
Optimisation: Is it the Best?

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Introduction

This paper is a critique of the techniques of optimisation as they are currently practised in the mining industry. The intent is not to belittle them, far from it; in the 40 or so years since the advent of the computer first spurred their development, various forms of these techniques have been applied to mine planning with the result that the quality of the plans has improved beyond anything even imagined at the time. Such is their acceptance now that managers and financiers almost routinely ask of any plans submitted for approval, "Have they been optimised?"

Take two examples.

- a) In the late 1950's a merger was proposed between four mines to form a company now known as Rio Algom. The evaluation of the proposal required the generation of cash flow projections for each of the individual companies concerned, and a combined cash flow for the combined entity. There were complex tax considerations and elaborate contractual commitments as well as the many possible combinations and permutations of production schedules.

Two accountants worked tirelessly and in great secrecy for about a year. Even so, they were able to produce just one

master schedule with no examination of the sensitivity of the proposal to many of the assumptions and no detailed study of the production alternatives.

Nowadays company models for the individual operations would probably already be available; they would have been set up for medium term planning and budgeting purposes. The development of another for the merged entity would take only days. If a spreadsheet program could not cope with the complexity, one of many powerful financial packages certainly could. Given such tools the whole exercise would take only weeks, not months, and perhaps more importantly, the effects of many different schedules could be investigated to find some optimum combination.

- b) In the early 1960's the foundation work for a feasibility study of an open pit at Palabora was being undertaken in South Africa. Two engineers were working on site and a third in Johannesburg. They created a detailed polygonal model of the orebody and drew up plans and sections showing the grades in each polygon. From these, working with planimeters and calculating machines, they estimated tonnages and grades for an initial trial open pit and then for

a second trial pit before deciding on an ultimate pit. This took them about two years and then was only done at one cut-off grade. The idea of trying another cut-off almost caused a strike.

Contrast this with the present state of the art where block models can be created by computer from bore hole data and sequences of pits can be generated in days if not hours. Multiple cut-off grade policies can be studied as a matter of course. In fact, the whole problem can even be Whittled, a process that needs no explanation in the present context.

Surely with such powerful tools now available to mine planners, the eventual plans must be the best. Of course, if optimum means best, as it does according to the dictionary, then further discussion is fruitless. However, are the words synonymous in the context of mine planning?

Definitions

Optimisation

This is a word which in the context of industrial planning, and mine planning in particular, has gradually come to be accepted as descriptive of a set of techniques that introduce analytical mathematical methods into planning activities. The techniques embody a process with three stages:

- 1) The creation of a mathematical model of the activity or some part of the activity. A mathematical model is a collection of variables, possibly a large number, whose values define the plan. Relations between the variables are established by a series of equations; these determine the structure of the model. A set of values for all the variables that is consistent with all the equations is one possible plan. For example, the variables could be the annual production levels for the remaining life of a mine. The equations

might then relate tonnages, grades and capacities.

- 2) The adoption of a criterion. This has to be some unique measure of quality or performance that is of overriding importance in establishing the merit of a plan. It has to be a function of some of the variables in the model. Thus it becomes possible to calculate a value for the criterion associated with every possible plan.
- 3) The development of an algorithm for finding the set of values of the variables in the model which gives rise to the maximum value of the criterion. The algorithm can be some mathematical routine for maximisation or simply some calculating procedure designed to search for a maximum.

The recent success of the techniques derives from the twin facts that sophisticated mathematical methods can be focused on the problems, and that computers of amazing power are available to cope with the complexity of real applications.

Best

The meaning of best is ultimately a philosophical one. It is difficult enough to reach agreement on what constitutes a very good plan, let alone the best plan. The merits of different plans can usually be ranked in some general categories, such as poor, mediocre and good; but selecting the best from among the good is a matter of judgement. It requires a consensus of opinions from among informed, professional and experienced participants. (Perhaps this is one function of a board of directors?) Many factors have to be reconciled - local, political, environmental, technical, and financial; and the reconciliation has to be achieved amid much uncertainty about grades, recoveries, costs, markets and prices.

