Enterprise Optimization for Mining Businesses

Presented at the SME national Convention

February 27, 2013

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Abstract

Whittle Consulting has developed a methodology for optimizing the entire mining business value chain. Mining is a complicated business, with many different economic, technical, and environmental parameters that need to be planned and refined before a project becomes a mine. Many of these parameters are assessed in isolation, due to expediency and the difficulty of predicting values for the variables under consideration. Costs, prices, reserves, geometallurgy, mining, water control, and the many facets of the social license to operate are absolutely critical to the valuation of a project. Optimizing across all of these parameters is rarely done.

Using activity-based costing and the theory of constraints, a robust cost model that incorporates the significant cost drivers as currently recognized is constructed, and this model can be used to optimize mine size and configuration, and plant size and operating envelope for the processing facility. A powerful NPV-based optimization engine is used to develop a schedule that optimizes value throughput in the business.

For a gold mine, cut-off grade optimization and the ability to stockpile material for later processing allows higher value material to be processed earlier, and the lower grade material is saved for processing at the end of the mine life which maintains the reserve base.

For a copper mine, the ability to model the price and cost effects of changing the con grade can be enlightening and frequently adds value.

For any operation with a milling circuit, geometallurgical parameters such as hardness, clay content, or alteration can be key cost drivers, and these can be modeled and optimized to produce the highest value material for processing in any given period.

These approaches have been used for mining businesses of all sizes, from junior companies to majors. This methodology can be used for multiple mines and processing facilities and it has been applied in metal mining, industrial minerals, and coal.

Typical results will be discussed, along with details of activity-based costing and the theory of constraints.

Enterprise Optimization

In today's financial and environmental climate it is imperative to develop robust projects with good economics. Taking a holistic view on the project's business system is critical for a project to be robust. Shareholders and analysts are demanding quicker and better returns on their investment dollars, and missteps in capital costs and project execution have hurt many mining businesses.

The business system for a mine is a complicated one, which is why there are many "rules of thumb" applied, and many decisions are made on limited data and then these decisions flow through the project and become almost law.

Methodology

Over the last ten years Whittle Consulting has developed an Enterprise Optimization (EO) methodology that has been proven to be a good strategic planning tool for mining businesses. This methodology draws from the manufacturing industry and cost accounting, and is focused on isolating the main cost drivers and constraints in the business system, and understanding the ramifications that these cost drivers and constraints have on all of the components of the business. EO studies consist of ten items which are routinely assessed: pit, phases, cut-off grade, stockpiles, schedule, product specification, product specification, logistics, and capital, and all simultaneously.

Ken Lane's seminal book *The Economic Definition of Ore* (1988) and more recently Jean-Michel Rendu's book *An Introduction to Cut-off Grade Estimation* (2008) demonstrate the importance of cut-off grade optimization. In the simplest terms, the concept is to run the highest grade and most cost-effective material through the plant- the highest-value increment. The cut-off grade to achieve this is a dynamic one, and often it is difficult to know exactly what it is. Many operations do this intuitively, by stockpiling material and then running the highest available grade. With a powerful multi-parameter optimizer running on today's microcomputers, it is possible to quantify what this cutoff grade should be and to plan the mine around getting the best material to the plant. Stockpiling is key to effective cut-off grade optimization.

Fundamental to the EO methodology is activity-based costing and the theory of constraints. Activity-based costing is concerned with allocating variable costs to cost drivers that are truly variable, and can change or become a limitation to the rate at which product can be produced. Typically in any business system there is a step or process that limits the rate of production and this constraint needs to be recognized, and treated differently than the other non-constraining processes (Goldratt 1984, 2002).

In the case of mining businesses the constraint is typically the processing plant, and specifically the mill or grinding circuit, as this is the single largest capital outlay and also the most difficult to expand. This element also tends to have a high variable cost as well. Power can be one of the biggest costs for a processing plant, and this can be modeled in the resource model fairly easily, using drilling rates or logging hardness based on empirical tests. Crushing and grinding test work can and should be correlated to geology and modeled in the resource model.

Geometallurgy has made great strides in the past several years in terms of understanding these parameters in terms of how they affect the processing facility, and how to model them in the resource model.

After determining the truly variable costs and isolating the constraint in the system, remaining elements of the variable costs are allocated to period, or fixed costs. These period costs tend to be much higher than just the G&A figures generally quoted, as many costs are incurred by an operation that do not disappear if the operation is not producing anything. Whittle Consulting has seen that about 30-50% of variable costs are actually fixed costs that "keep the lights on".

The period costs are used to penalize the constraint in the system, which forces the optimizer (Prober) to consider the effect of running the operation for one more period. This, in effect, is quantifying opportunity cost. This also has the effect of flat lining the period costs as the constraint in the system should always be at capacity, and if it is not there is value being lost to poor utilization of the constraining element.

WCL builds a business model that contains the cost elements to be used in the optimization. These models can be relatively simple, or very elaborate, but the goal is always the same: to isolate the critical cost drivers, and maximize value through the mining system. Contained in the business model is a series of calculations that are performed on every block in the resource model to generate revenue and cost fields that are then used for pit optimization and scheduling by Prober.

Mining costs can be modeled very simply or in a complex way, but it is important to have a depth and/or distance component so that the optimizer knows the cost implication for mining from the pit bottom or hauling to a distant dump at the end of the mine life.

Processing costs are similar in that they can be simple or complicated. It is important to consider what the cost drivers are, because a mine constrained by power will have a different optimization from one that is constrained by water. It is not uncommon to see operations that are constrained by kWh/t, or $/kWh. It is also common to see operations that are constrained only by "tons processed".

