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"Blending Numerous Feeds for Optimum Autoclave Throughput – Miners working with Metallurgists"

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ABSTRACT

To achieve optimum autoclave throughput at the Minara Resources Limited (Minara) Murrin Murrin processing plant, it is necessary to blend alternative available plant feeds to maximise the value generated in producing nickel and cobalt metal. The Murrin ores are combined with other high grade feed sources on the ROM pad to achieve specific blends that meet the processing constraints and are less problematic to process than if individually treated.

The autoclaves are essentially volume constrained so maximum throughput is achieved by maximising slurry density. The goal of the mine optimisation exercise is to determine the best feed blend from the mine for processing purposes

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because maximum profit is gained by maximising nickel/cobalt grades and high pressure acid leach (HPAL) feed density while staying within the acid production capacity of the acid plant [1]. Therefore, optimum blending will enable maximum profit. Optimised blending of Murrin ores with other high grade feeds ensures maximum cash flow, maintains process stability and reduces contaminant elements to manageable levels.

Whittle Consulting Pty Ltd (WCPL) has an association with Minara dating back to July 2002 and has assisted with global asset optimisation, strategic mine planning, workshops and corporate presentations. The WCPL Z3 and Prober proprietary software have the ability to relatively quickly analyse the modelled system and determine the Net Present Value (NPV) of various scenarios subject to production constraints. It becomes the medium for resolving major strategic questions without need for speculation and "what if" scenarios of additional mining, plant de-bottlenecking and expansion can be assessed and determine the value of the prize, and the operational strategy for maximising it.

Minara has over 150 potential sources of ore (pits, stockpiles and external feeds) and in conjunction with WCPL has optimised the mining/cut-off/stockpile strategy to maximise the value through the extensive ore processing / metal-extraction plant investment.

A multi-discipline strategic approach is necessary to optimise the business, aligning the views of all Company personnel - corporate, miners and metallurgists all working together as a team – to add value for all stakeholders.

INTRODUCTION

Murrin Murrin Operations are situated midway between Leonora and Laverton (65km to each) in the northeastern goldfields of Western Australia approximately 900km by road from Perth, as shown in Figure 1. The Murrin Murrin project is a joint venture between Murrin Murrin Holdings Pty Ltd, a wholly owned subsidiary of Minara Resources Limited, *(60%)* and Glenmurrin Pty Ltd, a wholly owned subsidiary of Glencore International AG, *(40%)*. The Murrin Murrin project is based on the mining and processing of lateritic ore for the production of up to 40,000tpa of nickel and 2,500tpa of cobalt briquettes.

This paper looks at the current blending practices at Murrin Murrin used to optimise throughput of the HPAL autoclaves. Blending at a strategic level (long term) ensures the optimal ore extraction sequence to maximise the NPV of the business while short to medium blending is aimed at the best utilisation of the available resources allowing for the prevailing operational conditions without compromising the long-term strategic direction. Blending of the different ore types can reduce problems with treating specific ores that have difficult ore handling characteristics or individually exceed system limits.

The Minara operation can be considered as mill or processing limited according to Ken Lane's ore definitions [2] and that the optimum cut-off grade(s) determined are a mine/mill balanced cut-off grade, that is for the current mining fleet, the cut-off chosen will ensure that the mill/plant remains at full capacity and will be fed the best net value "NetVal" material available from the total material mined.

The NetVal approach is similar in concept to Lane's "equivalent grade" but rather than assuming the secondary grade elements are equivalent to a fixed ratio of the primary grade, take into account the non-linear relationship between the various elements to derive a measure to enable a direct comparison between material parcels for the purpose of ore waste classification [3].

Multi-pit blending optimisation aims to maximise metal throughput in the early years to prioritise and get the cash flows earlier. The mining cost is only a modest part of the total value chain because Murrin has a complex recovery process so it is best to mine the right material to get the best medium for the processing path.

Global optimisation with a sophisticated holistic business model provides the platform for strategic planning at many levels – mining, processing, financial and marketing – and becomes the medium for resolving major strategic questions without need for speculation or debate.

