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# How Mining Companies Improve Share Price by Destroying Shareholder Value

**By B E Hall [1]**

## Abstract

*For some years, the mining industry has been consistently delivering returns below the market average. One of the causes is a disconnect between what is perceived to drive value creation by many industry analysts and senior corporate executives, and what actually drives the intrinsic value of mining operations. The perverse effect is that strategies that should increase value are perceived to have the potential to drive share prices down, and vice versa.*

*This paper challenges common perceptions of what drives a mining company's value. Anecdotal evidence suggests that the key drivers of value in the market, and hence in many boardrooms, are such things as increasing the reserves and production rate, and reducing unit operating cost. However, while the quoted reserves may satisfy ore reserves reporting code requirements to be economic, this does not imply that they are optimal. Often, a proportion of the quoted reserve reduces the potential value of the operation. Metal price increases, increased production rates, and operating cost reductions are all seen as conditions or actions that can improve value, and lead to cutoff grade reductions, thereby increasing ore reserves. However, modern cutoff theory and studies conducted by the author and his colleagues show clearly that, while breakeven cutoff grades will fall in these circumstances, optimum cutoffs may be much less volatile, and may even increase.*

*Results from case studies indicate that value is maximised by right-sizing, not maximising, the production capacities, and by optimising the cutoff strategy. Values of many existing underground mining operations can be increased significantly by a substantial cutoff grade increase. Also, an increase in downside risk, and hence reduced returns, can occur using typical life-of-mine planning strategies if prices received are lower than predicted. Since this is often the case, low industry returns may be a direct result of typical strategic mine planning processes.*

*Relatively simple cost-effective techniques are available to provide senior decision makers with information needed to assess the tradeoffs between their many conflicting corporate goals, and the balance between risk and reward. Often this information is not being generated at all. If it is, decisions affecting the value of the company are occurring by default at relatively low levels within the hierarchy, with senior executives apparently unaware of them or their potential impact. The paper concludes that without a re-evaluation of the way mining projects are valued, to demand proven value optimisation from mining plans by boards and mining analysts, the industry will continue to deliver below average returns.*

## Introduction

For many years it has been a common complaint 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. 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.

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.

In the discussion that follows, a precious metals mine is assumed. The terms "tonnes" for ore reserves and mineral resources, and "ounces" for the recoverable revenue-generating metal product, will be used. Typically, any increase in reported tonnes and ounces is seen as "good", and any reduction is seen as "bad". Statements in the financial press that greet newly

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released resource and reserves figures would seem to bear out this generalisation. Even more so do comments made by senior corporate executives during mine strategy optimisation studies, when the results of investigations indicate that a significant improvement in value 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 we accept that the market, and hence boards of directors who respond to market reactions, apparently assume a positive relationship between ounces 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 concept is, quite correctly, 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. It is therefore common knowledge that not all tonnes or ounces add value. Some tonnes and ounces clearly reduce value if they are mined. That is why it is necessary to invoke the concept of a cutoff grade – to distinguish what should be mined as ore and what should be discarded as waste.

In an ideal world, the tonnes and ounces 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 value-destroying ounces. 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 they are not concerned about reported accounting profits, as they are too easily manipulated: rather “cash is king”. How do these public sentiments translate into actions when it comes to project evaluation and determining strategy at mine sites?

Discounted Cash Flow (“DCF”) methods are used almost universally as the primary method for project evaluation. Net Present Value (“NPV”) and Internal Rate of Return (“IRR”) are the two most common parameters considered. This is rational, as ultimately, the real value of an operation depends on the stream of free cash generated by it. The owners of the operation cannot spend tonnes, ounces, or mine life. 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. Other measures are therefore frequently evaluated and enter into the decision-making process. 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, of both DCF and “accounting” types. 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. This is a major topic in its own right, and certain aspects relevant to this paper are discussed below.

If a project returns a NPV of zero using the Weighted Average Cost of Capital (“WACC”) 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.

The logical corollary to this is that theoretically it ought to be satisfactory to set a cutoff grade such that the NPV of the mining project is zero. This may be a perfectly acceptable option in some countries, depending on national policies for employment, utilisation of resources, and the like. It would generally not be acceptable in western “capitalist” nations, where corporate law requires company officers to work for the best interests of the shareholders. A return above the bare minimum is usually required.

It is important to note at this stage that most so-called “feasibility studies” are in fact precisely that and nothing more. They merely seek to demonstrate to the satisfaction of the various stakeholders that a particular option for project development is technically and financially acceptable, and it is therefore feasible for the project to proceed as defined by the assumptions and options included in the study. If a feasibility study does not demonstrate this, then it is common to find that project sponsors will search for other ways of developing the project to make it economic. However, 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. It is common to hear that a project being developed after a favourable feasibility study is being “optimised”. Typically this takes the form of finding better or cheaper ways of implementing the strategy identified by study. It rarely takes the form of seeking to find a different and better strategy.

Most mine plans are 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.

## 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), 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.

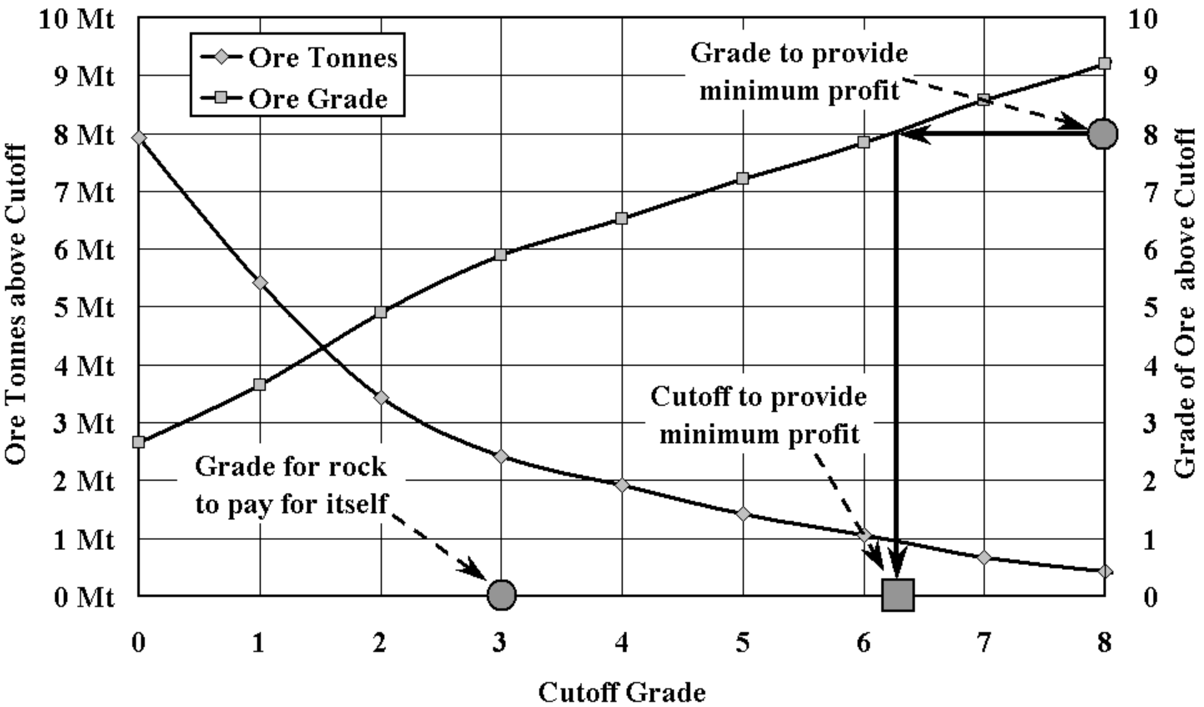
As noted above, most mines use a cutoff grade that is – or was at the time it was derived – some form of operating cost breakeven grade, but there is no logical reason why this should satisfy a goal of "maximising shareholder value". Calculating a breakeven grade to use as a cutoff is a relatively simple 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, most operations tend to be working with a cutoff definition described by Mortimer (1950) and which may be summarised as follows:

