Global Asset Optimisation

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ABSTRACT

Although there are now many tools and techniques available for optimising various parts of the mining and processing stream in isolation, so far an integrated approach that simultaneously addresses the various components has not been available.

In the last four years Jeff Whittle has focused on expanding the boundaries of integrated optimisation for the resource industry. The result is an approach that applies business and operational modelling techniques to construct integrated geological, mining, processing, transport and market models, which are then optimised by allowing powerful optimisation algorithms to control the values of those variables that are considered negotiable.

Confidently referred to as Global Optimisation, due to the number of variables that are simultaneously controlled, the result is a powerful business tool that can be used as a platform to support strategic decision-making at many levels.

In this paper, the author outlines a variety of modelling techniques applied during recent projects, the optimisation mathematics employed and the typical characteristics of a Globally Optimised business plan.

PROFILE

Whittle Consulting is a private venture by Jeff, Ruth and Gerald Whittle, which combines expertise in research, mathematics, computing and business planning. The focus is on developing and applying new procedures to identify opportunities and increase understanding of the management of portfolios of mineral and technical plant assets.

INTRODUCTION

There are now many tools (distributed by the mining software vendors or resulting from mining company's internal developments) and techniques for optimising various parts of the mining and processing stream in isolation. However, the last frontier is to make it all happen simultaneously.

In the last four years, Jeff Whittle (Whittle, 1999) has focused on expanding the boundaries of integrated optimisation, concentrating on the issues faced by large and complex mining and processing operations. By using advanced business modelling and analytical techniques, an integrated geological, mining, processing, transport and market model can be constructed, which is then manipulated mathematically to optimise the values of those variables that are considered negotiable. Utilising this procedure, it is possible to develop long-term plans that maximise the value of large geological and technical plant asset portfolios. As such the approach is a powerful business tool, which can be used as a platform to support strategic decision-making at many levels.

Not every part of a mining/processing operation can yet be simultaneously optimised, but the following work is confidently referred to as Global Asset Optimisation due to the increasing range of variables and the scope of assets that are considered together.

In this paper, the author outlines a variety of modelling techniques applied during recent projects, the optimisation mathematics employed and the typical characteristics of a Globally Optimised business plan.

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THE NATURE OF THE PROBLEM

Global Asset Optimisation addresses the issues raised in mining and processing operations with multiple pits/mining faces/ underground mines, multiple elements, stockpiling opportunities, blending issues and alternative processing and/or product options. The combination of these dimensions creates significant long-term planning and analytical challenges that often exceed the capabilities of readily available mining optimisation tools.

The factors that make mine planning more complex than other business planning challenges are:

1. *The link between time periods*. An orebody being mined is a depleting resource. When we decide what to mine and process in one period, we determine the starting surface for the next period, and therefore we limit the options of how to operate it.

   This inescapable link between time periods creates the need to determine an integrated chain of events, which results in a chosen path through the orebody with all the associated capital and operating decisions involved. Two different plans might ultimately mine and process the same tonnes and grades of ore and result in the same overall production, total revenues and costs. However, the order and timing of these activities and cash flows can make one plan far superior to all others in terms of financial viability and performance.

2. *Blending*. In many circumstances, individual parcels of material cannot be evaluated in isolation. Their value will depend on what other parcels are available in the orebody, and the timing of such availability. The blending possibility creates extensive mathematical permutations and interdependencies between the variables, significantly complicating the optimisation mathematics.

3. *Stockpiling*. Flexibility is created (at a cost) when it is possible to separate the time at which an ore parcel is mined, which might be driven by the parcels that surround it, and when it is used. Stockpiling creates more mathematical permutations to consider and complicates the links between time periods.

4. *Alternatives*. If material can be used or not, or used in different ways, more options and flexibilities are created, and once again more mathematical permutations to consider.

5. *Variation and uncertainty***.** Nature dictates that grades and physical characteristics are distributed with little consistency within an orebody. This often defies our attempts to categorise, describe simply and predict. With less than complete information we are forced to make approximations as to what material there is and how it will perform when mined, handled and processed. The inaccuracies and risks that arise from this must be understood and the resulting consequences carefully managed.