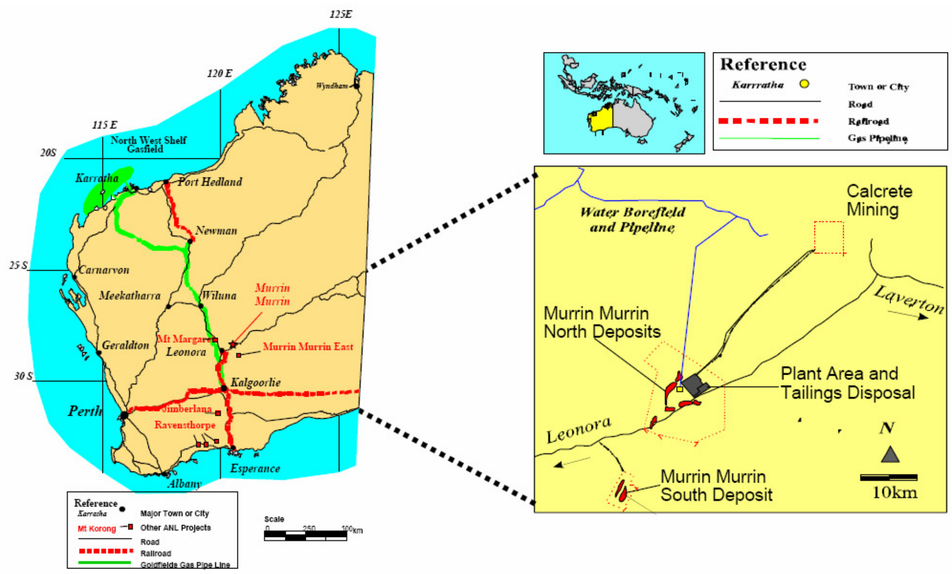

Figure 1 – Murrin Murrin Location

GEOLOGY

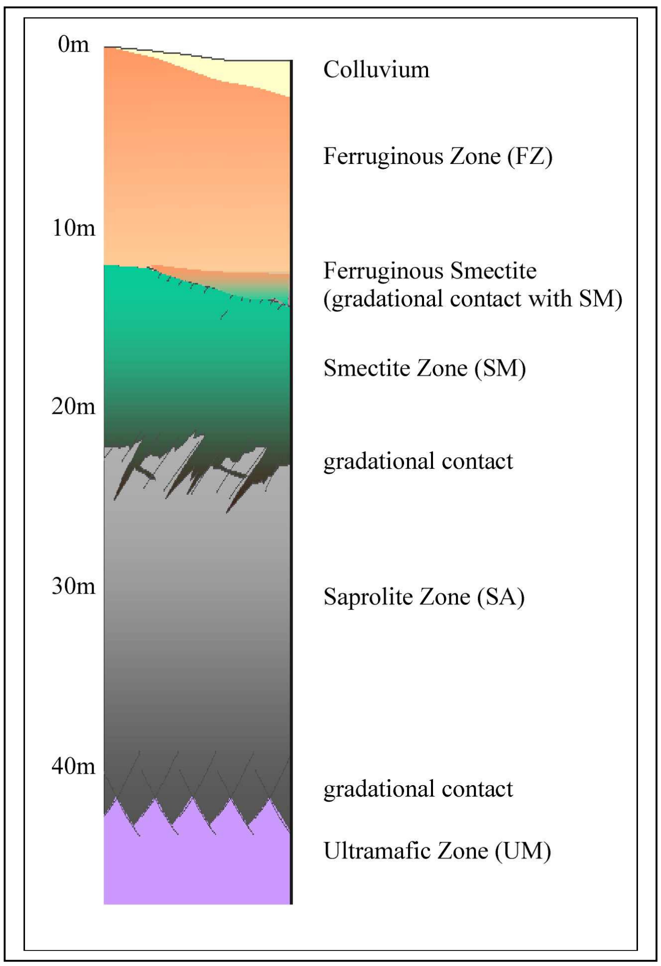

Figure 2 – Murrin Murrin Orebody Section

The laterite nickel and cobalt ore occurs primarily in three regolith units of serpentinised peridotite within the Archaean Norseman-Wiluna greenstone belt, comprising a ferruginous zone, a smectite zone and a saprolite zone as shown in Figure 2.

The **Ferruginous Zone** (FZ) is predominantly waste containing iron oxides and is depleted of nickel and cobalt. Minor amounts of nickel and cobalt mineralisation occur at the base of this zone at the contact with the Smectite.

The **Smectite Zone (SM)** is predominantly Smectite clay mineralogically dominated by nontronite, saponite, stevensite with minor chlorite, iron oxides and manganese oxides. It is generally enriched in nickel and cobalt and depleted in magnesium.

The **Saprolite Zone (SA)** is an altered serpentinised peridotite (metamorphosed ultramafic) dominated by the serpentine group of minerals. The grade of the nickel and cobalt within the saprolite zone is generally gradational and decreasing from the contact with the Smectite. The saprolite is also enriched in magnesium.

Geological resource models based on drill spacing at 50m x 50m to 100m x 100m are created in Vulcan software using median indicator Kriging for the major elements of nickel, magnesium, aluminium and iron and uses multiple indicator

Kriging for cobalt. Minor elements are estimated with inverse distance squared. Total Resources at Murrin are 320Mt @ 0.99% nickel @ 0.063% cobalt using a 0.8% nickel cut-off (Source: 2004 Annual Report [7]).

Grade control drilling is performed at 12.5m x 12.5m spacing is drilled to the full depth of the resource. Mining grade control models then use Hellman and Schofield's MP3 program that uses sequential gaussian conditional simulation techniques to estimate the major elements (nickel, cobalt, magnesium, aluminium and iron) and ordinary kriging for the minor elements.

MINING

Since mining commenced in 1999 over 80Mbcm of material has been mined from over 20 pits. Minara is in the process of upgrading the mining fleet and planning to shift up to 20Mbcm per annum for the next 5 years. By late 2005, the new fleet configuration will be:

- 4 x Hitachi 1900 Excavators (12.5 cubic metres bucket in backhoe configuration)
- 1 x Hitachi 1100 Excavator – (old fleet backup machine only)
- 11 x Caterpillar 785C Dump Truck (150t) with Philippi-Hagenbuch mine specific trays
- 3 x Caterpillar D10R Dozers
- 1 x Caterpillar 884 Wheel Dozer
- 2 x Caterpillar 992G Loaders
- 2 x Caterpillar 16H Graders
- 2 x Caterpillar 777D Water Carts
- 1 x Caterpillar 773E Service Truck

The Murrin laterite orebodies are generally less than 60m deep and mining is performed using conventional excavator and dump truck configuration. The operations are geographically spread over $200km^2$ in 3 major mining areas at Murrin North, Murrin South (25km SW) and Murrin East (45km SE) and over the life of the project it is expected to mine over 150 pits and reclaim from 450 stockpiles. Mining is undertaken using relatively low 2m bench heights to maintain high selectivity in mining the ore. Generally, only the waste is drilled and blasted with the clay ore able to be free dug or with dozer ripping.

An economic cut-off is applied in converting geological resources to mining reserves that take into account the rock type, elemental grades as well as mining, administration and processing costs. The mining reserves are calculated using the geological block models depleted for previous mining and optimised using Whittle Four-X mining software. Whittle Four-X pit optimisation calculates the maximum pit value for a given set of economic and geotechnical criteria. Based on actual production cost data and forecast metal prices, the generated set of reserves accounts for rock type and the block model grades, and are based on a Net Value cut-off rather than a grade cut-off. By varying the revenue factor applied, a set of nested pits is generated which provides useful information when designing intermediate pit stages.

Total mining reserves at Murrin are 143Mt @ 1.10% nickel @ 0.087% cobalt (Source: 2004 Annual Report [7]). At current throughput rates, this equates to a mine life in excess of 30 years.

All material mined and processed is tracked by Wenco (Global Positioning System - GPS) truck dispatch and recorded live in Minara's in-house Open Pit Reporting System (OPRS). The material tracking is 24/7 and real time reports can be generated from any web-enabled computer. Optimum blending requires this level of data tracking.

STOCKPILING

Historically, the different saprolite, smectite and ferruginous ore types were stockpiled separately in three nickel-grade ranges due to their differing grade, milling and metallurgical properties. During 2003/2004 it became apparent that solely applying a Ni% cut-off to determine the destination for ROM and stockpile material would result in some material with a higher NetVal being sent to stockpile, some material with a lower NetVal sent to the ROM for processing, and that some uneconomic material would be sent to stockpile.

Therefore, to maximise cash flow, material classification was based on NetVal to ensure that the most valuable material is sent direct to process via the ROM, and that no overlap in NetVal ranges occurs between stockpiles. A more detailed explanation of the benefits of applying the NetVal approach can be found in *Jaine and Laing 2004* [3].

