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Quantifying the Economic Risk of Suboptimal Mine Plans and Strategies

By B E Hall [1] & J de Vries

Abstract

When times are tough in the mineral industry – as they have been for some time – typical responses by mining companies are to cut costs and / or increase production. The latter is seen to spread fixed costs, thereby also reducing unit costs per tonne mined.

However, most mineral deposits respond to increased production rates by lowering ore grades, so the reduction in cost per tonne of ore does not necessarily result in a reduced cost per unit of metal produced. The authors' experience is that this process often leads to a mine plan that is a long way from optimal. Producing to the point where marginal cost equals marginal revenue may work well in a manufacturing operation, but it is not necessarily the best strategy for a mining company with a depleting resource. Variations in tonnage and grade with depth, ore reserve optimism and a variety of other factors conspire to produce variations in production rates and grade that often result in sub optimal outcomes and potential mine failure. Added to this is the focus of industry analysts and senior corporate management on such measures as unit costs and ounces in reserves. This is perceived to have the perverse effect of driving the share price down when strategies are adopted that actually improve the value of the mining operation, and vice versa!

Many mine failures can be prevented by a close examination of the tonnage grade curve and an understanding of how margins, net cash flows and resulting business risk change with cutoff grades and rates of production. A few relatively simple analyses early in the evaluation of a project can demonstrate the tradeoffs between the main decision parameters, leading to right-sizing of the operation. Once major commitments to major capital items have been made, and reserves have been publicly reported, optimisation of the operation becomes much more difficult than if it had been done earlier. Such investigations can also identify the upside potential and downside risks associated with factors outside the company's control. Many strategies that may enhance value in the good times significantly increase the downside risk in the bad times.

What is often called risk analysis typically looks at superficial issues, and does not evaluate the major factors leading to the potential for financial disaster. This paper illustrates some of these major risks, and demonstrates how they may be fully evaluated so that corporate decision makers can make fully informed decisions that take account of the real risks.

Introduction

For some time it has been generally accepted that investments in mineral industry stocks and shares have been delivering poor returns, at or even less than the so-called “risk free” rate of return. One of the key reasons for underperformance is a lack of recognition of the large influence on value of the cutoff grade policy adopted by a mine, and the risks inherent in inappropriate cutoff specification. Most mines use a cutoff grade that is – or was at the time it was derived – some form of operating cost breakeven grade. The goals that are implicit in the derivation of the cutoff grade become defacto high-ranking goals of the corporation, whether they are recognised as such or not. A cutoff grade calculated as a breakeven places the mine on a path whose implicit strategy is to ensure that every tonne that is mined covers the costs that were included in the breakeven calculation. There is no logical reason why this should satisfy a goal of “maximising shareholder value” or some other similar typical corporate goal. There is also no guarantee that this will reduce the financial risk of the project.

From discussions with senior managers and technical staff in a number of client companies, and from various writings in the financial press, it is clear that there is a general lack of understanding amongst decision makers and those who adjudicate on their actions – in particular company boards and industry analysts – as to what creates and what destroys value for a mining operation, and the tradeoffs between financial and economic risks and rewards.

Typically, any increase in reported ore tonnes or contained metal is seen as “good”, and any reduction is seen as “bad”. Statements in the financial press that greet newly released resource and reserves figures would seem to bear out this generalisation. Even more so do comments made by senior

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corporate executives during mine strategy optimisation studies, when the results of investigations indicate that a significant improvement in value and reduction in risk could be made by increasing the cutoff grade. A typical response is: "We could never go out and announce a reduced reserve to the market!"

If there is an inherent positive correlation between metal in reserve and "value", however that may be defined, then the strategy to maximise reserves, and hence value, is obvious: specify a cutoff grade of zero. The immediate reaction to that is that low grade tonnes may cost more to produce than the revenue they generate, so they are not profitable and should be excluded from the reserve. Not all ore tonnes or contained metal add value. Some clearly reduce value if they are mined. That is why the concept of a cutoff grade exists – to distinguish what should be mined as ore and what should be discarded as waste.

In an ideal world, the ore tonnes and contained metal that are reported as reserves would all add value. If this were so, then "more is better and less is worse" is the valid conclusion. However, the "reserves" for many operations, whether publicly reported or only used internally for planning purposes, contain metal that destroys value and increases risk. In this situation, "more is worse and less is better" is the correct but unintuitive conclusion.

What is Value?

It is common to hear corporate goals expressed in terms such as "maximising the value of shareholders' investment". Industry analysts can be heard to say that "cash is king" as accounting profits are too easily manipulated. How do these public sentiments translate into actions when it comes to project evaluation and determining strategy at mine sites?

Net Present Value ("NPV") and Internal Rate of Return are two common parameters considered. This is rational, as ultimately, the real value of an operation depends on the stream of free cash generated by it, and NPV is arguably the best single number surrogate for quantifying a series of cash flows. Most companies, however, have multiple, and often conflicting, corporate goals, so other measures are frequently evaluated. These may include undiscounted cash flow and such other factors as ore tonnes and contained metal, mine life, unit operating costs, and various "return on investment" measures. The need to generate sufficient cash at the right time to meet debt servicing and operating commitments will frequently be a major concern. "Option Value" is becoming more frequently mentioned, though currently few people in senior management positions are able to clearly articulate what is meant by this term, and how this measure is to be derived and presented for decision-making purposes.

If a project returns a NPV of zero using the Weighted Average Cost of Capital as the discount rate, then by definition all the investors, both debt and equity providers, have received their required rates of return. A project with an NPV of zero therefore ought to be acceptable, but in practice this is rarely if ever seen to be the case. A positive NPV is usually required, and there is probably an unquantified intention to cover downside risk by doing this, as well as perhaps a general misunderstanding of the underlying principle that a zero NPV is in fact delivering what the investors require.

If a certain level of downside risk coverage is inherent in the demand for a positive NPV, this can be explicitly accounted for by enhancing the evaluation model using the facilities of a stochastic simulation add-in such as @RiskTM or Crystal BallTM to quantify the probability of not making a satisfactory return. These techniques have been described elsewhere (Davis 1995, Carr 2002) and this paper will not discuss them further.

Most feasibility studies and life-of-mine plans merely demonstrate that a particular option for project development is technically and financially acceptable. If this is not demonstrated, project sponsors will search for other ways of developing the project to make it economic. If the project as defined by the study is apparently healthy and robust, there will typically not be any attempt to find a set of options that provides a significantly better outcome. Although it is common to hear that a project being developed after a favourable feasibility study is being "optimised", this typically takes the form of finding better or cheaper ways of implementing the strategy identified by study. It rarely seeks to find a different and better strategy. Most mine plans are therefore based on a strategy that has been (at some time, but not necessarily recently) demonstrated to generate an acceptable positive NPV, but not on a strategy which has been demonstrated to maximise NPV. The same can be said of all or most of the other measures used by the company – acceptable results will have been demonstrated, but not that the best possible outcomes are being pursued by the strategy adopted. Minimisation of risk may be considered qualitatively, but it is rarely quantified and included in the formal determination of the "best" option.

