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Optimising the Strategic Mine Plan – Methodologies, Findings, Successes and Failures

By B E Hall [1] & C A Stewart [2]

Abstract

"Maximising shareholder value" has become a common aim for mining companies. The authors have conducted a number of studies developing strategic mine plans to meet these goals, covering a wide range of commodities, styles of mineralisation, mining methods, and processing facilities, for single and multiple deposits. Various methodologies have been developed, and a number of common problems and outcomes have been identified.

Current cut-off policies at many mines ensure that shareholder value is not maximised, despite the stated corporate goals. Significant value gains are achievable, compared with the accepted strategy at the start of the study. Typically, the new optimal plan involves a significant increase in the cut-off grade, at least in the earlier years. An increase in the underground development rate or open cut stripping rate is often associated with this, at least in the short term, to establish the new strategy. Counter-intuitive results are often found. For example, the optimum cut-off is often relatively insensitive to changes in metal prices. Optimal cut-offs for different parts of an underground mine may be significantly different, even if mineralisation and cost structures are similar.

The paper describes a number of methodologies employed to identify optimum mine plans. In all studies undertaken, significant value improvement potential has been identified. In some cases, the company has adopted the recommended plan. However, in other cases, the status quo has been maintained. The paper identifies factors which the authors believe contribute to the likelihood a company adopting or rejecting a new plan that has been demonstrated to add significant value, and therefore to the value of actually conducting such an analysis in the first place.

Introduction

The authors and their colleagues at AMC Consultants Pty Ltd have conducted a number of mine plan strategy optimisation studies in recent years. The term "mine plan" is used in the widest possible extent, and may include for example various treatment and processing options, as well as "mining" considerations such as mining methods, haulage systems, and cut-off grades.

Studies have covered a range of types of operations, minerals, and locations, at various levels of detail, as shown in Table 1. This paper describes typical optimisation goals of studies conducted, methodologies used for optimisation, common findings of studies, and factors contributing to successful and unsuccessful studies. Results from a number of case studies are used to illustrate the paper. In each case the type of operation is identified, but the names of operations are not disclosed to maintain client confidentiality.

Optimisation Goals

Publicly stated corporate goals of mining companies typically include the concept of "maximising shareholder value", often with associated goals of reducing costs and improving efficiency.

Optimisation studies therefore typically have maximisation of Net Present Value (NPV) as a major goal. Other goals specified may include maximising the Internal Rate of Return (IRR), accounting profits (e.g. EBIT, EBITDA, etc) and accounting returns, based either on total assets (or capital or funds employed) or on shareholders' equity (net assets) (e.g. ROFE, ROCE, RONA etc). Minimising unit cost measures, such as cash costs per ounce or C1/C2/C3 unit costs, is a common goal, and achievement of output targets, such as maximising the metal produced, or exceeding specified minimum production targets, may be important.

Rarely expressed initially, but often coming into play when results of the study identify increasing the cut-off grade as a major strategy to increase value, is avoiding, or minimising, a reduction in publicly reported ore reserves. Also rarely expressed, but frequently implied and very important, are the risk management goals of maximising the ability to reap upside rewards, and minimising the danger of downside risks. The "ore reserves" goal indicates that there is, or is at least perceived to be, a difference between the "intrinsic" and "market" values of an operation, and the parameters that determine each. It is beyond the scope of this paper to discuss this in any detail, though parts of the discussion allude to it.

It is evident that many companies have multiple, and often conflicting, corporate goals. To these may be added various

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external government and social goals, such as minimisation of greenhouse gas emissions, maximisation of taxation revenues, provision of local employment opportunities and infrastructure, and so on. To provide corporate decision makers with adequate information to select the optimum strategy, the optimisation process must be able to identify not only strategies that will deliver the various goals, but also the trade-offs required to best achieve a combination of various conflicting goals.

Methodologies Used

A number of modelling and optimisation techniques have been used for the optimisation studies described. In all cases, these have been implemented in Microsoft ExcelTM. Commercially available and relatively inexpensive "add-ins" have also been used where appropriate, as described below. It is acknowledged that this is not necessarily the most efficient method, for both the model building and computational efficiency aspects of the study. However, it has the following advantages:

- Unique conditions and concerns at each site can be built into the evaluation model as a matter of course.
- Provision does not have to be made in the model for matters that do not apply at the site.
- Modelling techniques that have been developed in previous studies can be quickly adapted for the study at hand.
- Tabular and graphical output can be easily customised for the study at hand.
- The model can be provided to the client, who can audit and use it with existing standard computer hardware and software.

Table 1 - Summary of Optimisation Studies Conducted

Level of Detail of Study	Locations	Minerals
• Scoping/ Conceptual • Pre Feasibility • Feasibility	• Australia • Western Europe • East Africa • Central Asia • China • India	• Gold • Lead/Zinc • Nickel • Mineral Sands
Types of Operations		
• Single underground mine & treatment plant • As above, plus other independent ore sources (pre-existing stocks and satellite mines) • Single open pit mine and plant with stockpiling. • Single deposit and plant, with interacting underground & open pit mines • Multiple deposits with a single treatment plant • Multiple deposits with multiple treatment plants		

The authors' experience in virtually all studies is that the client does not opt to implement the strategy that fully optimises one of the corporate goals only, but rather identifies the trade-offs between its various goals, and selects a strategy that best meets some or all of the conflicting goals. Using spreadsheet software makes it simple to evaluate the behaviour of the various "goal" parameters as the values of a number of "strategic decision" parameters are varied both separately and together.

Lane's methodology

The "state of the art" cut-off grade theory was published by Lane 40 years ago (Lane, 1964) and made generally available in book form over 15 years ago (Lane, 1988). Despite the general knowledge of the existence of this work amongst relevant technical personnel, and further development of the theory and practice (e.g. King, 1998, 1999), many mines have not applied the methodology. Rather, the use of simple operating cost breakeven grades as cut-offs is common.