This description of best is, of course, not a definition at all. It is a commentary on the way mining decisions are taken in practice and the factors that influence them.

Analysis

As at best the definition of best is very fuzzy, attempts to make direct comparisons of optimum plans with best plans are unlikely to be productive. Therefore an evaluation of optimisation has to take the form of a review of the techniques, with assessments of their weaknesses. This can be done under four headings, the approach, the model, the criterion and the data.

The Approach

Criticisms of optimisation under this heading are more in the nature of warnings to the user than fundamental shortcomings. The point is that planning is a creative activity whereas optimisation is analytical. No amount of optimisation will actually formulate a strategy; it will only refine one that has already been adopted. In other words, in the total planning process optimisation is a secondary activity and not a primary one.

An extreme example is open pit versus underground mining. If underground mining is fundamentally a superior strategy then no pit optimisation will produce a better result. This is obvious, but there are variants not so obvious. It is sometimes possible to mine by both open pit and underground in tandem as at Andina in Chile. This introduces an additional degree of flexibility into the operation. It is also sometimes possible to exploit the orebody first by open pit and then by underground as currently under consideration at Palabora. These mixed strategies have repercussions on the optimisation routines and care has to be exercised in their application.

Many other combinations arise in practice. Multiple pits, multiple pits with intermediate stockpiling, and alternative processes are further examples. In every

case a strategy has first to be formulated and only then can optimisation techniques be developed or modified to fit the circumstances.

The Model

Because of the complexity of every application, the modelling always involves a degree of compromise between reality and manageability. The question is what price, in terms of realism, can be accepted in order to arrive at a representation which is soluble in practice.

Of course, there is always the temptation to adopt a model already known to be soluble. Linear programming is an historical example. It is a powerful technique, well suited to the computer, and it was one of the earliest programs to achieve success and acceptance in industry. As a consequence many practitioners went in search of applications and were often persuaded to distort the application itself to fit the technique.

In mining, there are three principal kinds of models commonly employed in developing long-term mine plans. They are orebody models, mine models and financial models.

• Orebody Models

It is nearly standard practice to adopt a regular block representation of an orebody. The computing convenience of such models outweighs other considerations, at least in the present state of the art. However, the big question is how to assign values to the blocks when the majority of them, often 95% or more, do not even contain any sample values. In order to answer this question, some structure has to be assumed for the pattern of grade variations through the deposit.

The common methodology is first to subdivide the deposit into regions that are reasonably homogeneous geologically, then to seek a deterministic interpolation procedure by calculating moving averages on some basis varying from the intuitively simple inverse square of distance to the

sophisticated Kriging. These yield a uniquely valued block model that gives an apparently solid foundation for further planning. Unfortunately, however, it does not reflect the reality of the inherent variability. This is a serious deficiency too often shrugged off.

The fact is that the sampling is usually too sparse to support a deterministic model. This means that logically the model should be statistical. The one technique to recognise this at present is conditional simulation that creates at random sets of block values each of which is consistent with the original data. The technique is in its infancy as yet and it is conceptually difficult as well as computationally demanding. However, it has the necessary virtue of realism. Methods need to be developed for coping with the multiplicity of sets of values in the subsequent planning, before it can be more widely applied.

• **Mine Models**

The dominant examples are in open pit mining. The pit is usually represented by a series of levels (easily conceived as benches) and a set of perimeters, one on each level, expanding upwards from one level to the next. Computational techniques vary from defining a pit bottom and climbing upwards at specified slopes to graph theoretic algorithms of the kind first proposed by Lerchs and Grossmann.

Much of the impetus behind these developments has stemmed from the apparent ease with which the problems could be expressed in a mathematical form and the challenge presented by the search for efficient and rigorous solutions.

In practice most attention has been concentrated on delineating the ultimate pit envelope because this has proved the most tractable problem. The more general problem of how to schedule production through time from the virgin surface to the ultimate envelope is a vast computational exercise beyond the capacity of current

machines. Therefore attempts have been made to adapt ultimate pit algorithms to identify nested expansion phases and to invent search procedures which will, hopefully, find good schedules in a reasonable time. How good any of the resulting schedules actually are though, remains to be demonstrated.