The Critical Importance of Cutoff Grade For Creating Value

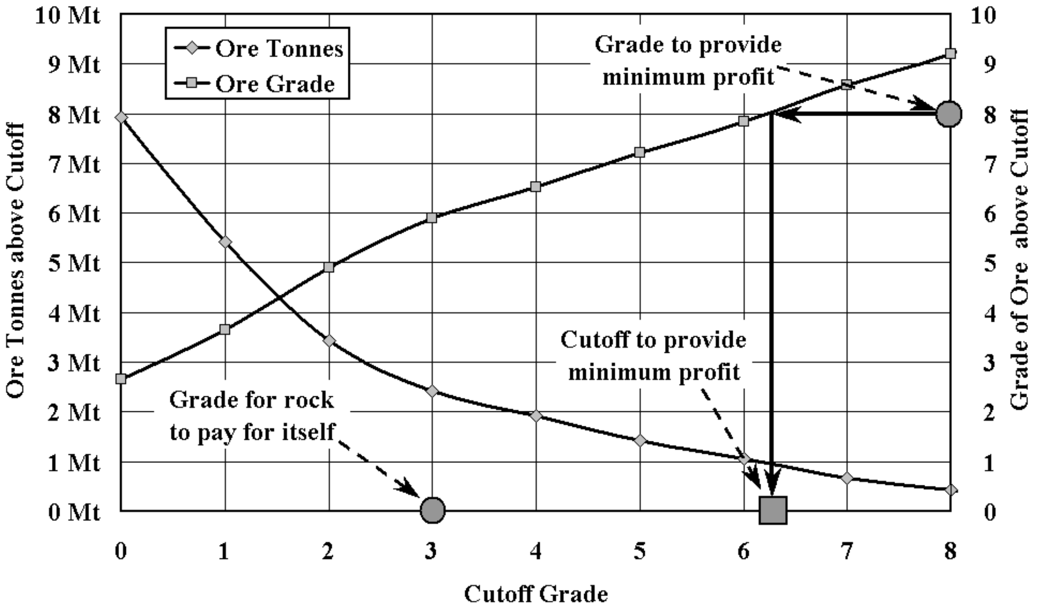
There is much emphasis in the industry on efficiency, productivity, cost saving, and the like. We may term this "Doing things right", and it is a good thing. But it is more important first to be to be "Doing the right things". Ultimately, the aim should be "Doing the right things right", but if the overall strategy is not right in the first place, no amount of efficiency in executing a suboptimal plan can maximise value.

For a given mineral deposit in a given social and economic environment, and with the existing infrastructure, the major parameters that a mining company can make independent decisions about are typically the mining method(s), mining sequencing, production rate, and cutoff grade (or "cutoff"). Since the size and shape of the orebody and hence possible mining methods and the range of feasible production rates may vary significantly with cutoff, it is the cutoff that is the key driver of value of the operation.

Once decisions regarding cutoff (and mining method and production rate) have been taken, most other factors are then to a large extent determined. Physical factors such as mining layouts and treatment plant design, and the capacities of various stages of the production process from mine to market will be known. Resulting from these are financial factors such as initial or expansion capital expenditure requirements, staffing requirements, and all the various components of the operating cost structure. Generally, mining companies will strive to maximise efficiency and productivity, and minimise costs, but once the major variables indicated above have been specified, there is generally limited potential for improvement.

As noted above, most mines use a cutoff grade that is – or was at the time it was derived – some form of operating cost breakeven grade, but there is no logical reason why this should satisfy a goal of "maximising shareholder value". Calculating a

Figure 1 – Mortimer's definition of cutoff illustrated



breakeven grade to use as a cutoff is a relatively simple process. It is merely necessary to specify the costs which are to be covered, and the net metal price received after allowing for metallurgical recovery and treatment and refining charges for the mine's product.

In the author's experience, technical and management staff in many mining companies, from senior corporate management to junior engineers and geologists, do not know why they are using the cutoff grades they are, nor how the values of those cutoffs were determined. Most operations tend to be working with a cutoff definition described by Mortimer (1950) and which may be summarised as follows:

1. The average grade of rock must provide a certain minimum profit per tonne milled
2. The lowest grade of rock must pay for itself.

In fact, the first leg of Mortimer's definition is generally ignored. When profitability is low, the requirement for a profit-based goal in the cutoff derivation is often recognised, but knowledge of how to implement it is lacking. Figure 1 shows a typical set of tonnage / grade curves, and indicates how Mortimer's definition works, including the profit-based goal.

The figure assumes that a breakeven grade of 3 units is required for the lowest grade material to "pay for itself", and this is therefore one possible cutoff. Also, an average grade of 8 units is assumed to be required to generate the required minimum profit, and this is achieved by setting a cutoff of a little over 6 units. The cutoff selected must be the greater of the two to achieve both the goals implicit in the definition, and in the case illustrated, this happens to be derived from the first leg of Mortimer's definition. In this case the breakeven pay grade does not satisfy the company's profit target.

In many cases where the need for profitability has been recognised, this requirement has been built into the breakeven grade, so that every tonne mined generates at least the minimum profit, and the minimum profit goal will be substantially exceeded. This will typically result in a cutoff that is significantly higher than it needs to be, and may have a significant adverse effect of the nature of the orebody, and the ability of the operation to sustain a viable production rate.

There is no reason why the cutoff required to give a specified minimum profit should always be greater than the breakeven pay grade. If the required average grade had been found to be 5 units, then the required cutoff for the minimum profit requirement would be approximately 2 units, and so the breakeven pay grade of 3 units would be selected, and the minimum profit required would be exceeded.

It can be seen that Mortimer's definition takes into account a profit-related corporate goal. The cutoff to be used will depend both on the economic calculations of the grades required to satisfy each leg of the definition, and the nature of the mineralisation, as described by the shape of the tonnage / grade curves. It does not however take account of the production capability of the orebody at any cutoff thus derived.

When documentation relating to cutoff derivation is available, it is usually, in the author's experience, a superficial breakeven analysis in line with the second leg of Mortimer's definition. Assuming that if the cutoff analysis had been any more rigorous it would have been recorded somewhere, the unpalatable conclusion is that much of the industry is working with cutoffs that, at best, have been derived using half a 1950's definition. Recognising that in many cases a simple breakeven grade used as the cutoff will not generate the required minimum level of profitability, and ignores the nature of the mineralisation, and that neither of these accounts for the production capability of the resulting "orebody", we may well ask if it is any wonder that the industry produces poor returns.