Even where Lane's methodology has been applied, comments seen or heard by the authors suggest that the concepts have sometimes been misunderstood and therefore incorrectly applied. For example, comments to the effect of "the mine can sell all it can produce, and therefore has no market constraint" miss the point that, for a "Lane-style" analysis, "market" deals with mineral or product. The "market constraint" is anything that limits the production, handling and sale of product. Any mine that separates a product from the ore stream will have a market constraint. Since most mine / mill operations can usually sell all that they can produce, the market constraint will typically be somewhere in the product side of the treatment plant circuit, such as the concentrate filters of a base metal plant, or the carbon stripping circuit of a gold plant.

Lane's methodology provides a rigorous analytical process which, though requiring some iterative calculations, will converge to provide a cut-off policy (i.e. a planned sequence of cut-off grades over the life of the mine) which will maximise the NPV of the operation for a specified set of production rate and economic assumptions. The effects of, for example, different metal price forecasts, and various potential upgrades of mining and processing capacities, can be evaluated by repeating the process for each proposed scenario and comparing the costs and benefits as appropriate.

Lane's analytical methodology has been used by the authors for some high-level studies, to give an indication of what may be achievable. However, in their experience, it has not been able to form the basis of a major strategy optimisation study, for one or more of the following main reasons:

- It optimises only for NPV. The values of other "goal" parameters can be determined for the strategy that maximises NPV, but there is no way within the methodology to identify how to optimise other goals, and how much NPV is lost by doing so.
- The analytical process can handle a limited number of physical constraints. In most of the practical cases evaluated by the authors and their colleagues, there are more constraints than these, typically involving multiple products in polymetallic base metals operations, sulphur processing constraints in refractory gold operations, and product quality constraints. Lane (1988, Chapter 16) identifies that in these cases his analytical process becomes unworkable, and use of a search technique to identify the optimum is necessary.
- Stockpiling and grade-dependent recovery relationships introduce further complexities. Lane (1988) provides analytical procedures for the former, and for simple relationships for the latter, but again notes the complexities and the need to apply numerical techniques in more complex situations.

"Hill of Value" calculations

Because of the practical concerns noted above for application of Lane's analytical methodology, most optimisation studies conducted by the authors and their colleagues make use of what has been called the "Hill of Value" technique. This is done by making use of an ExcelTM model which has been constructed in such a way as to be capable of handling all the combinations of various "strategic decision" variables that can be independently specified. These will typically include such things as:

- Cut-off grades, for either the whole mine, or for underground and open pit mines, or for various orebodies, lenses, areas or stages of the mine(s),
- Production rate targets, for all or parts of the mining operation(s), and for the treatment plant(s).
- Inclusion or not of various identified debottlenecking upgrades in the mines or treatment plants, and the timing of their implementation.
- Various mining method options, which may include different sizes of open pits (including no pit), and different methods or combinations of methods underground.

Other factors with the potential to impact on optimum strategy, and evaluated in some studies, include:

- Alternative economic forecasts.
- Varying degrees of exploration success.
- Alternative haulage / hoisting systems.
- Various workforce productivity and equipment efficiency scenarios.

The evaluation models are constructed in such a way that all of these parameters can be selected or specified independently, and various scheduling dependencies and constraints can be defined. The modelling logic then ensures that realistic mining and production schedules that honour all of these inputs are generated. Capital and operating costs are then modelled by standard techniques appropriate to the mining and processing methods, using appropriate fixed and variable costs for the various physical quantities modelled. Revenues are estimated by calculations appropriate for the metals being produced. Sufficient information is then available within the model to calculate whatever measures of value may be required for the study, as described above.

The "Hill of Value" technique and its application have been described in detail elsewhere (Hall, 2003, Hall and de Vries, 2003). It provides a clear picture of how a mine might change its strategy to optimise a particular goal parameter (Figure 1) or the trade-offs between various goals (Figure 2). Figure 1 is from a study conducted for an underground base metals operation, and is typical of most of the studies conducted. The implications of this figure are described further in the discussion of typical findings below. Figure 2 is from a study conducted for an underground gold operation. It shows how different parameters are optimised by different cut-off strategies, and how, for this case and the parameters shown, there is a range of cut-offs that delivers close to the optimum for all five parameters of interest, with very little loss of one if another is optimised.

Figures 3 and 4 illustrate how, with different price scenarios, deciding to target the upside potential may significantly increase the downside risk, particularly if suboptimal cut-off policies have been employed. These plots are schematic to emphasise the point being made, but case studies exhibiting the effect to a significant, though not as extreme, extent are discussed below.

Working on the principle that, if it can be described, it can be modelled, the authors have developed a number of spreadsheet modelling techniques for constructing robust models able to handle realistically the wide range of possible production strategies. Methods have also been developed to report values of a number of "goal" parameters for simultaneous changes in a number of "strategy decision" variables, to generate Hills of Value for a number of parameters as in Figures 1 and 2.

Figure 1 – Finding and climbing the "Hill of Value"