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

Figure 1 shows a typical set of tonnage / grade curves, and indicates how Mortimer's definition works. 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. Clearly 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. The converse of this is that the breakeven pay grade does not satisfy the company's profit target. However there is no reason why this should always be so. 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.

**Figure 1 –** ***Mortimer's Definition of Cutoff***




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.

In fact, it appears that the first leg of Mortimer's definition is generally ignored, although its absence is often lamented when profitability is low, but only qualitatively, as though people know there should be a profit goal included in their cutoff derivation, but do not know how to implement this. 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.

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 that half of the definition will not generate the required minimum level of profitability, and ignores the nature of the mineralisation, we may well ask if it is any wonder that the industry produces poor returns.

## Finding and Climbing the "Hill of Value"

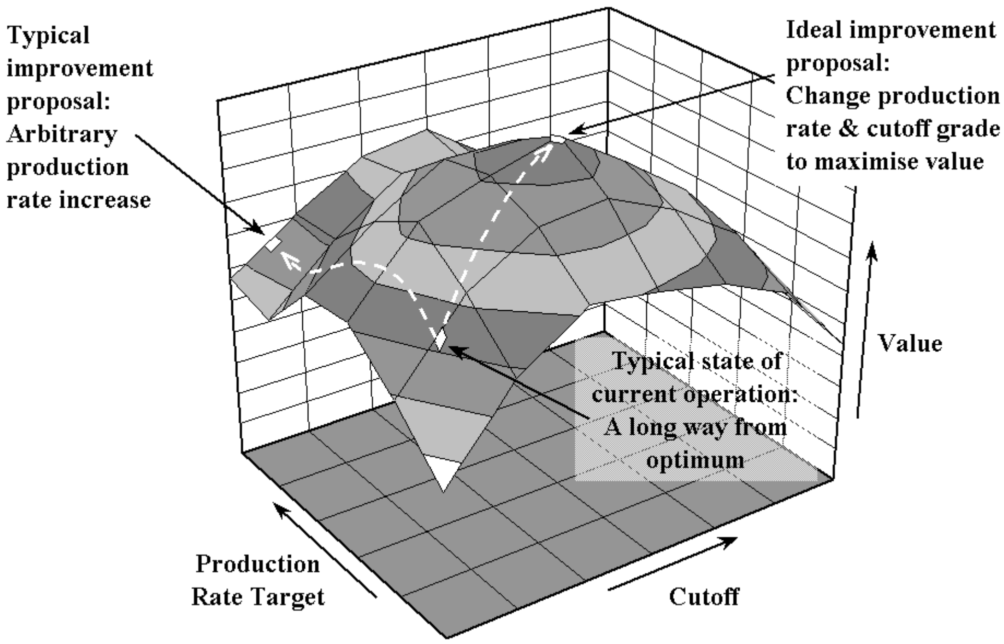
Unfortunately there is no similar simple "working backwards" process to derive a cutoff that maximises value. Lane (1988) presents an analytical technique which will result in the derivation of an optimum cutoff or cutoff policy. (A "cutoff policy" is a planned sequence of cutoffs over the life of the 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, additional 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 clearly.

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. But what is often needed in the short term to accomplish this increase in production is a lowering of 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. One of the author's colleagues has dubbed this "The Temptation of Tonnage" (de Vries and McCarthy, 1999). This may be a valid tactic in the short term – indeed Lane's methodology will indicate if this is so in cases where the theory is applicable – but is frequently a destroyer of value if pursued in the longer term.

**Figure 2 –** ***Finding and Climbing the Hill of Value***




Typically in such expansion studies, one or two higher production rate targets are specified, and a study, perhaps similar to a feasibility 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.

The vertical axis in Figure 2 is deliberately labelled "Value" without specifying what measure is being used. In this figure it happens to be NPV, but it can be any measure that may be of interest to the company. Clearly, 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. Figures 3, 4 and 5 are from another more recent study, and show Hills of Value for NPV and Gold Production, and a Valley of Cost per Ounce, for various cutoffs and underground mine production targets. In this case, various lower grade stockpiles and open pit sources were available to "fill the mill" for much of the mine life, so production target does not have as large an effect as in Figure 2. Figure 6 shows NPV at 3 different discount rates, plus gold output and unit cost, all as a function of cutoff, 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.