Current typical industry practices would therefore seem to unwittingly increase the risk of poor economic performance.

Finding and Climbing the "Hill of Value"

Unfortunately there is no similar simple "working backwards" process to derive a cutoff that maximises value and / or minimises risk. Lane (1988) presents an analytical technique which will result in the derivation of an optimum cutoff or cutoff policy. (A "cutoff policy" is a planned sequence of cutoffs over the life of the mine.) Lane's process is somewhat more complex than calculation of a simple cost breakeven, and is directed solely at maximising NPV. Other corporate goals cannot be assessed using Lane's methodology, and in many cases, real-world complications render his relatively straightforward analytical processes inapplicable, though the underlying principles may be applied in more complex analyses.

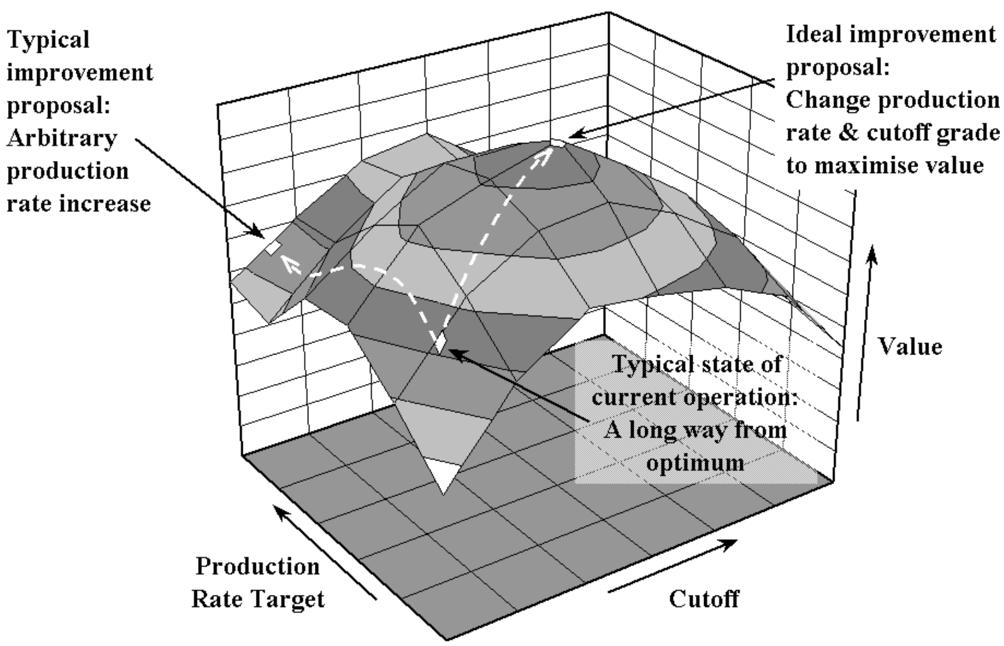
Lane's methodology accounts for both economic factors and the nature of the mineralisation, as does Mortimer's full definition, and in addition takes into account the capacities at various stages of the production process from mine to market. Six possible cutoffs are derived for the increment being considered in a Lane-style cutoff analysis (cf. two for Mortimer's definition), one of which will be optimal. The theory can be applied to determine a single optimum cutoff for use in the short term, or an optimum cutoff policy for the life of the operation. The theory and methodology are not explained further in this paper, but are fully described in Lane's textbook (Lane, 1988).

Even though Lane's theories were initially published nearly 40 years ago (Lane, 1964), and were made generally available in textbook form some 15 years ago (Lane, 1988), the author's impression, through discussions with numerous experienced geologists and mining engineers, is that, although most are aware of the existence of the theory, very few have read it, understood it, and applied it at their mines. To attempt to overcome many of these problems, the author has been using a technique he has termed the "Hill of Value". The methodology simply makes use of the advanced modelling and three-dimensional charting capability of Microsoft ExcelTM to derive value surfaces showing the overall relationship between value and two independent variables, which will typically be cutoff and another key value driver, such as production rate target. Figure 2 is a Hill of Value from a real study conducted several years ago, and it demonstrates the concepts of the technique.

When profitability at a mine is low, typical responses are to embark on a cost cutting exercise, and to increase production rate to spread the fixed costs over a larger tonnage base and hence reduce the average unit cost. In the short term, to accomplish this increase in production, it is often necessary to lower the cutoff to make more ore available. If the cutoff used at the mine is a cost breakeven, then the reduction in cutoff may appear to be justified by the reduction in unit costs arising from both cost cutting and the production rate increase. The new mine plan then typically continues using this lower cutoff for the foreseeable future. This has been dubbed "The Temptation of Tonnage" (de Vries and McCarthy, 1999). It may be a valid tactic in the short term, but is frequently a destroyer of value if pursued in the longer term. Lane's methodology if applicable will indicate quantitatively to what extent this cutoff lowering may be valid, but it may also show that a cutoff increase is required.

Typically in such expansion studies, one or two higher production rate targets are specified, and a study is conducted to evaluate these two options alongside a base case "change nothing" option. Often, a significant increase in capital expenditure will be required at some point as the production target is increased, and if the new capacity is not fully utilised, value will not be added. Increasing the production rate arbitrarily– even with a cutoff reduction – may result in an increase in value, but often it will not, and even if it does, the increase in NPV may be too small to justify the risk of spending project capital for an expansion. The real problem is that, unless a Hill of Value such as in Figure 2 has been generated, there is no way of knowing what combination of the key decision variables results in the maximum value creation potential for the operation. Clearly, all other things being equal, the optimum strategy is the combination of cutoff and production rate that defines the peak of the Hill of Value in Figure 2.

Figure 2 – Finding and climbing the "Hill of Value"



The vertical axis in Figure 2 is labelled "Value" without specifying what measure is being used. In this figure it is NPV, but it can be any measure of interest to the company. If the evaluation model is robust enough to generate NPV for all the combinations of cutoff and production target, it should be a trivial matter to report and plot similarly any other parameters desired. In another study, Hills of Value for NPV and Gold Production, and a Valley of Cost per Ounce, for various cutoffs and underground mine production targets were produced. Figure 3 summarises NPV at three different discount rates, plus gold output and unit cost, all as a function of cutoff, and for a given production rate target. As is to be expected, the same cutoff is not optimal for every value measure of interest. However, the Hill of Value technique clearly shows the tradeoffs required to optimise one or more at the expense of the others, and depending on the shapes of the curves, may permit selection of a cutoff policy that generates close to optimum results for a number of the measures of interest.

