Measuring and mitigating risk in mining operations

Abstract

CRU Strategies has developed an approach to identify and measure the risks that cause business variability. The objective of this approach is to offer a proven methodology to companies in order for their shareholders or boards of directors to be able to decide with more and more transparent information at hand, therefore making more informed decisions.

The promises made by mining companies' administrations to their shareholders are not often realised due to the inherent variability embedded in their strategic plans, business plans and budgets. The concept is not to search for zero variability without concern for shareholder value, but to understand the variability, and to measure, manage, and mitigate it when possible. Most mining companies assign deterministic values to the key inputs or variables of their business plans, thereby defining a deterministic value of their production and of the value of their plan. On the other hand, by assigning probability distributions to certain variables, a histogram, for example of net present value (NPV), can be achieved, and the promise to the board would shift from a certain production level or revenue to a value with a certain level of confidence.

There are different categories of risk, for example: location risks, project risks, market risks and resource risks. There are also different categories of appetites for risk, from the most conservative approach with typically a lower return, to speculative activities with higher expected returns. CRU's approach consists of identifying the most important risks of the operation in order to measure their impact and of identifying and measuring possible mitigation actions that could reduce the Value at Risk (VaR) at a certain confidence level that should be determined by the company's shareholders. Today, the incorporation of risk in mine business planning is in a development phase, and will continue to be improved as companies understand its importance, application and usefulness.

The risk approach consists of identifying the risks of the operation and, through a qualitative scoring methodology, ranking them in order to illustrate the most important. The model is custom made for each operation and basically it incorporates the risks identified, and therefore variability, through probability distributions. By using the Monte Carlo Simulation process, a histogram of the desired variable is obtained. The next step consists of quantitatively measuring the Value at Risk (VaR) of each risk independently in order to build a ranking. This ranking is very important because it provides the value focus on which the mine administration and shareholders should concentrate their resources when building mitigation plans. This process is iterative; the new mitigation plans are re-entered back into the model in order to obtain the new VaR.

Introduction

After the financial crisis of the early 1990s, the financial sector saw an increased need to assess risk when managing portfolios. Commonly used models, such as net present value (NPV), summarised risk only through the selection of a discount rate. This is because NPV assumes input quantities to be constant and renders a single numerical output. NPV therefore summarises both value and risk in a single result.

In order to better manipulate and adapt predictions to diverse risk scenarios and observed input variability, the financial sector developed a tool that enables the use of input ranges, rather than single values. This model, known as the Value at Risk (VaR), expresses its results through an output range, which differs from the NPV's result in that it associates a different value to each risk level. This allows for a more thorough risk analysis and a more risk-oriented management plan (Manfredo and Leuthold, 2001; Best, 1998).

Even though the VaR methodology was initially created in the financial sector, it may be applied to the measurement of different types of risk (for example, market, credit, liquidity and operational risks) and VaR therefore has been increasingly used for corporate-level management. Following this trend, this paper focuses mainly on the application of VaR in the mining industry at corporate level, an area in which CRU Strategies has significant experience.

VaR methodology provides a more comprehensive and realistic estimation of value than could be achieved through the implementation of models such as the NPV. VaR enables a more risk mitigation-oriented management plan, and CRU Strategies' approach allows clients to consciously select a determined level of risk, and thus base management decisions on the client's risk appetite. To illustrate this, an example of the application of the VaR methodology carried out by CRU Strategies is discussed towards the end of this paper.

Theory of stochastic modelling and analysis

In models such as the net present value (NPV), risk is included by the selection of a discount rate. Input and output quantities are assumed to be constant. NPV therefore summarises both value and risk in a single output number. The output prediction leaves a small or no margin for further manipulation and adaptation to various risk scenarios. As a result, financial institutions developed the VaR indicator. Based on stochastic models, VaR not only assigns monetary value to different levels of risk, but also serves as a guide to their efficient mitigation.