**Figure 3 –** ***Net Present Value as a Function of Cutoff and Production Target***

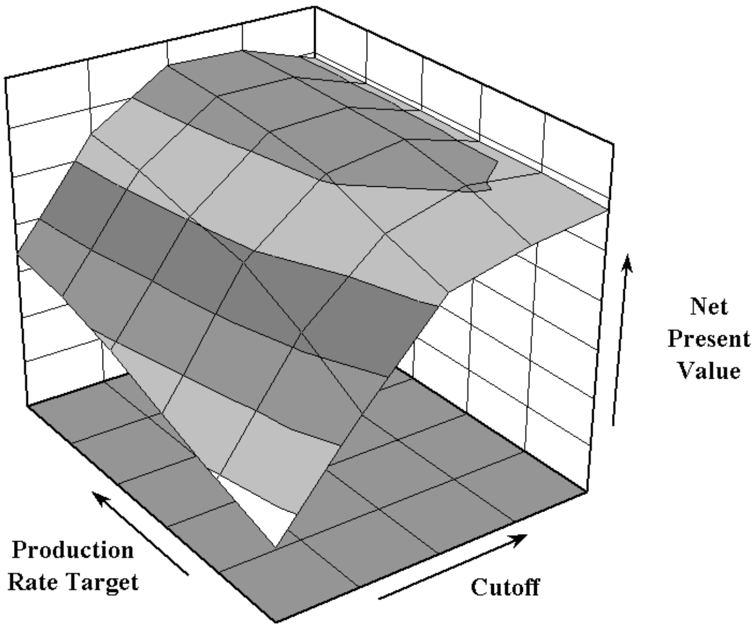



**Figure 4 –** ***Gold Output as a Function of Cutoff and Production Target***

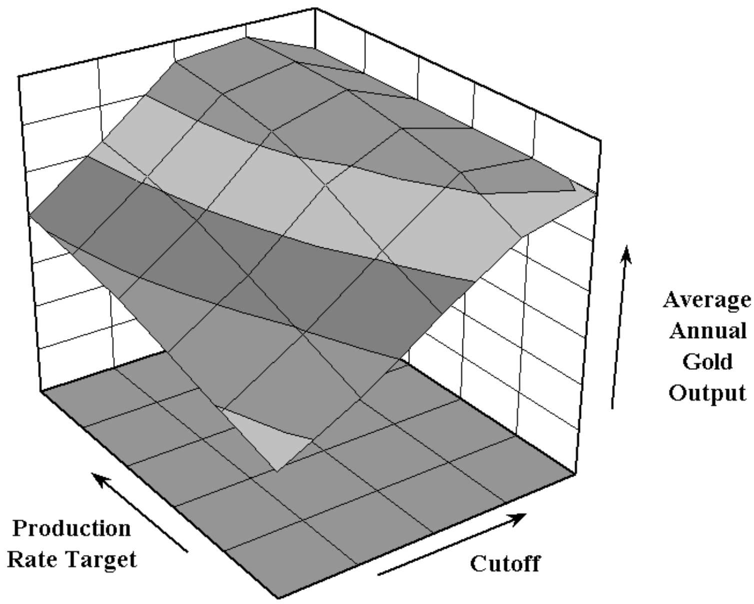


**Figure 5 –** ***Cash Cost as a Function of Cutoff and Production Target***

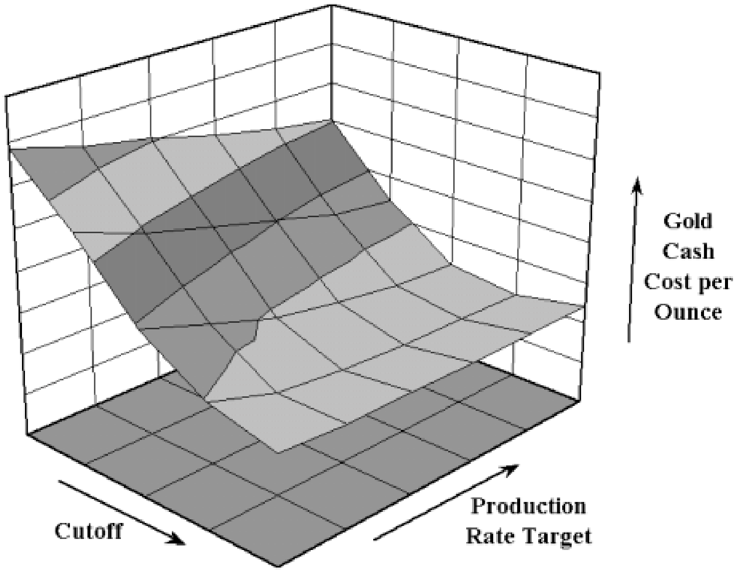
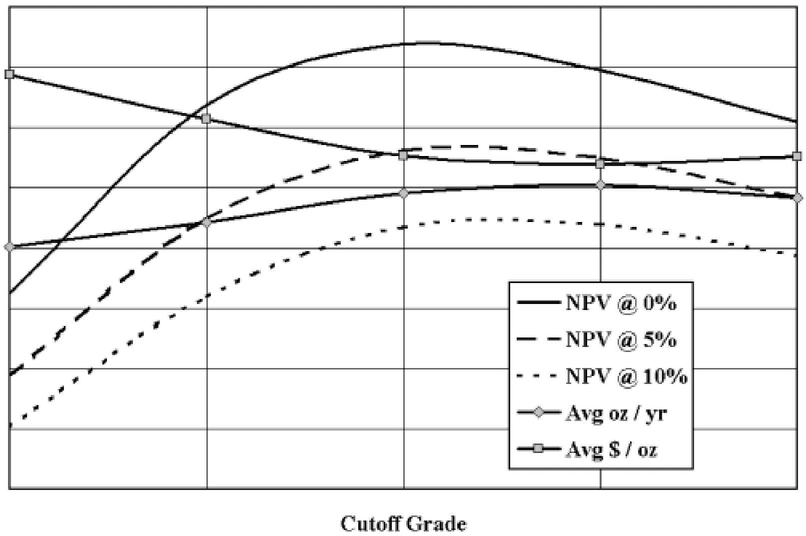



**Figure 6 –** ***Multiple Parameters as Functions of Cutoff***




## 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.

- Many underground mines are operating with a cutoff that is some 65% - 75% of what is required to maximise NPV.
- 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.
- 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.
- 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.
- 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.

Several of these points are discussed in more detail below.

## 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 subsections highlight key aspects of various study components, with particular reference to how they may need to be handled for an optimisation study where this differs from a typical single scenario study.

### Geology

*(Note: In this section, terms such as "reserve", "resource", and "orebody" are used in their more colloquial sense, and not according to the strict definitions in the various codes for public reporting of reserves and resources.)*

A reliable model of the resource 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 the current one. Resolution of this real and valid concern requires evaluation firstly of the nature of the uncertainty.

If the concern is that ore boundaries at some cutoffs cannot be defined adequately with current data, this need not be a problem. The study's purpose is to identify strategies, not to produce detailed designs for implementation in the immediate future. It may proceed without further concerns so long as, at the various cutoffs and within the limits of accuracy set for the study, (a) the general nature of the sizes and shapes of lenses of ore are realistic, (b) the overall tonnages and grades are accurate, and (c) ongoing data gathering will permit boundaries to be defined when needed for future detailed design.

If one these conditions is not satisfied, it may still not be necessary to do a lot of work to upgrade the geological model. So long as the limitations of the model at certain cutoffs are recognised, work can proceed, perhaps with some alternative values for use in the uncertain cutoff ranges (such as pessimistic, optimistic and most likely values), and Hills of Value generated. If the peak values lie in a cutoff range of reasonable geological certainty, the overall result is as reliable as it can be at that level of study, and further geological modelling will not be necessary. If however the peak lies in a cutoff range with lower geological certainty, then more work will be required on the geological model in a subsequent iteration of the study. In this case, 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.

Having acquired a suitable geological model, it is then necessary to generate orebody outlines at each cutoff. These should then be examined qualitatively and quantitatively to identify, if required, domains which may have or require different geotechnical characteristics, mining methods, scheduling constraints, metallurgical parameters and treatment options, and the like.