Broad Conclusions From Optimisation Studies Conducted

A number of Hill of Value optimisation studies, some supplemented by other techniques, have been conducted by the author and his colleagues over the last few years. The techniques have been successfully applied in underground mines, open pits, and beach sands dredging operations. This section highlights a few of the key conclusions that have been drawn. It should be emphasised that at this stage a rigorous statistical analysis of results has not been conducted to back up these conclusions – in most cases there are too few data points to do so – but certain trends are becoming apparent.

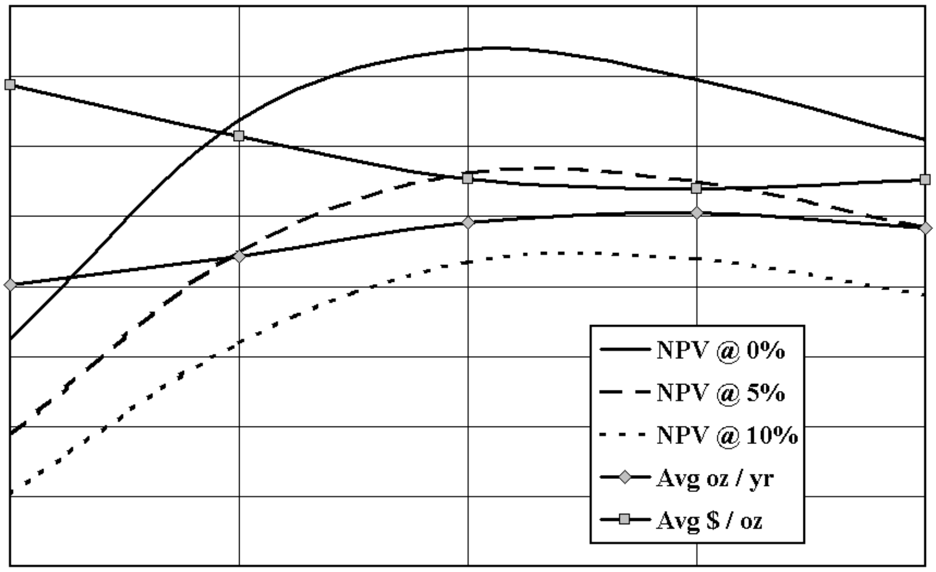
1. Many underground mines are operating with a cutoff that is some 65% - 75% of what is required to maximise NPV.
2. Open pit mines may be able to improve value by increasing their mining rate of total rock (ore plus waste) without incurring the capital costs of increasing the ore treatment rates. This permits higher grade ore to be treated immediately while lower grade material is stockpiled.
3. Volatility of the optimum cutoff (to maximise NPV) is frequently much lower than the volatility of the breakeven grade when metal prices or costs change. The optimum cutoff may actually increase when prices increase or costs fall.
4. The optimum cutoff policy for operations with multiple ore sources, each with its own production constraints, may be one that sets different cutoffs for each source, adjusting their reserves so that all sources are depleted simultaneously.
5. Lower returns resulting from lower than predicted metal prices may be being made significantly worse than they needed to be by adopting suboptimal strategies based on price predictions that prove to have been optimistic.

The "Hill of Value" in Practice

The Mine Optimisation process using the Hill of Value technique is in principle no different from any other "Life of Mine" study that a technically competent planning team would conduct, except that, due to the number of combinations of options to be tested, somewhat more manual design work than usual may be needed, and evaluation models need to be substantially more flexible than those typically used for a "single scenario" study. As with any study of this nature, various levels of detail and accuracy may be specified. Typically, a less accurate higher level study may be conducted first to identify the most likely value maximisation strategies. This may be followed by a more detailed study of a smaller number of options if deemed necessary.

The following discussion summarise key aspects of various study components, with particular reference to how they may need to be handled for an optimisation and risk management study where this differs from a typical single scenario study. These matters are discussed in more detail elsewhere (Hall, 2003).

Figure 3 – Multiple parameters as functions of cutoff



Geology

A reasonably reliable model of the mineralisation for the range of cutoffs to be investigated must be created. Often the existing model is adequate, at least for a higher level study. However, it is not uncommon for the geologists to be uncomfortable with the reliability of the model at cutoffs significantly higher or lower than a particular range. As long as the limitations of the model at certain cutoffs are recognised, initial work can usually proceed without a major geological study. If the peak of the Hill of Value lies in a cutoff range with lower geological certainty, the difference between the maximum value and the maximum value obtainable in the cutoff range with an acceptable level of geological uncertainty will indicate how much can profitably be spent to increase confidence at the cutoff that maximises value, or varying geological costs can be included in the Hill of Value calculations at different cutoffs.

Mining parameters

Having acquired a suitable geological model, it is then necessary to generate orebody outlines at each cutoff. For an underground mine, it is necessary to identify suitable potential mining methods at each cutoff. Realistic mining shapes can be designed for each of these, and hence mining reserves derived for each cutoff and method. For open pits, bulk or selective mining methods may be indicated at different cutoffs. Conceptual mine designs and schedules must then be developed for selected representative cases. By applying a suitable level of engineering judgement, the number of scenarios to be fully planned can be minimised, and parameters for other scenarios interpolated.

Metallurgical parameters

Recovery relationships must be specified for the range of cutoffs to be evaluated. Other parameters that may vary with treatment plant feed quality may need to be identified. Constraints at various stages of the metallurgical process need to be identified, and the actions required to remove them. It is important to distinguish between real physical constraints and operating preferences that are not genuine physical limitations. It may be important to investigate the merits of retaining or relaxing existing rules. Metallurgical plant upgrade options must have their effects on such things as recovery and product quality identified. The optimum cutoff and production policy with one set of upgrade options implemented will not necessarily be the same as with a different set.

Operating costs

Several different categories of costs need to be identified, together with the physical parameters, or cost drivers, on which they depend. Because ratios of various physical quantities will vary with different cutoff and production policies, simple “dollar per tonne” cost models are usually inadequate for a study of this nature, as these simple unit costs are derived for one set of relationships between parameters, which will not be valid for many of the scenarios to be evaluated. “Fixed” and “Variable” cost components and their physical drivers over the full range of activity levels to be investigated must be identified.

Ongoing capital costs

Several different types of ongoing or sustaining capital expenditure may need to be identified and handled appropriately. Modelling processes must be able to produce capital cost schedules to a reasonable level of accuracy over the range of production options evaluated.

