Economic Significance of Geotechnical Uncertainties in Open Pit Mines

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ABSTRACT

Risk assessment is a challenging task due to the need to deal with uncertainties over long time periods. There is a wide range of potential risk sources and the way these risks are assessed and managed is critical to the long-term success of an open pit operation. Advances in technology have led to the implementation of larger pits which has, consequently, increased the potential economic impact associated with geotechnical failures. Failure to represent geotechnical risk in monetary value may lead to difficulty in obtaining support and approval (e.g. appropriate resources for geotechnical investigation) from clients or management. It is, therefore, important to illustrate the relationship between geotechnical uncertainties and economic risk to stakeholders. Using an open pit mine case study, this paper outlines a method for quantifying economic risk caused by geotechnical uncertainties. The framework and procedures can be easily justified and followed. The final geotechnical risk estimate is objective. The method allows the impact of geotechnical failures on project value to be predicted. Finally, geotechnical risk in the open pit is compared with uncertainties associated with commodity price, exchange rate and inflation rate. This is carried out to observe how geotechnical risk measures up against economic factors that are often perceived as important variables in mining projects.

Keywords: geotechnical uncertainties, risk management, economic risk, open pit slope

1 INTRODUCTION

The ultimate aim of a mining operation is to maximise its overall profit. As such, most research activities have been focused on technical aspects such as slope stability modelling. In order to effectively communicate their recommendations to decision makers, geotechnical practitioners need to present results that are easy to understand in a financial context. Therefore, it would be logical to link geotechnical analysis results with economic implications. This paper focuses on economic considerations of the geotechnical engineering aspect in open pit slope designs. The steps in quantifying economic risk associated with pit slope stability are briefly outlined. Using the Telfer Gold Mine as a case study, the paper compares the economic impact of geotechnical uncertainties with other key economic variables. While safety is an important consideration in mine designs, a significant amount of work has been covered by other researchers in this area in recent years and will not be discussed in this paper.

2 BACKGROUND

Only a limited number of studies have been conducted for the assessment of relationship between geotechnical uncertainties and economic risk. As the most important decisions in the mining industry are made by management staff, any design approach linking slope stability analysis results with monetary values could improve communication between geotechnical practitioners and decision makers.

Ideally, mine planning and geotechnical professionals should work closely together to produce the optimal slope design. In reality, however, Hustrulid et al. (2001) observed that there is a tendency for each discipline to specialise in its own area with limited awareness of the needs of other disciplines. He also commented on the limited influence the geotechnical professionals may have on final decisions. One of the reasons for this could be the lack of understanding of geotechnical risks and their potential economic impact by other disciplines.

3 BENEFITS OF QUANTIFYING ECONOMIC RISK ASSOCIATED WITH GEOTECHNICAL UNCERTAINTIES IN PIT SLOPES

Slope stability modelling techniques are likely to become more sophisticated as technology advances. To take advantage of slope modelling advancement, geotechnical practitioners should focus on ensuring that their slope analysis results are presented in a context that can be easily understood by decision makers. With management staff most likely coming from a finance background, management will place more value on slope analysis results if their impact on profit is highlighted. By presenting geotechnical risks in monetary terms, practitioners may find it easier to highlight the significance of geotechnical uncertainties to senior managers and be more persuasive when applying for additional resources.

Mining operations aim to maximise project value, hence, many of the major decisions are undoubtedly driven by economics. Most managers, mine planners, bankers and clients are not interested in geotechnical terms. Rather, the onus is on the geotechnical practitioners to express their slope analysis results in economic terms and to report them in a way that is easily understood by all stakeholders.

4 CHALLENGES OF QUANTIFYING ECONOMIC RISK ASSOCIATED WITH GEOTECHNICAL UNCERTAINTIES IN PIT SLOPES

The economic impact of slope failures on a mining project is difficult to predict because slope failure recovery is often a reactive process. Since the choice of recovery action requires considerations of many factors, decisions on mine plan adjustments and slope remediation are only made after slope failures have occurred. The location of failure, availability of equipment and existing stockpile levels are just several factors that would influence the management of slope failures. To improve the accuracy of the method presented in this paper, actions likely to be taken by mine planners can be predicted and incorporated into the projected mine schedule. It can be assumed that certain decisions would be made under particular sets of conditions. For example, the timing of large-scale slope failures would influence the response of mine planners. If slope failure is to occur early in the mine life, the failed volume would more likely to be cleared out and the slope remediated. On the other hand, if a major slope failure was to occur shortly before mine closure, it might not be economically feasible to clear the failed slope and continue mining, rendering mine abandonment as a more economical option.

5 QUANTIFYING ECONOMIC RISK ASSOCIATED WITH GEOTECHNICAL UNCERTAINTIES IN PIT SLOPES

The rate of return is commonly employed to measure the profitability of projects. It is effectively the rate of return that makes the net present value of a project equal to zero.