Prober is an NPV-based optimization engine written by Jeff Whittle in the early 80s, and this calculator has been under continuous development for the last 29 years. A portion of this software was commercialized and is marketed by Gemcom software. However, a significant portion is held by Whittle Consulting and is used to do more complex optimizations concerning variable cut-off grade, stockpiling, multiple pits, multiple processes, process and product specification, logistics, and capital scaling.

Pit and phase shapes, either from the client or designed by Whittle Consulting, are loaded and each block coded with which shape it falls in.

Prober is a scheduling tool, and when presented with a resource model coded with the data from the business model it divides the material to be mined into value bands, based on criteria from the programmers. This greatly speeds up processing time, but a certain amount of block resolution is lost. These value bands need to have the resolution for isolating marginal material

at the low value end of the scale, near $0/ton, and tend to have larger value increments for greater values. A typical value banding scenario would be $5 increments above and slightly below zero, and $10 increments for higher value bands. It is important to note that value banding is essentially doing a cut-off grade assessment for every block, and after this point discussion of "cut-off grade" becomes esoteric.

A vertical drop rate and total period tonnage are used to limit the optimizer's activity. The vertical drop rate indicates to the optimizer how many vertical benches it can take per period. A total tonnage limit is the highest mining rate that can be used, and typically this rate is only reached a portion of the time since mining should not be a constraint on the business. If mining is the constraint, then this would need to be changed.

With these constraints in place, and possibly others, the optimizer will schedule top down within the period shapes and value bands that are presented from the resource model. Prober will make initial decisions on mineralized material routing in terms of process (P), discard (D), or stockpile (S).

If processing is forced for all cash positive material, this would generally be considered a "fixed cut-off grade" option. However, since the value assessment is already done there is likely material that is cash positive but below an external arbitrary cut-off. This can make establishing a fixed cut-off grade base case problematic.

If processing and discarding are both available for a value band, the optimizer can make a choice for routing based on NPV. This is considered the variable cut-off option.

If processing, discarding, and stockpiling are all available options, then material that is discarded can be saved for later. This is a "fully optimized" mining and processing option for material routing.

The "PSD" options are the basic toggles in Prober. Other "free form" options can be made and these can take many site-specific forms. If an element of the business can be quantified in terms of money, it can be modeled.

Case Studies

Open Pit Copper Heap Leach

This case study represents a copper heap leach project. The processing facility consists of a large heap leach operation, and the heap leach pad needs to be built from mine waste rock. This balance is important as the ore can't be stacked unless there is enough pad space available. Due to this, there is a constraint on ore placement based on tonnes of waste rock delivered to the pad construction. A ratio of ore tons to waste tons was used to constrain ore mining to ensure pad construction material was placed in advance of the ore placement.

The SX-EW plant is assumed to be the constraint in the business system for this case. The SX-EW is a large capital expense, and also has the most stringent throughput constraint.

The initial plan indicated that the SX-EW facility would be full in the first annual period. The EO model was constructed using quarterly periods, and a 300 day leach cycle was also modeled. These results of this indicated that the SX-EW was not initially at capacity, and that additional mining lead time was needed to make sure there was enough ore stacked and pregnant solution available.

Dashboards are useful for represented complex systems in a graphical fashion. One of the greater challenges in optimization studies is how to convey the complex information generated in the optimization process. *Figure 1 Dashboard for Open Pit Copper Heap Leach* presents the dashboard for the optimized case.

Points to note on this figure are:

1. Mining has an early peak, and then levels off due to the pit configuration.
2. Crushing and stacking capacity is sized for the later, lower grade material respecting a later need for additional volume.
3. Run of mine (ROM) leach material is deferred by 8 periods as a de-risking measure.
4. The SX-EW, considered to be the constraint in the system, is at or near capacity for all periods until very near the end of the mine life.
5. Due to the lagged recovery and the desire to fill the SX-EW as early as possible the pad is loaded and a spike in recoverable copper in the heap is seen in the period just preceding the SX-EW start.

The nature of this study was such that a more sophisticated model was developed than the one that represented the validation case. As such some of the modeling techniques produced results that decreased NPV, but generated what is felt to be a more accurate model. This project has an element of run-of-mine (ROM) heap leach ore. The client was not comfortable with depending on this material for early copper production, and asked that this material be delayed for two years. Also, a volume constraint was added to more closely match the site conditions. The effect of these constraints reduced NPV by 8%.

The effect of the ROM delay and limit can be seen on *Figure 2 Open Pit Copper Heap Leach Value Contributions*.

The gain in cash flow for this project is subtle, but there is added cash flow in periods 7-10 which can be seen on *Figure 3 Open Pit Copper Heap Leach Cash Flow*.