Debottlenecking or Project Capital

This is typically proposed to increase capacity in some part of the production system, or to improve product quality. The optimum cutoff and production policy with one set of upgrade options implemented will not necessarily be the same as with a different set. Project capital expenditure should be justified on the basis of the difference in maximum values obtainable with and without the expenditure, and not on the basis of the difference in values at a fixed cutoff or production rate. Failure to recognise this principle may result in loss of potential value or increase in financial and economic risk.

Risk Analysis and Counterintuitive Outcomes

Lane’s theory, the Hill of Value, and related methodologies are powerful tools for improving the profitability of mining operations, though they are rarely applied in practice. Once a suitable evaluation model has been developed, it can be used to generate much more useful information than just Hills of Value. It becomes a significant risk assessment and management tool for project viability and profitability.

Hills of Value for risk management

Figure 4 shows Value vs Cutoff curves for two different metal price predictions. What cutoff strategy should the operation adopt? The temptation is to select the cutoff that maximises the value at the higher price, since this clearly maximises value overall. However, the figure shows that if a higher cutoff to maximise value at the lower price is selected, and the higher price then occurs, most of the potential increase in value is obtained anyway. The real gain obtained by selecting the lower cutoff (to maximise value with the higher price) is in fact quite small. But if the lower cutoff that maximises value at the higher price is selected, and the lower price then occurs, the loss may be substantial.

Figure 5 shows actual gold prices and consensus predictions over a number of years. It can be seen that the predictions are generally optimistic. Similar data plots for other base and precious metals show similar trends, not necessarily all the time, but certainly for long enough periods of time for mining strategies to be developed, implemented, and rewarded by sales into the markets.

Noting therefore that not only are predicted prices often optimistic, but also that cutoffs are often set at values below those which maximise value, Figure 6 indicates how the downside risk shown in Figure 4 may be significantly magnified by typical operating policies using breakeven grades as cutoffs.

The trade-off between risk and reward evident in Figures 4 and 6 will be dependent on the shapes of the Hills of Value, and these will obviously vary from project to project. The magnitudes of the risks and rewards flowing from cutoff policy selection are such that they cannot be delegated to junior technical staff on mine sites, nor even to more senior technical staff in head offices. They have a direct and major impact on the value and financial strength of the company, and must be a matter for board consideration and decision making.

Figure 7 shows real curves from a recently completed study. The figure shows NPVs for a range of cutoffs, all other things being equal, for gold prices of A$500 and A$600 / oz. The

Figure 4 – Risks and rewards of optimum cutoffs

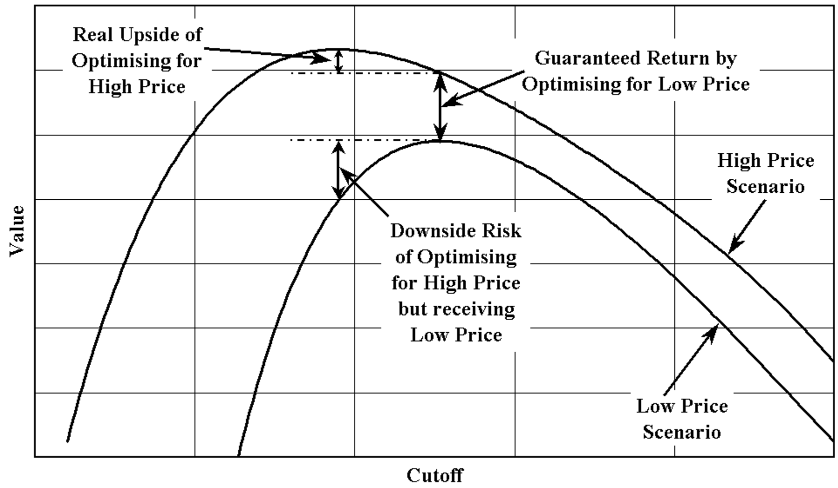


Figure 5 – Actual gold prices and consensus predictions

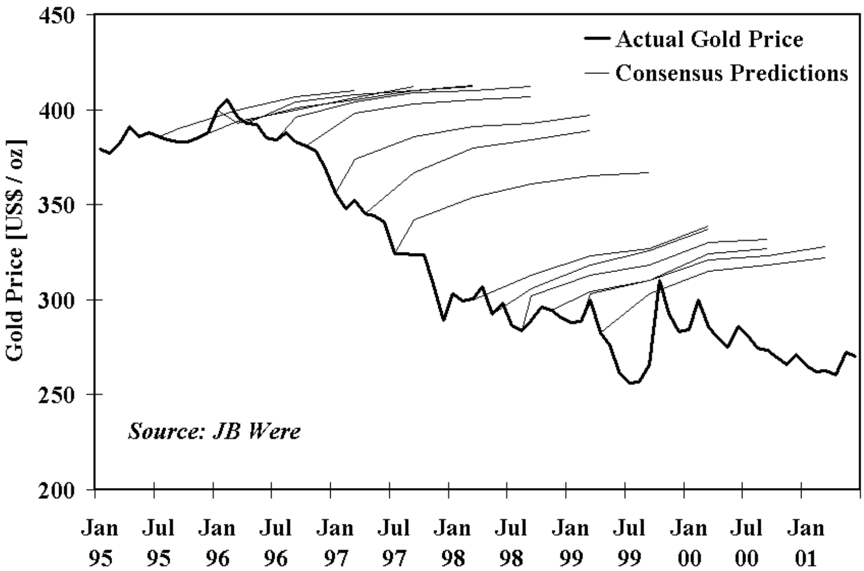


Figure 6 – Risks and rewards of incorrect price predictions and suboptimal cutoffs

