Optimising Project Value and Robustness

G Whittle[1], W Stange[2] and N Hanson[3]

ABSTRACT

An important aspect of the project evaluation process is the achievement of a clear and quantitative understanding of the primary drivers influencing project value and risk. A business scenario-based approach is required to ensure that the project meets value and risk hurdles over the short, medium and longer term. Adopting an optimising approach can aid significantly in the development of a project concept into a business that is optimal and sustainable in the longer term.

Through the application of case studies, based on work performed with various mining organisations during the last five years, this paper will demonstrate how project value and robustness can be optimised. Experience has demonstrated that applying this approach results in significant value improvements and risk reduction – primarily by application of a rigorous, fact-based analysis and optimisation process that rapidly increases management team understanding and insight of key driver of value and risk.

INTRODUCTION

Much of the effort expended during project development ultimately contributes towards developing an accurate estimate of the project value under an assumed set or range of conditions. Mining projects are sufficiently complex that an evaluation of the same basic project can be significantly different depending on the degree to which the project evaluation has been optimised. In addition, an estimate of project value is of limited utility if the robustness of the project around this value estimate has not been adequately quantified.

Although the scale and inherent complexity of mining projects are such that optimisation and risk assessment are challenging, this paper contends that:

- Optimisation of even the largest project is now technically feasible and practical. Due to the significant value premium achieved ‘best-practice’ evaluation needs to encompass rigorous optimisation.
- Assessment of project robustness, although less well developed, can be readily achieved by application of a quantitative risk management framework that has proved effective in other disciplines, such as the trading of financial instruments. Value at risk (VaR) (Dowd, 1998; Jorion, 2001) is proposed as an effective approach and this paper illustrates how a VaR-like framework can be used to quantify project robustness.

This paper presents a novel integrated approach to project optimisation and robustness assessment. The benefits of the approach are demonstrated by applying them to a hypothetical, but realistic, Cu/Au project – Marvin (Hanson, 2007). The nature of the Marvin project and its key parameters are summarised in Appendix 1.

In our view the primary benefit of adopting the approach proposed in this paper is not the fact that an ‘optimum’ value, and associated risk profile, is derived but rather that the key drivers of value and risk are clearly and quantitatively revealed. This understanding facilitates the effectiveness of the overall development process by keeping management focus on the ‘critical few’ key risk and value drivers to ensure development achieves maximum improvement in value and reduction in risk for any given level of expenditure and activity. Concentrating on a single plan too early can hide potential value that could be realised and/or reduced understanding of risk.

This is best achieved by definition and analysis of the likely business scenarios in which the project is to be developed and operated in the medium and longer term, eg in the current climate much more focus is required on managing around resource and infrastructure constraints, as well as understanding the impact of potential price trends. Although not addressed in this paper the application of scenario-analysis for strategic development and planning is well established (Ringland, 1998).

The benefits associated with the approach proposed extend past the project development phase. The insight and understanding gained in developing the integrated risk and optimisation model can be captured in a strategic asset management plan which should be transferred to the operations management team. This team should then update the risk and value model and plan to ensure that as business conditions change, as well as the understanding of the orebody and its mining and processing improves, the operation can be managed to a more rigorous risk and value profile.

This paper is structured as follows:

- A review of the current status of relevant risk and optimisation work is undertaken.
- An integrated risk and optimisation architecture which can be applied to project evaluation is provided.
- A case study, based on the hypothetical Marvin orebody (see Appendix 1) is conducted. An analysis of the case study demonstrates the benefits and typical outcomes of such an approach.
- Conclusions drawn from the work are presented.

REVIEW OF OPTIMISATION AND RISK APPROACHES

If optimisation is not applied the typical approach to evaluation is to define a ‘mid-case’ approach with a consequent poor quantitative understanding of the many trade-offs between interacting variables. The range of assumptions that make up a ‘mid case’ or ‘most likely case’ typically encompasses:

- geology: tonnes, grades, variability, continuity;
- geotechnical parameters: what pit slopes or underground structures are supportable, with associated hydrology, civil works options, berm construction, stockpile, waste and tailings competency;
- mining cost, productivity and dilution: equipment performance potential may be clear but the end result depends heavily on geology and geotechnical issues;
- metallurgy cost, recovery and throughput; and
- market metal prices, and for some commodities the demand for certain product specifications (eg iron ore and coal).

The ‘mid-case’ approach does not guarantee that the evaluated basis is financially optimal and provides little quantification of

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1. Managing Director, Whittle Consulting Pty Ltd, Suite 13, 333 Canterbury Road, Canterbury Vic 3126.
Email: gerald@whittleconsulting.com.au

2. Client Director, Deloitte Consulting, Level 5, 180 Lonsdale Street, Melbourne Vic 3000. Email: wstange@deloitte.com.au

3. MAusIMM, Geologist and Consultant, Imageo, 100 Mary Avenue, Wheelers Hill Vic 3150. Email: norm.hanson@imageo.com.au

the project robustness – it is never clear whether the mid-point approach is overly conservative or optimistic. Throughout the evaluation process we eagerly lock in the single favoured value for each of the above parameters. This is normally driven by the need to define sufficient detail so that 'accurate' cost estimates can be derived as quickly as possible. For new projects in particular, where there is a lack of actual operating experience, the truth is that many of the key parameters could be within a fairly broad range and are likely to change over time.