This section outlines the procedures to quantify impact of slope designs on the project rate of return. The steps recommended for applying these concepts are summarised in Figure 1.

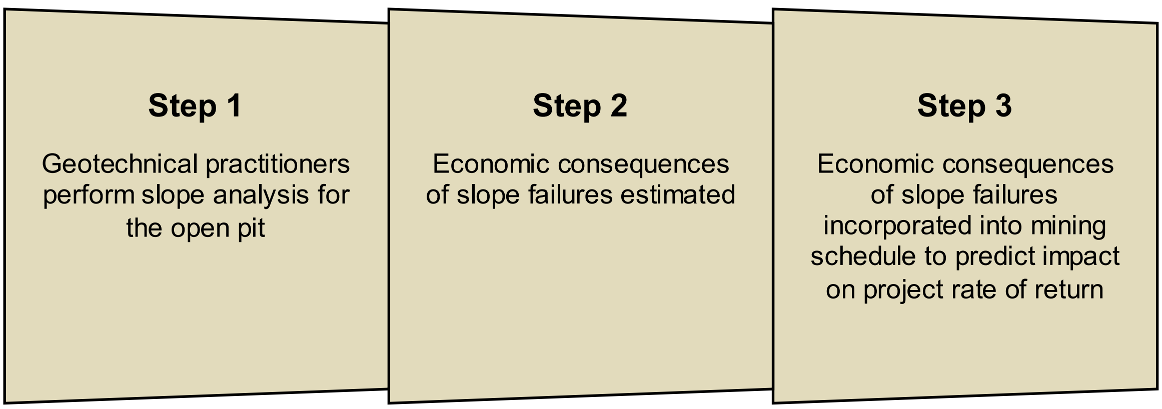

Figure 1 – Steps in quantifying economic risk of pit slope designs

5.1 Quantifying the economic consequences of slope failure events

A way to assess the economic risk associated with geotechnical designs is to estimate the impact of slope failures on the rate of return. To do this, the Probability of Failure (PoF) and the consequence of failure need to be estimated. The PoF and failure tonnage can be established by examining results from slope stability analyses. It is difficult to predict the consequence of failure as it depends on a number of factors (Lai et al., 2009a). Some of the more important factors are briefly described below.

1. Failure tonnage – Higher failure tonnage leads to higher direct cleanup cost. Lilly (2000) suggested applying an efficiency factor of 70%-80% to the normal mining cost due to the challenge in excavating failed material. In addition to this, higher failure tonnage also leads to longer cleanup time, therefore delaying equipment from returning to mining activities.

2. Availability of mining equipment for clean up – If mining equipment is running at capacity, they would need to be mobilised from production activities. This will delay the mine's overall production.

3. Location of failure – Slope failures situated close to an operating ramp may cause damage to nearby mining equipment. Mining operations may also be disrupted leading to deferred processing of ore. However, if slope failure occurs in an area that does not affect current or planned mining operations, it will incur a much lower cost. The type of slope remediation required varies depending on the location of failure. Furthermore, if failure occurs on top of or within an orebody, it may prevent the ore from being mined.

4. Interim or ultimate slope – Slope failures would disrupt the planned mining sequence of a pit. If a failure event occurred at an interim slope, cleaning up the failed tonnage effectively brings forward material that is intended for mining later, hence causing further disruption to the original mining schedule. If failure occurred at the ultimate slope, failed material is in fact extra unplanned material, increasing the total tonnage of material being mined (CANMET, 1976).

5. Grade differentiation between stockpiles and the ore being mined – If slope failure prevents ore material from leaving the pit, lower grade stockpiles would instead be fed to the processing plant. In this instance, the cost of failure may include the delay in production of the high grade ore. The cost is the time value of money, caused by the immediate processing of the lower grade stockpile rather than the production of high grade ore from the pit.

Once the consequences of slope failure are established, they can be incorporated into the mining schedule to simulate the effects of slope failures on project rate of return. The steps below are proposed to incorporate slope failure costs into the project rate of return.

1. The open pit is divided into several geotechnical domains. Each domain represents sections of the pit that share similar geotechnical properties.
2. Numerical models are employed for slope stability analysis. Probabilistic analyses are carried out using the Latin Hypercube sampling method (McKay et al., 1979) to determine the PoF of different failure modes. The steps used to quantify PoF of failure modes spatially over the pit slope walls are described in Lai et al. (2009b). The composite probability method suggested by Call and Kim (1978) is applied to combine PoF of different failure modes to determine the overall PoF of each slope.
3. Based on the slope analysis results, mine operators are presented with the recommended slope designs.
4. The economic consequences of slope failures are then estimated.
5. The effects of slope failures can be incorporated into the mining schedule. This is carried out by applying the Latin Hypercube sampling method to simulate slope failures throughout the entire mine life and including the failure costs in the mining schedule. The economic returns of the project can then be estimated.