The NetVal calculation responds to Rock-type, Ni, Co, Mg, Al, Fe, Cl, Haulage, Density, SG, Free Acid setting, metal price, exchange rates, royalties etc. It is clear that classifying ore by Nickel grade alone is a poor approximation for economic reality.

All pit material is now blocked out in the pit on the basis of Net Value. All positive NetVal material is sent to the ROM or to a designated stockpile for future treatment. There are 5 destinations for pit material:

- Waste – Below cutoff – sent to dump or backfilling of mined out pits
- Low }
- Medium } Stockpiled adjacent to the pits for future reclaim
- High }
- ROM

Pits that are less than 5km from the plant have the ROM ore directly hauled from the pit to the ROM, while pits in excess of 5km have a local ROM pad and 150t road trains rehandle this ore to the ROM.

BLENDING

Prior to the introduction of blended stockpiles in September 2002, all ROM material was stockpiled by pit sources and by rock type. Two Komatsu WA900 loaders reclaimed the numerous fingers according to a frequently changing recipe mix seeking to maximise grade and provide as consistent a blend as possible, but was dictated by available stocks. This hand-to-mouth inconsistent mill feed resulted in large variations in expected head grades, creating processing issues particularly slurry density and was almost impossible to reconcile.

Over the last 3 years the ratio of smectite to saprolite has reversed from 1:2 to 2:1. Reasons for this change were:

- Introduction of net value which targeted high nickel and cobalt grades with lower contaminants
- Increased mining rate allowing for more ore to be mined and stockpiled
- Better understanding of the rheology whereby the smectite clays are easier to process once they have dried out

Minara uses a 4-finger ROM layout configuration; each finger has the approximate dimensions of 300m long x 70m wide x 10m high giving a capacity of 210,000 cubic metres or roughly 250Kt that is sufficient for 3-4 weeks mill feed. The fingers are built and then reclaimed in the order of construction to ensure adequate drying of the clay ore. With blended stockpiles the ROM ore is trucked directly from the pit by the Minara dump truck fleet if the pit is within 5km or rehandled by contract side-tipper road trains. Both fleets carry a nominal 150t payload.

The ROM fingers are progressively built keeping the advancing face as "square" as possible. This allows for a more even distribution of the ore reporting across the face. A single 10m high tip face is used rather than building successive layers so as to minimise compaction surfaces from haul truck traffic. When completed the upper surface is ripped with a bulldozer to alleviate any compaction that may have occurred during construction. During reclaim the ROM finger is cut perpendicular to construction in thin slices with each slice representing roughly 6 hours mill feed. Parallel guidelines are pegged on the surface of the stockpile to act as guides during reclaim aiding in producing a consistent blend. This ensures as homogeneous a blend as possible reporting to the autoclave storage tanks.

Issues that arise from the blended ROM finger method are:

- Increased oversize material at the start and end of reclaiming each finger due to the natural segregation of rill material as it is tipped over the advancing face. Generally the oversize material is harder (siliceous or magnesite) which restricts the feed rate (and lower grade) and produces a lower slurry density.
- Road trains preferentially dumping material in one spot at the tip head
- Not built square (longitudinal) and not reclaimed evenly (perpendicular)

These issues are largely overcome by:

- Starting a new finger before 1st finger is exhausted
- Close supervision of the road train operators and training of the tip-head operators
- Shift inspections by mine supervisors and geologists

3 years ago all mill feed was by 2 Komatsu WA900 loaders (20t bucket capacity). The introduction of blended fingers and increased ROM capacity necessitated the use of a loader/truck combination; this change has increased productivity, provides further blending of the source material as it is loaded into the back of the truck, and also seen the loader tyre life double due to reduced high speed tramming across the ROM.

Over the 3-4 week period that the ROM finger is fed, the reclaimed face is further exposed to the air and additional drying can take place. The mill is able to tweak the process control adjusting mill weights, water addition, screening parameters, cyclone splits, thickener bed levels and thus improve the density reporting to the autoclave storage tanks.

HPAL DENSITY

Murrin clays exhibit varying rheological behaviour. HPAL feed density is rheologically constrained and is dependent on the ore types being fed to the ore preparation circuit and how these ores have been dried. Plant history has shown that optimising the ore blends can produce an effect of 2-3 % in HPAL density increase.

The HPAL feed density, a key operating parameter for 'front end' production performance, has improved in consistency over the years which has provided steady state conditions and is a significant contributor to improving the plant economics.

PROCESSING

First ore was processed in January 1999, and as at the end of June 2005 over 14 Million tonnes of ore had been processed producing approximately 140,000 tonnes of nickel and 9,000 tonnes of cobalt.

Murrin Murrin is a world-class hydrometallurgical project, using sulphuric acid in high-temperature, high-pressure autoclave vessels to aggressively leach nickel and cobalt from low-grade lateritic (oxidised) ores. Hydrometallurgical processing offers significant environmental benefits compared to traditional pyrometallurgical processes, such as smelting, and much of the energy, heat and consumables used in the Murrin Murrin process plant are recycled.

Sherritt International high-pressure acid leach (HPAL) technology recovers nickel and cobalt in a Fluor Daniel designed and engineered plant. Crushed ore is slurried, pressure leached with sulphuric acid, and the metals are recovered by further leaching. The current design capacity of 40,000tpa of LME A Grade nickel metal and 2,500tpa of LME Cobalt would make Murrin Murrin one of the world's largest nickel producers.

The slurrying mill discharges onto a classification screen and undersize is split into 3 streams before being pumped to the autoclave feed slurry storage tanks. Roughly a third of the feed reports direct to the storage tanks, a third to a set of cyclones and the remainder is pumped to the new paste thickening circuit that was commissioned in August 2003. The improved milling circuit provides for additional circuit product density, the effect of which has provided a 2-3% w/w increase in pulp density over the base case value. Oversize is stored in the scats stockpile for future re-treatment.

The HPAL area receives slurried feed, preheats it to 235°C and then mixes it with hot concentrated sulphuric acid inside four titanium-lined autoclaves under 4,450 kpa pressure at 255°C where the nickel and cobalt are leached into solution. The autoclaves discharge leached slurry to the counter-current decantation (CCD) washing area, where it is mixed with flash-steam heated water, producing a clear solution of nickel and cobalt in preparation for hydrogen sulphide precipitation of mixed nickel/cobalt sulphides. Precipitated iron and aluminium tailings are washed and stored in the tailings dam.