The advantage of VaR is that it allows inputs to be stochastic, meaning that reasonable estimates of input ranges are used instead of single deterministic values. VaR therefore provides a probable range of outputs relating to corresponding levels of risk. This allows for a more thorough risk analysis and a more risk-oriented management plan (Jorion, 2001). A fundamental implication of Value at Risk-based management is that management gains an understanding of the value associated with each particular risk and is therefore able to develop a capital rationing approach to mitigate that risk. By identifying risks and associated levels of uncertainty, management will be able to value risk and make sensible investment and operational improvements to mitigate such risks.

Assumptions regarding the inputs will affect the output range modelled by Monte Carlo Simulation. Therefore, the quality of these assumptions is crucial. In order to avoid the *flaw of averages*[1], inputs are assumed to resemble a stochastic process. A stochastic process is one in which variables evolve without a determined pattern and thus without the possibility of being completely controlled and predicted. The evolution of stochastic processes is described through a probability distribution. This implies that inputs utilised in the VaR methodology must have an assumed associated probability distribution, which requires careful justification.

The most basic assumption regarding a stochastic process refers to whether its distribution is discrete or continuous. A distribution is said to be discrete when the number of possible outcomes with a positive probability of occurrence is countable. The number of geological failures that a mine can undergo in a given time period (0, 1, 2, and so on) is an example of a discretely distributed variable. On the other hand, a distribution is continuous when it describes events that occur over a continuous range. Variables such as production cost variance and reserve size are continuously distributed. The characteristics of these distributions may vary drastically, making the continuity or discreteness of a distribution one of many essential questions to answer before undertaking the VaR methodology.

[1] The flaw of averages relates to the fact that basing actions on average indicators may lead to wrong managerial decisions, given the loss of information that takes place in the averaging process. An example of such a flaw is that of an investment in machinery to provide for production capacity equal to the average expected demand for a product. This investment will not render an income equal to the product of price and average level of demand quantity, contrary to what an average-based income estimate would indicate. This occurs because the production structure enables the firm to cover the low points in demand, leaving the high peaks uncovered due to the restricted capacity of the production structure.

Once the distribution of inputs is suitably defined, they must be associated to certain parameters[2]. These distributions are applied to a production model in order to estimate the firm's output range. The Monte Carlo method is used to complete this process. The method consists of projecting the firm's outcome using a random set of input values and repeating the process with varying inputs, based on the distributions previously established for them. This results in various projections of the firm's final outcome, which will be expressed through a probability distribution.

The results given by this method allow for a management plan that is based on production values associated with particular levels of uncertainty, facilitating sensible investment and operational improvements to mitigate such risks. Even though the application of stochastic models may prove highly efficient as a risk mitigation guide, their implementation may be an extremely complex task. The determination of correlations between risks and the incorporation of risk into mine planning are two main impediments to the successful implementation of stochastic modelling in risk mitigating activities.

For the VaR estimation to be a useful management tool, the utilised model must accurately represent the operation and the relevant risks. This not only requires a proper identification of risks and their distributions, but it is also important to properly assess the correlations between risks. Failing to consider these correlations will affect the model's output in the sense that it will not effectively represent the reality of the operation, and may not return the best possible estimation of the Value at Risk.

Proper determination of correlations is a highly complex task due to the fact that as the number of inputs increases linearly, the amount of possible correlations will increase exponentially. A model with numerous inputs requires a significant effort in the identification of correlations, the determination of their relevance, the estimation of correlation values and their inclusion into the model. This problem may either be solved by assuming no correlation between inputs when such an assumption is due, or by incorporating the different correlations into the model.

The incorporation of stochastic risk analysis into mine planning may present another significant modelling challenge. Given that mine plans and extraction sequences may vary in response to fluctuations of either price or other key inputs, the model may need to be dynamic in order to reflect these fluctuations. This means that actions taken by management in response to input variability must be considered by the model in order for it to be an efficient tool in the determination of Value at Risk.