6 MODELLING OF ECONOMIC VARIABLES

Before the influence of geotechnical uncertainties on return can be compared with economic variables, an appropriate model must be identified to represent the economic variables. For illustrative purpose, the autoregressive model was selected for this research project due to its relative ease of application.

The autoregressive model (Levine, 2011) is useful for variables whose historical movements can be used to forecast future movements. Essentially, the regression is performed on lagged values of the variable. The residuals of the models have been represented as percentage change. The autoregressive model is defined as:

$$P_t = c + \sum_{i=1}^{m} \varphi_i P_{t-i} + \varepsilon_t \tag{1}$$

where P_t = value at time period t
c = constant
φ_t = autoregressive coefficient
i = number of time lags
ε_t = residuals
m = order of the model

The autoregressive coefficient, φ_i, captures past movements of commodity price and is used to project future movements. It provides the weighting of previous data and represents the strength of relationships between data of current and previous time periods. Values of φ_i are computed in Microsoft Excel using the Least Squares Method. To simplify the process, only linear autoregressive models have been considered.

The order of the model, m, enables varying number of time lags to be considered in the forecasting model. When deciding on the appropriate order, the benefits of having additional parameters representing the data must be weighted with the benefits of a simple model.

More information on the procedures of determining the parameters of an autoregressive model can be found in Levine (2011).

7 SENSITIVITY ANALYSIS

Sensitivity analysis is generally performed to examine how different factors affect the output. In this paper, this was carried out on uncertainties associated with gold price, copper price, AUD/USD exchange rate, inflation and geotechnical variables to assess their influence on the operation's rate of return. Uncertainties associated with the four economic variables are often managed using sophisticated financial instruments or by locking into contracts early on. Compared with geotechnical uncertainties, the risks associated with economic variables attract greater attention from the public. The risk management software, @Risk (Palisade Corporation, 2008), was used to perform sensitivity analysis. The percentiles selected for examination were 1%, 5%, 25%, 50%, 75%, 95% and 99%. The results from the sensitivity analysis will assist in determining whether geotechnical uncertainties warrant greater awareness from other stakeholders.

8 CASE STUDY – TELFER GOLD MINE

The Telfer Gold Mine is owned by Newcrest Mining Limited and is located in the East Pilbara Shire of Western Australia. It falls within the Great Sandy Desert and is about 485 km east-south-east of Port Hedland and some 1300 kilometres north of Perth. Economic quantities of gold and copper have been found in the operation. The open pit is mined using conventional trucks and hydraulic excavators. The risk assessment procedures introduced in this paper were carried out on Telfer Gold Mine and the results are compared with five economic drivers and presented here.

8.1 Sensitivity analysis results

The results for sensitivity analysis are shown in Figures 2 and 3 and Table 1. The Sensitivity Tornado graph in Figure 2 illustrates graphically the influence of five economic drivers over the project rate of return. Figure 3 shows how varying percentiles of the five economic drivers change the project rate of return.