Calcrete is mined and crushed at a quarry 45km from the plant and is hauled to the Murrin plant where it is milled and then used to neutralise the waste residue before it is stored in the tailings dam. The nickel/cobalt sulphide produced is leached in an autoclave by pure oxygen, producing a metal sulphate solution. Iron, copper and zinc impurities are removed, cobalt is separated and a concentrated cobalt solution feeds the cobalt hydrogen reduction area. The remaining nickel solution feeds the nickel hydrogen reduction area. The metal sulphate solutions are hydrogen-reduced in parallel autoclaves. The resulting powders are dewatered, dried, briquetted and sintered to form pillow-shaped briquettes.

ADDITIONAL FEED SOURCES

High grade plant additives have been processed through the Murrin plant to successfully increase the HPAL head grade economically. The additional feeds are usually rich in nickel (>3 %) but have other elemental components in them that restrict high plant addition rates. These additives include:

- Iron Cake
- Kwinana Nickel Refinery (KNR) residue
- Kambalda Nickel Operations (KNO) residue
- Leinster Nickel Oxide (LNO)

Iron cake is a precipitated solid residue produced in the iron removal process in the Murrin refinery. Due to the high nickel and cobalt values (20% & 1% respectively), it is recycled back into the process at the front end. KNO & KNR residues originate from the Kwinana Nickel Refinery and are treated under commercial terms with BHP-Billiton (formerly WMC). The KNO was stockpiled near the Kambalda nickel concentrator for many years before being road trained to Murrin for treatment and was exhausted in early 2005.

At Leinster Nickel Operations (LNO) owned by Western Mining Resources, transition and oxide material were stockpiled, as there was no economic processing route for this material at the time. A preliminary commercial agreement was signed in 2005 for the treatment of this material through the Murrin plant and this “win-win” situation benefits both companies by treating this “ore” that was otherwise “waste” material.

In August 2005, a separate ball mill circuit will be commissioned to process all additional feed sources. Bench scale testwork and recent plant trials have demonstrated that LNO oxide material can be treated successfully at a treatment rate equivalent to 5% of mill feed at Murrin Murrin without deleterious impact on metal recovery, product quality or circuit chemistry. Further optimisation of this circuit will occur post-commissioning including increasing throughput, reprocessing of stockpiled scats and directly treating Murrin pit ore.

It is likely that other sources of supplementary feed will be identified over time and each will follow a similar process of bench scale testwork and plant trials before being considered for the Murrin circuit.

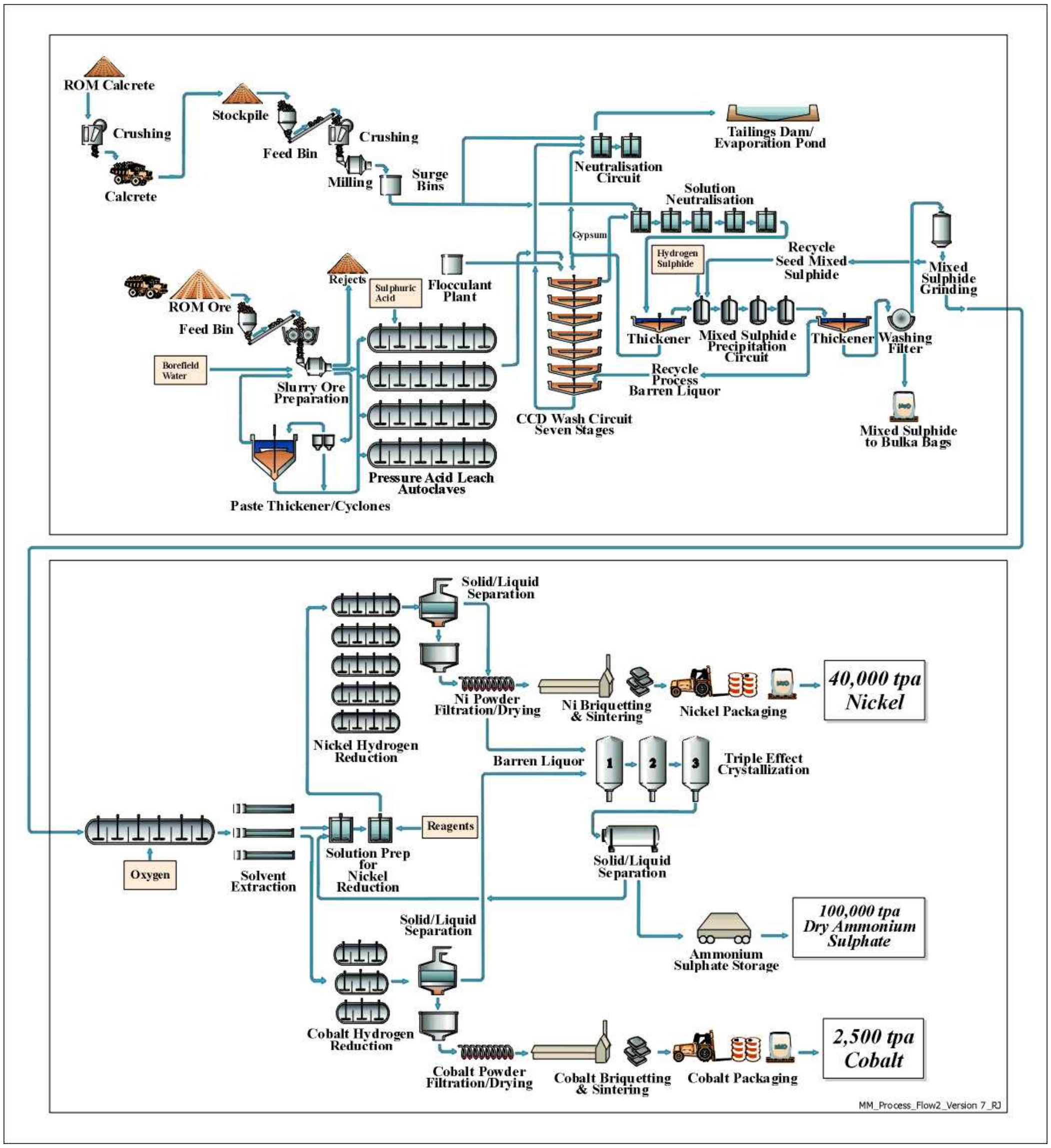

Figure 3 – Murrin Murrin Process and Technology Flow Chart [6]

SYSTEM MODELLING

A Processing Summary model has been developed for Murrin, which captures in detail the geological, mining, mineral processing, throughput and recovery relationships for each type of ore and each of its potential processing paths within the mill/leach/refinery system. The result is effectively an integrated business model that comprises the existing known relationships between geological, engineering, metallurgical and financial input parameters. This model is then controlled by a powerful mathematical optimiser that can handle the nature and scale of the system defined. As a detailed expression the formulation responds to ore grades, rock type blend, varying density characteristics and processing settings such as acid concentration and sulphur costs, all of which are integrated into the optimisation model.