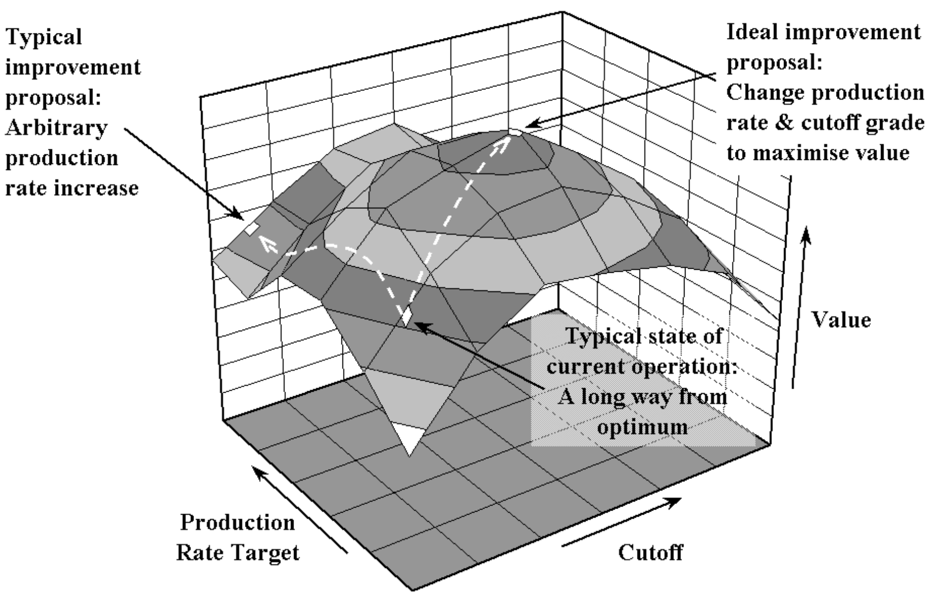


Figure 2 – Multiple parameters as functions of cut-off

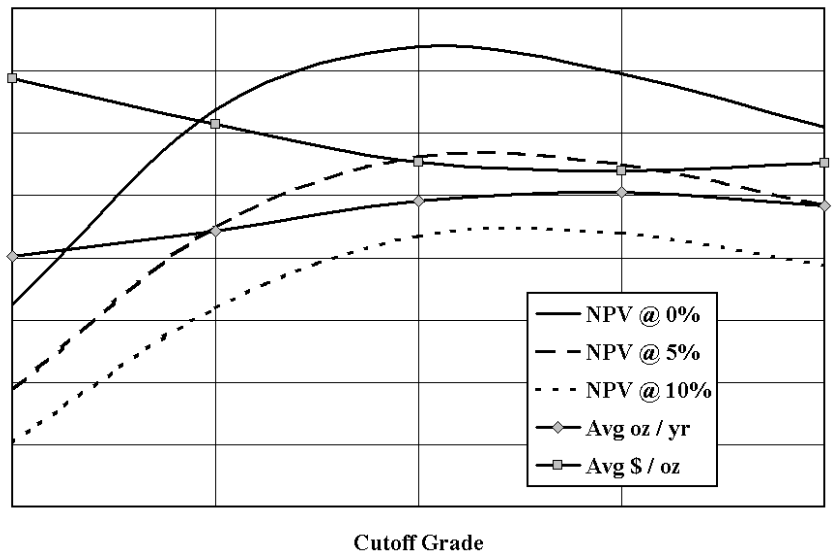


Figure 3 – Risks and rewards of optimum cut-offs

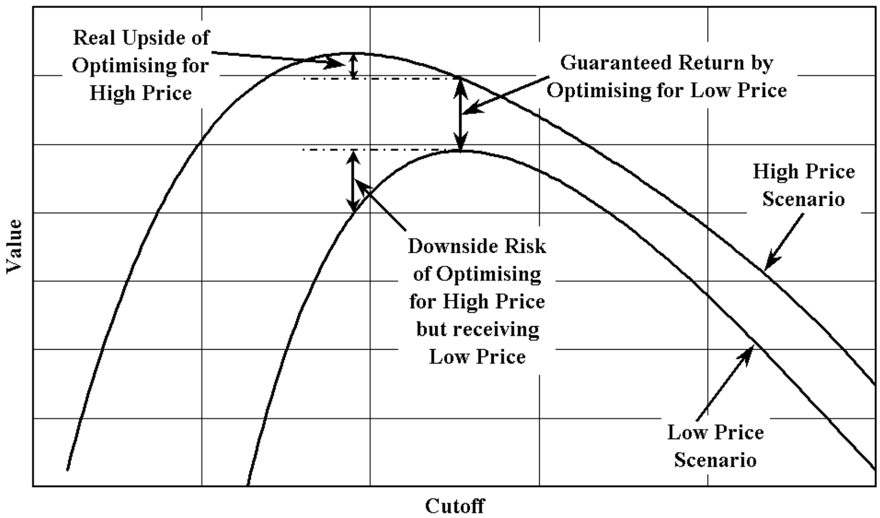
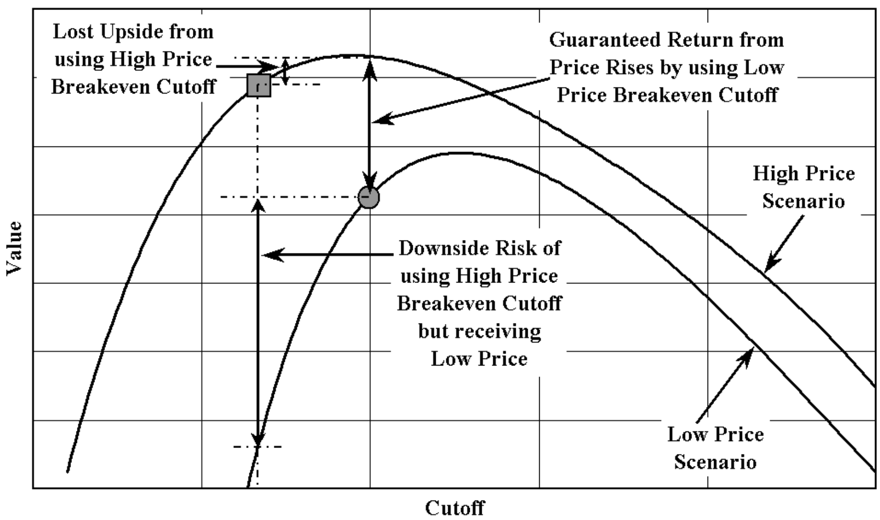


Figure 4 – Risks and rewards of incorrect price predictions and suboptimal cut-offs



Despite the power of the “Hill of Value” methodology to demonstrate how the values of a number of corporate goal parameters may vary with changes in operating strategies, its main drawback is the rapid increase in the number of cases to be evaluated as the number of “strategy decision” parameters, and the number of options for each of these, increases. Other techniques then become necessary.