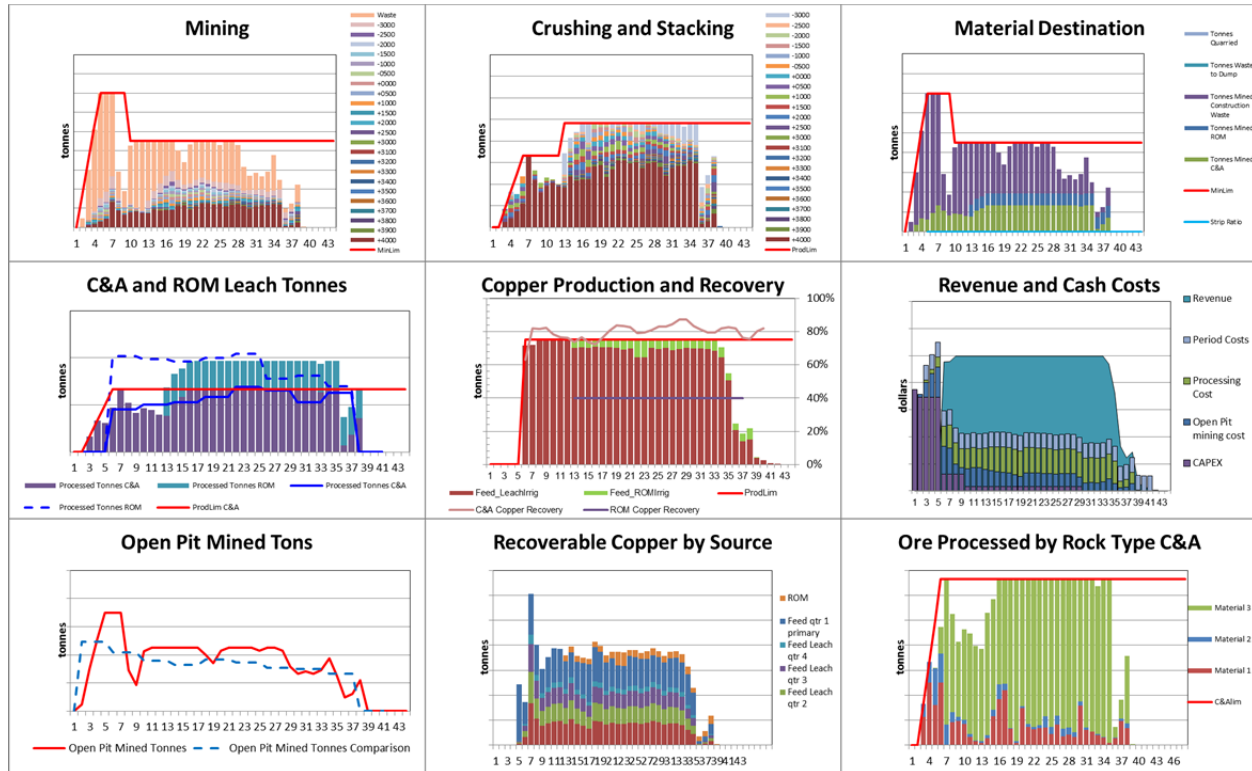**Figure 1 Dashboard for Open Pit Copper Heap Leach**

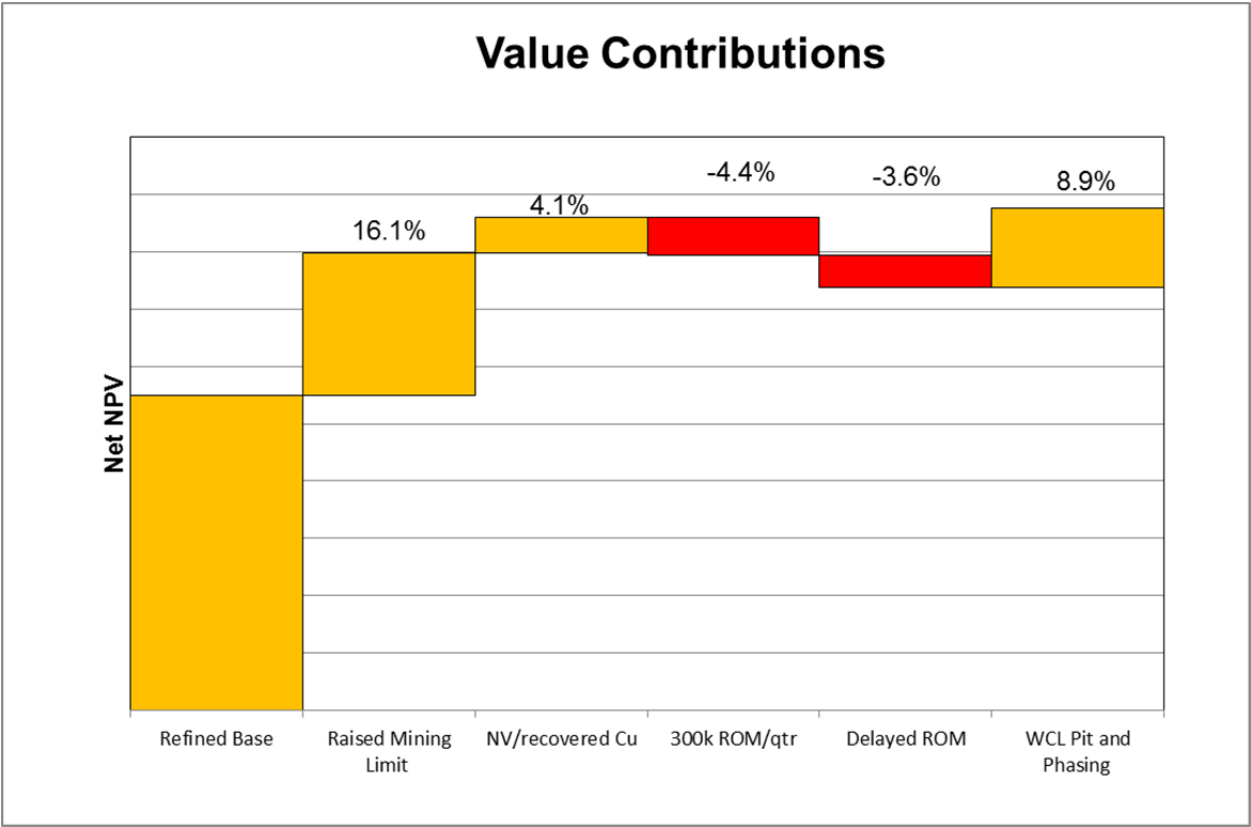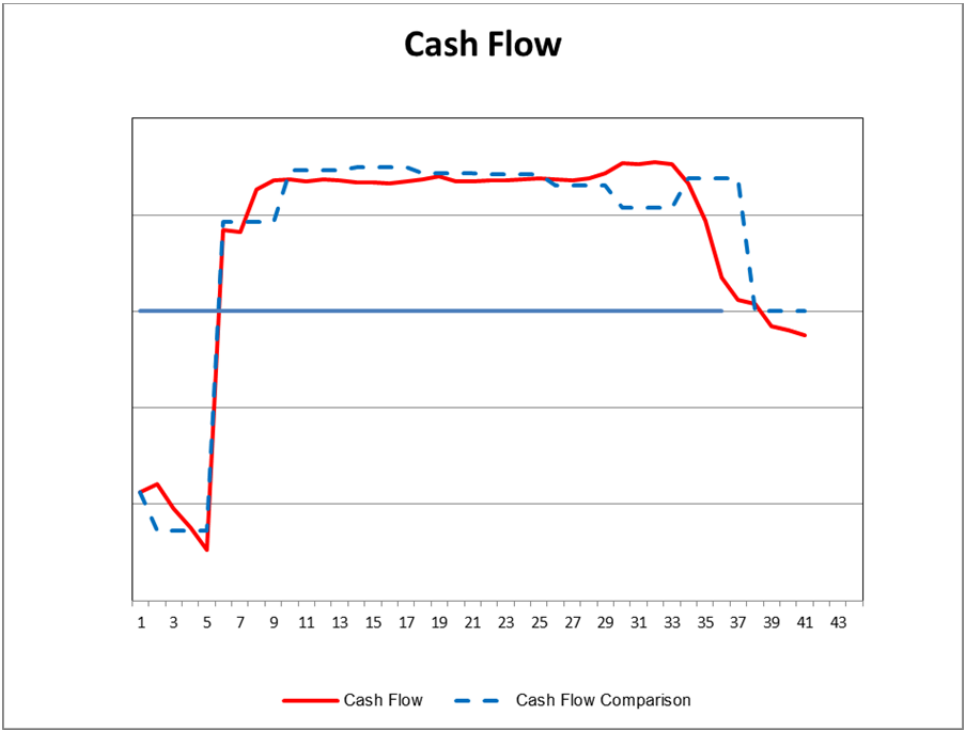**Figure 2 Open Pit Copper Heap Leach Value Contributions**