Classification of mining industry risks

There are risks in all walks of life and in every activity we undertake. From getting up in the morning (for example, the risk of falling out of bed) or arriving at work on time (for example, the risk of heavy congestion) to more complex and perhaps higher value risks such as interest rate variations on one's mortgage. In the mining industry there are numerous risks that can be addressed and risk analysis benefits from clear and concise classifications. CRU Strategies' work on risk in the mining sector has benefitted from the following categorisation:

- Geological risk
- Geotechnical risk
- Project risk
- Operational risk
- Environmental risk
- Market risk
- Macroeconomic risk
- Political risk
- Counterparty risk

[2] Parameters are distribution dependent. For example, the normal distribution is defined by the mean and standard deviation.

Geological risk generally depends on the probability of the actual ore body being different from that predicted in the business plan. Risks in this category relate to the inherent properties of the ore. The ore grade (Cu, Mo, Ag, Au, As, etc.) could vary, as could the work index, which influences the grinding line in the concentrator. Humidity and carbonate (CO_3) contents also vary, which affects the recovery in the copper leaching process. In general, risk analysts also include the resource and reserve uncertainty risk in this category. This relates to the accuracy of the planned size of the ore base measured by geologists. Greater risk is usually associated with the size of the resource share of the ore body as opposed to the reserve share. **Geotechnical risk**, on the other hand, typically involves slope failures in open pit mines and major collapses or rock bursts in underground mines. Such incidences affect the composition of the ore processed at a plant level.

Mining companies often undertake new projects to improve operations, increase output capacity or replace ore bodies. They can be carried out at mine level (for example, greenfield deposit development), plant level (for example, increased treatment capacity or mill replacement) and at smelter/refinery level (for example, emissions reduction at the smelter). **Project risk** occurs whenever such projects are implemented. Variations from planned resource employment, involving time or money, are especially relevant as deviation from budget could result in significant losses. For example, cash flow could be seriously affected if the start-up of an expansion was delayed or if the costs of such a project were incorrectly estimated.

Operational risks result in variable production and recovery, and result from significant negative risks such as a train failure, poor shift management, or a lack of spare parts for haulage trucks. These risks are essentially different from operational uncertainty; that is, output variability which relates to other risks such as geotechnical, geological or environmental risks.

Over the past few decades **environmental risk** has become more important as regulations have tightened and regulators have increased their monitoring and control of mining operations. Risks falling into this category relate to compliance with environmental standards and regulations. Non-compliance could result in anything from a minor sanction (for example, a cash penalty) to a major shut down. The latter, especially, will have a considerable negative impact on shareholder value. Environmental risks often strike the least suspecting and usually have a significant impact on value.

Market risks generally relate to commodity prices, freight costs and production costs such as energy, treatment charges and refining charges. Although management's ability to influence market risk is highly restricted, the risk must be measured in order for management to make informed decisions. For example, the price of copper is relevant when a new or ongoing project is valued. An unexpected drop in prices could be the reason for not going ahead with the project or for forgoing additional investment to extend existing operations.

Political risk is the risk that the return on an investment suffers as a result of political instability or significant political change in a country or region. Instability affecting investment returns could stem from a change of government, legislative bodies, foreign affairs or military control. Political risk is notoriously difficult to quantify because there are limited sample sizes and case studies when discussing individual countries. Nevertheless, some political risk can be insured against through international agencies and other government organisations. Political risk can be so severe that investment returns suffer and can develop to such an extent that the capacity to withdraw capital from an investment is removed[3].

Finally, **counterparty risk** is the risk of one or multiple parties failing to honour the commitments stipulated in a contract. This is commonly known as default risk. In the mining sector it generally refers to the commercialisation of output, for example the inability of clients to make payments.

---

[3] For example, the case of 'corralito' in Argentina at the end of 2001, where the government expropriated value from pension funds, eliminating fund transferability, and where capital was not allowed to exit the country.

Conceptual framework for risk-adjusted decision-making

A degree of business variability is inherent in the mining industry, in part as a result of the risks outlined above. The nature of the mining industry is such that some uncertainties cannot be fully eliminated and some risks cannot be fully mitigated. For example, uncertainty surrounding the precise grade of an ore body is not fully resolved until metallurgical testing at the mill is completed (that is, after the ore body has actually been mined). Likewise, the risk of wall failures or rock bursts can rarely be fully eliminated.