Genetic algorithms

Genetic algorithms (GAs) have been described as one of the best techniques currently available for being reasonably sure of being reasonably close to an optimum solution, when there is no analytical method of finding the optimum, and when the number of cases is too great to permit evaluation of each to identify the best.

The authors have used Paliside Corporation’s EvolverTM and RiskOptimizerTM, both of which are relatively inexpensive and easy to use add-ins for ExcelTM. The first of these is a pure GA, while the second combines the GA with the stochastic simulation capabilities of the @RISKTM add-in, which allows the GA to optimise on statistical outputs from simulations rather than a single value derived by a standard deterministic spreadsheet model.

It is beyond the scope of this paper to describe the operation of a GA. It is sufficient here to say that it is essentially a “hill climbing” technique. However, to avoid the problem of most hill climbing methods, in that they will only climb to the top of the hill on which they start, the GA will not only climb the hill it is on, but also randomly “look around” to see if there is a higher hill elsewhere in the solution space. Because the GA technique is employed in cases where there are too many potential scenarios to evaluate each one, there is no guarantee that a higher hill will be found, even if it does exist. However, the authors’ experience has been that, if a GA analysis starts with the best results from a Hill of Value anlysis, improvments of 5% to 15% in the value of the parameter being optimised are not uncommon.

Values of decision variables that have been flexed under the control of the GA have included:

- Cut-offs applied to different mining stages, and to pits and underground mining areas.
- Sizes of pits being mined.
- Sequencing of mining various deposits.
- Allocation of desposits to multiple treatment plants.
- Timing and size of plant upgrades.

Since the GA has to target one parameter to optimise, it cannot account for the trade-offs between various corporate goals. GA optimisations conducted by the authors have typically focussed on maximising NPV, though some analyses have also considered maximising return on assets, and minimising losses at “bottom of cycle” prices. The alternative strategies identified in each case may be compared to identify similarities and differences, and decisions can be made as appropriate to address any identified trade-offs.

Results from GA analyses conducted have either confirmed the strategies already proposed on the basis of experience, previous studies, and engineering judgement, or identified new counter-intuitive strategies that add value. These are discussed in more detail in the “Findings” section below.

Advantages of using a GA are:

- It is relatively simple to implement.
- It may show how improvements can be made in existing strategies.
- It may identify new strategies.
- Logs of the analyses can be used to identify not only the “best” solution, but also factors common to many or all of both high value and low value cases, to guide further planning.

Disadvantages of using a GA are:

- It can only optimise one parameter. However, this can be any parameter (not just NPV, as for Lane’s methodology) and different parameters can be optimised in separate analyses. It may also be possible to weight and combine two or more parameters’ values into a single value for the target of the GA optimisation.
- There is no guarantee that the best possible solution has been found. (But on the other hand, any identified gain is theoretically better than nothing.)
- Conducting a reasonable number of calculations may take a long time.

Linear programming

Linear programming (LP) and its derivatives are classical analytical techniques for maximising or minimising an “objective function” subject to a number of constraints. It has been applied (or at least been identified as applicable) in a number of common mining industry problems.

In one optimisation study conducted, it was desired to maximise value not only subject to the more usual constraints of physical capacities in various stages of the process, but also taking account of several quality constraints imposed on both the ore feed and the product.

In the final investigations, the client opted merely to honour the physical constraints and report the quality parameters resulting. During the evolution of the study, however, methodologies were developed to express the quality constraints in linear form, and to utilise a LP add-in for ExcelTM. The nature of the problem required iterative calculations, as in a “Lane-style” analysis, for a number of periods, to converge on an optimum cut-off grade and mining rate plan, with the LP analysis in each period taking account of results from both preceding mining stages and earlier iterations. The whole process was able to be successfully controlled by Excel “macros”.

Although final results were not generated using this LP process in the study, “proof of concept” of the methodology was demonstrated.

Common Findings

A number of common outcomes are being found in all of the mine plan strategy optimisation studies conducted to date. Although the number of these studies is small relative to the number of mines in the industry, the consistency of these results and the commonality of planning processes employed by mining companies would suggest that these findings apply to a large number of mining operations.

An increase in cut-off leads to an increase in value

"Hill of Value" studies have consistently demonstrated potential value (NPV) increases of between 10% and 50% over what is obtained by "traditional" studies using breakeven cut-off analysis. Cut-offs are typically 30% to 50% higher. This has been found for a range of commodities and for both underground and open pit mines. Figure 1 is typical of many studies.

Parameters other than NPV may also be used for decision-making. For gold producers, the cash cost per ounce is a commonly quoted metric. The cut-off that minimises unit cost is frequently higher than that which maximises NPV, as shown in Figure 2. This effect has also been seen in base metals studies.

Figures 1 and 2 have been derived from underground studies. The ore production target from the mine is one of the independent variable axes in Figure 1, and is the same at all cut-offs in Figure 2. It is assumed that the development rate can and will be increased as necessary to account for the reduction in ore tonnes per metre of development as the cut-off increases. An injection of development "working capital" in a short-term campaign may be required if an increase in cut-off at a working mine is proposed. Both of these increases in development costs are taken into account in the analyses shown in the figures.

An increase in mining rates leads to an increase in value

The cut-off is only one parameter in the mine plan strategy. It is usually not possible to change the effective cut-off alone and add value: changing a mining or treatment rate is also usually necessary. This is because most operations will adjust their mining plans, including the effective cut-off, to deliver the best result according to the constraints within which they are operating. It is those constraints that must be identified and changed if possible to permit the cut-off to be changed and value to be added.