### Mining parameters

For an underground mine, it is necessary to identify suitable potential mining methods for each domain or logical group of domains. Realistic mining shapes can be designed for each of these, and hence mining reserves derived for each cutoff and method.

To establish the database for the evaluation model, conceptual mine designs and schedules must then be developed for selected representative cases. In the worst case, this will require complete mine design and sequencing for each combination of cutoffs and mining methods being evaluated. This may initially seem like a large volume of work, and it will usually be a substantially larger task than doing a design for a single cutoff and mining method as in a typical feasibility study. It is the author's experience that, even if this full design process is required, the value added as a result far outweighs the additional time and cost required. However, in many instances it has been found that by applying a suitable level of engineering judgement, the number of scenarios to be fully planned can be reduced significantly, and parameters for other scenarios interpolated.

Constraints at various stages of the mining process need to be identified, and the actions required to remove them. Since different cutoffs are to be evaluated, many relationships that are implicit in existing mine plans will need to be explicitly identified. A typical example is the ratio of development metres to ore tonnes, which may vary significantly with cutoff, with impacts on both physical constraints and requirements to meet targets, as well as on the cost structure, which is discussed in more detail below.

Similar processes apply in open pit mines, where it may be necessary to develop alternative mining sequences for various combinations of parameters such as ultimate pit size, cutoff grade for rock to be treated as ore, and rock mining and ore treatment rates.

In both underground and open pit cases, if the mine has been in operation for some time, the current mine plan may have become something of a "self-fulfilling prophesy", as various mining and treatment rates at the existing cutoffs, and the provision of the plant and equipment required to achieve them, will have been adjusted to achieve appropriate balances over time. Little if any value can be gained by changing the cutoff unless other parameters are changed as well, which will often require some capital injection. This is a good situation if the mine plan has been developed to optimise value, however that may have been defined. But as indicated above, mine plans are often not developed to optimise value, and so many mines are highly constrained to deliver a suboptimal result.

### 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.

As in mining, constraints at various stages of the metallurgical process need to be identified, and actions required to remove them. Since different cutoffs are to be evaluated, many relationships that are implicit in existing plans will need to be explicitly identified. An example is the ratio of product quantity to ore tonnes, which will typically vary significantly with cutoff. It is not uncommon, when attempting to elicit product constraints, to have these expressed as ore tonnes, which implicitly assumes an unchanging relationship between ore and product quantities. For example, filtration capacity limits concentrate tonnage, not ore tonnage. The two are related by head grade and recovery, but the relationship changes with cutoff. For an optimisation study it is essential that the real constraints are identified, not inapplicable surrogates. Similarly, if there are different ore types with different milling rates, and changes of cutoff may vary the proportions of different types in the feed, it may be necessary to express the overall ore treatment constraint as available operating hours, rather than tonnage treated.

It is also important to distinguish between real physical constraints and operating preferences. For example, it is often stated that ore blends in the mill must lie within certain limits. In reality, these constraints are often not genuine physical limitations. There may well be good economic reasons why the guideline is desirable. However, in an optimisation study, where it may be advantageous for other reasons to vary these parameters, it is necessary to identify what the real effects of going outside recommended ranges are. Typical effects are reduced recovery, lower throughput rates, and / or increased costs to ameliorate some of the adverse effects. If these extended range effects can be identified, the evaluation model can be built in such a way as to investigate the relative merits of retaining or relaxing the rules.

Metallurgical plant upgrade options, both for increasing capacity in various parts of the process, and for improving product quality, 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 Costs** are typically defined to be those whose monetary amounts remain constant in each time period, regardless of physical activity. Very few costs are truly fixed. These include such things as costs to retain title to mining tenements, and the minimum labour costs necessary to administer a mothballed operation. In reality, most Fixed Costs are specified for a given time period and level of physical activity. Many administration and overhead costs fall into this category. That these costs are not totally unchangeable is evidenced by the common intention to “reduce fixed costs” as production reduces at the end of a mine’s life. When assessing fixed costs it is therefore necessary for the relevant time periods and activity levels to be identified.

Simply asking operating staff what proportions of their costs are fixed may elicit a misleading response. Their focus is usually short term. Typically a significantly larger proportion of costs will be fixed in the short term than in the longer term. A deeper analysis may be required for an optimisation study.

**Variable Costs** are typically defined to be those whose monetary amounts vary in direct proportion to the quantity of a driver physical parameter. Typical examples may include fuel cost per vehicle operating hour, and explosives cost per tonne of rock (of a particular type) or per metre of development (of a particular size in a particular rock type). Physical cost drivers explicitly modelled in studies for underground mines will typically include such things as:

- Development metres
- Ore tonnes hoisted and milled
- Truck tonne-kilometres or hours
- Backfill tonnes
- Concentrate or product quantities

**“Capacity” or “Step Variable” Costs** are in essence fixed costs associated with a relatively small time period or range of activity level. Typically these will include such things as fixed costs associated with the number of vehicles in the mining fleet. A typical example is a step increase in labour cost for truck operators as the number of them increases in proportion to the expanding truck fleet as the mine gets deeper. It will be necessary to identify the capacity of an individual unit of equipment, and to flag both the capital cost associated with the increase, if any, and the step increase in operating cost when the underlying physical driver, such as truck operating hours required, crosses various thresholds.

For all cost categories the important physical cost drivers must be identified. The level of detail required for cost modelling will depend on the level of accuracy of the study, and information required as outputs. As an example, many labour cost components are often considered to be Fixed. Because of the variations in ratios between physical quantities in the multiple mine plan options to be evaluated, it may be necessary to first model labour numbers in exactly the same way as monetary costs as discussed above, as Fixed, Variable, and Step Variable. Labour costs then become truly Variable, being driven by the labour numbers thus derived, at various monetary costs per person, with the potential to identify and cost separately various classifications of workers.

Other costs may also be calculated by intermediate physical and cost relationships. Fuel costs may be cost per litre of fuel, for litres consumed per vehicle operating hour. Explosive costs may be cost per tonne of explosive, for tonnes of explosive per tonne of rock. Even some Fixed Costs may become Variable if it is convenient to model them as driven by a parameter such as “Months of Activity” in each time period.

For reasons peculiar to each study, it may or may not be pertinent to calculate intermediate physical quantities such as numbers of workers or litres of fuel. As in all studies of this nature, the required level of detail and accuracy needs to be specified at the outset, so that appropriate data can be gathered and provision made in the evaluation model, which is discussed in more detail below.

## Capital costs

Several different types of capital expenditure may need to be identified and handled appropriately.

**Mine Development Capital** will often be derived initially as an operating cost, and then transferred to capital.

**Sustaining Capital** will typically be modelled as a monetary amount per tonne or per year. In studies for new mines, it may be set as a proportion of the initial project capital expenditure.