Workshop sessions were held on site in 2002 with all participant stakeholders - mining, processing and corporate – to identify the major cost drivers of the business (see figure 4) and sign off on key mining, processing and financial parameters (see Table 1). Senior management sponsorship ensured that the workshops had high visibility and were given suitable priority. The workshops led by WCPL were positively received and set the strategic framework for the business. Over time the model has become more sophisticated with more robust algorithms and is regularly updated to incorporate available feed sources, historic plant performance, updated costs and projected financial parameters. The participative approach ensured that the model captured the collective knowledge of the organisation, and had widespread understanding and buy-in when applied. The model had to be accepted, not just be right.

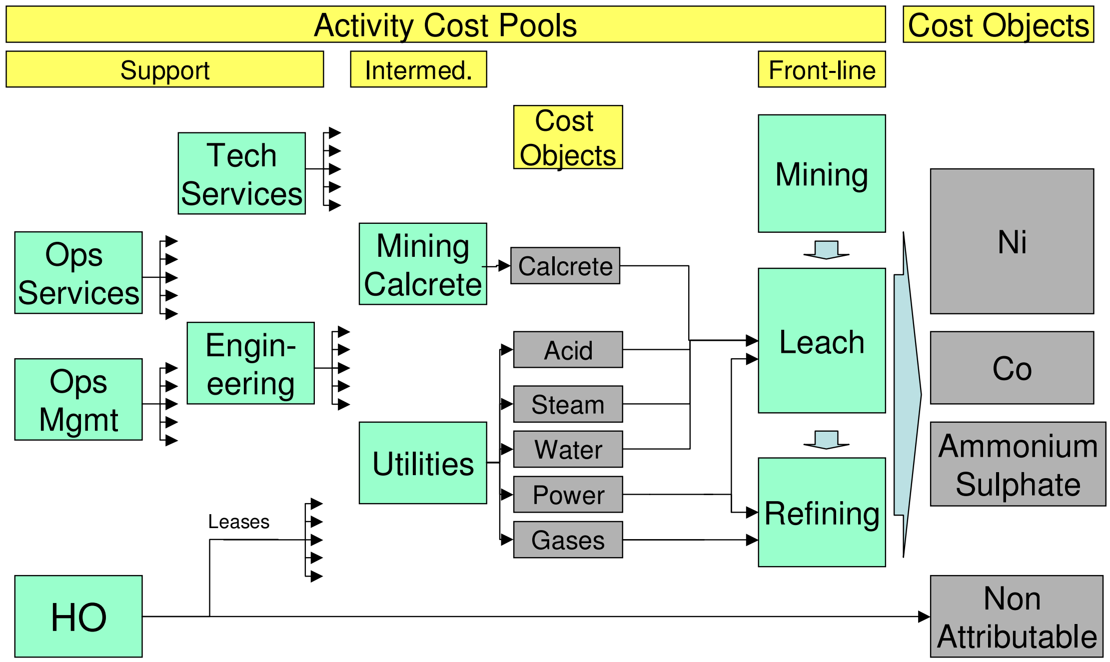

Figure 4 – Activity Based Cost Model

While not required at Murrin Murrin at the present time, WCPL have developed other processing models to cover additional 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 also typical for some ore types to be eligible for more than one processing method. A fuller explanation of the WCPL global asset optimisation methodology can be found in *Whittle 2004.* (5)

BUSINESS MODEL INPUTS

A detailed business model has been developed that models the processing relationships of the various rock-types and forms the basis for calculating the net value of each parcel of each rock type. The inputs into the business model have been summarised in Table 1.

Category	**Input**
Geological Block Model	Block Centroid coordinates and Dimensions
	Nickel, Cobalt, Magnesium, Aluminium and Iron grades
	Density (SG)
	Ore type
	Block % below surface topography
	Pit Name
Deposit	Chloride grade
	Haul cost
	Region and Deposit name
Processing	Scats reject + Beneficiation of Nickel, Cobalt and Magnesium
	Pressure Acid Leach Density
	Recoveries: Mill, Pressure Acid Leach, Counter Current Decant Thickeners, Mixed Sulphide Precipitation Circuit and Refinery
	Rock Type particle density

Category	**Input**
	Acid consumption factors and constants
	Calcrete consumption parameters
	Ammonium Sulphate saleable by-product multiples
Economic/Financial	Commodity prices: Sulphur and Calcrete
	Metal prices: Nickel, Cobalt and Ammonium Sulphate
	Exchange Rates
	Royalties
Cost components	Capital
	Mining
	Hauling
	ROM Handling
	Milling
	Pressure Acid Leaching
	Calcrete Neutralisation
	Acid
	Refining
	Fixed
	Selling and Transportation

Table 1 – Business Model Inputs

OPTIMISATION PROGRAMS

Jeff Whittle from WCPL has developed two optimiser programs "Z3" and "Prober" of which both use mathematical search algorithms in conjunction with CPLEX linear programming evaluation routines. Both consider all periods simultaneously, using NPV to evaluate options over different time periods.

The main features of "Z3", the first program developed by WCPL and utilised at Murrin, are as follows:

- A search algorithm systematically works through samples of the mining fractions
- Decision rules are applied to focus in on combinations of fraction that give the best results
- The resolution of the search increases progressively
- A linear programming evaluation routine optimises the blend
- Processing and production outputs for each set of mining fractions sampled are generated
- Random starts are performed to confirm results and create alternative solutions

"Prober" is an extension of the random start concept and uses the following approach:

- A set of mining fractions are selected at random
- Linear programming is used to locate the nearest local maximum, by controlling the mining fractions that present a linear relationship within a bench
- The procedure is repeated say 50 or 100 times until there is a very small difference between the first best, second, third etc results that have been achieved giving a high level of confidence that the overall "global" optimum had been identified.