The word "effective" is used here to identify the cut-off that is actually being applied. It is not uncommon in the authors' experience to find that this is significantly different from the "official" cut-off. An "effective" cut-off as low as 50% of the "official" cut-off has been encountered. In these cases we hear comments to the effect of: "The cut-off is 'x', but we can't fill the mill at 'x', so we have to use a cut-off of 'y' in practice to keep the mill full". What this type of statement typically means is:

- The total operating cost breakeven grade is 'x'.
- The person making the statement believes that this total operating cost breakeven grade 'x' is the number that should be used as the cut-off.
- The mining and treatment capacities (as defined by Lane (1988)) are such that the optimum operating cut-off is in fact either the mining-limited cut-off or the mining – treatment balancing cut-off, which happens to be 'y'.
- This cut-off 'y' is the correct cut-off to be using, given the existing constraints (and so long as it is not less than the marginal breakeven grade or Lane's "mining-limited cut-off"). The mine has simply derived it by a practical approach rather than by understanding and applying cut-off theory.
- The existing constraints should however be challenged to determine whether a better mining strategy is available.

Figure 5 – Effects of changing mining rate and ROM cut-off in an open pit

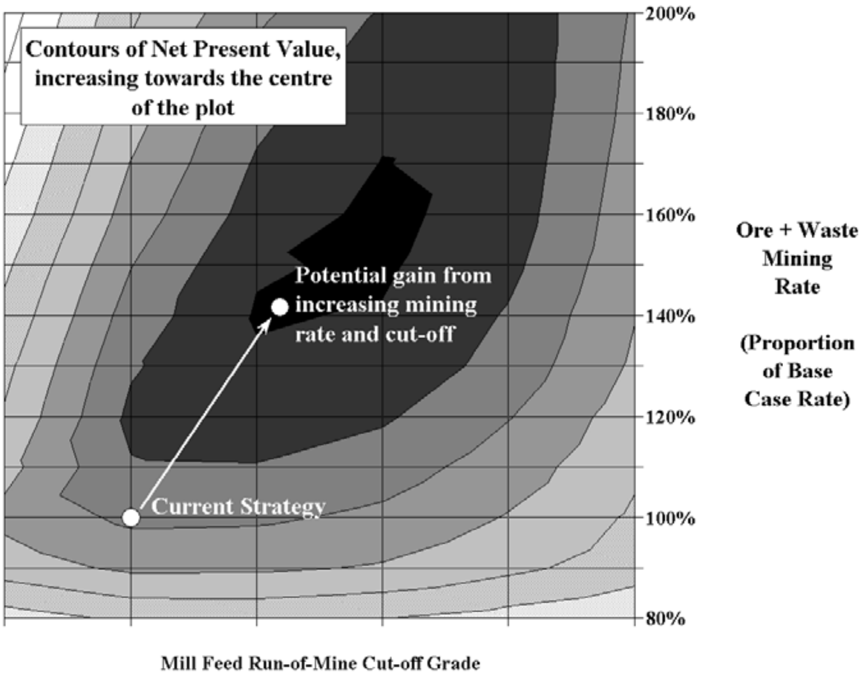
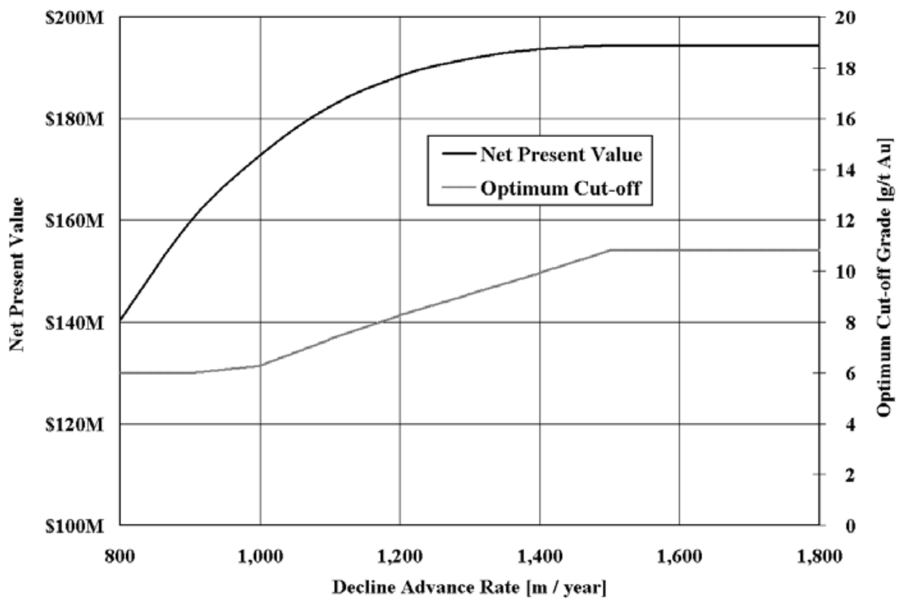


Figure 6 – Effects of changing decline advance rate



The mining - treatment balance (as defined by Lane) is often the operating strategy used in practice, based on the common understanding that both the mill and mine usually need to operate at capacity to maximise profitability. This then becomes a self-fulfilling prophecy. If the cut-off has been specified by non-optimal means and the mill is being filled, then the waste stripping or development rate which maintains the equilibrium will be seen as acceptable.

Pressures to reduce costs frequently drive the waste mining and development rates as low as possible. However, a number of studies for both open pit and underground deposits have shown that improved value can be obtained by increasing the mining rate of total ore and waste. In open pits, the ability to treat higher-grade ore through increased mining rate, with stockpiling of lower grade material, brings forward the revenue stream and offsets the effects of increased mining expenditure, but only up to a point, as shown in Figure 5, which was derived for a large base metals open pit. In the case of an underground operation, an increased waste development rate, particularly in decline development, may allow access to more production areas. This again may allow higher grade material to be mined and value to be improved (Figure 6), even though lower grade material maybe sterilised, rather than stockpiled for later treatment as in the open pit case. It should be noted that Figure 6 was created in a high level study to make a case for a more detailed study for an underground gold mine. It was derived by a simplified analysis where the NPV took account of the cut-off grade, operating cost and revenue effects, but not the timing effect of the earlier mining of the decline at higher advance rates. A more detailed study would also demonstrate an optimum development rate at the peak of a rising then falling NPV vs decline advance rate curve.