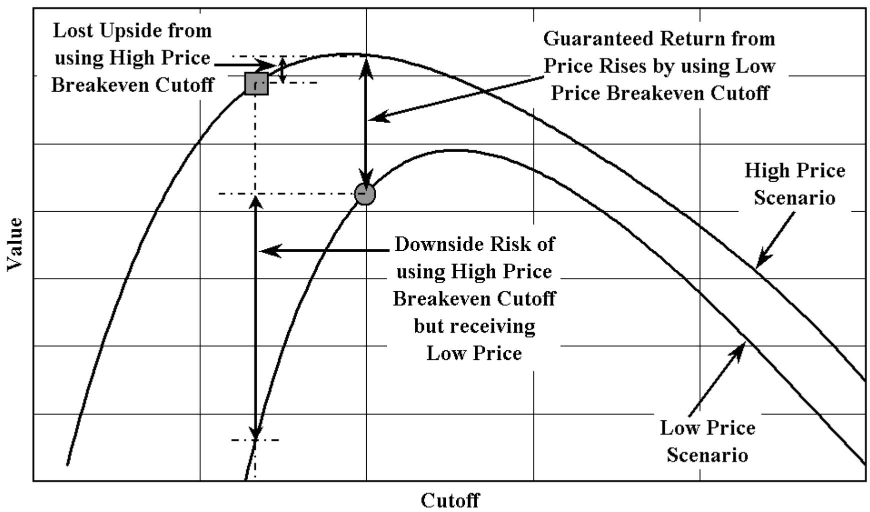
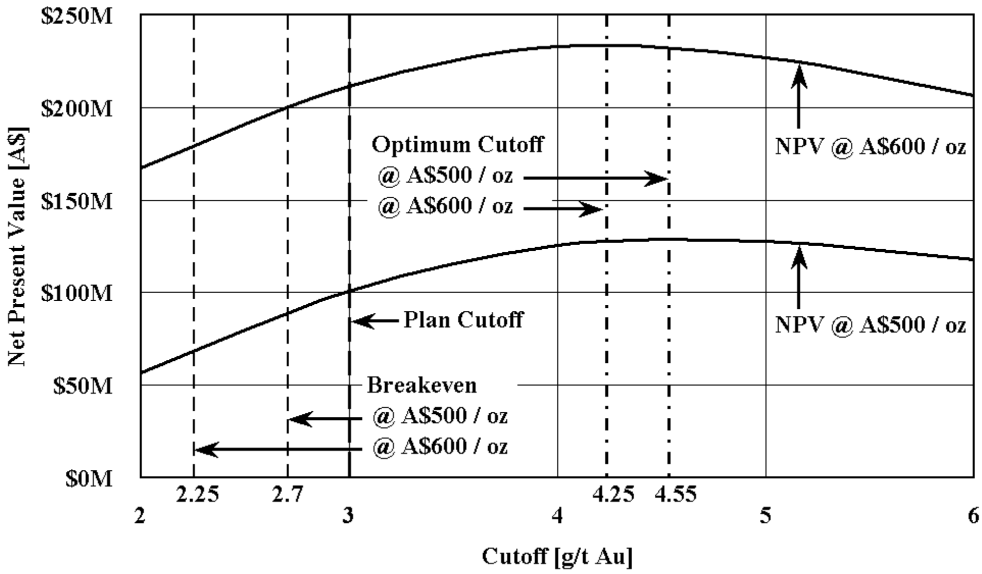


Figure 7 – Case study results at different prices



operating cost breakeven grade at each price is indicated, as is the mine's planned cutoff for both present and future stope designs.

It can be seen that, for example:

- For a 20% increase in price from $500 to $600, the breakeven decreases by 17%, but the optimum cutoff decreases by only 7%.
- A cutoff selected in the range of say 4.0 to 4.5 g/t Au is near the flat top of the Hill of Value, and will result in small variations in NPV, of the order of 1% to 2% of the maximum value at each gold price.
- For cutoffs in the range of 2.0 to 3.0 g/t Au, representative of the breakevens and planned cutoff, NPVs vary by some A$4 million to A$5 million for each 0.1 g/t change in cutoff at both gold prices.
- If the $500 breakeven were selected as the cutoff and a price of $600 was received, the NPV would be some A$25 million greater than it would have been using the $600 breakeven as the cutoff.
- If the $600 breakeven were selected as the cutoff and a price of $500 was received, the NPV would be some A$20 million less than it would have been using the $500 breakeven as the cutoff.
- NPVs received by using the Planned, $500 Breakeven, and $600 Breakeven cutoffs are respectively 10%, 15% and 25% less than the NPV using an optimum cutoff of 4.0 to 4.5 g/t Au if the price received were A$600 / oz. A 10% variance is equivalent to some A$23 million.
- NPVs received by using the Planned, $500 Breakeven, and $600 Breakeven cutoffs are respectively 20%, 30% and 45% less than the NPV using an optimum cutoff of 4.0 to 4.5 g/t Au if the price received were A$500 / oz. A 10% variance is equivalent to some A$13 million.

In this case study, there is little risk associated with using an incorrect metal price for selecting the optimum cutoff. Technical staff can make suitable recommendations without being aware of the company's risk-reward profile. However, if lower cutoffs are to be used for some reason, there are significant risks associated with the selection of the metal price to be used for determining the strategic policy. Technical staff are unlikely to be in a position to make informed recommendations, but can only present information such as the above discussion to senior decision makers.

Counterintuitive effects of cutoff optimisation

Cutoff changes with variations in metal prices and costs

It has been suggested that, during times of high prices, it might be advantageous to increase the cutoff, thereby increasing the head grade and payable metal production, and hence cash flows, always assuming that the planned ore tonnages can be maintained. Conversely, when prices are low, it might be better to lower the cutoff, conserving higher grade ore for better times. (These strategies if generally adopted, would also increase overall supply of product into the market and drive down high prices, or reduce supply and drive up low prices, thereby acting as a price stabilisation mechanism.)

These postulations are at odds with conventional wisdom, which suggests that cutoffs should move in the opposite direction to price changes. If a mine's cutoff is defined to be a breakeven grade, this conventional wisdom will apply. But if the cutoff is (unconventionally) set to maximise NPV, the conventional wisdom may not apply. Formulas in Lane's methodology include not only the conventional variation in breakeven, but also the time-value-of-money cost or benefit of varying the timing of the receipt of the NPV of the rest of the operation. This depends on the amount of material in current mining areas which is treated as ore.

For example, any incremental ore treated from current mining areas will result in a deferral of the mining and treatment, and hence the receipt of the value, of the rest of the operation. There is a time-value-of-money cost associated with this. An increase in predicted price will drive down the breakeven grade for the defined cash costs, which do not change. However, the price increase will also increase the NPV of the rest of the operation, and hence the time-value-of-money cost of deferring it. The grade of incremental material must therefore cover both the "normal" cash costs and the time-value-of-money cost which its mining would induce. The converse is true if prices fall. In a high value operation the change in the time-value-of-money cost may outweigh the change in "normal" cash costs breakeven when the price changes.

The author's experiences, as exemplified in Figure 7, confirm the reality of these effects. Increasing optimum cutoffs with increasing prices have not been observed in studies conducted to date, but the proportionate changes in optimum cutoff are significantly lower than the corresponding proportionate changes in "normal" breakeven.

As a general principle, these Hill of Value techniques can be used to assess the trade-offs between risks and rewards of various strategy options which may be selected by the mine in conjunction with various possible scenarios for parameters outside the mine's control. The important thing is not so much to identify what the value of a particular option may be, but rather what combinations of circumstances will make the results of one set of selected options better or worse than those of another: in other words, what circumstances would cause the mine to decide to change its strategy, and whether to aim to maximise potential upside rewards or minimise potential downside losses.