Figure 3 Open Pit Copper Heap Leach Cash Flow

Open Pit Gold Mine with Mill

An open pit gold mine in a remote location was assessed. This operation was power limited. The owners had good information on power usage in the existing operation and they had bond work index data by rocktype. Using this data a power-constrained model was developed and calibrated to the existing operation. This contributed significantly to an NPV improvement of 24.

The effect of this constraint can be seen in *Figure 4 Open Pit Gold Power-constrained Model*, where the optimizer is able to process more material in the early periods due to the material's lower power consumption. As indicated in *Figure 5 Open Pit Gold Power-constrained model* cut-off grade was another good source of value as the mine had a favorable grade-tonnage curve and also had the ability to stockpile material for later processing. This figure also indicates how closely related variable cut-off grade and stockpiling are. Stockpiling has a greater impact when the cutoff grade is allowed to change.

The cash flow improvement can be seen in *Figure 6 Open Pit Gold Power-constrained model Cash* Flow Comparison.

Figure 4 Open Pit Gold Power-constrained Model
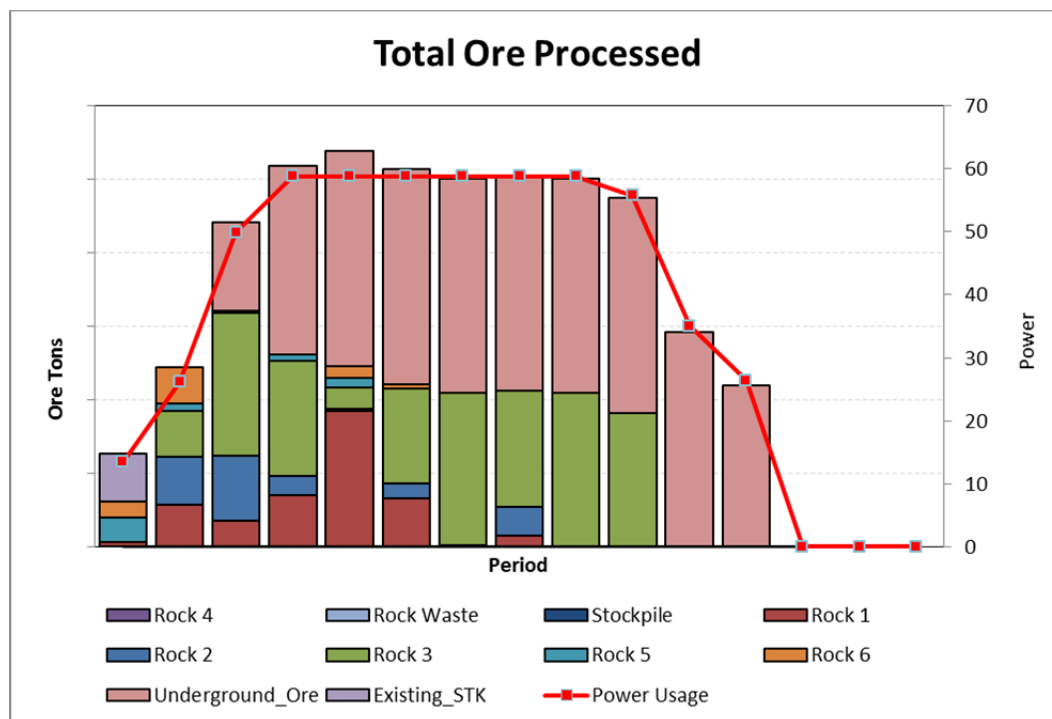
For this study, stockpiling had little effect until a fully-variable cut-off grade was used. The combined effect of cut-off grade and stockpiling added over 6% to the NPV for this project. Pit

and phase design utilizing the power-constrained data added nearly 16% additional NPV. This is indicated in the waterfall graph in *Figure 5 Open Pit Gold Power-constrained model.* The effect of these levers on cashflow can be seen in *Figure 6 Open Pit Gold Power-constrained model Cash* Flow Comparison.