Minara's 150 independent sequences over 30 years create an unusually large and fragmented search space. To give the optimiser a "head start", the pits are ranked by NetVal per tonne and that sequence is loaded into the input file. From experience, the solution is found much quicker and more accurately than if it had to search through infinite non-optimal solutions and be caught on local maxima. If all pits are mineable within one period, it is reasonable to consolidate all the benches into one pit. This vastly simplifies the mathematics and creates the special situation with no local maxima and produces a repeatable unique solution.

In conjunction with running Z3 and Prober, another linear programming program "MineMax", is used to conduct optimised strategic mine planning. MineMax is used in-house by the strategic mine planning group, using identical data sets to WCPL and performs schedule optimisation using the same mathematical model to represent the mine and its production constraints. The major difference between the programs is that WCPL finds a range of best solutions while

MineMax solves for a unique solution given the system constraints. There are no absolute right answers with schedule optimisation as the highest NPV solution may not be best when considering practicality, risk, consistency, political, social, environmental, etc issues, not all of which will have been incorporated into the business model.

Using both WCPL and MineMax Multi-Pit/Blending/Alternative-Path-Processing/NPV-Maximising/Mine-Scheduling software packages allows Minara to undertake Strategic Mine Planning using different approaches. This gives confirmation and greater confidence in the resultant mine plans as the outputs are compared and contrasted. Contrasting differences in the results also provides the opportunity for improvements and further developments in the software.

Given the amount that Minara has at stake in its business, and the comparatively small cost of asset optimisation analysis, the continued use of all optimisation tools is necessary – each providing a different perspective on the issues – as part of the process of gaining insight and understanding into the drivers of value within the business.

MODELLING METHODOLOGY

The Murrin geological models have over 100 million blocks and must be consolidated before commencing optimisation to reduce the complexity of the mathematical problem. Firstly, the models are optimised using the business model input parameters in Whittle Four-X to produce ultimate pit shells. The pit shells are grouped into regions and the deposits are cut into logical mineable shapes (see figure 5). Each pit can consist of one or more sequences (phases or pushbacks), related by bench RL and phase order. A sequence has a name and consists of one or more panels (benches). A panel consists of zero or more parcels. Each parcel is defined by its mine material type that can depend on rock-type and grade band, the quantity (tonnes or BCMs) and attributes (grades) of material, mining cost per unit quantity and the number of processing paths. In Murrin's case, the number of consolidated blocks has been reduced to approximately 10,000.

The optimiser will mine all or part of a panel in a particular period (see figure 6). Parcels within a panel are "mined" in proportion. That is, if, within a period, 20% of a panel is mined, then 20% of each parcel in the panel is mined. If mined, a parcel may be processed in the same period, stockpiled for processing in another period, or discarded as waste. Rules of sequence are respected according to the pit structure, as are any additional earliest start dates or start after rules. Mining limits can be set by site, pit, sequence, mine material type, period – expressed in quantities or panels (benches) per year.

A processing path produces one or more blend feeds according to rules set for recovery, throughput and processing cost (see figure 7). Processing turns mined material into one or more 'Blend Feeds' that may simply be rock, lump and fines, slurries, concentrates, rejects, by-products, or even fully extracted metal – depending on the operation and how it has been modelled. 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 may be either blended in the same period, stockpiled for blending in another period, forced to be used or discarded as waste. The schematic ore-processing path is illustrated in figure 8. Blending rules can be set to control grades/attributes/density, volumes/quantities, throughput and costs. A blend feed can be eligible for zero or more products. Products are valued according to price rules which can have base price for quantity of product or price gradients on grades /attributes. Production can be limited by product or in combinations.