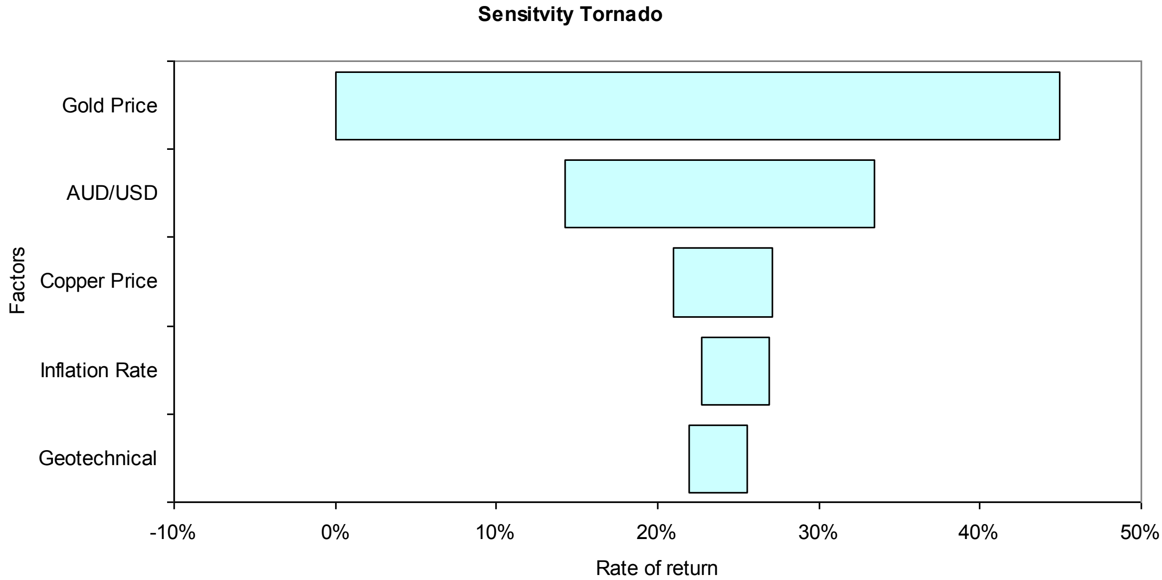

Figure 2 – Sensitivity Tornado graph for sensitivity analysis

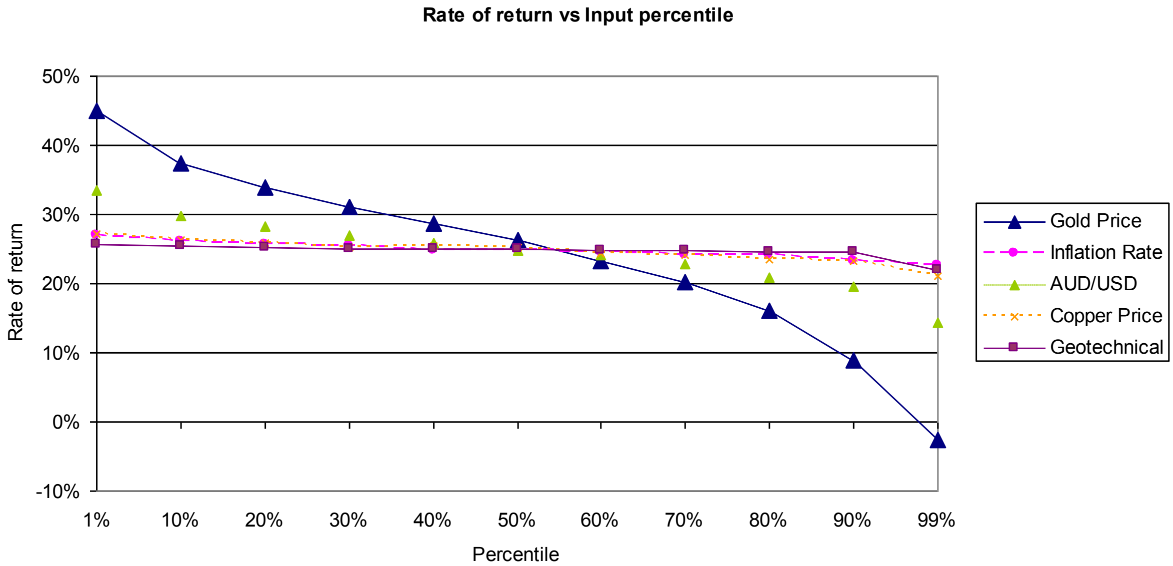

Figure 3 – Sensitivity analysis results

Table 1 - Sensitivity analysis ranges

Sensitivity Analysis Factors	1 % Rate of Return (%)	99% Rate of Return (%)
Gold price	-2.67	44.95
Copper price	14.27	33.47
AUD/USD exchange rate	22.71	26.90
Inflation rates	20.99	27.13
Geotechnical	21.97	25.58

Figures 2 and 3 show that gold price has the largest impact and can cause the operation's rate of return to vary from -2.67% to 44.95%. The AUD/USD exchange rate is the second most influential factor in the analysis, followed by copper price and inflation rate. Geotechnical uncertainties have the lowest impact on return, but its influence is still comparable to the economic factors. Table 1 shows that only gold price variability has the potential to cause the operation's average return to be less than zero.

8.2 Discussion

The results indicate the significance of geotechnical uncertainties. An appropriate level of resource should be allocated to manage this risk. It can be argued that geotechnical uncertainties warrant a similar level of scrutiny as commodity price and inflationary cost. However, with so little published work on economic risk of pit slopes, it is logical to assume that there is insufficient attention on this risk factor.

The autoregressive method used in this study is relatively straight forward. More sophisticated models may provide better account of uncertainties caused by economic factors. However, this method does not require expensive specialised software. It allows practitioners with basic training in economics an indicative comparison of the influence of geotechnical uncertainties and economic variables on return.

9 CONCLUSION

An increasing number of risk sources are being quantified in monetary terms in the mining industry. While the variable nature of rock and soil makes it difficult to place a dollar value on risk, it is important that geotechnical engineering does not fall behind in interpreting data in monetary terms. The paper outlined the steps in quantifying economic risk associated with pit slope designs.

The Telfer Gold Mine has been used as a case study to demonstrate the techniques proposed in this paper. The results indicated that the operation's rate of return was most sensitive to gold price. Although the return was found to be least sensitive to geotechnical uncertainties, it was still comparable to some of the key economic variables. This highlights the significance of geotechnical uncertainties and should encourage more economic analysis to be developed and implemented.

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