It is noted in passing that, when mines are operating in a low working capital mode with restricted waste development underground or waste stripping in the pit, a frequently suggested strategy is to increase the production rate so that the cut-off can be lowered and more "ore" treated profitably. This may involve some form of debottlenecking in the treatment plant to increase the ore treatment capacity.

Figure 5 clearly shows that significant gains in value may be achieved by simply increasing the rock mining rate and cut-off. A proposal to increase the ore treatment capacity should be evaluated by developing a second hill of value similar to Figure 5 for the new capacity, and including the capital cost of the upgrade. It would be expected that the peak of the new hill at any mining rate would be at a lower cut-off than for the original hill at the same mining rate, but the difference in optimum cut-off may not be as great as anticipated (see the discussion on the effect of changes in margin below for a potentially analogous situation). The optimum mining rate / treatment rate / cut-off strategy can only be determined by an examination of all the alternatives on the two hills of value thus derived.

Optimum cut-off is relatively insensitive to margin

Changes in both operating costs and metal prices will affect the margin obtained. It is common in sensitivity studies to find that the value of a project is much more sensitive to changes in revenue factors than cost factors. To identify how robust strategic decisions regarding cut-offs may be, the authors have typically generated Hills of Value for variations in both metal price and cut-off. At the optimum cut-off grade, the strategy is relatively unaffected.

Figure 7 shows results of a study for an underground gold mine, using gold prices of A$500 and A$600 per ounce, and illustrates a finding common to a number of studies. The volatility of the optimum cut-off is lower than the volatility of the breakeven grade when metal prices increase or costs fall. A 20% change in price would result in a 17% change in the breakeven grade. However the change in the optimum cut-off in Figure 7 is only 7%, and the flatness of the curves near the optima is such that selecting the optimum for one price will generate only a small loss of potential value if the other price were to eventuate.

When determining strategic policy, there can be significant risks associated with the selection of the metal price to be used if lower than optimum cut-offs are selected. The operation studied had a "planned" cut-off of 3 g/t Au. Breakevens at $500 and $600 were 2.7 and 2.25 g/t Au respectively. Using these three cut-offs, NPVs are respectively 10%, 15% and 20%

less than those received by using the optimum cut-off of between 4 and 4.5 g/t Au, if the price received were A$600/oz. If the price received were A$500/oz, the proportional losses in NPV increase to 20%, 30% and 45% at the three alternative cut-offs.

Similar mining areas may have different cut-offs

Conventional wisdom suggests that mining areas with similar characteristics (in terms of grade distribution, orebody characteristics, and cost structures etc) would have the same cut-offs. Analyses have indicated that this is not necessarily so. Evaluation of the results of GA optimisations have indicated that, for underground mines with multiple mining areas, and open pit operations with a number of pits feeding a central plant, NPV may be maximised when different cut-offs are applied to different mining areas so that all are depleted at the same time.

Figure 8 illustrates the principle. A common feature of scheduling mine production towards the end of the mine's life is a low production rate "tail" of material that is not able to cover the fixed costs of the operation. Value is maximised in this case if the mine is closed when the production rate drops below the sustainable level. The tail in mining area A after the closure date contains high grade material, while the production from area A before the closure contains lower grade material which is nevertheless above the common cut-off used for both mining areas. Figure 9 shows the same operation with different cut-offs for both areas. In this figure, area B is assumed to be producing at the same production rate and cut-off as before. Area A is also producing at the same rate, but with a higher cut-off, so that at the time the operation closes, the best possible material has been mined.

Although this principle is easy to comprehend in theory, identifying optimum strategies in practice may not be trivial. Real case studies have exhibited more complex behaviour to take account of interdependencies between underground mining areas, and potential variations in sequencing of open pit deposits. GA optimisations have generated counter-intuitive results: some areas may have cut-offs significantly lower than the overall optimum, and deep parts of the mine may have significantly lower cut-offs than shallower areas. Figure 10 shows schematically cut-offs applied to individual mining areas for an underground gold operation. Area cut-offs were specified in this study to be integer values only, and ranged from 3 to 6 g/t Au, while the optimum mine-wide cut-off was 4 – 4.5 g/t Au. The NPV resulting from the use of area cut-offs was of the order of 10% greater than that at the optimum mine-wide cut-off found by a Hill of Value analysis.

Successes and Failures

All studies completed using the processes described above have demonstrated that significant gains in value can be realised by changing strategy. For purposes of this discussion, three categories of successfulness of the studies have been identified.

- "Successful" – the analysis has been completed and the client has implemented a new plan as a result.
- "Partly successful" – the analysis has been completed and the client has accepted the results, but has elected not to change strategy.
- "Unsuccessful" – the analysis has not been completed to the stage where firm recommendations can be made, and the study has been terminated.

An evaluation of the factors contributing to the success or otherwise of mining strategy optimisation studies indicates the following.

Characteristics of successful studies

For a study to be successful, it is critical that the company's senior management – those who will have to make the decision to change the operation's strategy, and implement the change – are fully involved in the study process from the beginning. They must understand the nature of the study, and its potential benefits. The study team must ensure that the management team is consulted on a regular basis, in particular to ensure that all factors of concern to decision-makers are addressed adequately in the study.