The typical project optimisation process

Pit and schedule optimisation for mining projects is well developed. This typically involves comprehensive geological and operational modelling, and usually the application of sophisticated mathematical optimisation software. The process involves identifying the combination of controllable variables that maximise the value of the project in the context of a given set or range on assumptions. 'Whole-of-Business' optimisation is an area in which significant progress has been made (Whittle, 2004; King, 2004; Hall and Hall, 2006) and it is now feasible to routinely apply value optimisation to large/regional-scale assets during development as well as during ongoing operations.

Geological models are created at a point in time based on drilling data of different spacing and density of drilling. Even when conditional simulation has been performed, it is common practice to construct a single block model flagging each block with the confidence level that the drilling data in that area supports. It is possible later in the analysis to exclude or at least discount apparent ore in the 'inferred' category.

From that point on the block model is regarded as a 'reality'. Different dilution formulae are sometimes applied, but generally there is pressure to lock in these assumptions early in the process, due to the large amounts of re-work that is involved in changing them.

Metallurgical recoveries are set based on test work in the case of new projects. In most situations the inherent variability in these tests are simply 'averaged out'. How representative the test samples are of the orebody concerned is as uncertain as the geological modelling process itself. Based on engineering design, ultimate plant throughput is determined and just as importantly the ramp up to this is defined. The impact of delayed ramp-up is sometimes explored.

Alternative market scenarios are more often explored, usually in terms of an upside and downside case for metal prices. Metal prices arguably have the largest impact on project valuation, and do have an impact on what the optimal operational plan will be.

With this set of information pit optimisation or underground mine conceptual design takes place. Depending on whether the study undertaken is a prefeasibility or definitive feasibility study, varying amounts of actual mine design work will take place. This may involve specification of haulage roads, dewatering and detail of waste movements and waste/ore stockpile design. It is common for the detailed mine design work to only be performed for areas to be mined within say the first five years, with other areas left at the more conceptual design status, perhaps using the shapes that came out of the pit optimiser.

In the case of pits, applying the Lerchs-Grossman (L-G) algorithm with varying revenue factors (say from 0.4 to 1.4) provides useful guidance for a value-based phasing strategy. The early mining shapes are generated by high-grade and/or low stripping ratio – the extent to which they can be designed in as early high-value phases depends on practical consideration such as minimum mining width and haul road access.

Once a set of optimal pit shapes has been generated the life-of-mine schedule, subject to defined operational constraints, is optimised. The schedule optimiser should control:

- the rate and location of mining, within the shapes defined in the previous stage of the planning process;
- the cut-off grade(s) between waste, stockpile and processing;
- which processing method an ore parcel will report to, if more than one alternative exists;
- blend specification, observing any minimum or maximum limits but otherwise negotiating the attributes based on an understanding of the material available from mining and stockpiles and the sensitivities of the plant cost/recovery/throughput to feed characteristics; and
- production volume, mix and specification (where applicable).

If the optimisation analysis is performed properly, then the result is a life-of-mine (LOM) plan that maximises the net present value (NPV) for the project for the specified set of assumptions (geological, geotechnical, metallurgical, market, environmental, etc).

If the result is best amongst a range of alternatives, or meets some predetermined criteria, and fits in with the company's overall investment strategy, then the project is considered favourable and the next phase of development is sanctioned.

Typical characteristics of an optimised life-of-mine plan

Based on a large range of projects undertaken, some on a regional scale, a number of characteristics of an optimised life-of-mine plan have been observed. To maximise the current value of a project (as measured by the NPV) the optimiser is typically making choices that:

- avoids doing anything that destroys value, ie where the cost exceeds the benefit;
- brings forward larger/positive cash flows; and
- delays smaller/negative cash flows.

In general an optimised life-of-mine schedule tends to have the following characteristics:

- After initial waste stripping, which should be performed as late and as quickly as possible, low stripping ratio phases result in modest mining rates. As these are depleted, it is necessary to increase mining capacity due to increased stripping ratio:
  - to deliver a constant amount of ore to the plant (if the plant is input limited), or
  - a constant amount of metal contained (if the plant is output limited).
- High early head grades which decline ultimately to the marginal cut-off grade at the end of the LOM. This behaviour is enabled partly by:
  - the pit optimisation or underground block prioritisation presenting high-grade sources of ore within the mining system, or
  - the opportunity to raise the early cut-off grade (increasing waste or stockpiling) to maximise overall schedule value (as per Ken Lane).
- The result is either:
  - decreasing production rates (if the plant is input limited), or
  - increasing mining and processing rates (if the system is output limited).

Any specific situation may involve many variations from the above guidelines. It is common practice to constrain the optimiser to produce schedules with steady or smoothed mining and production rates, even though they are financially suboptimal. This possibly reflects the (irrational) human desire to keep plant and equipment busy, or more likely reflects poor cost modelling, which overstates the benefit of not utilising available labour and equipment on a short-term basis. In a regional situation, ie where there are several facilities around major mineral provinces (eg Pilbara, Bowen Basin) this typically indicates significant potential for improved management and sharing of assets.

The importance of quantifying risk/robustness

There is little point in embracing optimisation without an accompanying ability to understand how optimisation strategies, decisions and trade-offs impact on project robustness and risk. This allows the robustness of the optimal project configuration to be compared with scenarios that are less favourable financially in a meaningful way.