The discussion above has focussed on metal prices, as these are correctly seen to have a major impact on the value of an operation. The discussion shows however that substantial variations in price will not necessarily have a major impact on the optimum mining strategy. A similar argument can be applied to costs. Ultimately an increase in price received has the same effect as a cost reduction: both result in an increase in margin. The counterintuitive conclusion is that, just as price rises may drive the optimum cutoff up, cost reductions may do the same.

Different cutoffs for different areas

Another counterintuitive result that has come out of a limited set of studies using genetic algorithms to enhance the capability of a Hill of Value model is that, in certain circumstances, different cutoffs may be required for different operating areas. This is not especially controversial if they have different metallurgical parameters or cost characteristics. However, where these factors are identical and the areas are producing simultaneously, different cutoffs may still be the optimal strategy if the reserve tonnages and maximum production rates are different.

The scenario typically occurs where there are separate orebodies or mining areas in an underground mine, or different open pits supplying mill feed in surface operations. As time progresses, ore sources will be progressively exhausted, and production will come from fewer and fewer sources. Eventually the stage will be reached where production reduces to the point where it is no longer economic to continue producing at the rates achievable from the remaining sources, and the mine will close. By increasing the cutoffs from the outset in these remaining sources, higher grade material can be extracted while the mine is still producing, rather than being left unmined using a lower standard cutoff.

Analyses using genetic algorithms have indicated that the optimum strategy may be to adjust the cutoffs for all the sources so that production is maintained at a high rate up to a certain point, at which time all mining areas are shut down immediately to avoid a high cost low production rate tail. The cutoffs for each area must be set so that each has produced the highest possible ore grades during its life. The studies indicate that it is not just the late stage sources whose lives should be adjusted in this way, but also some of the earlier sources, especially those that logically precede the late stage sources that would constitute the late stage low production rate tail. Other sources may have their cutoffs reduced to extend their lives to balance the schedule of production sources.

Further work is required to investigate these types of scenarios. It is unlikely that there is a general solution to be applied in all circumstances, other than to recognise that optimum cutoffs may be driven not by costs nor tonnage / grade curves nor plant capacities, but by the mining schedules and the interdependencies between production sources. From the risk management perspective, the conclusion is that closure production plans need to be developed well before the end of the mine's life. The viability of the operation, its life, and the returns it generates in the final years, may be significantly impacted by decisions made years earlier.

Objections

In developing and applying the Hill of Value and associated methodologies at a number of operations, a number of common objections have arisen, especially when the results indicate that the optimum strategy is to increase the cutoff above what has been in use, thereby reducing reserves and mine life. The headings of the following subsections are typical statements of the objections, and the text of each subsection indicates responses to the objections. The discussion here summarises objections that are particularly relevant to risk management. These objections, and others, are discussed in more detail elsewhere (Hall, 2003).

Value is maximised by producing until Marginal Cost equals Marginal Revenue

This is a principle that is taught in all basic economics courses. It has been developed in the context of manufacturing industry, where the main assets of the firm are its production facilities. Resources and markets are external to the firm, and successive time periods are essentially independent. If goods are not made and sold in the period being considered, the opportunity is lost forever. Decisions about what to produce and sell made in one period do not influence the life of the firm, which is typically assumed to be infinite. The value of the firm is therefore maximised by making independent decisions that maximise the value obtained in each period.

The mining industry is different. Although it has production facilities, its prime asset is its mineral resource, which is finite. Decisions made about what to do with a portion of the resource in one time period will affect what remains of the resource for exploitation in later periods, and hence its value.

Producing so that marginal cost equals marginal revenue is almost guaranteed to ensure that a mineral deposit does not deliver the maximum value possible. This is directly at variance with the experiences and economic understanding of many senior mining industry leaders who do not have a mining industry background, and also perhaps of many who do, since the difference is not, in the author's experience, widely recognised in the industry. There is a real risk that unthinking application of conventional economic wisdom will reduce the value of a mining operation.

The best strategy can be identified by simple studies and intuition

Industry results have been inadequate for a number of years, and even if they were good, Hill of Value analyses indicate that they could be significantly better. The experiences on the basis of which some claim to have developed an intuitive feel for what is right for an orebody are experiences that have led to suboptimal outcomes, and hence the intuition is faulty and cannot be relied upon. The risk of arriving at a sub-optimal result from failure to do a rigorous study is high.

There is no time or money available for optimisation in the feasibility study. It can be done when the mine is in production and costs and performance are known better.

An optimisation study can obviously be done at any time. There is an understandable desire to reduce the time and cost involved in preproduction studies. However, as noted above, many feasibility studies merely prove the feasibility of a particular strategy for an operation, with no guarantee that it is anywhere near optimal. Once the strategy has been selected, items of plant and equipment are sized appropriately, and reserves are reported publicly. Both of these factors may severely limit the ability of an operation to change to a plan that can generate higher values, either practically through physical limitations and the cost of removing them, or politically through a perceived inability to report a reduced reserve to the market.

This objection highlights the industry's tendency to focus on cost rather than value creation. A full optimisation study may be more expensive than conducting a simple breakeven analysis, but this cost is usually small compared to the total cost of a feasibility study, and potential value gains identified in studies are typically orders of magnitude greater than the cost of the study. While a full optimisation study will usually identify significant additional value that may be available whenever it is done, the sooner this is identified, the greater it is likely to be, and the greater the chance that it can be realised. Figure 8 illustrates the potential risk associated with failure to conduct a rigorous analysis, particularly where there are significantly different options available.