**Fleet Replacement Capital** may be modelled simply as a specified proportion of the fleet acquisition cost each year. Alternatively, more detailed calculations may model the annual hours per vehicle in each time period, and from this, the rebuilds and replacements schedule. Associated capital and operating costs may flow from this, according to the accounting rules in the country concerned and the types of expenditure incurred.

**Debottlenecking or Project Capital**, as noted above, is typically proposed to increase capacity in some part of the production system, or to improve product quality. In the treatment pant, these are usually relatively easily distinguished. In the mine, capital items are sometimes identified as "essential to maintain production" and are automatically included in the capital programme in a typical single scenario study. For a wide-ranging optimisation study, many of these items may be better described as "maintaining existing capacity".

Whereas electing to spend Debottlenecking Capital will result in an increase in capacity, electing not to spend Capacity Maintenance Capital will result in a reduced capacity. Since any proposed capital expenditure should be justified on the basis of the benefits it brings, it is the author's contention that the "base case" for Capacity Maintenance Capital should be that it is not spent, and the mine production capacity is reduced accordingly. The capital should then be justified on the basis of increased production, which co-incidentally happens to be at the previous level. In the author's opinion, this should be done for any capital expenditure justification – and it may well be that a very simple analysis overwhelmingly supports a decision in favour of spending – but especially in an optimisation study, the true optional nature of the expenditure should be recognised and the value of the option evaluated.

A typical example in a mine is the cost of increasing the trucking fleet as the mine gets deeper in order to maintain the production rate. The real base case is to continue with the existing fleet and allow production to decline. That may be the only concern in many cases, but eventually the situation will be reached where acquiring an additional truck triggers other capital expenditure. This may be for example additional workshop facilitates, or in the case of an underground mine, a major ventilation system upgrade. While it might be simple to justify incremental trucks from time to time, the larger cost for other associated infrastructure may not be justified. Again, the optional nature of such expenditure should be recognised and its value properly evaluated.

For all types of capital expenditure, the impact of the resulting new facilities on ongoing future labour numbers, and maintenance, operating, and sustaining capital costs, must be identified and incorporated into the evaluation.

## Exploration

Most mines will have exploration programmes in or adjacent to the mine, which if successful may add to the reserve of the mining operation being evaluated. There may also be a programme of exploration in the surrounding area, which may if successful generate feed for the treatment plant, but not require the use of the facilities of the mining operation. In both cases, the effects of additional discoveries on optimum mining plans may need to be evaluated.

Typically, this analysis would use a range of postulated exploration outcomes as input data. The types of evaluation that might be undertaken are discussed in the section on Risk Analysis below.

## End of life issues

Because a range of cutoffs, reserve tonnages, and production rates are being evaluated, the life of the operation will vary significantly over the combinations of options considered. The shorter the mine life, the greater the impact on value of end-of-life lump sum cash receipts and payments. The major items to be considered are typically:

- Redundancy payments to the workforce
- Rehabilitation costs and commitments
- Salvage values of assets

Accounting provisions will normally be made for these during the life of the project. Some cash costs may be incurred during the life of the project, but typically these occur as lump sum payments at the end of the life, or spread over a specified number of subsequent time periods. It is usually important to distinguish between the accounting provisions and cash flow effects in order to calculate accurately the different cash flow and accounting measures of value that may be specified.

In a typical single scenario study, many of these items will be fixed in terms of both quantum and timing. In an optimisation study, the impact of variable reserves and life will need to be taken into account. Timing of end of life expenditures will obviously move appropriately. The quantum of both cash amounts and accounting provisions, for items occurring both at the end of the project and during its operation, may also need to be varied depending on the project life.

## Other financial issues

Product prices and treatment, refining and sales terms must be estimated for the maximum duration of the analysis. Typically, alternate scenarios or sensitivity analyses will be required. The types of evaluation that might be undertaken in this respect are somewhat different from those done in standard project evaluations, and are discussed in the section on Risk Analysis below.

Taxation effects may need to be taken into account. Taxation rules are complex, and tax accountants are typically loath to reduce them to a few simple rules for inclusion in an optimisation study. Nevertheless, especially if high capital / low operating cost options and low capital / high operating cost options are to be compared, it may be necessary to include some assessment of taxation effects in the analysis.

Discount rates, inflation rates and exchange rates to be used in the analysis must be specified. The mining company's financial staff will usually provide these.

### The evaluation model

As noted above, an evaluation model for a wide-ranging optimisation study needs to be substantially more flexible than that typically used for a single scenario analysis. The preceding subsections discussing various factors to be considered in the study give some indication of the sorts of capabilities required in such a model. It is not intended to repeat all of these here. Rather, this section highlights the more critical capabilities required.

All of the models used by the author have been developed solely using Microsoft ExcelTM. Relatively cheap commercially available add-ins have also been used to enhance the capabilities of the base model, providing the capability to use such techniques as Monte-Carlo simulation, genetic algorithms, and linear programming optimisation. In general, this makes models readily available to clients, who are then in a position to audit the models and results as desired. There are no “black boxes”. To handle the wide variety of combinations possible in a single integrated model, modelling techniques need to be somewhat more sophisticated than are typically found in single scenario models. All the techniques used are familiar to, or readily understandable by, advanced users of Excel.

A simple but robust method of specifying the options to be used in any one calculation is necessary. The author has found that a single options specification sheet, making use of Excel “Combo boxes” and “Check boxes”, allows the user to make rapid and error free selection of combinations of options.

Once options are selected, the model must be able to implement them. In particular, all the parameters associated with various upgrade options, such as capacities in various parts of the production system, metallurgical recoveries and product qualities, and capital and operating base costs, must be correctly set for all time periods, according to which options are specified for implementation. The modelling of physical activities must be able to take account of all imposed constraints, including production rate limitations for individual domains, mining blocks, or the whole mine, limitations on ore tonnes treated and product generated, and blending or product quality constraints. All these constraints must be honoured or a misleading non-feasible production scenario may be developed.

Financial calculations must then identify where reducing production rates at the end of the mine life make continued operation unprofitable to truncate the life at that point. Timing of end-of-life cash flows must take account of the mine life thus determined. Capital expenditure will typically be stopped some specified time before the predicted end of life. Various accounting provisions, such as those for end-of-life cash costs, and in particular depreciation calculations – whether for taxation or financial accounting purposes – must be adjusted to suit the mine life determined.

Finally, graphical Hills of Value or similar tabulated values, for all the measures to be used to define value, must be created and presented in an understandable fashion. Excel provides “Data Table” capabilities to generate “what if” scenario analyses. One-way Data Tables can tabulate values of a large number of model outputs for many values of a single input variable. Two-way Data Tables can tabulate values of one model output only for combinations of values of two input variables. The author has extended the One-way Data Tables capability to generate a multi-dimensional “what-if” analysis, tabulating values of a large number of model outputs for any desired combinations of values of all key input variables.