Project risk analysis

There are a number of conventional approaches to assessing the risk or robustness of a minerals project (Torries, 1998):

- *Sensitivity analysis* – varying one or more parameters to see what impact this has on the project value of the project.
- *Scenario analysis* – group values of key parameters by scenarios and then understand how project value changes under different scenarios. For example Rolley and Johnson (1997) demonstrate how different resource models impact on estimates of project profitability.
- *Probabilistic analysis* – key inputs, such as metal prices and costs, are characterised as probability distributions and Monte Carlo simulation is used to simulate the project valuation under a range of inputs sampled from the underlying distributions. This implies that resulting outputs (costs, revenues, NPV) are distributed and appropriate statistics can be collected to characterise these quantities such as average, standard deviations, etc. For example Mardon, Goode and Rozman (1995) demonstrate the application of the @Risk software package with Whittle 4D to quantify the uncertainty of project value (NPV) and cash flow by treating critical input variables (ore tonnes, grade, capital costs, operating costs, etc) as probability distributions rather than point or mid-case estimates.
- *Conditional simulation* – can be used to quantify the distribution of grades within an orebody. These grade distributions can then be used in combination with a Monte Carlo based probabilistic evaluation model to understand how grade variation impacts project value. For example Rossi and van Brunt (1997) demonstrated how conditional simulation could be used in conjunction with the Lerchs-Grossman pit optimisation algorithm to better quantify the level of risk in an evaluation.

AN INTEGRATED OPTIMISATION AND RISK FRAMEWORK

This paper demonstrates that in order to achieve best outcomes optimisation should be considered in a manner that is completely integrated with an approach that provides a quantitative measure of the risk or robustness of the evaluation. Although this is often hinted at in the literature, to the knowledge of the authors a fully integrated approach has not been developed, primarily due to the large data volumes and intensive computation requirements.

The first step in achieving this is in developing a methodology for assessing project risk/robustness.

Quantifying project risk/robustness

In recent years there has been a strong adoption of the value at risk (VaR) approach to quantifying risk (Jorion, 2001). Since the early 1990s financial services industries, typically with complex and large financial risk issues (eg trading) have increasingly adopted VaR to quantify and manage risk. There is also some indication (McCarthy, 2006) that mining companies are adopting this style of approach – albeit at a corporate level – to manage portfolio risk.

The technical definition of VaR is:

> *The maximum (worst) loss possible over a target time horizon at a given level of confidence.*

A VaR-like approach has been applied to valuation of businesses and projects (Godfrey and Espinosa, 1998; Schiefner and Schmidt, 2003; Shimko, 2001) and this approach is proposed as an appropriate basis to evaluate the robustness of a project.

The VaR approach to project risk assessment is implemented as follows:

1. Define the VaR parameters:
    - level of confidence parameter, typically one to five per cent (this parameter defines what proportion of outcomes the VaR can be worse than).
    - The time horizon – in project evaluation it is likely to be the life-of-mine or long-term planning horizon.
2. Define the key inputs for which the robustness assessment is to be conducted. These are typically quantities such as ore grades and characteristics, equipment performance characteristics, financial and cost structures, product prices, etc.
3. Define the distributions that these inputs are likely to have, including how these distributions may change, possibly over time, as well as how distributions may be correlated, eg the grade of a secondary mineral is correlated with the primary mineral. In many respects this is the most difficult aspect of VaR to do well in a project development situation. There are several ways in which distributions can be defined:
    - the use of historical data for similar projects and operations;
    - estimations by subject-matter experts; and
    - use of detailed models, eg a detailed mine operations simulation model can be configured to provide distribution data, eg how variations in truck loading cycles result in variations of mine productivity and costs for different stripping ratios.
4. Develop a discounted cash flow model which converts the selected inputs into appropriately timed capital, operating cost and revenue impacts.
5. Use a tool like @Risk from Palisade Corporation to run Monte Carlo simulations of project value for many combinations of the input distributions.
6. Analyse and interpret the outcomes.

In undertaking a VaR evaluation we are only considering risks that can and should be expressed in a quantified financial manner. This implies that risks and issues which are not amenable to this treatment (eg social, safety and environmental risks) are dealt with separately using an appropriate methodology such as enterprise risk management and that VaR is quantified within the appropriate policy 'envelopes'.

To better explain the concept Figure 1 shows the VaR for the case study presented in the next section. It can be seen that the expected value of the project NPV over the project life (ten years) is $2884 M. However, there is a five per cent probability that the NPV is less than $1560 M – the VaR. The VaR could also be expressed as the five per cent tail value as a proportion of the expected NPV, ie 54.2 per cent.