Figure 7 – Case study risk/reward trade-off at different prices

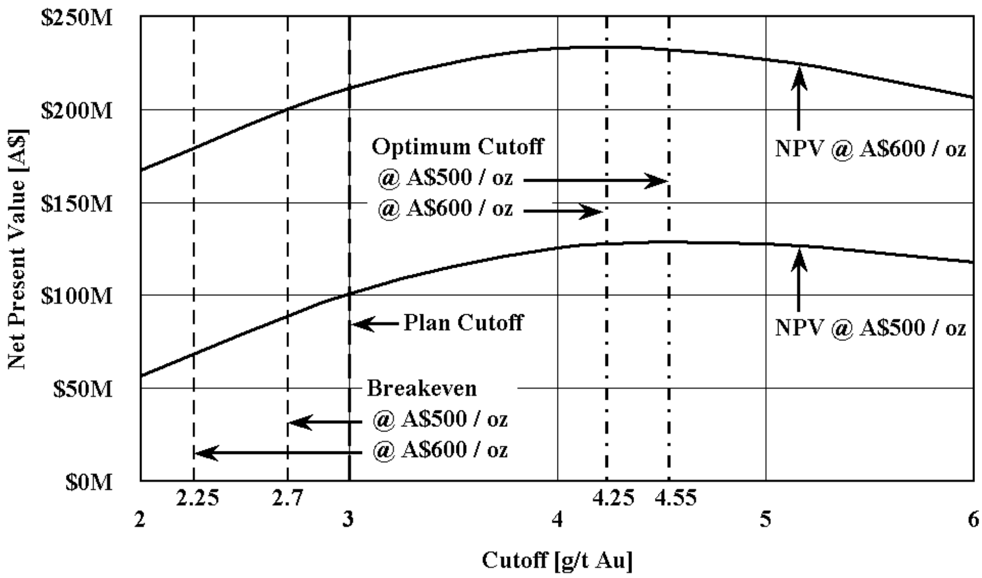


Figure 8 – Typical production profile with all mining areas using same cut-off

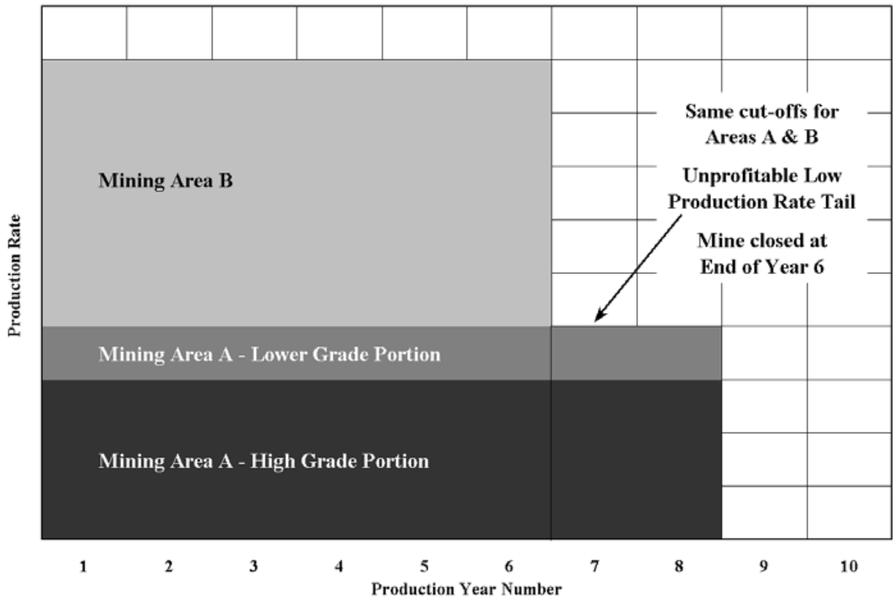
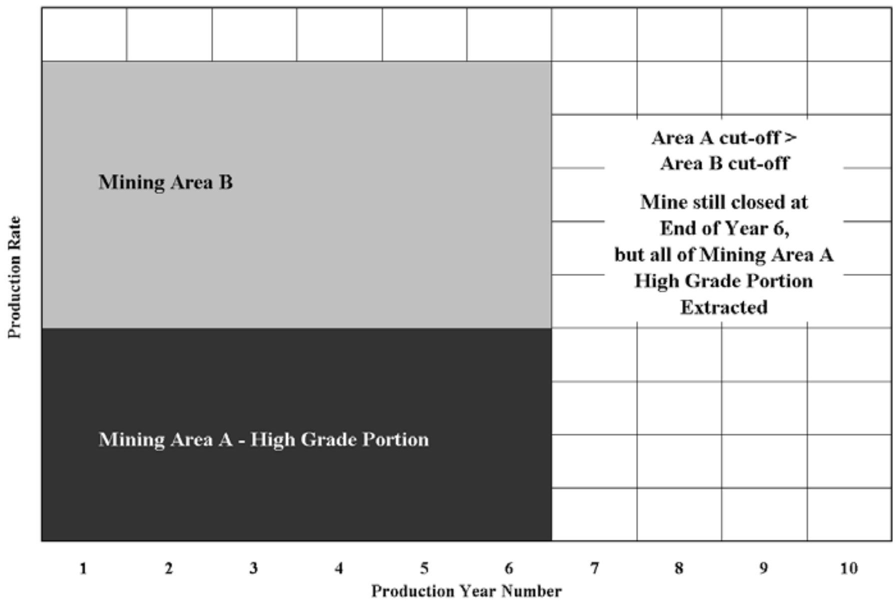


Figure 9 – Production profile delivering higher value, different mining area cut-offs



The commitment of the company's senior management must be manifested practically by the commitment of technical staff to assist in the generation of the input data required for the study. The technical staff associated with the study must also understand the nature of the study, why the information they are preparing is important, and how it is to be used. Continuity of staff in these technical roles is highly desirable.

The study team must then able to collate all the data, generate results, and present these to decision makers, in an understandable way, and in accordance with the project's timetable.

Characteristics of partly successful studies

There are two types of partly successful study.

In one type, the potential benefits are clear, but the level of detail of the study is insufficient to be able to make a firm recommendation for change. In each case where this has occurred, a more detailed study has been commissioned to address those issues.

