level depends on the purpose of the exercise and the risk tolerance level of management. There is presently no standard benchmark, however many financial institutions use values between 95% and 99% (Dowd, 2005).

Application of VaR in pit slope designs

In addition to measuring risk of asset returns caused by uncertain market factors, VaR may also be applied to assess economic risk of pit slope designs due to uncertain geotechnical properties. The application of VaR to pit slope design requires the forecast period of time as well as the level of confidence.

The period of time is the duration the geotechnical parameters are expected to remain steady. This assumption may need to be adjusted and revised periodically as geotechnical parameters can be affected by factors such as precipitation, weathering of rocks and nearby mining activities. The mining industry does not usually quantify the variation of geotechnical parameters over time and further research would improve this aspect of design.

In Australia, the Joint Ore Reserves Committee code provides guidelines for ore resource and reserve reporting. The code can be used as a reference to determine the appropriate confidence levels for slope risk assessment of design zones. This helps to ensure a consistent confidence level is achieved across the mine plan.

Estimating VaR using Monte Carlo Simulation

This section describes the steps used

to estimate VaR through Monte Carlo simulation using geotechnical data.

The geotechnical data collected onsite is used to generate distribution curves for geotechnical parameters. Sets of random numbers are drawn from the distribution curves to produce a simulated slope that either fails or remains stable. The simulations are carried out repeatedly to enable the distribution curve for failure volume to be plotted. This is then translated into a distribution curve for returns. A drawback of the method is that the distribution curves for geotechnical parameters need to be assumed. This can be unreliable if only a small dataset is available.

The steps for estimating VaR from results of the slope stability programs are briefly described below:

1. The slope stability program is run probabilistically using the Monte Carlo simulation and the failure volume of each run is determined;
2. These data are then used to calculate the costs of failure, expected revenue and return for each run. The results are used to plot a histogram of the expected return associated with all the runs to obtain the returns distribution graph;
3. The confidence level is then selected and the corresponding percentile of the distribution calculated. The resulting value is the VaR;
4. The final VaR value is submitted to management for evaluation; and
5. All of the above steps are repeated for all major slope failure mechanisms and for all slope design options of interest.

VaR values are expected to complement well with expected return values because they provide management with risk and return figures. When assessing the design options, management will consider the risk adjusted return and other objectives set by the company. This ensures risks associated with alternative design options are quantified and compared to assist management in the decision-making process.

Variance and standard deviation values are common measures of risk. However, the approach does not indicate the amount of money a firm is likely to lose. A VaR value provides management with a monetary value and hence enables better control over risk exposure.

Risk adjusted returns

This section outlines an approach that incorporates both risk and return in the decision-making process. Multiple designs are often presented to management. Decision makers are often asked to balance between risk and return under very limited guidelines. Several measurements of risk adjusted return have been used in financial sectors to rank investments options by taking into account both risk and return.

Traditional Sharpe ratio

One of the quick and simple methods to estimate risk adjusted return is the traditional Sharpe ratio (Dowd, 1998):

$$\text{Traditional Sharpe ratio} = \frac{R_p - R_b}{\sigma_{ed}}$$

Where R_p = expected return.
R_b = benchmark return.
$R_p - R_b$ = expected differential return.
σ_{ed} = predicted standard deviation of differential return.

The traditional Sharpe ratio is the expected differential return per unit of risk associated with expected differential return. It is clear from the equation that a higher Rp or a lowered leads to a higher traditional Sharpe ratio and, therefore a higher risk adjusted return. The ratio can be used to rank different strategies based on their risk-adjusted return.

Case study—Telfer Gold Mine

Telfer Gold Mine, owned by Newcrest Mining Limited, is located in the east Pilbara region of Western Australia. The open pit contains three major geological units—Outer Siltstone Member, Middle Units and Malu Quartzite Member. Minerals of gold and copper are mined up to 1.3 km below ground.

The operation started off as an underground mine in 1977 and was suspended in 2000 due to concerns in rising costs. Later, a feasibility study carried out in 2002 concluded that mining was economically viable, leading to the commencement of open pit operations in mid-2003.

Slope stability analysis

The case study only presents results on the highly weathered Outer Siltstone Member in the hanging wall of the main dome. The analyses were carried out on 24 meter benches.

Discontinuities in the main dome are classified into five joint sets, J1, J2, J3, J4 and J5. Of the five joint sets, only J1, J3 and J5 were identified as joint sets with potential to cause slope failure. These three defect sets were then plotted onto a stereonet in Dips to investigate the potential failure mechanisms in the hanging wall. Kinematic analysis was then carried out on these joint sets. The results are summarised in Table 2.

Failure mechanism	Slope angle	Joint set
Planar	45–50	J3
Planar	55–70	J3, J5
Wedge	45–70	J1 & J3
Rock mass	45–70	n/a

Table 2. Major failure mechanisms in the hanging wall.