A further complication arises from the impact of the financial implications of a schedule on cut-off grade policies. This can be calculated by the application of another optimisation technique but any modification of cut-off policy must, in turn, affect the schedule. This additional loop multiplies again the total computational burden.

Underground operations are less amenable to optimisation techniques. The use of powerful computer aided design systems permits intensive trial and error evaluations to determine development programs and detailed stope designs. These are computer based graphical models but they do not commonly incorporate large-scale optimisation algorithms.

• **Financial Models**

These have found widespread application throughout industry and commerce. As a consequence very sophisticated systems have been developed which are capable of modelling operations to whatever degree of detail is thought necessary. In mining they are commonly used for planning, budgeting and economic evaluations.

Optimisation techniques frequently refer to economic criteria that require cash flow projections. For these, quite a lot of detail is necessary in order to achieve realistic accounting. However, the forecasting in several areas is of very doubtful reliability.

The most difficult, yet by far the most important, is price forecasting.

Nevertheless, the universal practice in mining is to adopt deterministic financial models. It is assumed that all the variables in the model take on specific values and

that deciding those values is simply a matter of estimation. The values are sometimes flexed according to some probabilistic selection procedure, as in a monte-carlo sensitivity analysis, but this is about the only concession to the obvious fact that many of the variables, particularly price, are stochastic.

The Criterion

The adoption of a single criterion is clearly unrealistic in projects with significant economic and social implications. It is possible to impose conditions within the structure of a financial model so that certain combinations of values are excluded, but, even so, any single criterion is an over simplification. In reality a plan has to involve some compromise between conflicting requirements.

The commonest criterion in use today is the net present value of the cash flow arising from the operation. The discount rate is usually derived from an analysis of the cost of capital based upon the capital asset pricing model. This model, like so many econometric models, has an intuitive appeal, but whether or not it fits the facts is far from proven. The estimates from market data tend to be crude and the issue of tax is glossed over.

An example is the scale of a planned operation. For a large deposit there is often no obvious limit to the size of a planned mining installation and it is usually the case that the apparent economic return improves with increasing size (the economies of scale). Yet it is clearly imprudent to pursue this optimisation too far. More and more investment is being dedicated to one project that could encounter difficulties. This is the risk inherent to some degree in every project and is another criterion to be considered. The optimisation could be formulated as the maximum return with the minimum risk but it does not take a mathematician to appreciate that the two objectives are irreconcilable without some compromise formula.

Also, average rates of return are confused with cut-off rates. The theory is that the cost of capital is the average return achieved by similar projects, and this figure is then recommended as a cut-off return for investments. Yet every miner knows that the cut-off and the average can never be the same and are usually very different.

Risk has already been mentioned. The capital asset pricing model claims to incorporate risk but there is an inherent contradiction in this concept when applied to a project. If a project involves risk then its outcome is uncertain. This being the case a unique return cannot be associated with it. Therefore, little meaning can be attached to assertions such as "the greater the risk the higher the return", in the context of a project.

The Data

This is a well recognised problem (GIGO). In the early days many optimisation routines were described as exercises in the maximisation of costing ignorance. In planning, data has to come from several sources each with its own problems.

Grade data has already been mentioned. Great care is usually taken over sampling and assaying but the scarcity remains an expensive obstacle because of the cost of further sampling. Cost estimates can come from accounting systems but these systems are usually designed for budgeting and control purposes. They require interpretation and rearrangement for planning. Engineering sources usually present them more suitably but engineers and technical people like to work in unit costs, regardless of fixed and variable elements.

The definition of the relevant data also requires care and thought in many applications. For example, the assignment of costs to blocks in open pit studies is not a simple exercise. What about time costs? Originally the recommendation was to share them between mining and processing;

now the importance of capacities is recognised. Are the same costs relevant for cut-off grade determinations? How can the effects of discounting be incorporated?

These questions can be answered well enough for practical purposes but reliable capital costs are much more difficult to obtain. And, of course, there remains the question of price. This is of such importance and so elusive that headquarters usually have to issue edicts.