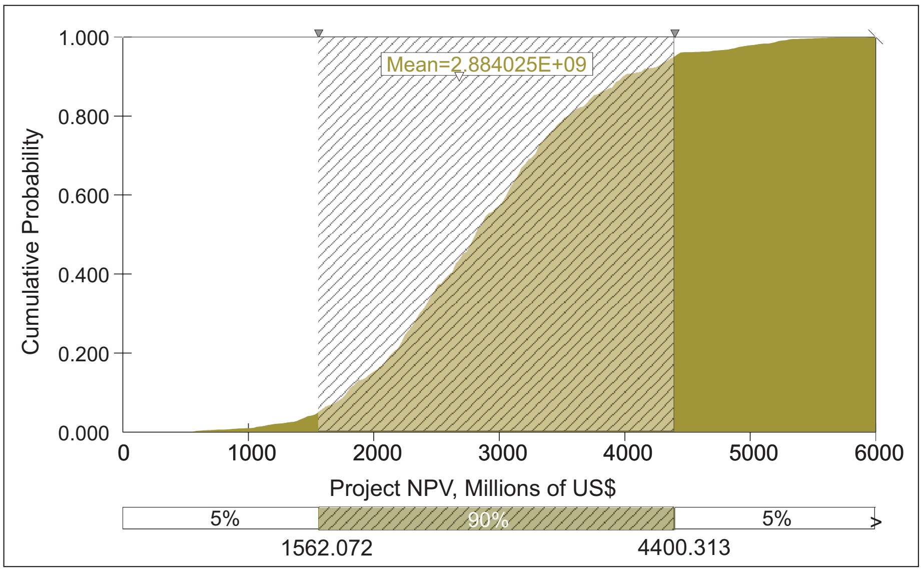

FIG 1 - Net present value for value at risk for Marvin case study.

One of the key benefits of the VaR approach is that it is straightforward to manage the 'cascading' of risk through different levels of an organisation, ie expressing the robustness of a particular project, component of a project or a development portfolio consisting of many projects.

Integrating optimisation and risk quantification

Based on the experience of the authors and access to a uniquely powerful software system for project optimisation the conceptual architecture in Figure 2 is proposed for integrating project optimisation and quantification of risk using VaR. The architecture is based on the application of a Monte Carlo approach where all of the project information is assumed to be expressed as probability distributions. The key elements of the architecture are:

- *Probability analysis system* – this is the toolset used to manage the probability distributions which underlie the VaR approach. @Risk from Palisade was used for this work.
- *Pit optimisation* – given a specific input data set the L-G pit optimiser determines the optimum pit design. Whittle FourX was used for this work.
- *Global optimiser* – the Global Optimiser takes as input the optimal pit design and then performs a 'whole-of-business' optimisation to find the LOM schedule that optimises the project NPV, subject to defined constraints, eg constant metal production rate. The software used is proprietary to Whittle Consulting and represent decades of research in terms of best-practice 'whole-of-business' optimisation of mining projects (Whittle, 2004).

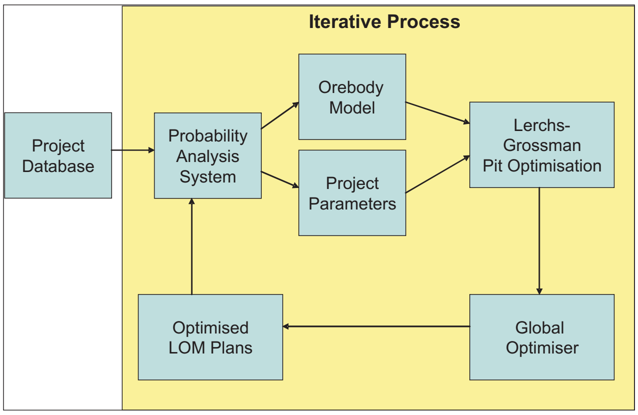

FIG 2 - Integrated risk and optimisation system.

The following processing sequence takes place on every iteration:

- The probability analysis system 'samples' all of the key inputs from the project database. The project database is defined in a manner where key inputs are described by probability distributions rather than 'point' estimates. Various techniques can be applied for estimating these distributions, as discussed above.
- The sample data set is processed by the L-G pit optimisation algorithm to produce the optimal pit and phase design and then by the global optimiser to maximise the 'whole-of-business' NPV over LOM.
- The optimised LOM schedule and associated data are stored in a database accessible to the probability analysis system – allowing the output information to be analysed in a probabilistic manner to produce distributions of key information such as NPV, cash flow, mining schedules, etc.
- Typically the system runs for upward of 100 iterations – 500 were used in the case study requiring some 40 hours of computation time.

CASE STUDY – MARVIN COPPER

The Marvin Copper project is a fictitious project but it incorporates many features of a typical sulfide mineral deposit (Hanson, 2007). The project is more fully described in Appendix 1.

Parameters

The Marvin resource model consisted of some 30 000 blocks with an Au and Cu grade estimated for each block. Some 500 iterations were applied resulting in some 15 000 000 blocks processed for the integrated risk and optimisation study. Key parameters which were investigated in this study are described in Table 1.

TABLE 1

Summary of input distributions and parameters.

Parameter	Average	Standard deviation	Distribution	Comments
Cu grade factor	1.0	0.05	Normal	All Cu grades on the block model are multiplied by this factor to generate a distribution of Cu grades on each block.
Au grade factor	1.0	0.075	Log-Normal	As for above but applied to the gold grade.
Short-term (three-year) Cu price, $/t	$6195	$930	Log-Normal	The possible distribution of copper prices over the next three years.
Long-term Cu price, $/t	$4956	$1230	Log-Normal	As for the short-term Cu price but for longer-term periods (four years into future and onwards).
Short-term (three-year) Au price, $/oz	$664	$70	Log-Normal	As for copper short-term price but for gold.
Long-term Au price, $/oz	$730	$150	Log-Normal	As for gold long-term price but for gold.
Cu recovery factor	1.0	0.03	Normal	The metallurgical recovery estimate for Cu is multiplied by this factor to illustrate the impact of variability of copper recovery.
Au recovery factor	1.0	0.05	Normal	As for copper but applied to gold.
Selling cost, Cu, $/t	$2000	$250	Normal	Costs incurred in selling copper.
Selling cost, Au, $/oz	$8.20	$1.03	Normal	Costs incurred in selling gold.
Mining cost – $/t	$2.10	$0.32	Log-Normal	Mining operating costs.
Processing cost – $/t	$7.50	$0.94	Log-Normal	Processing operating costs.
Pit slope – east	45.0	2.0	Triangular	Distribution of pit slopes – eastern side of pit
Pit slope – west	40.0	2.0	Triangular	Distribution of pit slopes – western side of pit