The aim of the modelling phase is to capture the details of the geological, mining process, mineral processing and market alternatives, using particular modelling techniques. The result is effectively an integrated business model that embodies the existing knowledge on geological, engineering, metallurgical and financial issues. This model is then controlled by a powerful mathematical optimiser that can handle the nature and scale of the system defined.

MODELLING METHODOLOGY

The focus is on strategic scheduling. Every situation is different and, although the modelling techniques outlined below have all been applied in more than one situation, the procedure cannot yet be described as 'generalised'.

Let us envisage a Global Asset Optimisation exercise for a situation involving several deposits, several processing options and alternative products.

Pit shell optimisation

When preparing for a Global Asset Optimisation, conventional techniques are used to determine pit shells (eg using Whittle Four-X software) for each deposit. In this process it is necessary to take a single and initially isolated view on the definition of ore, and how it will be treated. It is necessary to make assumptions about what material will qualify for the blend, via what processing method it will travel, and which product the ore will ultimately report to. Pit shell optimisation is a static piece of analysis in that no attempt is made to determine *when* a block of material will be mined, so it is not possible to consider the fact that prices, costs, capacities and recoveries may change over time. These factors can only be considered during schedule optimisation.

It is not actually necessary to determine the ultimate pit shell with any degree of certainty at this stage. This statement may seem ironic as determining the ultimate pit has been the hallmark of Whittle methodology. In a Group Asset Optimisation, however, the ultimate pit for a particular deposit will be influenced by factors outside the deposit itself, and can therefore only be confirmed during detailed schedule optimisation of the total system.

The approach is, therefore, to develop nested pit shells that are efficient in terms of:

1. stripping ratio, and
2. prioritising ore based on its value, given its expected most likely outcome.

The schedule optimisation of the total system will at some point run out, or reach a break-even point, or a point of inadequate cash flow or returns. What has been mined at this point is therefore deemed to be the ultimate pit, and this will change as assumptions in the overall scenario are modified. The ability of a deposit to participate in a group schedule will determine its timing, rate and ultimate size.

Pit shell design is by no means a perfect procedure in the context of the Global Asset Optimisation, but we need to start somewhere. Once a round of schedule optimisation has been performed, a different view of what the most likely outcome for different geological materials may develop, in which case another iteration of the pit shell optimisations may be warranted.

It is implicit in a pit that phases can be mined consecutively or concurrently, subject to the rule that an outer phase cannot overtake an inner phase in descending at any point of time. Details of any required minimum/maximum lead/lags, earliest start dates, start-after rules, alternative mining methods, tonnage rates limits, vertical rate limits, costs, dilutions, etc must also be considered.

Underground mine design

The Global Asset Optimisation does not attempt to get inside and control the specific mining activities within an underground mining area or 'block'. In a Global Asset Optimisation an underground block will be one of the components of the overall system involving many other underground blocks and/or pits.

An existing local schedule is taken for an underground mining block, which typically involves upfront capital development and time, maintenance of access and ventilation during ore mining and periods of interspersed backfilling. This schedule is summarised as a quarterly (ie three-monthly) schedule, of costs and tonnes/grades of ore produced. A quarter of underground mining activity is, in a mathematical sense, no different than a bench in a pit when it comes to scheduling, in that it represents an inventory of ore that can be obtained in a certain sequence, at a certain cost and rate.

The Global Asset Optimisation schedule will determine when and how a particular underground mining block will feature in the master plan, by considering how it relates to all other sources of material in the total system. As with pit shells, once a round of scheduling has been performed, this may present some feedback with which to re-do the specific design and local internal schedule of a particular underground block, to enable it to fit better into the big picture.