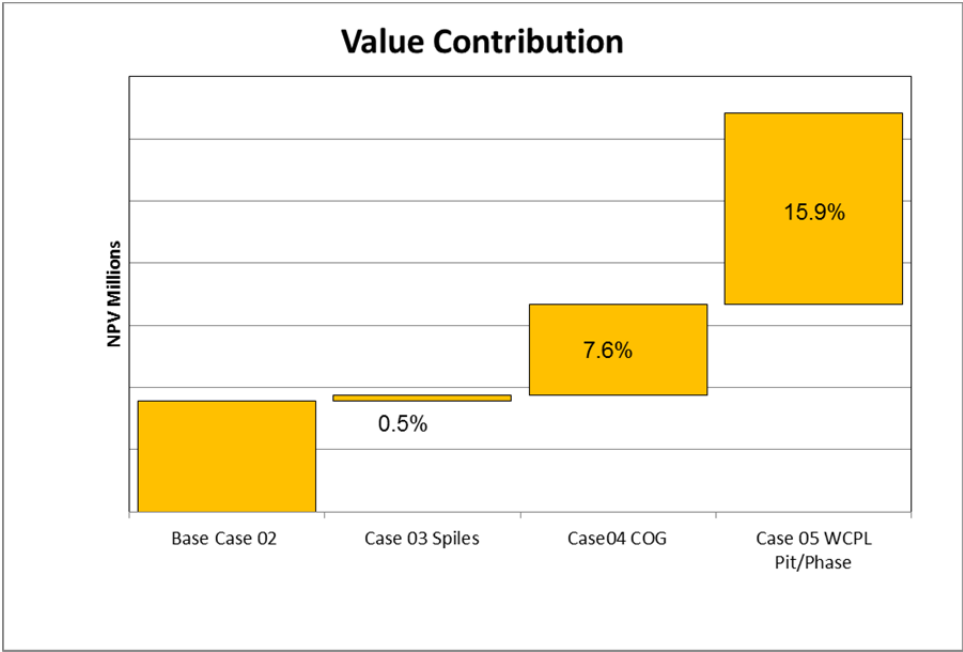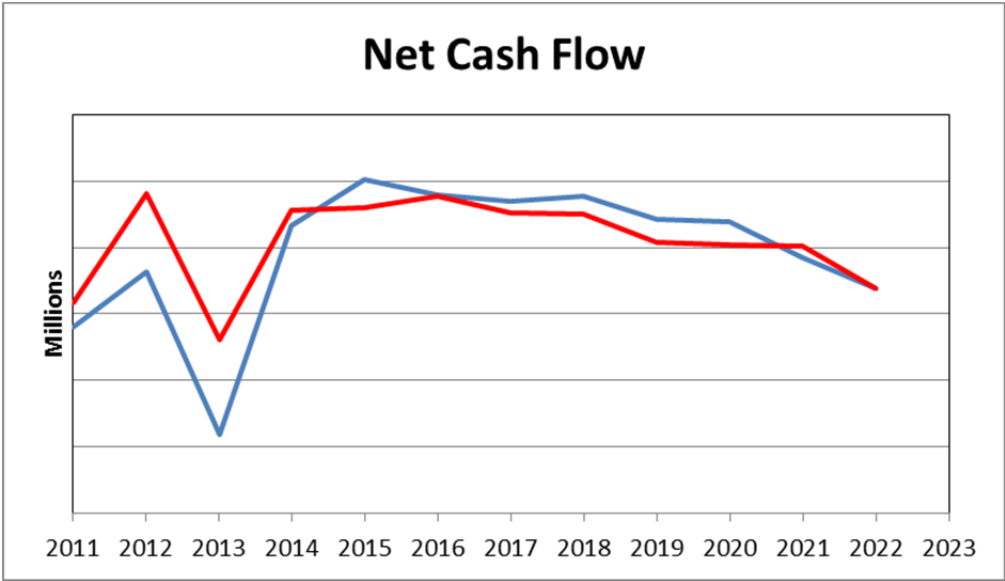**Figure 5 Open Pit Gold Power-constrained model Value Contributions**

Figure 6 Open Pit Gold Power-constrained model Cash Flow Comparison

Open pit copper/gold with mill and flotation

A large open pit mine for copper and gold supplied information on grind size relationships to recovery, as well as concentrate grade relationships to recovery. These were modeled and the results indicated that a variable grind policy added value.

Figure 7 Open Pit Copper Gold Grind versus Recovery indicates the relationship between the size of the grind and the recovery of metal. This has important throughput rate considerations as a courser grind allows more material to pass through the mill in a given period of time, although at a lower metal recovery.