## 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 7 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. Figure 8, however, 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 7 –** ***Value vs Cutoff for 2 Price Scenarios***

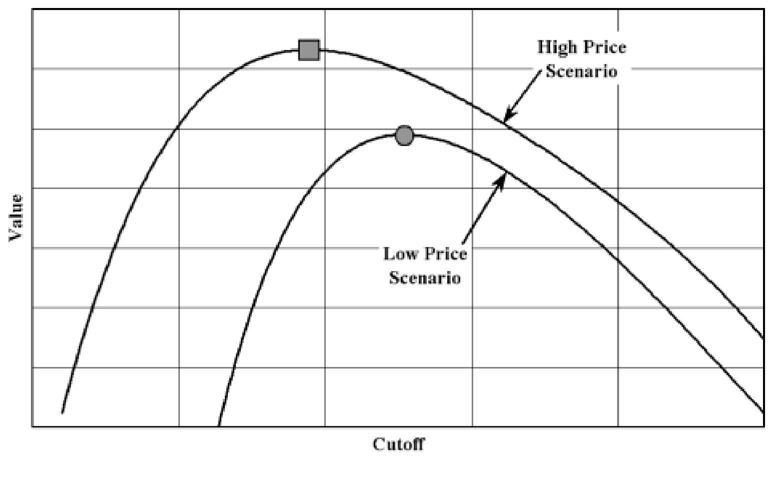


**Figure 8 –** ***Risks and Rewards of Optimum Cutoffs***

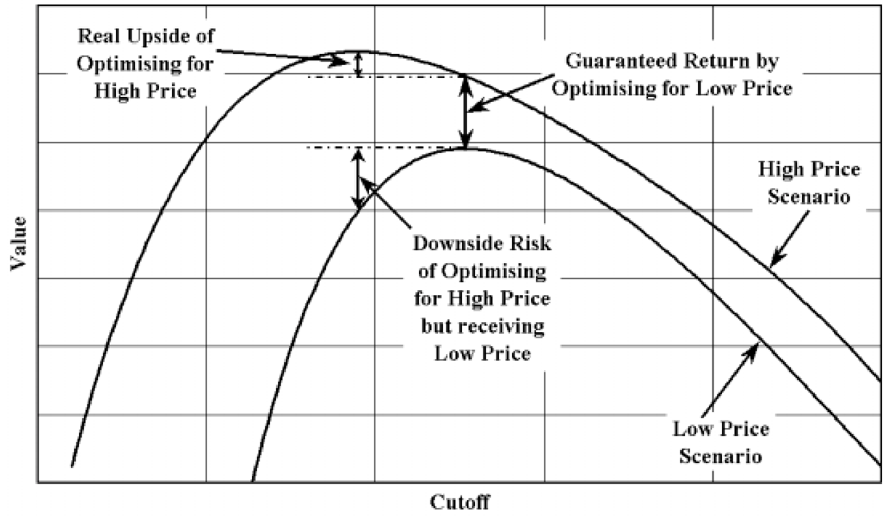



Figure 9 shows actual gold prices and consensus predictions over a number of years. It can be seen that the predictions are generally optimistic. Similar data plots for other base and precious metals show similar trends, not necessarily all the time, but certainly for long enough periods of time for mining strategies to be developed, implemented, and "rewarded" by the metal 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 10 indicates how the downside risk shown in Figure 8 may be significantly magnified by typical operating policies using breakeven grades as cutoffs. Is it any wonder that the industry produces poor returns?

The trade-off between risk and reward evident in Figures 8 and 10 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.

The conceptual curves in Figures 8 and 10 have been deliberately constructed to illustrate the point the author is attempting to make. Figure 11, however, 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 operating cost breakeven grade at each price is indicated, as is the mine's planned cutoff for both present and future stope designs.