Economic risk of major potential failure mechanisms

An economic risk analysis was carried out on each of the major potential failure mechanisms. This involved using Monte Carlo simulation to make 1000 runs for each design option. The VaR estimates for all major potential failure mechanisms are presented in Table 3. These were calculated for one meter width of slope. VaR estimates are represented in rate of return, for instance, a VaR of -0.88 implies a loss equivalent to 88% of capital cost. For planar failures, the VaR values take into account the spacing of the joint sets. For wedge failures, probabilistic analysis was carried out to assess the frequency J1 and J3 are likely to intersect. Joint spacing data collected earlier were used to simulate J1 and J3 occurrences over a 100 m width slope. The total number of J1 and J3 intersections was then divided by 100 to determine the expected occurrence of potential wedge formation per meter slope width. This allows for the expected occurrence of potential wedge formation to be calculated. VaR estimates of rock mass failure are predicted based on a 2D model. This is considered reasonable as VaR estimates are presented for one meter slope width. However, more accurate estimates can be achieved by using a 3D model. The results in Table 3 show that rock mass failure poses the greatest financial risk to the mine. Consequently, the traditional Sharpe Ratio will be employed to this failure mechanism to determine the optimal pit slope angle.

Determination of the optimal slope angle

As discussed earlier, one of the major challenges posed to engineers is selecting the economically optimal slope angle given conflicting risk and return indicators. The traditional Sharpe ratio provides an alternative solution to assist in the decision-making process. The approach is demonstrated in Table 4.

Failure mechanism	Slope angle	Joint set	VaR 95%
Planar	45	J3	-0.88
Planar	50	J3	-0.89
Planar	55	J3	-0.89
Planar	60	J3	-0.92
Planar	65	J3	-0.92
Planar	70	J3	-0.95
Planar	45	J5	No planar failure
Planar	50	J5	No planar failure
Planar	55	J5	-0.93
Planar	60	J5	-0.97
Planar	65	J5	-1.01
Planar	70	J5	-1.04
Wedge	45	J1 & J3	-0.38
Wedge	50	J1 & J3	-0.39
Wedge	55	J1 & J3	-0.39
Wedge	60	J1 & J3	-0.39
Wedge	65	J1 & J3	-0.39
Wedge	70	J1 & J3	-0.39
Rock mass	45	n/a	-1.15
Rock mass	50	n/a	-1.16
Rock mass	55	n/a	-1.31
Rock mass	60	n/a	-1.17
Rock mass	65	n/a	-1.19
Rock mass	70	n/a	-1.19

Table 3. VaR estimates of all major failure mechanisms in the hanging wall.

Slope angle º	Expected return	Return standard deviation	VaR 95%	Sharpe ratio
45	0.15	3.56	-1.15	0.024
50	0.2	3.35	-1.16	0.040
55	0.12	3.87	-1.31	0.014
60	0.29	3.31	-1.17	0.068
65	0.31	3.14	-1.19	0.078
70	0.46	5.44	-1.19	0.073

Table 4. Summary of slope analysis results based on new geotechnical data.

Historically, engineers are mainly concerned with the mean and standard deviation of returns associated with each slope angle. As illustrated in Table 4, implementing a 70º slope produces the highest expected return. However, this option also carries a very high standard deviation on returns, implying very high risk. Engineers that are more concerned with risk will select the option with the lowest standard deviation of returns and design the slope at 65º. In the absence of more information, the decision to balance the risk and return will have to be made based on personal judgement with limited quantitative analysis.

This paper proposes examining two extra criteria—VaR and Sharpe ratio. Corporate management should set the VaR at a level consistent with the company's overall risk strategy. All proposed designs that exceed the tolerable VaR should not be investigated as they are considered too risky from management's perspective. The Sharpe ratio should be used in conjunction with VaR to assess options with conflicting risk and return parameters. The ratio calculates the excess return compensated by the risk taken. In Table 4, designing the slope angle at 65º leads to the highest Sharpe ratio, therefore it is the economically optimal slope design.

In this case study, the company's opportunity cost of funds has been taken as the benchmark return. Others may prefer to use expected return associated with existing designs as the benchmark return.

Conclusion

Engineers have a challenging task of balancing the risk and return of pit slope designs. As the depth of open pit mines increase, these decisions become even more vital for the mining companies.

Risk management tools from the financial sector have been employed to assess slope risk. The VaR approach originates from the banking sector and is used to assess a wide range of financial risks. In this paper, the VaR approach has been employed on pit slopes, assisting engineers in filtering out design options that exceed the company's risk tolerance. The minimum total cost approach, which incorporates the failure cost and slope formation cost, has been briefly mentioned. However, instead of working with the expected total cost, the VaR approach focuses on the tail end events of the distribution curves. This highlights the potential catastrophic consequences of failures and provides management with a better sense of slope failure cost.

The steps required in estimating VaR of slope designs were briefly mentioned. This should give readers an idea of how to implement the VaR approach using results from slope stability programs.

Little guidance is often available to engineers in selecting slope design options. This task is more challenging when the available options have conflicting risk and return values. By using Telfer Gold Mine as a case study, the traditional Sharpe ratio incorporates both risk and return into one value and assists engineers in determining the economically optimal slope angle.

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References

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