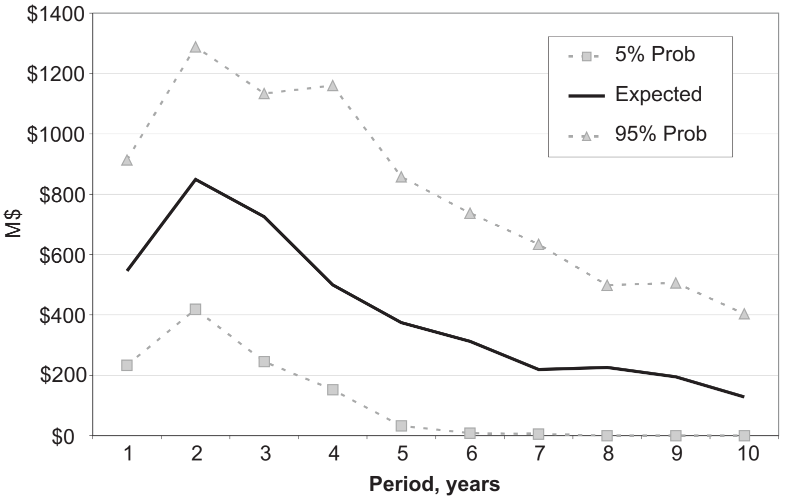

FIG 3 - Annual cash flow probability envelope.

Case study findings

Impact of optimisation

The base case is defined as the application of Whittle FourX to develop the optimal pit design, which also selects suitable pushbacks, and schedule as generated by an experienced user. The project NPV calculated in this manner is $2.3 billion. The application of the global optimiser in addition to FourX provides an expected project valuation of $2.9 billion (see Figure 1) – an increase of some 25 per cent. We conclude that the small incremental cost and effort associated with application of rigorous optimisation is more than justified.

Project valuation

Figure 1 illustrates the probability distribution of the optimised project NPV. It is surprisingly broad, given the relatively small variability in the input parameters. This clearly illustrates that the way in which variables interact in a large complex system results in non-intuitive outcomes. Although the distribution is broad it can be clear seen that the optimiser has been very effective at ensuring maximum NPV outcomes – the distribution comprises only positive values. In similar work without use of an optimiser it is often found that the NPV shows a finite probability of being less than zero, ie of the project destroying value. Applying optimisation inherently improves robustness.

Cash flow

Figure 3 illustrates expected annual cash flows, including the five and 95 per cent probability boundaries. There is a five per cent probability that annual cash flows are break-even or nil from year six onwards. Figure 4 demonstrates how the cash flow distributions evolve over project life. As the project life progresses the distribution skews towards zero; however, the optimiser is effective in avoiding negative cash flows.

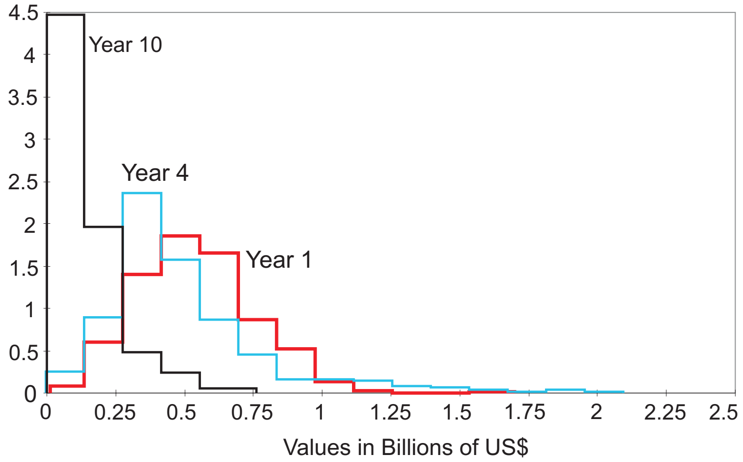

FIG 4 - Evolution of cash flow distributions.

Project life

Figure 5 illustrates the distribution of optimal project lives – illustrating that periods of ten to 14 years are most common.

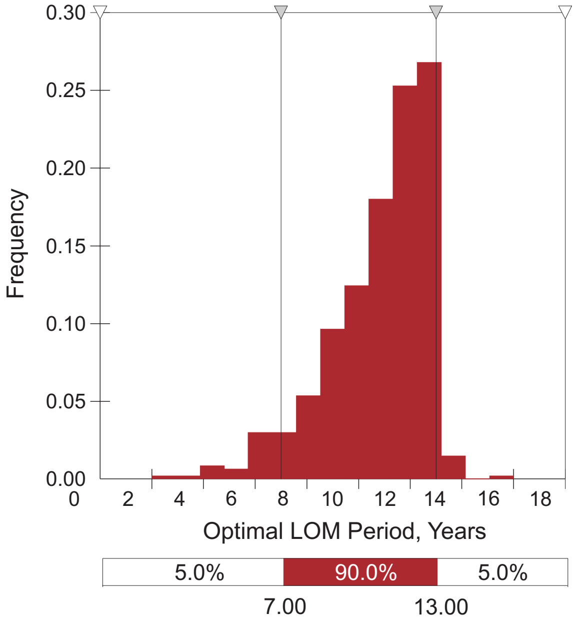

FIG 5 - Optimal project life.