Pit geology

In the case of pits, geological blocks are consolidated into 'grade bands' within a bench of a phase/pushback (see Figure 1). Grade banding techniques are designed to summarise ore data, but

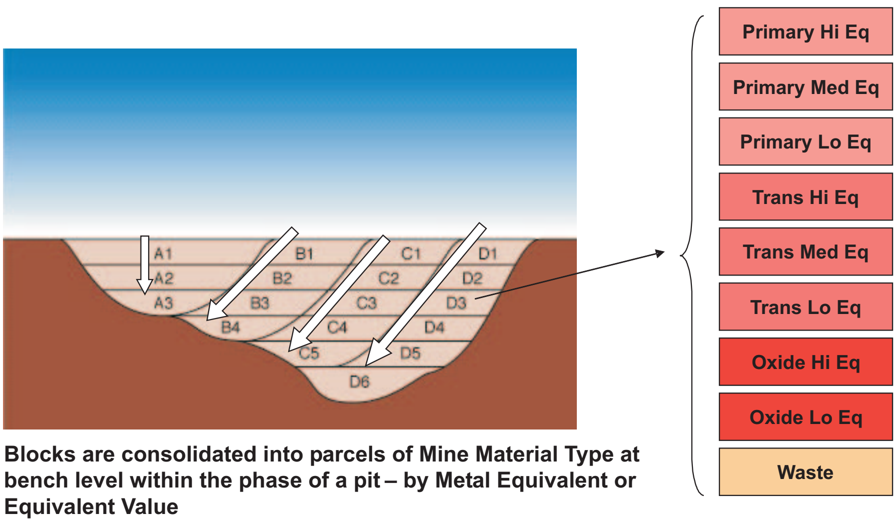

FIG 1 - Mining by phase and bench.

maintain a relevant segregation of mineralogy, and either a matrix of relevant ore grades/attributes or a ranking of ore based on an equivalent metal or net-value calculation can be used. It is typical to work with between eight and 20 grade bands, depending on what is relevant for cut-off grade, stockpiling or blending, and the actual operational grade control capability that exists. A geological model with many millions of block records will therefore reduce to a grade-banded database of several thousand records. There may be several deposits in the system being modelled and the grade banding approach is likely to differ for each.

The level of consolidation chosen for grade banding influences the resolution at which ore/waste can be defined, stockpiling versus immediate processing, and processing path selection will be made (see Figure 2).

It is likely that a particular band of Mined Material will report to different destinations in different periods, as the decision will be influenced by what else is going on in the global optimisation at the time a parcel is mined.

Grade banding is a subject in its own right and is the key to significant value in the schedule optimisation, by facilitating appropriate decisions on cut-off grade, stockpiling, processing path selection, blending and product mix.

Grade banding is important for the scheduling of pits in a system and could theoretically be applied to the ore generated by an underground mine. Our experience is, however, that underground operations by nature focus on premium high-grade ore of one type and do not generate the wide spectrum of grades and ore types that pits tend to, so banding is less relevant.

Ore processing

A Processing Summary model is developed, which captures the cost, throughput and recovery relationships for each type of ore and each of its potential processing paths. This summary will cover between say three and 50 channels, and allows us to capture in great detail the metallurgical sensitivities. There will be separate channels for each plant and for different groups of ore types if they have different costs, throughput or recovery in that plant. Different channels can be created for the same plant operating in different modes.

Non-linear expressions, multi-stage paths, recycle loops, etc can all be accommodated. Processing models have been developed to cover mills, concentrators, acid leach, smelters, refineries and to include consideration of mineralogy, grades, blending limits, synergy from blending, hardness, sizing, SG, density, viscosity, rejects, by-products, intermediate stockpiles, additives, consumables, maintenance, sustaining capital, shutdowns, purchase/sales of intermediates, etc with changing capacities, availability and performance over time.

In a group asset situation, it is typical for some ore types to be eligible for more than one processing method. These methods may change in availability, capacity, cost and performance over time – all of which will be captured. Rules, which are applied as filters based on one or more characteristics of the ore, will be formulated to define what categories of Mined Material can go through each processing path, and what will happen when it does. At this stage we are just capturing all the alternatives, not attempting to determine what makes sense or what is best under what circumstances – the optimiser will do that. We are not even presuming that material will be processed by one of these paths; the optimiser may choose to discard it.

Processing turns Mined Material into one or more 'Blend Feeds' (see Figure 3), which may simply be rock, lump and fines, slurries, concentrates, rejects, by-products, or even fully extracted metal – depending on the operation and how we have chosen to model it. Different processing paths may produce the same Blend Feeds (perhaps with different qualities, quantities, or cost) or totally different ones. Blend Feeds are not necessarily the finished product, but they are available for further use in the system.