**Figure 9 –** ***Actual Gold Prices and Consensus Predictions***

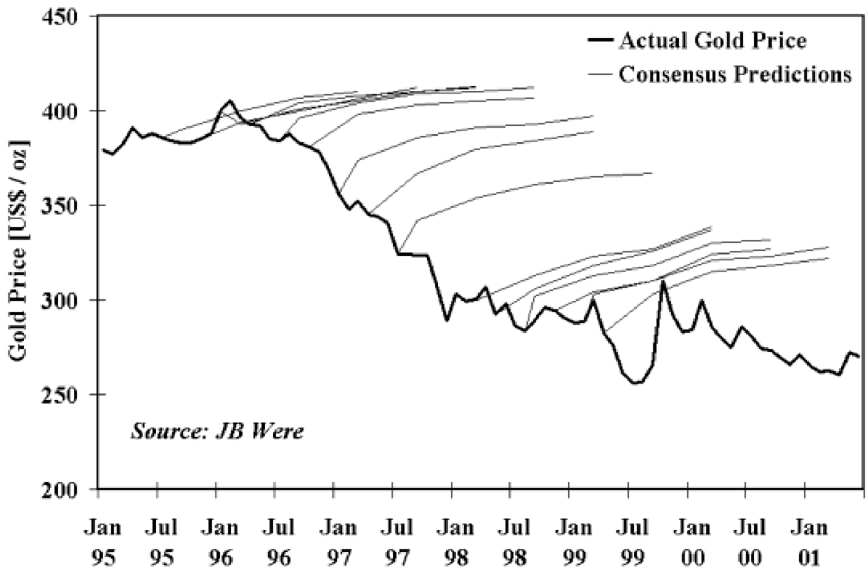


**Figure 10 –** ***Risks and Rewards of Incorrect Price Predictions and Suboptimal Cutoffs***

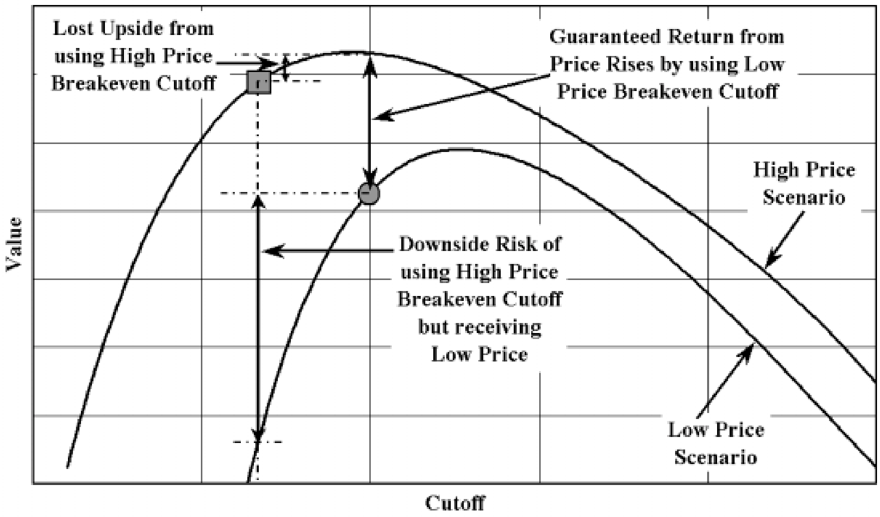
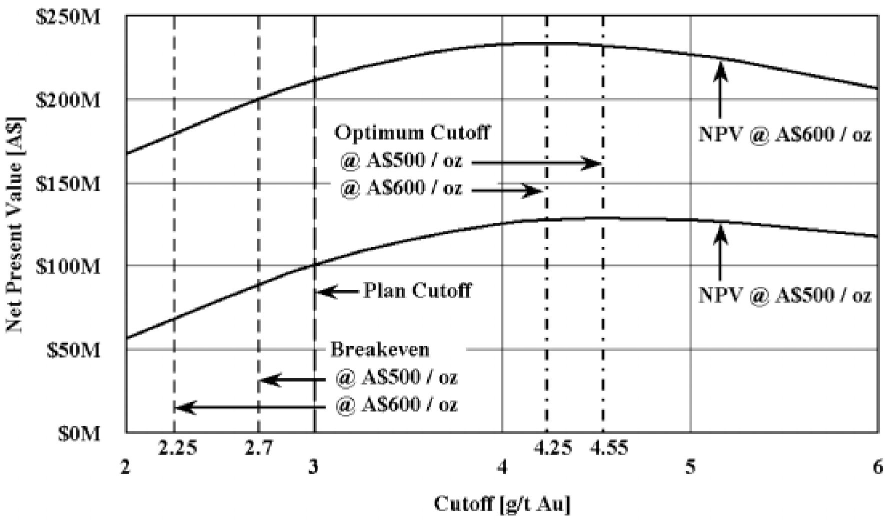



**Figure 11 –** ***Case Study Results at Different Prices***




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 price and cost changes

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 the conventional variation in breakeven. They also account for the time-value-of-money cost of deferring the receipt of the NPV of the rest of the operation, which would result if additional lower grade material in current mining areas were to be treated by lowering the cutoff.

The rationale may be summarised as follows. 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. 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 11, 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 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 from this is that, just as price rises may actually 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 that would have been left unmined using reserves defined by some standard lower cutoff can be extracted while the mine is still producing.

Analyses using genetic algorithms have indicated that an optimum strategy may be to adjust the cutoffs for all the various 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 must be set so that each area 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.

## 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.

### 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. Ignoring the effects of the ability to hold inventory of resources and final products, successive time periods for a manufacturing firm are essentially independent. If goods are not made and sold in the period being considered, the opportunity is lost forever. Also, 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. Because of the independence of successive time periods, and the assumption that a manufacturing enterprise can continue operating indefinitely, the value of the firm is maximised by making independent decisions that maximise the value obtained in each period. These decisions are made in the context of the firm's known or planned production capabilities in each period. Decisions about whether to expand the production capabilities are a different issue, and not related to the argument being developed here. Similar arguments apply in service industries.

The mining industry is different, however. 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. As extreme examples, we could choose to "rape and pillage" the resource this period, and make it totally unminable forever after, or alternatively, choose to husband the resource so carefully now so that it is able to continue producing for a greatly extended time into the future. Either strategy might have been shown to produce the best result for the one time period being considered, but clearly the decision about what is best for the deposit overall cannot be made by looking only at what is best in each period independently.

Therefore, maximising return in one period by producing so that marginal cost equals marginal revenue may not produce the best result for the whole life of the operation. Including the time-value-of-money costs as part of the marginal cost may go some way towards improving the situation, but these are purely financial tests that still ignore the nature of the mineralisation, the capacities of the various stages of the production process, and their impact on the life of the mine.

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.

### A costly detailed study is not required – the best strategy can be identified by simple studies and intuition

This objection is related to the previous one, in that it relies upon the assumption that principles perceived to have delivered good results in the past in the mining industry, or in other industries generally, were correct, and need only be replicated to continue achieving the same results. Therein lies the problem – results have in fact been inadequate for a number of years, and even if they were "good", Hill of Value analyses such as those described above indicate that they could be significantly better. Two conclusions flow from this. Firstly, simple analyses such as breakeven calculations are not guaranteed to result in mining strategies that maximise value. Secondly, 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 other concern with this objection is that it 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 orders of magnitude greater than the cost of the study.

### 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.

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.

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

The author has encountered this response on a number of occasions. "Competent persons" responsible for publicly reported ore reserve figures will know how easy it is to get additional material into their companies' reserve figures, but how difficult it is to get it out again if conditions change and inclusion of certain material can no longer be justified. There is a real aversion to reporting a reduction in reserve, presumably because it is assumed that everything in the reported reserve adds value, when in fact, as has been demonstrated above, 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. This however does not help a mine that is already in operation with a suboptimal reported reserve. Companies that are in this position should be able to demonstrate to opinion-forming analysts and financial commentators the wisdom of their apparently unconventional plans, 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. One example is cited to suggest that the perceived problem may not be real. In July 2002, Newcrest Mining Ltd reported revised reserves figures, which had been derived using a gold price of A$500 / oz rather than A$450 / oz used previously. "MiningNews.net", an internet mining industry news website reported analysts' reactions as follows.

"Newcrest Mining's latest ore reserve calculation has proved to be a flop with sceptical gold punters. The company's shares finished 15 cents lower at $7.15 today as investors digested the complicated re-jig of reserves and resources published after the market closed on Tuesday." One analyst was quoted as saying "All in all, the newly stated ore reserve is a disappointment as it was reasonable to expect that a revision in assumed gold price from A$450 to A$500 per oz would have delivered an increase of some 15-20%." Reported comments from other analysts were in a similar vein, but with some positive aspects. One agreed that the total reserve figure was "lower than the market generally had been expecting. But our view is that, on a valuation basis, it doesn't change anything."

The share price subsequently rebounded the following day, but this event occurred in the middle of a two week long price slide for the stock from over $8.00 to under $6.70 per share. The price history and general comments by the analysts would seem to indicate that, for this company at least, with large resources and long life, the lower than expected reserve figure was not an issue. This of course might not be the case for less robust companies with smaller reserves and shorter lives. Investigation of the reality or otherwise of the feared effects of reporting reduced reserves might be an interesting mineral economics research topic.

The other concern that this exemplifies is that those who are making public pronouncements on reserves are apparently unaware of the fact that an increase in price may have little effect on the optimum cutoff, and may even cause it to increase rather than reduce. It would seem that the analysts quoted were assuming that the cutoff to be applied would be some form of breakeven. It is then interesting to speculate on how "the market" was estimating what the increase in reserves should be. An 11% increase in price would produce a 10% reduction in breakeven grade, and this is apparently assumed to generate a 15% - 20% increase in ounces in reserve. If we assume that the old reserve grade is twice the old cutoff grade, and that the additional material brought into the reserve by lowering the cutoff by 10% is at a grade 5% lower than the old cutoff, the reserve tonnage increase required to produce the estimated contained gold increase is 33% to 44%. The author does not have access to Newcrest Mining's tonnage / grade curves, nor to the cutoff grades that were in use, so these figures must be seen as hypothetical. However, it is reasonable to ask if the market's expectations were realistic in the first place.