Mining tonnage

Figure 6 illustrates the expected total mining rate (ore and waste) over the project life including five per cent and 95 per cent boundaries. Again, the distribution is broad and illustrates the trend of declining mining rate over time. This is because the optimal schedule favours high mining rates and creation of stockpiles initially and then the processing of lower-grade stockpiled material in later years. Figure 7 illustrates how the distribution of mining rates varies with time. This information allows the risk associated with various fleet and sourcing approaches to be evaluated.

Processing plant grade

Figure 8 illustrates the feed grade of gold and copper to the processing plant. It can be clearly seen how the optimiser brings forward high-grade material to maximise NPV.

Drivers of value and risk

The architecture illustrated in Figure 2 has the benefit that key drivers of value and risk can be ascertained from the data generated. The following table illustrates the relative impact that each of the key inputs has on key outputs such as NPV and annual cash flow in years one, four and eight. This facilitates an understanding of where project development effort should be focused to ensure reduction of risk and/or value improvement.

Table 2 represents a summary view of factors impacting risk and value. The system used provides a wealth of information at a much greater level of detail that supports in-depth analysis and development of action plans to increase value and mitigate risk.

TABLE 2

Key value drivers over project life.

	NPV	Cash flow (1)	Cash flow (4)	Cash flow (8)
Pit slope	1	2	4	5
Selling costs	2	6	1	4
Mining costs	4	4	6	1
Process costs	6	7	7	6
Price – short term	7	1	3	3
Price – long term	5	5	2	7
Recoveries	3	3	5	2

Note: 1 indicates the highest impact and 7 indicates smallest relative impact.

Probabilistic pit design

The system illustrated in Figure 2 provides valuable probabilistic information with respect to the ultimate pit design. The blocks that make up the various phases of the optimal pit design are calculated by the L-G algorithm. This information is collected for each iteration and then analysed statistically. Figure 9 is the plan view of the probability that each block is in the optimum design.

The 95 per cent probability pit phases define the high-certainty area for mining whereas the five per cent probability footprint can be used to guide location of infrastructure to ensure future development options are not complicated by obstructing infrastructure.

The various probability ultimate pit shapes are shown in Figure 10. Where the edges of the various confidence pits are close together, this is a stable pit wall location and can be

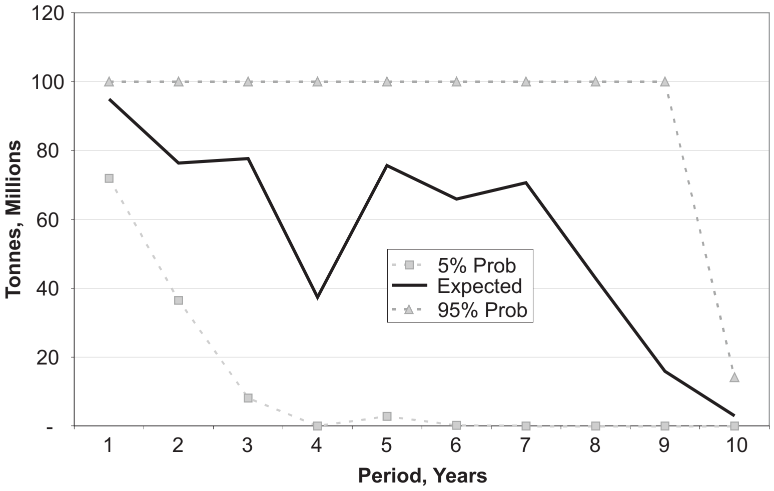

FIG 6 - Mining tonnage probability envelope.

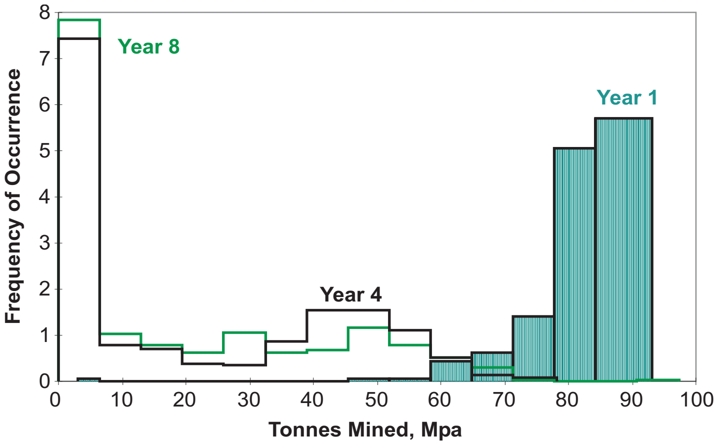

FIG 7 - Evolution of mining tonnage distributions.