The other type of partly successful study is typified by a major component of the proposed strategy being an increase in cut-off grade, together with a perception by the company's decision makers that the market would respond adversely to the consequent reduction in reported reserves. It is beyond the scope of this paper to discuss why the market should reward a strategy that reduces value and punish a strategy that adds value, or whether in fact this is even the case. We note however that this perception exists amongst decision makers in some mining companies.

Cases have also been encountered where commitments made to financiers or governments may effectively preclude changes to cut-offs, at least in the short term. One could however suggest that it would be wise where possible to identify optimum strategies before such commitments, and public announcements, are made.

Characteristics of unsuccessful studies

Unsuccessful studies typically exhibit one or more characteristics opposite to those of successful studies.

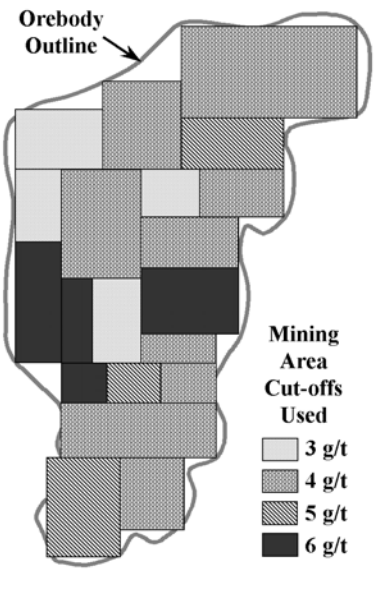
Senior managers and decision makers may be ambivalent regarding the study. They may believe they already know the best strategy, and therefore do not need to conduct the study.

Technical staff may not understand the potential benefits, may be too busy with other more urgent tasks, and / or may see the optimisation study team as a threat, if it is feared that the optimisation study may generate a "better" plan than they have produced. If these are combined with lack of management commitment to ensure that the study proceeds at a satisfactory pace, the data required is not forthcoming, and the study grinds to a halt.

Turnover of both management and technical staff may be a significant contributor to these problems.

The authors' unsuccessful projects have ranged from a case where so little data was forthcoming that no useful modelling could be done, to another where the analysis was largely complete, but waiting on the provision of a few key data items. This latter case was almost in the category of the first of the two types of partly successful study noted above. Dummy data used to develop the model was reasonably accurate, and though real data would have changed the absolute values of reported numbers, conclusions and decisions were unlikely to be affected. Other delays and problems from other factors described above made it impossible to complete the study satisfactorily at the time.

Figure 10 – Longitudinal projection of a case study deposit, showing cut-offs by mining area for maximising NPV, as determined by genetic algorithm optimisation



Conclusion

Most mining companies have publicly stated corporate goals of "maximising shareholder value", often with associated goals of reducing costs and improving efficiency. Many of these companies have multiple, and often conflicting goals. Companies tend not to opt to implement the strategy that fully optimises one of the corporate goals only, but rather to select a strategy that best meets some or all of these conflicting goals. The strategy optimisation process must therefore be able to identify not only strategies that will deliver the various goals, but also the trade-offs required to obtain the optimum combination of various conflicting goals.

Despite the general knowledge of the existence of Lane's cut-off theory, many mines have not applied the methodology. Rather, the use of operating cost breakeven grades as cut-offs is common. Lane's analytical methodology has not able to form the basis of detailed strategy optimisation studies in our experience, as it optimises only for NPV, and the analytical process can handle a limited number of physical constraints. Stockpiling and grade-dependent recovery relationships introduce further complexities.

The "Hill of Value" technique has been found to be capable of handling all the combinations of various "strategic decision" variables that can be independently specified. These will typically include such things as cut-off grades, production rate targets, identified debottlenecking and upgrade stages in the mines or treatment plants, and various mining method options. "Hill of Value" studies have consistently demonstrated potential value (NPV) increases of between 10% and 50% over what is obtained by "traditional" studies using breakeven cut-off analysis. Cut-offs are typically 30% to 50% higher. Genetic algorithm optimisations have also been shown to add further value.

It is usually not possible to change the cut-off alone and add value: changing a mining or treatment rate is also usually necessary. A number of studies have shown that improved value can be obtained by increasing the mining rate of total ore and waste in open pits, and development rates in underground mines. These are often reduced in practice to save costs, but optimisation studies indicate that the loss of value is often greater than the costs saved.

Changes in both operating costs and metal prices will affect the margin obtained. To identify how robust strategic decisions regarding cut-offs may be, the authors have typically generated Hills of Value for variations in both metal price and cut-off. When determining strategic policy, there can be significant risks associated with the selection of the metal price to be used if lower than optimum cut-offs are selected. At the optimum cut-off grade, the strategy is relatively unaffected by cost or price changes.

Conventional wisdom suggests that mining areas with similar characteristics would have the same cut-offs. Analyses have indicated that this is not necessarily so. Evaluation of the results of GA optimisations have indicated that, for underground mines with multiple mining areas, and open pit operations with a number of pits feeding a central plant, NPV may be maximised when different cut-offs are applied to different mining areas so that all are depleted at the same time.

For a study to be successful, it is critical that the company's senior management are fully involved in the study process from the beginning. The technical staff associated with the study must also understand the nature of the study and be committed to assist in the generation of the input data required for the study. There must also be a commitment to implement the strategies identified.

In some cases, the potential benefits have been clear, but the level of detail of the study is insufficient to be able to make a firm recommendation for change. Where this has occurred, a more detailed study has been commissioned to address those issues. Another type of outcome occurs when a major component of the proposed strategy is an increase in cut-off grade, but a perception by the company's decision makers that the market would respond adversely to the consequent reduction in reported reserves prevents the recommended strategy's implementation.

Studies have been conducted for a variety of minerals, mining methods, and numbers of deposits and treatment plants, in a number of parts of the world. They indicate that significant improvements in value (however it is measured) and reduction in risk can be obtained by relatively simple but more comprehensive analysis, modelling a wider range of options, than is usually done. Decision makers can be provided with significantly more and better information than they are used to receiving, to facilitate the optimisation of their strategic mine plans.

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