Conclusions

It is clear from this review that optimisation, as might be expected, has a number of minor weaknesses. Their avoidance is largely a matter of care and attention to detail. In one area, though, the matter is more serious.

Long term mine planning is a sandwich. In the centre is the meat, a blend of complicated calculations about tonnages, grades, recoveries, costs and revenues. Underneath is a thick slice of uncertainties about the ore in the deposit. On top is another thick slice of uncertainties about the economic future. It is this bread which rather spoils the taste.

The fundamental question is how to deal with uncertainties. The present approach in the industry is to adopt what could be called a Roman Road approach - set off in a particular direction and keep going. Some of the territory may not be well known and the going could get rough but the plan is never to deviate. Grades are averaged, prices are averaged and a plan is established with a ruler, straight and narrow.

It is possible, once a plan has been established, to calculate the consequences of different assumptions about the grade variations through the deposit and about the values attached to the economic parameters. These calculations show how robust the planned results are in relation to the assumptions. Such calculations are often

made and this is the analysis that is usually referred to as a sensitivity analysis.

Beyond this, it is possible to completely rework the plan for different assumptions. These calculations show how robust the planning process itself is in relation to the assumptions. Such exercises are only rarely undertaken because of the amount of work involved.

Studies of both kinds give useful information about a plan. Robustness is an important criterion. But neither envisage any flexibility within the plan itself. Should not the road adapt to the terrain that is actually encountered in the event? Is it not a blinkered approach to progress in a straight line rather than twisting and turning according to the circumstances at the time?

This is the essence of planning in conditions of uncertainty. The plan should incorporate options that can be exercised when and if certain circumstances arise. This is the area that deserves much more research.

Some Observations

There is nothing novel about strategies that recognise uncertainties and try to anticipate them, nor about tactical changes in plan according to circumstances. Dire circumstances sometimes force changes regardless of underlying long term considerations, but there is usually no recognition of such eventualities in the optimisation process.

The example of size and risk is a good illustration. The original studies for Bougainville considered concentrator capacities up to 120,000 t.p.a. The returns (net present values) improved with every increase in size. Yet finally a compromise of 90,000 t.p.a. was chosen. In the view of some of the planning engineers the reason was that the directors got cold feet. But this observation was not the criticism it appeared to be. The directors were in fact reacting to a perceived risk not recognised in the optimisation analysis. A provision

was made for increases in size and several years later there was a large expansion coupled with the processing of lower grade ore. This was claimed as an optimised expansion at the time, but in the light of subsequent events it seems doubtful that the risk was adequately appraised.

Starting at one size with the option to expand is a strategy with many advantages. The financial exposure is less and valuable experience is gained before the next investment. It is actually quite a common strategy too, although it is not always deliberately adopted as such; events just happen that way.

How to adapt to price fluctuations is a contentious question, yet it is probably the most significant question in mine planning. The mainstream optimisation strategy is to access the better grades in the deposit at an early stage and to work to a higher cut-off in the early years. Yet this is demonstrably a poor strategy if the early prices are low. It is easy to say that production should be increased in times of high prices and decreased in times of low prices, but this is not a sufficient definition of a policy. What precisely are high and low prices for operational purposes and what range of production levels should be considered? Any tactical change in production assumes a measure of flexibility in the mine plan. Flexibility therefore becomes an important criterion, so should it not be explicitly considered?

It is sometimes argued that any gearing of production to price is a form of speculation, but any policy in conditions of uncertainty, is speculation in the sense that the result is not precisely predictable. Full production at present price is only a default policy. The commercial and financial implications of different policies are probably paramount. Although the long-term prospects are improved, can the operation afford to cut production when the price is low? Can it survive? Does it become vulnerable to take over? What actions are

competitors taking and how will they affect the market? Is a temporary closure a practical tactic?

Such questions do receive attention, of course, and there are examples where the tactics for survival in times of a prolonged recession have been closely studied. However, they are seldom seen as an integral part of a long term planning study. Perhaps this is where option theory has some relevance? Certainly optimisation techniques cannot begin to claim to produce the best plans until they incorporate uncertainty and the response to uncertainty, explicitly in some way.

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