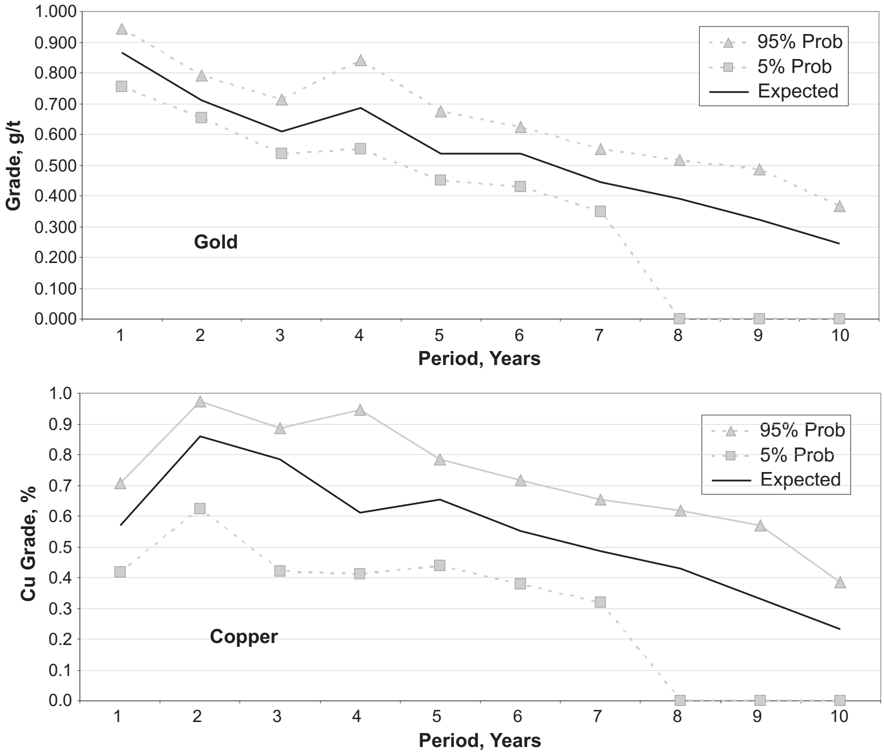

FIG 8 - Processing plant feed grade.

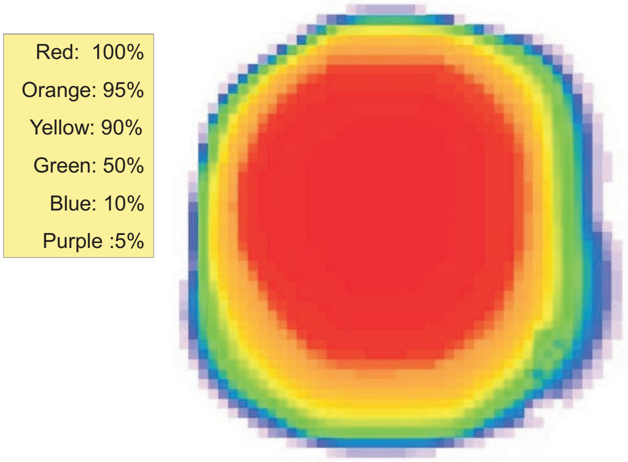

FIG 9 - Probability plan of final pit.

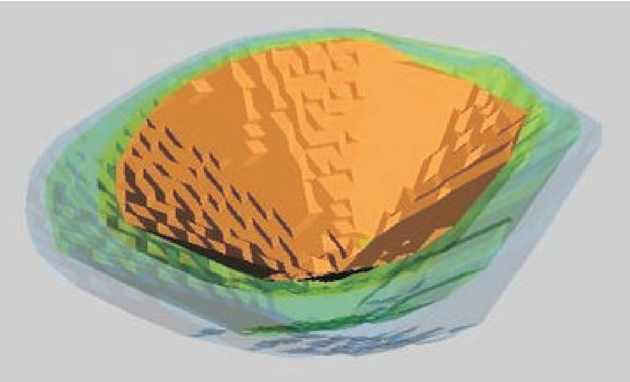

FIG 10 - Final pit probability shapes.

reliably used for infrastructure, haul roads, etc in that we can be certain that this wall will exist. Areas where pit edges are widely spaced are more speculative and should not be committed to at an early stage, but can be better defined as operations progress.

CONCLUSIONS

This paper has demonstrated a novel, integrated approach to project optimisation and risk quantification. It has also demonstrated that the approach can be realistically employed on industrial-scale problems.

The key findings from the work are:

- Quantifying value at risk as well as expected project value allows a conclusion to be drawn as to whether it is more productive to be reducing variation/risk, increasing value or both. Eliminating risk is as good a way of improving a project as increasing the expected evaluation.
- Project development can be consciously 'steered' in a manner that reduces risk, improves value, or both.
- We can quantify the cost of eliminating some aspects of uncertainty: more drilling, more test work, fixed price contracts for mining or other services, hedging. For example it may be illustrated that more drilling may be the least effective use of cash to reduce risk.
- Variation can be viewed in both a pessimistic way – at risk, downside, etc, or optimistically – upside, maintaining options and opportunities.
- With this approach we can still identify outcomes that we can place an estimate of confidence in – say 95 per cent, rather than believing that we can be sure of nothing when the data is less than ideal.
- The range of variability within probabilistic resource models (such as conditional simulations) can be fully exploited using the VaR approach and does not have to be reduced to a single model.

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APPENDIX 1 – MARVIN PROJECT

This is a fictitious project but it incorporates many features of a typical hydrothermal sulfide mineral deposit in the Lachlan Fold Belt of New South Wales, Australia. This data set was built in 1996 and evolved for RMIT geological engineering student projects. In 1999 it was used for the Whittle Challenge, part of the 'Optimising with Whittle' Strategic Mine Planning Conference, Perth. The following information was provided to the Whittle Challenge and provides context to the project and its model. Costs and methods have been updated to represent current economics and practices.