Blend Feeds can be allowed to be stockpiled, allowed to be discarded, or forced to be used.

Blending to products and market

Blending may simply be the adding together of the available Blend Feeds, with or without set criteria on the characteristics of the combined product. Alternatively, it may involve more complex stages of extraction such as leaching, smelting, refining, or combinations of all of these.

'Blending' is the concept of being able to determine the required criteria of the resulting product, which may involve the combination of Blend Feeds (ore, concentrates, etc) with attributes or characteristics that are complementary. In building a blend, it is likely that many of the components that participate would not qualify alone. Blending is a very powerful mechanism, which represents a significant opportunity but also a significant challenge to plan and optimise. Just as Mined Materials can have alternative Processing Paths, so too can Blend Feeds have alternative Blending Paths and/or more than one product destination (see Figure 4).

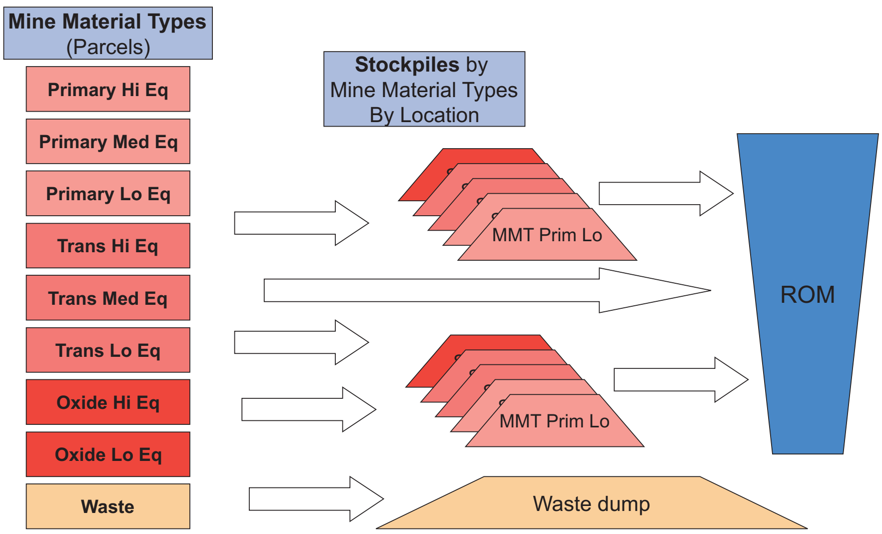

FIG 2 - Waste/Stockpile/Process.

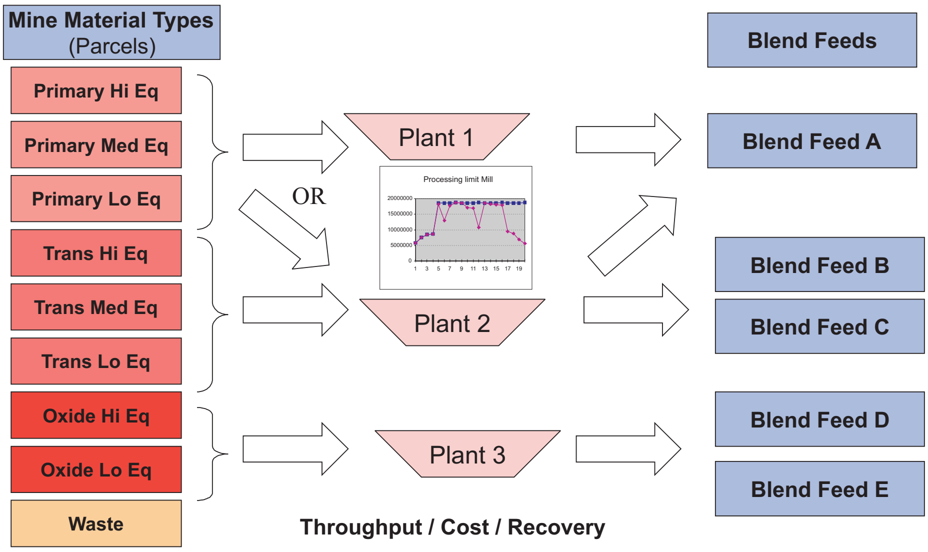

FIG 3 - Alternative processing paths.