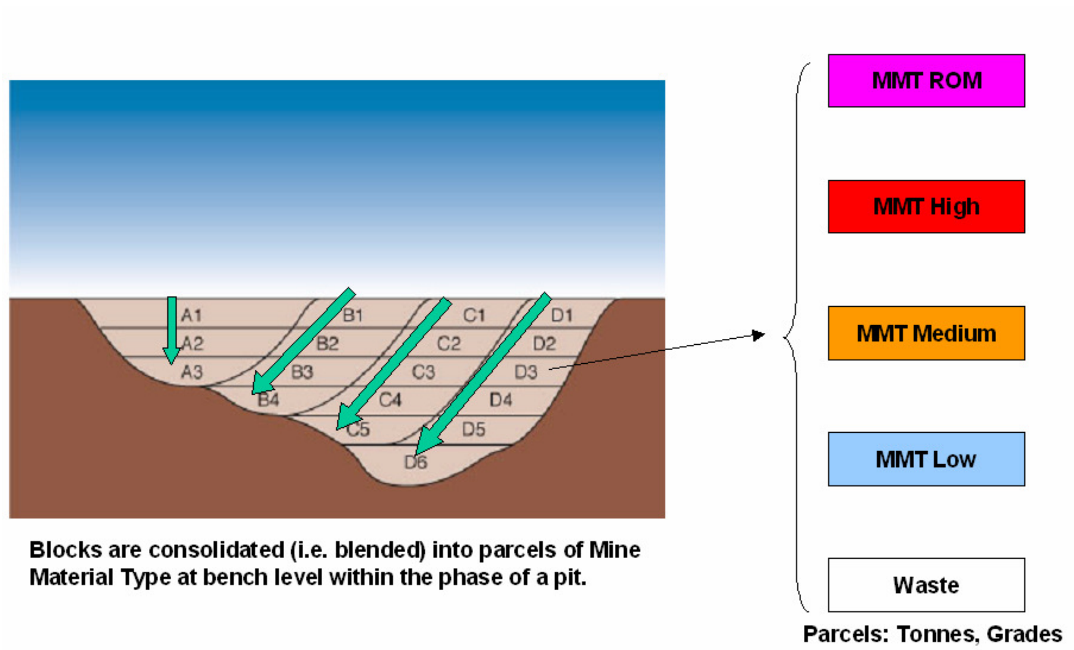

Figure 5 – Mining by phase and bench

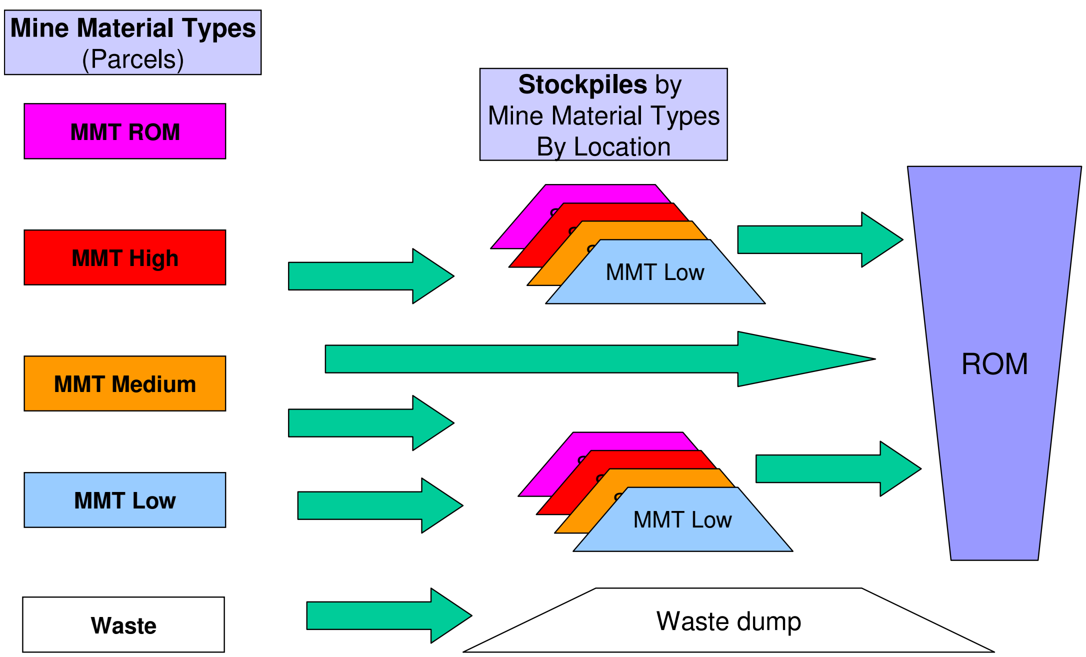

Figure 6 – Stockpiling Process

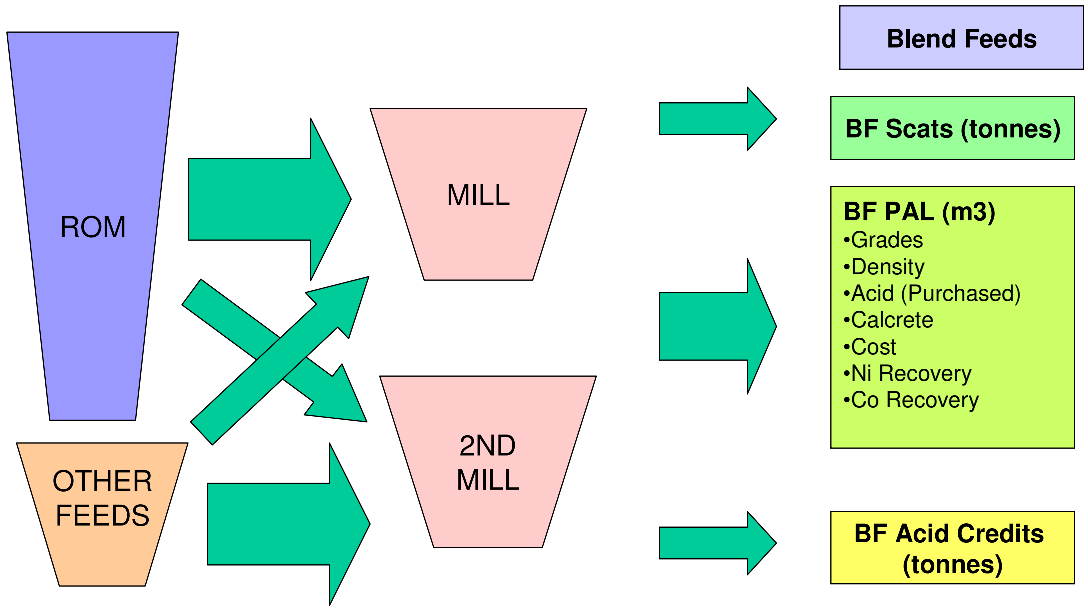

Figure 7 – Processing to blend feeds

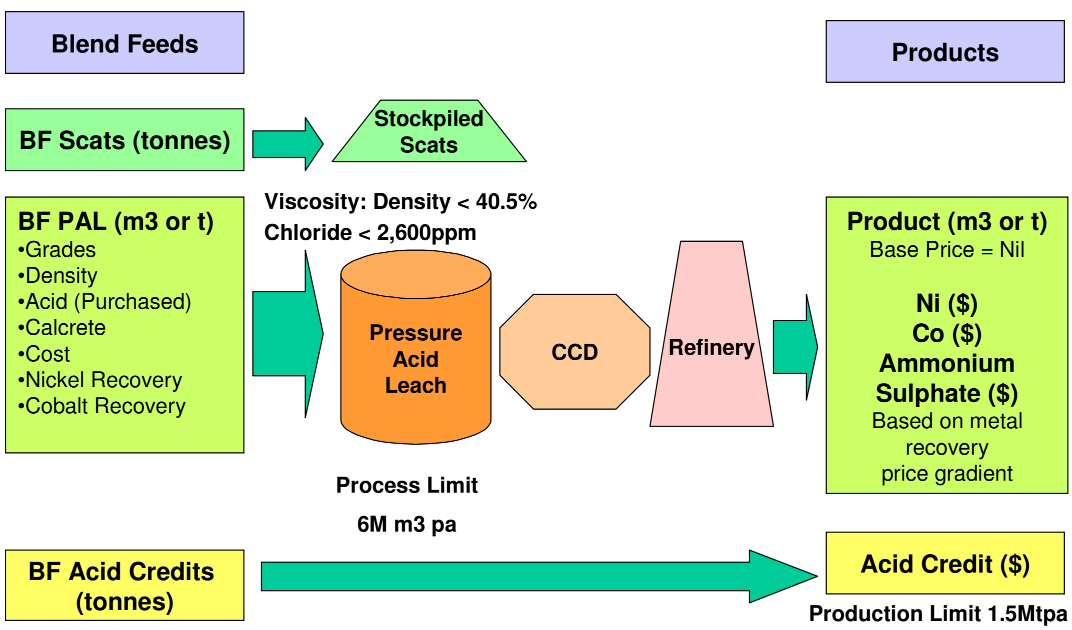

Figure 8 - Blending to Products

RESULTS

The output sheets generated by the optimiser are mapped into a spreadsheet to permit further financial input and a standardised set of graphs can be produced to visually see the changes between optimisation scenarios. Figure 9 shows some typical output graphs. Commercially sensitive information has been removed from the graphs.