CRU Strategies has developed a conceptual framework to incorporate quantitative risk analysis into the strategic and tactical decision-making process in the mining industry. The purpose of the risk-adjusted decision-making framework is not to eliminate variability in results, but rather to understand the magnitude and probability of the impact of such variability on shareholder value, and to enable variability to be managed and mitigated on a consistent basis in line with corporate risk appetite.

The framework incorporates two key elements which are described in detail below:

1 – The quantification and modelling of risks
2 – The alignment of decision-making with corporate risk appetite

Quantifying and modelling risks

In order to improve decision-making, risks must be clearly identified and accurately modelled. In addition, the relationship between each risk must be clearly understood to ensure that any correlations between risks are incorporated into the model. CRU Strategies has developed a sequential approach to quantifying and modelling risks in the mining industry:

1. Review operations to identify principal risks. The review of operations should include: site visits, interviews with operators and managers, and access to historic planning and performance data. Ideally, a team of independent experts would carry out the review, each focusing on a relevant area of technical expertise, such as geo-statistics, metallurgy, and environmental impact. Facilitated workshops and brain-storming sessions can be used to identify the full range of risks. While the scope of the review will depend on the level of decision being analysed, if the aim of decision-making is to maximise value at a given level of risk, the operations must be reviewed and modelled at least until the point of the first saleable product.
2. Build and review the 'base-case' deterministic model. Deterministic models can be used to evaluate the magnitude of the impact of risks on value[4] (using techniques such as scenario analysis), but are not well suited to quantifying associated probability. The results of the deterministic model often provide a useful benchmark (the 'base-case') for comparison with the results from a stochastic model. Deterministic models are widely used in the mining industry and existing models can often be adapted to incorporate stochastic analysis, reducing the risk that stochastic decision tools will be considered a 'black box' and be resisted or even ignored.
3. Assess and rank risks qualitatively. Following a detailed review of operations and deterministic modelling, major risks can be assessed and ranked on a qualitative basis. Facilitated workshops are used as a forum for discussing, ranking and prioritising risks for detailed analysis. A consensus decision-making process should be used to ensure agreement on risk ranking and prioritisation.

[4] In order to understand the impact of risks on value, it is important that an appropriate modelling methodology is used. CRU Strategies has developed a Value Based Costing modelling approach which ensures that the creation of value is clearly transparent at all levels of an operation.

4. Quantify risks (distribution type and parameters). The risks need to be defined in a format that allows quantitative modelling. This requires the selection of a suitable probability distribution[5], the definition of relevant parameters, and an assessment of correlation. For some risks, such as uncertainty surrounding grades, recoveries and operational performance, sufficient historical data may be available to define a distribution and correlation based on observed results. For other risks, such as political or environmental risks, data may not be available and in this case expert opinion must be sought. It is important that the assumptions and conclusions of experts are rigorously tested for robustness. This is typically done through a combination of training experts to provide risk-neutral assessments, and a programme of interviews and workshops.
5. Incorporate stochastic risk analysis into the deterministic model. The final stage of risk modelling is to incorporate the risk analysis into the deterministic model. Typically this is done using a MS Excel add-in such as @Risk[6] or Crystal Ball[7], which enables Monte Carlo Simulations to be carried out. The stochastic model generates a distribution of outcomes, which allows transparent analysis of the value under different scenarios. The incorporation of stochastic risk analysis may present some significant modelling challenges.

The output of the stochastic risk analysis model will be a distribution of the desired variable (typically the NPV of the operation). The model will also allow the impact and probability of each independent risk to be assessed and compared.

Aligning decision-making with corporate risk appetite

One of the aims of CRU Strategies' framework is to enable decisions to be taken on a consistent risk basis. At a corporate level, the aggregate level of risk should be consistent with shareholders' expectations of the risk appetite of the company.