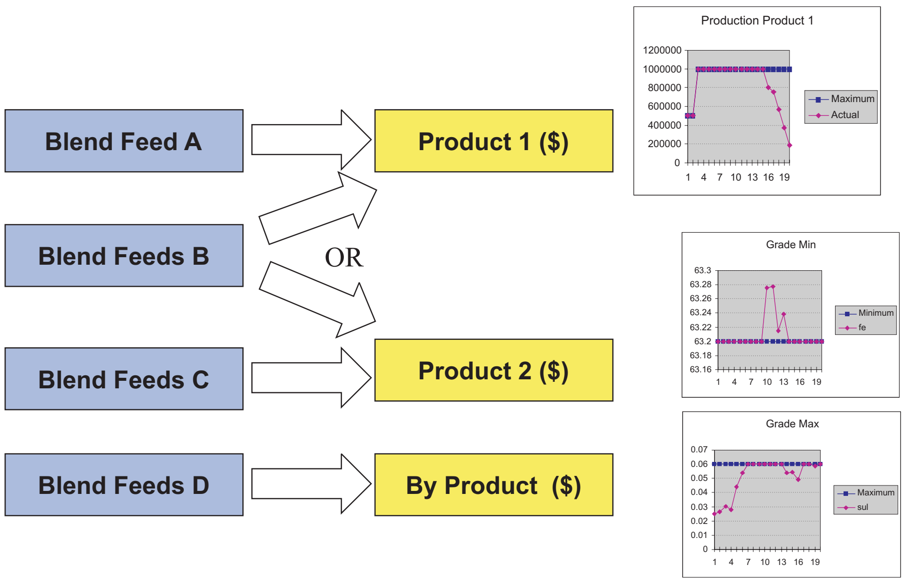

FIG 4 - Multiple products.

Product attributes determine the blending criteria and may be defined as strict limits (upper, lower or both) on particular grades or other attributes of the final blend, or with flexibilities, with or without penalties and rewards for variations. The valuation of the final product may involve constant or changing prices, exchange rates, royalties, transport and further treatment/refining allowances.

The model therefore contains all the material under consideration, the rules by which it can be accessed, and the details of all the options by which it could be treated and blended. No attempt is made to draw conclusions about the solution, only to comprehensively lay out all the possibilities.

CONSTRUCTING THE MODEL

No model is perfect – but some models are useful

Although it sounds complicated, the methodology is well developed, and mining companies usually have sufficient existing information and knowledge within the organisation to consolidate into a comprehensive model of this kind. Information is never perfect, so it is a matter of making the best use of the information that is available and understanding its risks and weaknesses.

Increasing numbers of templates are being developed that help deal with a range of situations/challenges without having to revert to research or problem-solving mode. Upfront discussion on appropriate scope and level of detail is important to ensure the focus is kept on the material and relevant issues. The capacity of the optimiser, and indeed our/your mental ability to deal with complexity, is large, but not unlimited – nor are budgets for this type of work. Choices have to be made that involve judgement on where to focus and to what level of detail.

OPTIMISATION

Modelling is not rocket science, the optimisation of such a model is

A model of any scale with these mechanisms can exceed the capacity of conventional mathematical optimisation tools, including Linear Programming and the various mining and scheduling optimisation software packages available.

At this point, specialised proprietary mathematical procedures are required to control the variables in the model that are considered negotiable, in order to maximise the objective function of Net Present Value (NPV). Development of such an optimisation capability and the limits and flexibilities these provide on various modelling techniques, has been the subject of Jeff Whittle's research and development program for the last four years. The result has been two optimisers referred to internally as 'Z3' and 'Prober'.

From the outset we have used adaptations of the 'Z3' optimiser. Z3 is the combination of a mathematical search algorithm that works in conjunction with a linear programming evaluation routine. The search algorithm samples the feasible domain of alternative life-of-mine mining plans; the evaluation routine determines the optimal cut-off grade, stockpiling, processing selection, and blending and production plan that the specified mining plan can support, and determines the NPV. Based on the NPV fed back by the evaluation routine, the search algorithm applies complex decision rules to focus on combinations of mining variables giving good results, and discarding combinations showing poor results. The Z3 optimisation procedure is well developed and is used to routinely optimise models with several thousand mining variables, and many more processing variables.