Taken together, these points indicate that an education process may be needed to change the thinking of those who make influential public statements about companies' plans. How much is required is beyond the author's power to predict. How it is to be achieved is also a valid question, and it is the author's hope that papers such as this, presented in the appropriate forums, may be a part of the process. What is certain is that if nothing is done, nothing will change.

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.

### The increase in value is not great, so it is not worth the trouble of changing everything to chase it

Hills of Value are often relatively flat near the optimum, and tend to steepen as the cutoff gets further away from the optimum. The scales that are needed to plot a reasonably large portion of the curves to display their overall behaviour may result in a visual impression that is expressed as this objection. However, when the values are closely examined, it will often be seen that, even in relatively flat areas of the curves, reasonable cutoff changes can generate value differences of tens of millions of dollars of NPV, or 10% - 20% of current planned NPV, or more.

Potential value gains of these magnitudes will often be similar to or even significantly greater than NPVs generated by proposals to spend capital to add value in some way, or the NPV effect of highly applauded continuous cost improvement programmes that consume much management time and effort. This is not to say that these initiatives should not be implemented, but rather that, if some initiatives are pursued with vigour, it is irrational to dismiss others that can deliver similar or better returns with often significantly less effort.

### Reducing the mine life reduces the probability of exploration making another discovery that could profitably extend the life

This is a valid concern. The immediate response is that it can be accounted for in a Hill of Value optimisation analysis in exactly the same way that it has been accounted for in deriving the existing cutoff policy and mine strategy. The logic of the process might need to be extended in the evaluation model to account for the variations in mine life that will be encountered in this type of optimisation study. Typically, however, this issue has not been addressed in deriving the existing mine plan. Despite the inconsistency of objecting to a proposed new plan because it has not been included, it is a valid concern that should be evaluated over a range of possible cutoffs, including the existing one. In the absence of existing accepted methodologies, two are suggested.

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 in its normal way. 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 alternative favoured by the author, and about to be implemented in a study in progress, 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. This may be expenditure both on specific localised targets and on broader regional exploration. The simple rationale is to assume that, if the mine life is to be shortened, then that funding should rationally 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.

It is interesting to note in passing that, if exploration were to be successful, then earlier discovery through faster exploration would increase the value of the operation further, since the value of the discovery will be received earlier than it would have been through slower exploration at a lower cutoff. This would suggest that, if there was a high probability of success, then the optimum cutoff determined by the Hill of Value process including fixed total exploration expenditure could actually be increased further, to bring the receipt of the value of the discovery even further forward. This rationale will not be pursued further in this paper.

### The analysis doesn't account for the option value of the lower grade material excluded by the higher cutoff

As with the impact on exploration success, in most cases the previous analyses have rarely taken this into account. But again it is a valid concern, and like exploration success, it is worthy of consideration at all possible cutoffs, including the existing one.

The first problem is identifying what is meant by the term "option value". It has been in use for a number of years, but its application in evaluations of mining strategies is rare. It is suggested that there are perhaps two ways of considering option value. One is the purely financial calculation methodology of the Black-Scholes equation. The other is "Real Options Valuation" ("ROV") methodology. It is not the purpose of this paper to discuss each of these in detail, and a few brief comments only are included to indicate possible responses to this objection.

The Black-Scholes equation has the appearance of providing a rigorous and generally accepted way to value flexibility. However, there are problems in estimating accurate values for the various parameters in the equation, since it was developed for one particular class of financial instrument, not the physical realities of an operating mine (Samis 2002). In the author's opinion, this ultimately makes it highly questionable whether it is relevant at all in these situations. There is a real danger that simply applying a formula may not take account of the physical options that may or may not exist in reality – the "Real Options" – and option values thus derived may in fact be illusory and misleading.

ROV methodology (Samis 2002), on the other hand, requires specific identification of the options that are "really" available to an operation, and might be exercised or not under certain circumstances. In the context of this discussion, the option value would typically be the value arising from the opportunity to mine and treat lower grade material that has not been mined earlier in the mine's life if, for example, metal prices were to rise later. The methodology then in this instance would require estimation of the probabilities of metal prices being at certain levels at various times in the future, and the evaluation model to be constructed in such a way as to allow the option – to mine or not to mine lower grade material – to be exercised. The modelling principles required can be specified, and such a model would be constructed relatively easily. Whether it would be practical to run is another matter.

Lower grade material left unmined initially can only have an option value if there is a real option to mine it later. If lower grade material has been sterilised, so that it can never be mined, it has no option value. For example, in an underground mine, it may be impractical to reaccess and extract lower grade material immediately surrounding a previously extracted higher grade stope. At a surface operation, low grade material that has been tipped as waste may be irrecoverable. If this marginal material did not add value if it had been mined or treated as ore at the time that the adjacent ore was mined, then it never had and never will have any "value".

If on the other hand lower grade material is not sterilised but can be accessed and mined later in an underground mine, or can be stockpiled for possible treatment later at an open pit operation, then there is a "real option" that can be valued. As in all situations, if the problem can be described, it can in theory be modelled and evaluated. The author is currently involved in a project that is evaluating this effect to a limited extent, by considering the effects of different specified metal price predictions over the time frame of the study. However, it needs to be recognised that a study that would attempt to derive an optimum mining strategy applying ROV techniques fully and rigorously would not be a trivial exercise, both computationally and in the interpretation and application of the results. The author has only recently begun to think about the implications of such a project, and would be happy to discuss the topic further with other workers in the field.

In summary, "option value" is something that should be considered, but results generated simplistically may well be misleading. It is potentially an area for a significant amount of theoretical study and practical trials before a useful methodology is generally available for applying it in cutoff grade strategy optimisation.

## 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 never heard 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.

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.

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 corporate strategies, particularly with regard to cutoff policy specification, demonstrably deliver real, not perceived, value maximisation, the industry will continue to deliver below average returns.

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## References

DeVries, J. and McCarthy, P. L., 1999. The Temptation of Tonnage. Circular letter to clients of Australian Mining Consultants Pty Ltd.

Lane, K. F., 1964. Choosing the optimum cut-off grade. Colorado School of Mines Quarterly, Vol 59, No 4, p811-829.

Lane, K. F., 1988. The economic definition of ore, cutoff grades in theory and practice. Mining Journal Books: London.
Mortimer, G. J., 1950. Grade Control. Trans Inst Min Metall. Vol 59, 1950 pp357-9.

Samis, M. R., 2002. Advanced Valuation Methods for Natural Resource Projects. Course Notes