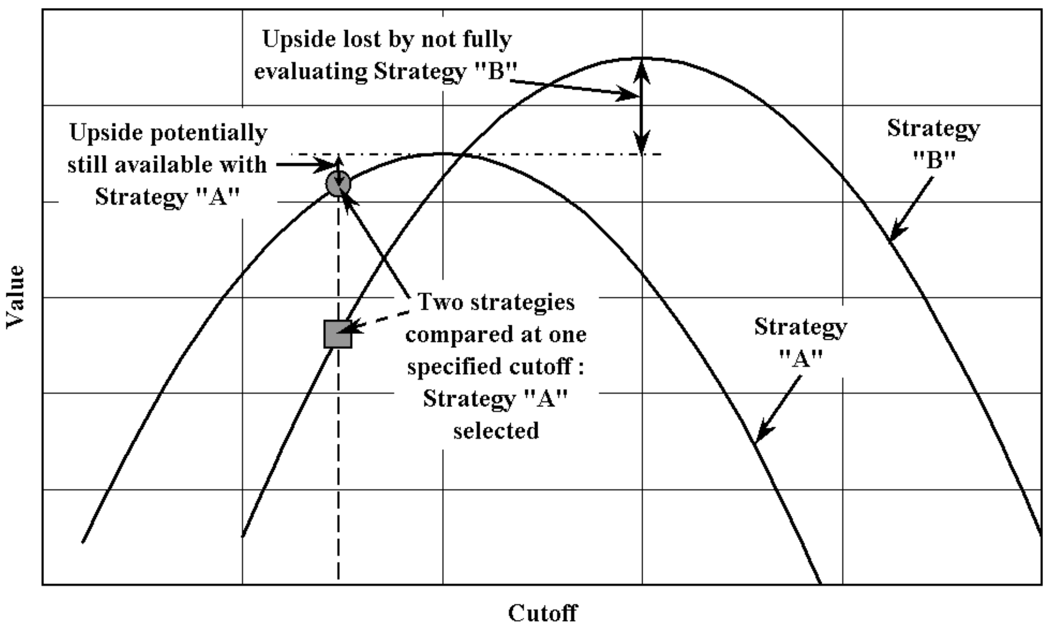
The market will react adversely if a reduced reserve is reported.

The author has encountered this response on a number of occasions. There is a real aversion to reporting a reduction in reserve. As noted above, it is typically assumed that everything in the reported reserve adds value, though this is often not the case. The quantum of the reserve base available for depreciation and amortisation is also a concern for many companies. The perverse effect of these issues is that there is a fear that announcing strategies that increase value will actually drive share prices down.

Ideally a study should be done to optimise the mine strategy, including cutoff grade, before reserves are first reported publicly, so that the optimum rather than a suboptimal figure is in the public domain from the beginning. Mines that are already in operation with a suboptimal reported reserve should be able to demonstrate to opinion-forming analysts and financial commentators the wisdom of their apparently unconventional plans to improve value, but it is acknowledged that this may not be as successful as might be hoped.

It may be, however, that the underlying assumption that reporting reduced reserves will cause the share price to fall is not valid. If the assumption is false, then reporting reduced reserves should then not be a concern to mining companies. Cases have been observed where newly reported reserves that were lower than analysts were expecting did not apparently result in share price reductions. For companies with large resources and long life, this might not be a major issue, but this might not be the case for less robust companies with smaller reserves and shorter lives.

Figure 8 – Potential losses through failure to conduct a full analysis



To the extent that downward revisions of reserves draws unfavourable comment in the financial press, there is a real concern that those who are making public pronouncements on reserves and their impact on values of companies are apparently unaware of how optimum cutoffs and values may change as a result of for example price or cost changes. There is a real risk that through lack of knowledge and understanding, shareholder value is being driven down by those whose role it is to improve it, both officially – the boards of mining companies – and unofficially – the analysts who make pronouncements that affect share prices.

How to handle this issue is of course the prerogative of each company. The Hill of Value technique merely provides decision makers with a lot more information than they have traditionally had to assist in making decisions affecting the value of their firms. The Hill of Value shows how much shareholder value is being written off if the decision makers choose, for whatever reasons, to select a strategy that does not deliver maximum value.

Reducing the mine life reduces the probability of exploration making another discovery that could profitably extend the life. This is a valid concern, though typically it will not have been addressed in deriving the existing mine plan. It is perceived that increasing the cutoff and reducing the mine life increases the risk of premature closure of mining operations in a region.

One way to evaluate this effect is to conduct some form of probability analysis. The evaluation model can be enhanced using the facilities of a stochastic simulation add-in such as @RiskTM or Crystal BallTM to include in each year of operation a probability of exploration success, and probability distributions of the tonnage and grade of material discovered, if any. These discoveries would then become additional reserves to be handled by the model. This technique is simple in concept, but acquiring the input data for the probability distributions may be problematic, and interpreting the results would be more complex.

The comments above assume that annual spending and exploration activity do not change, regardless of the predicted mine life. The author suggests that this is an unrealistic assumption. The alternative treatment of this concern, favoured by the author, and implemented in a recent study, is to recognise that, given the mine life as it exists in the current plan, there is an implicit commitment to spend a certain amount on exploration over the life of the mine. If the mine life is to be shortened, then that funding should still be spent, but over the shorter mine life, or preferably some shorter period to allow for development of discoveries before existing resources are depleted. The probability of exploration success is thus identical in all scenarios, and the peak of the Hill of Value for NPV will take into account the timing of the exploration cash flows.

Conclusions

The fact that all mines have cutoff grades indicates that it is well known that there is some mineralised material at every operation that is not economic. This uneconomic material is correctly excluded from the reserves. What is not well understood is that reserves of material above the cutoffs in use at many operations also include material that is not economic, in that its inclusion in the mining plan reduces the value of the operation, however that may be defined.

The goal implicit in the method by which the cutoff has been determined will effectively become the corporate strategy. Many mines are operating with a cutoff that is calculated as some form of operating cost breakeven. The author has yet to hear a company announce that its goal is to ensure that every tonne of ore mined pays for itself. Yet this is the corporate strategy that is effectively put in place by utilising a breakeven cutoff grade. If the company's goal is to maximise value, however that might be defined, the cutoff grade policy selected must be determined by reference to that goal, and demonstrably lead to its achievement. The cutoff policy selected should also take account of the risks inherent in various possible strategies.

This paper has demonstrated how the Hill of Value technique and related methodologies can be used to select a cutoff policy that meets some or all of the various goals that a company may have, and to identify any trade-offs that may be required when some goals are incompatible with others. It has also been demonstrated how these techniques can be used to evaluate the trade-offs between potential upside rewards and downside risks, and how current strategy-setting methodologies may in fact be exacerbating the poor returns that the industry has been delivering in recent years. The techniques presented offer corporate decision makers substantially more information on which they can base their decisions than they have typically had in the past, and it is ultimately their prerogative to specify the cutoff policies that will best achieve the corporate goals within the constraints of the corporate risk-reward profile. This is a task that cannot be delegated to technical staff on site or in backwaters in corporate head offices.

It is apparent from comments made to the author by senior staff in a number of companies, and from comments in the financial press, that analysts and corporate decision makers are focussing on measures that are not correlated with value creation. Unfortunately, because of that focus they then have the potential to become the value drivers in the market place. Mine plan strategies that should add value have the potential to drive down share prices, and vice versa.

Until all associated with value creation in the mining industry – senior corporate decision makers, technical staff at all levels, and analysts – recognise and demand that mining plans and strategies, particularly with regard to cutoff policy specification, demonstrably deliver real, not perceived, value maximisation, the industry will continue to deliver below average returns for above average risks.

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