The recently announced development of the 'Prober' optimiser accelerates and increases the capacity of this type of optimisation. It uses a random sampling and local optimisation approach, which is faster than but not yet as comprehensive as Z3, (but rapidly developing). As the processing of a sample is relatively fast, hundreds of samples can be optimised. When there are many results within a small tolerance in terms of NPV, we are confident that the overall optimal result has been located. This gives the capacity to handle larger and more complex models, with faster and more consistent results.

Optimisation of a comprehensive model can take between half a day and several days to process using the latest PCs. An advantage of Prober over Z3 is that each sample is independent, so the program can be run across many PCs in parallel to get a result within a shorter elapsed time.

The models being optimised are large and complex.

> *The breakthrough in optimisation has been to set out to 'find' the overall optimal answer using a search algorithm, rather than to try to formulate the problem and 'calculate' the answer.*

This philosophy is common to both Z3 and Prober methodologies.

WHAT A GLOBAL ASSET OPTIMISATION DOES

This approach involves the construction of a detailed business model. This would in itself be a useful exercise, because the model could be used to perform consolidations of different strategies and test the merits of different scenarios on a trial and error basis. Combined with an optimisation capability, however, such a model finds its own best configuration with an apparent intelligence that cannot be achieved by humans. This makes it a very powerful analytical and business-planning tool.

By using a Global Asset Optimisation model to assist the planning process, an integrated business plan can be developed, which combines and links the geological, operational and economic dimensions. The mining schedule will respond to the detailed options, opportunities to earn value-in-use and sensitivities within the various streams mined material could take to get the metal in the orebody to market. It can be considered that the various ore parcels have to compete for space in the (limited) processing streams that they are eligible for, and in the interests of increasing the value of the total system not all of them will get their first preference.

Within a run, the optimiser will make precise trade-offs and determine simultaneously the following:

- mining schedule: where and at what rate to mine;
- cut-off grade: what to discard, stockpile or process;
- stockpiling recovery;
- processing path selection;
- blending and product destination; and
- production quantity, mix and timing,

whilst considering the consequences on all periods (which are inextricably linked), using discounted cash flow as the measurement.

By iteration, questions of capital scale and timing, operational configuration and the impact of market scenarios can be addressed.

SOME EXAMPLES OF GLOBAL ASSET OPTIMISATION MODELS

The decision to proceed with the creation of a Global Asset Optimisation model has been prompted by a range of situations:

1. a desire to look for the next level of value in an asset portfolio, having already optimised all the components individually;
2. a new project that has a range of options in terms of scale and configuration, with too many permutations to consider using manual techniques; and
3. an existing operation that is contemplating expansions or changes to its geological or technical asset base, or is experiencing changes in technical performance or market factors of which it wants to fully understand the implications and opportunities.

Although the initial construction of a complex model typically involves several man weeks of work, once completed it is generally the quickest and surest way of evaluating a range of scenarios, sensitivities and business issues.

In some cases the Global Asset Optimisation model is the only consolidated technical expression of the group's activities, and can serve as a medium for communication between the different functions and across divisions in a large organisation.

Some Global Asset Optimisation models constructed have had the following dimensions:

1. An iron ore operation with a large central pit with a dozen phases and several surrounding satellite pits. Selective beneficiation helped achieve a range of products with strict blending criteria. Transport capacity expansions were foreseen.
2. A multi-seam truck-shovel coal operation, wishing to expand its product range and output, concerned about the timing and rate of commencing operations in adjacent orebodies.
3. A base metal producer, with 30-plus existing/foreseen underground and open pit operations in separate divisions, contemplating a major pit development that would yield a combination of metals affecting the currently independent production streams and involving both the closing down and development of new technical infrastructure.
4. A nickel/cobalt producer with over 100 potential pit sites, wishing to optimise the mining/cut-off/stockpile strategy to maximise the value throughput of their extensive ore-processing/metal-extraction plant investment.