CRU Strategies perspective of confidence level applied to different types of decisions in the mining industry

Confidence level	Stakeholder profile
98% - 99%	Banks, holders of investment grade bonds (assessing whether the cash flow will cover debt service and repayment requirement)
90% - 95%	Corporations assessing the value of non-core businesses; conservatively managed income orientated investment portfolios
80% - 90%	Corporations making decisions to invest in mainstream businesses; balanced equity portfolios
75% - 80%	Corporations making decisions to invest in strategically important growth segments; moderately aggressive equity portfolios
67%	Highly entrepreneurial businesses, commodity traders, innovative risk management and financial products; aggressive equity portfolios
50% or less	Speculative activities with disproportionately high potential return – grassroots mining exploration, biotechnology research and gambling

Source: CRU Strategies

The first question that must be addressed is how to quantify the risk appetite of a corporation in general, and in respect of the specific decision under review. In essence this question can be phrased as "how confident of success do we want to be?" If management takes a decision at a 90 percent confidence

[5] Classical probability theory defines a large number of probability distributions which fall into two broad categories: continuous distributions and discrete distributions. In practice, a large proportion of risks can be modelled with a reasonable degree of confidence using just four distributions: normal, triangular or uniform distributions if the variable is continuous; or simple discrete distributions if the variable is discrete.
[6] www.palisade.com
[7] www.crystalball.com

level, it is implicitly accepting a 10 percent probability that the decision will turn out to be incorrect. CRU Strategies has developed a perspective on the typical risk appetite of mining companies relating to different types of decision.

Once the risk appetite is defined and quantified, independent risks can be compared and ranked on a consistent basis. Typically, such an assessment involves comparing the Value at Risk (VaR) at a given confidence level to produce a risk-adjusted ranking. For the purpose of strategic planning relating to core assets, CRU Strategies typically compares VaR at an 80 percent confidence level.

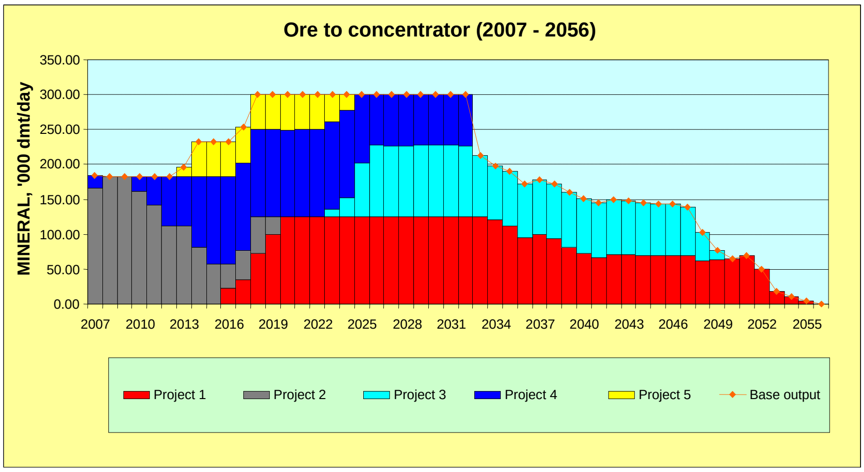
The risk-adjusted ranking provides a value focus for the management of risks. Risk management and mitigation plans should be prioritised on the basis of the risk-adjusted ranking. The process is iterative: mitigation plans are incorporated into the base-case model and the process can be repeated.

Application of risk-adjusted decision-making to the copper mining industry

CRU Strategies has undertaken several consultancy assignments in risk valuation and mitigation in the last couple of years in various types of operation – both open pit and underground. These have followed the process detailed in the previous section and have given management important insight into the Value at Risk and the possible gains from mitigating identified risks.

This section considers an example taken from one of CRU Strategies' recent assignments (call it RiskCo), in order to illustrate how decisions can change as a result of greater risk transparency. This case involved almost every category of risk explained above. RiskCo developed a business plan which forecast value creation based on a production profile that incorporated current operations as well as various projects which were to come on-stream in the near future. The management's planned production, including both replacement and expansion projects, is illustrated in the chart below.