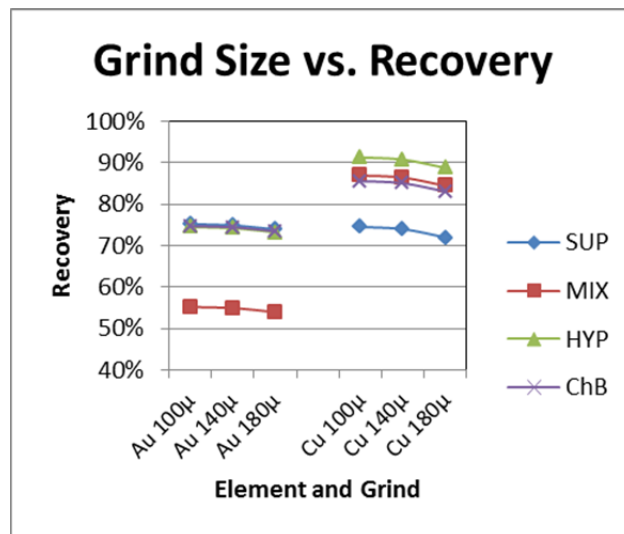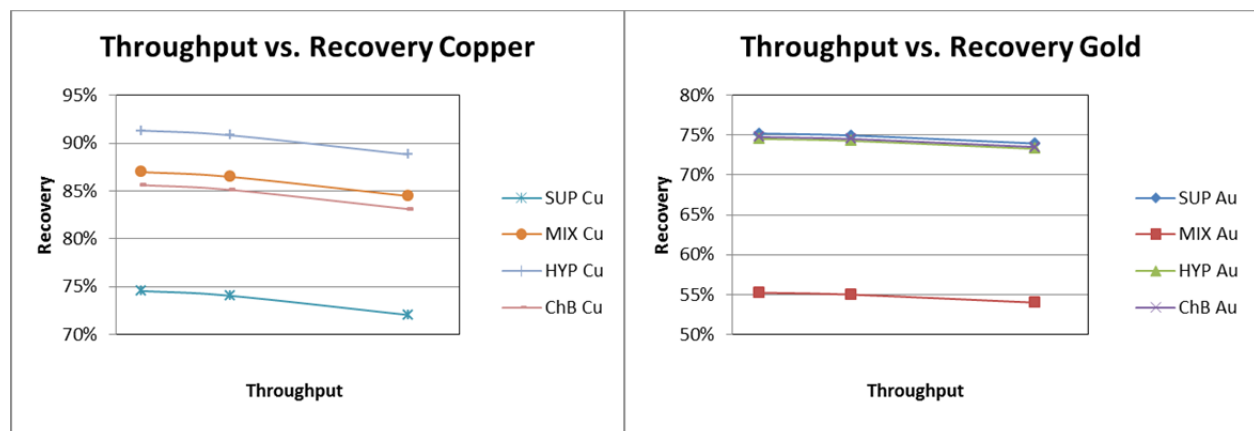**Figure 7 Open Pit Copper Gold Grind versus Recovery**

Figure 8 Open Pit Copper Gold Throughput versus Recovery indicates the relationship between throughput and recovery.

Figure 8 Open Pit Copper Gold Throughput versus Recovery

In addition, the concentrate grade was assessed to see whether it could be flexed to add value. In this case the optimizer chose the 23% concentrate in every case. This was interesting as the owner was shipping higher grade concentrate. The combined relationship grind, recovery, and

concentrate grade is presented in *Figure 9 Open Pit Copper and Gold, Grind- Recovery- Con grade.*

Figure 9 Open Pit Copper and Gold, Grind- Recovery- Con grade
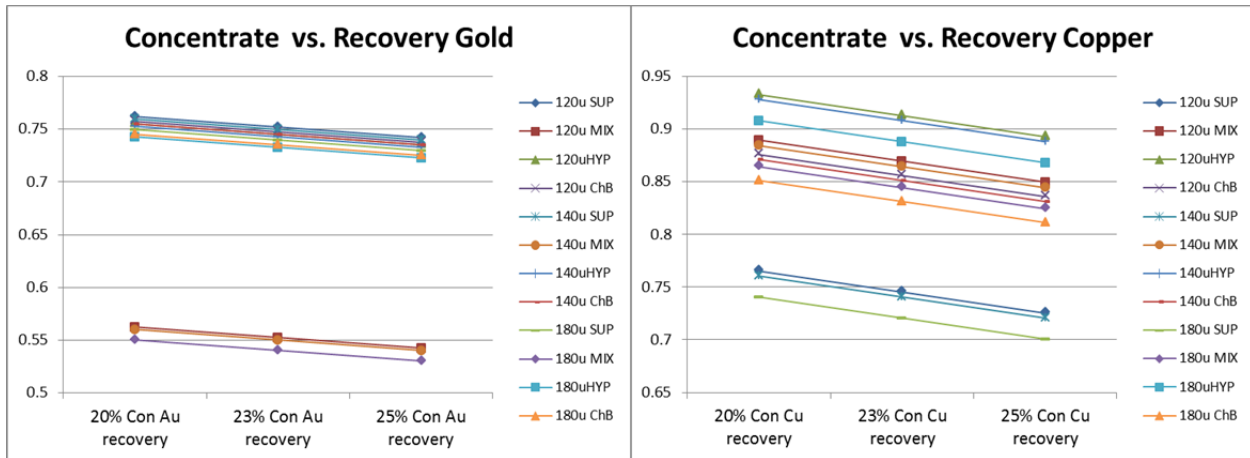
For the grind size decision the optimizer specified a finer grind for the higher grade material for both copper and gold. The additional cost in money and time is more than offset by the additional value of the higher grade material. This was not evident initially but after analyzing the results it is clear that the optimizer is taking a portion of the mined material and running similar portions for each grind size offered, based primarily on metal grade. *Figure 10 Open Pit Copper Gold Grade by Grind* indicates grade by grind by period for this optimized case.