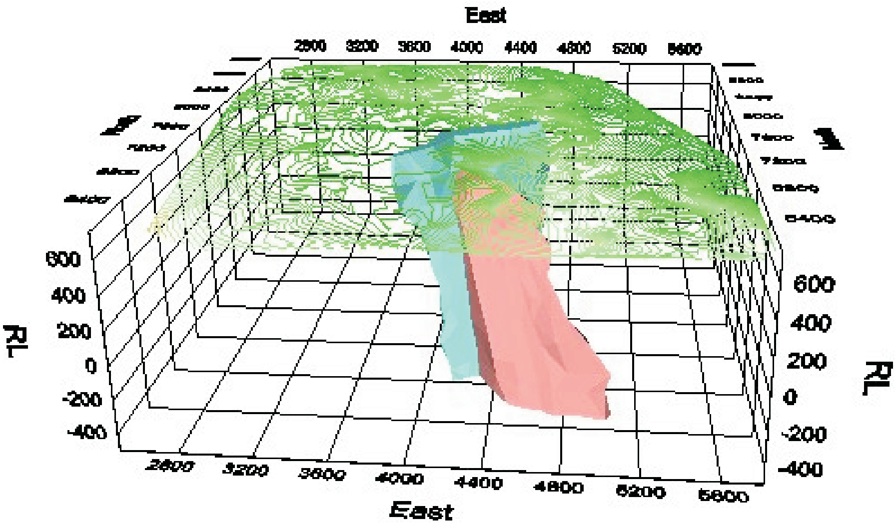

FIG A1.1 - View of the orebody looking east.

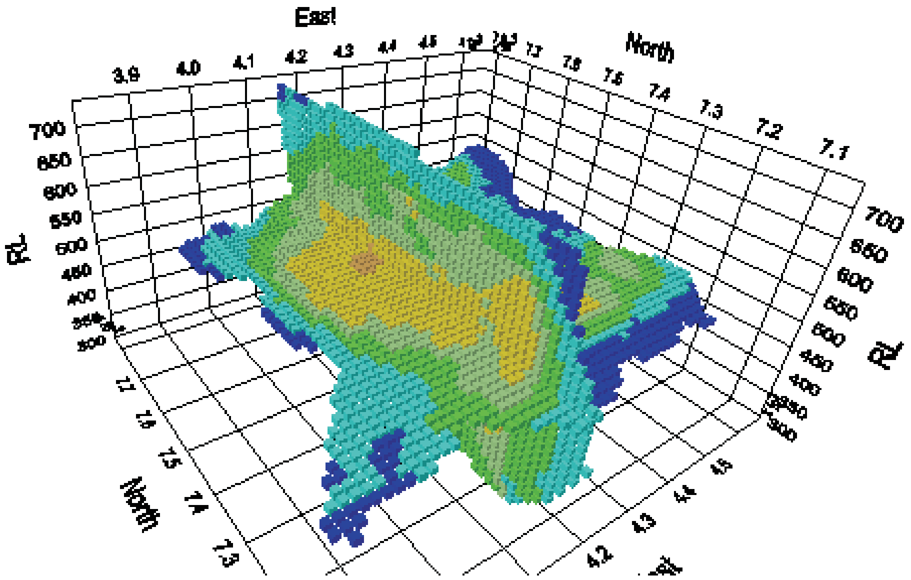

FIG A1.2 - Cut-away view of the OK block model.

Location and exploration history

The Marvin copper-gold deposit is located approximately 100 km North of Orange in the eastern Lachlan Fold belt at latitude 149 00 E and 32 40 S on the Bathurst 1:250 000 scale map sheet (see Figure A1.1). Mining and exploration in the area dates back to the 1850s when gold and copper were discovered in the area. The Marvin copper deposit was discovered in late 1996 using a detailed induced polarisation (IP) survey for targets for an extensive drilling program. Subsequent drilling at Marvin has been performed to delineate the favourable host rock for geological mapping and resource/reserve estimation.

Geological setting

The eastern portion of the Lachlan Fold belt contains a number of Ordovician Volcano-intrusive complexes which host porphyry style copper-gold mineralisation and high sulfurisation hydrothermal mineral deposits (Newcrest Mining staff, 1998).

Marvin is located within an altered acid volcanic sequence making up part of one of the aforementioned Ordovician volcanic belts. The main mineralised zone is closely associated with a quartz porphyry/breccia zone that has been interpreted by Chiswell (1998) as an intrusion into andesitic tuffs. At depth a granodiorite pluton may have acted as the heat source for a hydrothermal mineralisation event. The mineralisation is distinctly zoned with a bornite/chalcocite core and disseminated chalcopyrite/pyrite halo. This deposit is very different in style from all others in the area due to the abundance of chalcocite and bornite. These hydrous minerals, unlike chalcopyrite, are soluble.

Drilling and resource modelling

There have been three phases of drilling to date:

1. discovery RAB drilling program,
2. first deep drilling campaign, and
3. a second phase of deep drilling.

This has provided information for a preliminary block model to be created to be used for project evaluation. The material has been categorised as measured, indicated, inferred and pre-resource to assist in project evaluation.