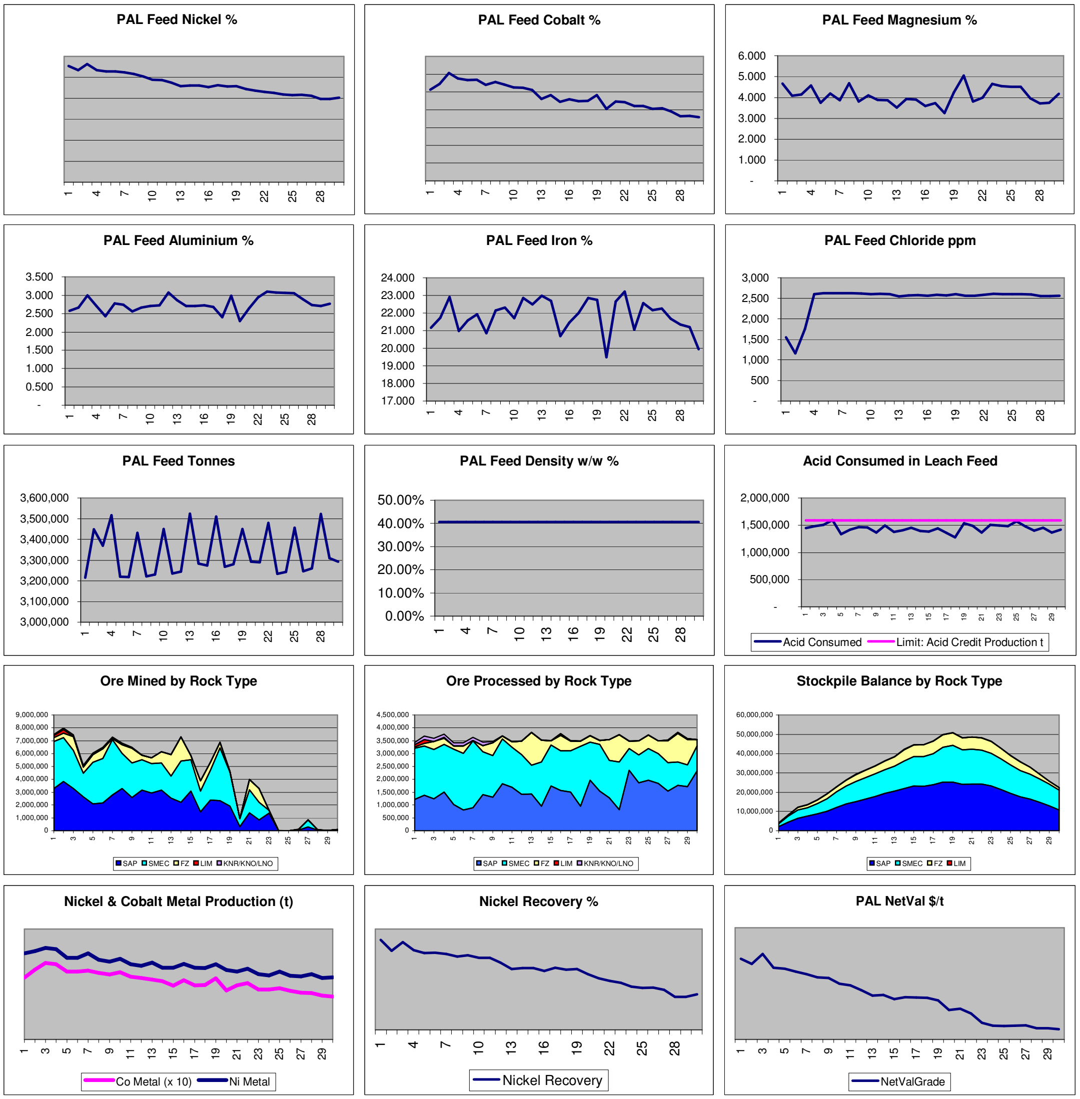

Figure 9 – Typical Optimisation Output (Commercial sensitive information removed)

DISCUSSION

While mining decisions are normally optimised on mining cost, stripping ratio and grades, the global optimisation approach at Murrin involves feeding the drivers and sensitivities of the processing system in a far more sophisticated and realistic manner. The optimiser effectively negotiates the feed grade within a workable range based on:

- A balanced decision between the cost of mining more and the benefit of revealing more ore from which to skim the highest grades first, leaving the rest for stockpiling
- A balanced consideration of mining costs and efficiencies versus processing costs and efficiencies
- Using stockpiles to prioritise the order of processing ore
- Controlling the blend of rock types to achieve:
    - Grade constraints (Ni, Co, Mg, Al, Fe & Cl)
    - Blend constraints (Saprolite, Smectite and ferruginous rock type ratios)
    - Mill recovery and density objectives
- Maximising HPAL throughput to capacity
- Maximising HPAL density to upper limit%
- Purchasing additional acid when warranted
- Optimising Ni/Co product mix
- Maximising NPV

The WCPL optimiser provides the opportunity to manage the mix of minerals from ore body through to market in a way that collectively maximises the overall value of the company's assets.

CONCLUSIONS

Minara uses Global optimisation with a sophisticated holistic business model to maximise the value generated in producing nickel and cobalt metal. In taking a multi-discipline strategic approach to the business all stakeholders have been able to participate in the decision making process. It is necessary to align the long-term strategic planning processes with the operational view in order to maximise the total value of the business, as gains in the short-term that deviate from the long-term plan can diminish value. Blending at a strategic level (long term) ensures the optimal ore extraction sequence to maximise the NPV of the business.

Through the addition of other high grade feed sources and controlled blending techniques, Minara is able to provide a relatively homogeneous slurry for the autoclave feed that maximises NetVal and meets the processing constraints of the system. The autoclaves are the bottleneck to the system so it is vitally important to maximise the nickel/cobalt metal through the system. Optimising ore blending at Murrin has been proven to increase the HPAL slurry density up to the optimal autoclave throughput.

Whittle Consulting Limited (WCPL) has played a vital role in assisting Minara with global asset optimisation and strategic mine planning. Through the use of the Z3 and Prober proprietary software, the Net Present Value (NPV) of various scenarios have been quickly analysed, assessed and implemented resulting in added value to the business.

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