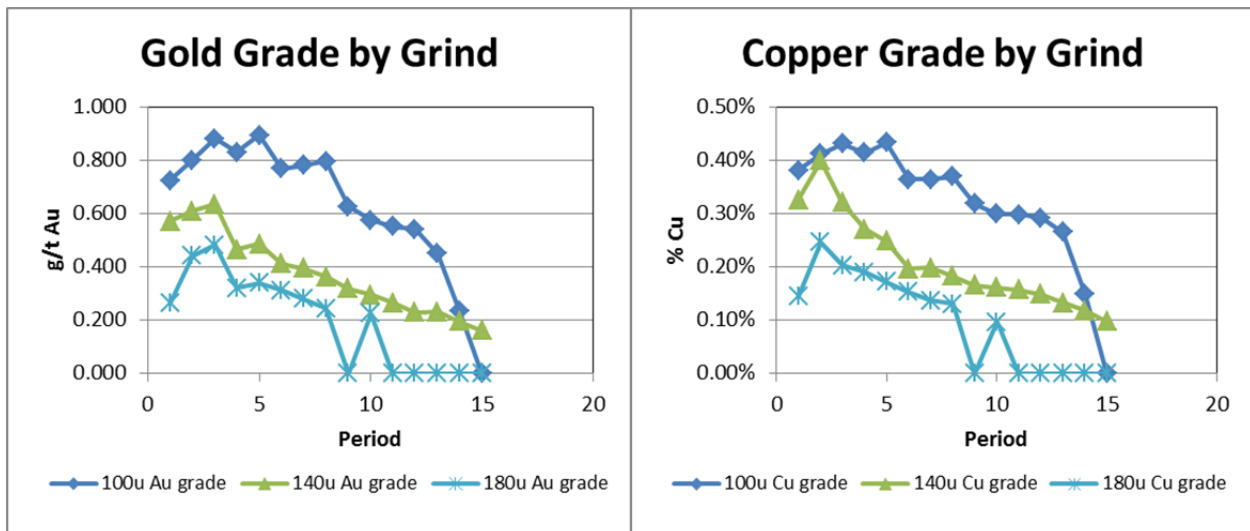**Figure 10 Open Pit Copper Gold Grade by Grind**

Figure 11 Open Pit Copper Gold Ore Tonnes by Grade indicates the proportion of material for each grind size offered by period. The course grind material (180μ) with a lower recovery is used to varying degrees for the first half of the mine life, but is not chosen after period 10 due to the decreasing opportunity cost as the end of the mine draws nearer. The finest grind (100μ) is used consistently, with a significant amount being used in the first three periods, and then this

proportion decreases in period 3 and then gradually increases for the rest of the mine life, again as the opportunity cost decreases.

Figure 11 Open Pit Copper Gold Ore Tonnes by Grade
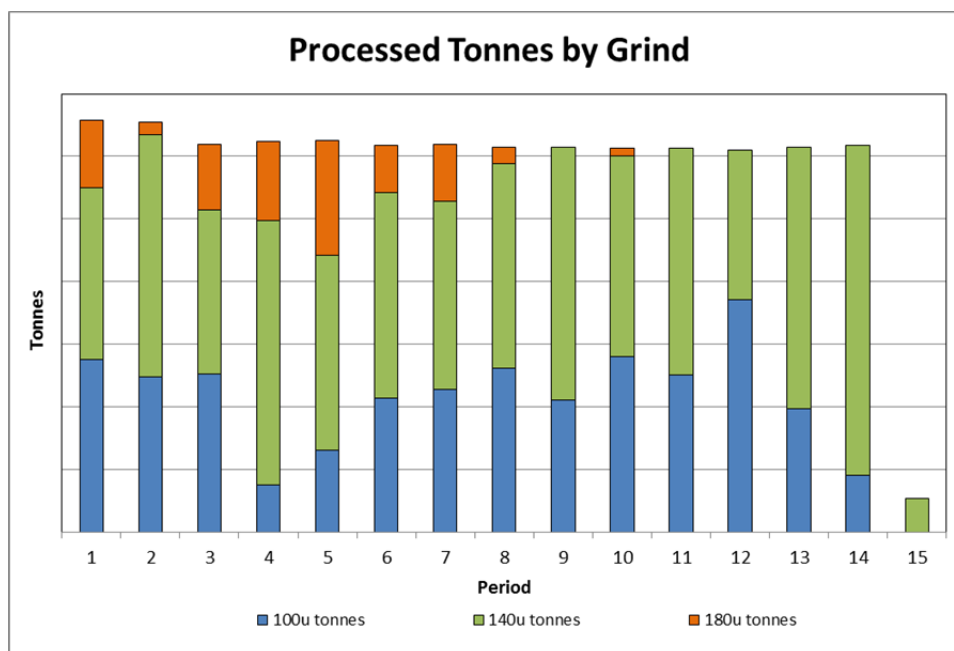
The value contributions for this case are presented in *Figure 12 Value Contributions for Open Pit Copper/gold Mine.* Significant drivers in this case were the pit and phase design based on Enterprise Optimization economics, cut-off grade and stockpiling in tandem, the process specification for variable grind size, and the product specification of a lower concentrate grade. This owner has decided to find additional stockpile space to incorporate this additional value to the business.