5. A metal business unit with several pit and underground mines, faced with timing and capacity decisions for existing mine and plant expansions and introduction of new processing technologies to suit the changing mix or ore types.

In each case the model-building project and the model itself has been tailored to meet the business needs of the subject organisation. Model construction, validation and interpretation of results have therefore involved a cross-section of participants within the organisation (Whittle, 2001).

SOME TYPICAL RESULTS

Every situation is different, but some examples of the characteristics of a Globally Optimised group of assets include:

1. Pit phases and underground blocks (ie mining sequences) tend to have negative cash flows (waste stripping or capital development) in front of positive cash flows (from rich ore). The optimiser is NPV-driven, so it will wait until it is justified to incur the negative cash flow to start a phase, but, having done so, it then will mine the sequence at the maximum rate in order to get the best value. This compresses the negative and positive cash flows in time, to maximise the NPV. This behaviour is both logical and convenient, as it minimises the number of active locations and means that local operations are performed at their foreseen rates.
2. The above may not occur for a sequence that is contributing a key characteristic to a blend, in which case it may trickle in over a long period of time to compensate as required for characteristics of ore from other sources.
3. Although there may be dozens of constraints built in to the model (mining, processing, blending), the system is likely to be limited by two or three of these at any one time. The active set of constraints will overlap and change dramatically over time. For example, a system may be mining limited in early years due to waste stripping; refinery limited once the high-grade ore is accessed; mill throughput limited once the highest grade ore is depleted; and grade blending limited when only poor ore with excessive contaminants are left. The introduction of a new orebody or plant expansion during the time frame can shift the bottlenecks dramatically.
4. Through ore source prioritisation, grade control and stockpiling activity, the head grade processed tends to look like a typical 'Ken Lane' descending curve (Lane, 1988). Changes in capacities, costs, prices, recoveries, and orebody access can make significant bumps and irregularities in this curve.
5. In some cases the last bit of capacity is not used, even at the bottleneck in the system. Point one above works in reverse as well, in that many sequences are not economic if they cannot be mined at a sufficient rate. If mined slowly, the delay between the upfront negative cash flows and the following positive cash flows is so great that the discounting effect reduces or negates the NPV. In this case the optimiser will choose to under-produce, rather than add components at uneconomic rates.
6. In a blending situation, it is not uncommon to have ore taken from a pit shell that is regarded as outside the expected ultimate pit, and for seemingly economic ore to be left in the bottom of pit shells within the ultimate pit. Blending is a time-dependent activity and ore needs to be accessible at the right time to contribute to the blend.
7. Large pushbacks with high pre-strip and deep ore create large waves in the NPV terrain being searched. Sometimes relatively minor changes in parameters can cause large pushbacks to flip in or out of the schedule with dramatic effects on total tonnage and mine life, but with minor impact on the NPV.
8. There is generally more than one plan that will give a result very close to the maximum NPV. The search algorithms give a variety of results and it is worth looking at the best few to understand the similarities and differences. There may be five or ten slightly, or very different, schedules produced that have an overall NPV within a fraction of a per cent of each other. They will tend to have some similar characteristics – those that are fundamental to a high-value schedule. They will also have some differences – which indicate some flexibility that will have little impact on the overall value, but may have other implications. The choice between these schedules should be made on criteria other than NPV, as they all qualify almost equally on that basis, so it is important to consider practicality, risk, consistency, political, social, environmental, etc issues, not all of which will have been fully incorporated in the model.

CONCLUSION

The work described in this paper has advanced the ability to achieve integrated or global optimisation by several degrees, providing new insights into the operations to which it has been applied. Much has been achieved, but there is still a lot to be learnt about the management of large groups of mineral and technical assets in a dynamic market. Although the mathematical objective of each optimisation run is NPV, the real benefit of this type of study is the understanding gained on the drivers and sensitivities of value within the system. It is just as important to eliminate less important projects/ideas from the management agenda as it is to prioritise the good ones or develop new ones.

The Global Asset Optimisation approach is helping to develop new insights into complex problems and is increasing knowledge and understanding of the opportunities and options.

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