RiskCo's production profile in the base case

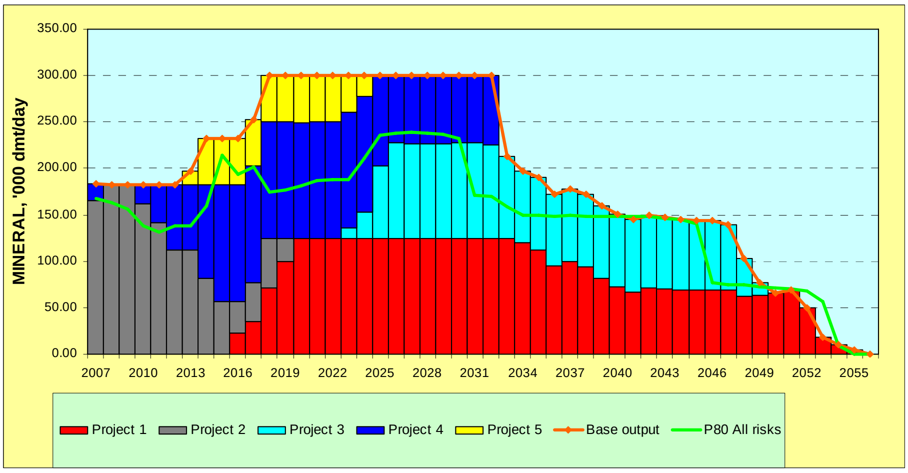


CRU | ANALYSIS

The base assumption here is that cash flows were considered as certain, representing a very strong commitment to shareholder value delivery at the level indicated by the base output. Nevertheless, when risks are incorporated into the business plan, the picture is very different, as shown in the chart on the next page.

In the chart the base-case output is still shown by the red line. The green line shows a risk-adjusted output, which represents the 80 percent confidence of reaching at least this level of production (also referred to as the P80). The simulation illustrated that there was a significant risk of falling short of planned output. The analysis also resulted in management taking various actions to mitigate risk and maximise shareholder value. For example, the expansion considered in 2013 and 2014 appears superfluous because there was already insufficient ore to feed the concentrator during the 2007 to 2013 period. As a result, the immediate issue was how to fill the concentrator in the first years of the plan.

RiskCo's production profile with the incorporation of risk



CRU | ANALYSIS

In general, a mitigation plan must address the problem of moving towards the base-case output, which is done by recovering portions of the Value at Risk. CRU Strategies suggested that RiskCo focused on assuring ore feed to the concentrator over the next five years, thus delaying some of the planned expansion projects while retaining the value maximisation objective. Although this reduced the immediate value of the plan, it also reduced the Value at Risk – improving confidence and reliability. The plan therefore enabled management to start anew – to develop a framework for future expansion built on firm control of existing operations.

References

Best, P.W. (1998) *Implementing Value at Risk*, John Wiley & Sons Ltd, Chichester, United Kingdom, pp. 1-13.

Jorion, P. (2001) *Value at risk: the new benchmark for managing financial risk*, McGraw-Hill, New York, United States of America, pp. 81-101.

Manfredo M.R. and Leuthold R.M. (2001) *Value-at-Risk Analysis: A Review and the Potential for Agricultural Applications*, Review of Agricultural Economics, Vol. 21 (1) pp. 99-111.

Authors:

Juan Esteban Fuentes[1], Tom George[2] and James Whittikar[3]
CRU Strategies
Augusto Leguía Norte 100, Of. 505-506-507, Las Condes, Santiago, Chile
Phone: +56 2 231 3900 and +56 2 231 4314
[1] Consultant, juan.esteban.fuentes@crugroup.com
[2] Consultant, tom.george@crugroup.com
[3] Formerly Principal Consultant, now Project Manager, Abacus Mining & Exploration, Canada

This paper was presented at
MiNiN2008
III International Conference on Mining Innovation
and is re-produced with kind permission.
www.minin2008.com – info@minin2008.com – Phone: +56 2 652 1519 – Fax: +56 2 652 1570