The improvement in NPV for this case is striking, as indicated in *Figure 13 Cash Flow for Open Pit Copper/gold Mine.*

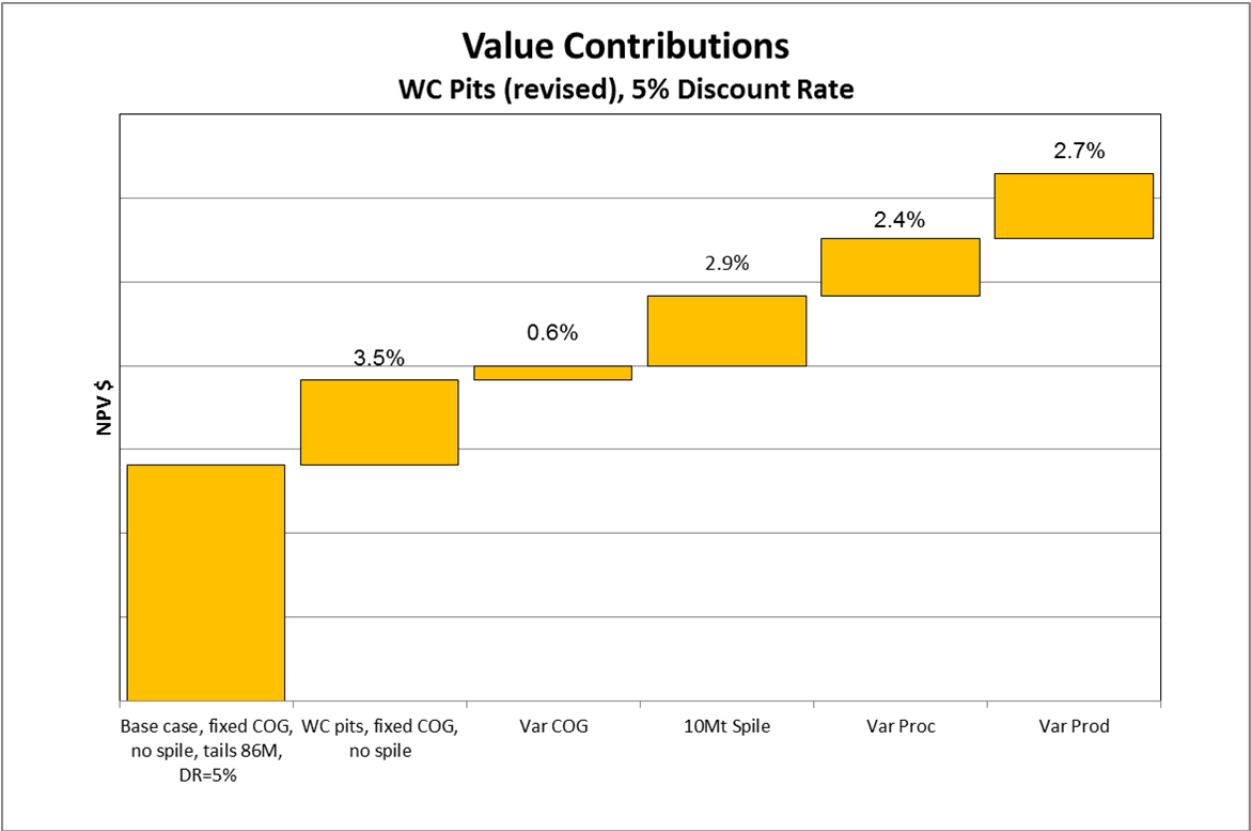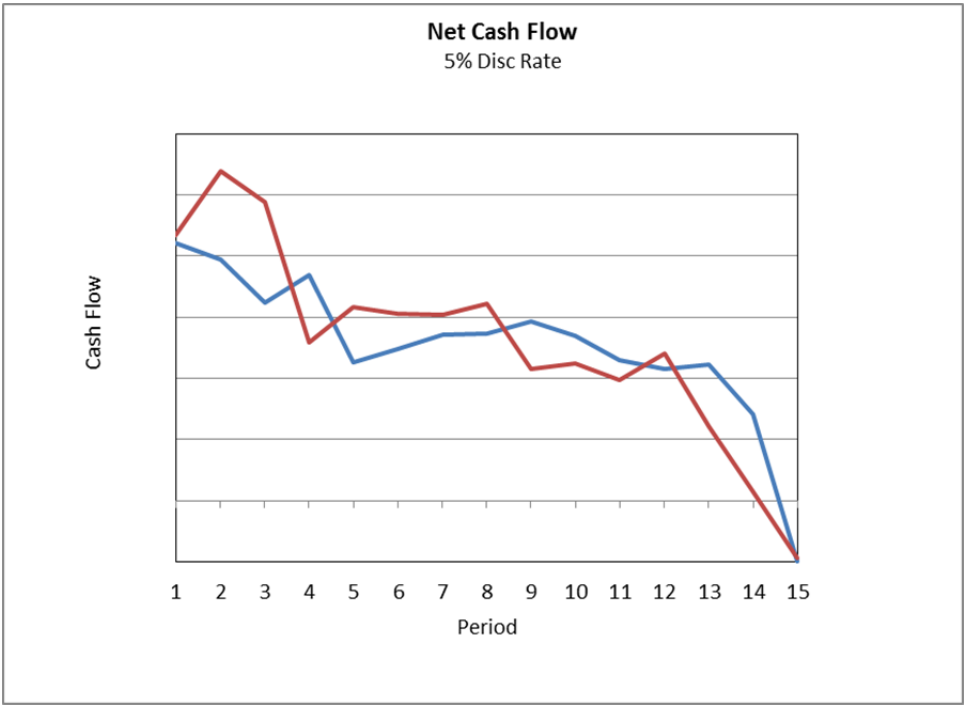**Figure 12 Value Contributions for Open Pit Copper/gold Mine**

Figure 13 Cash Flow for Open Pit Copper/gold Mine

Conclusions

Enterprise Optimization techniques have been used for many mines and projects with varying degrees of improvement. The holistic view of the mining business leads to different decisions from what may have been made at the department level in terms of costs and capital expenditure. Techniques such as these are likely to become the new standard by which mines are designed, analyzed, and run. Companies are recognizing that shareholders want to have more than ounces in the ground; they want to see the money as well.

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