Enterprise optimization case study: PanAust's Inca Oro Project, Chile

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ABSTRACT

Whittle Consulting's (WCL) Enterprise Optimization (EO) solution is an integrated approach to maximizing the Net Present Value (NPV) of a mining business by simultaneously optimizing up to 10 different mechanisms across the mining value chain. The EO methodology which WCL has developed over the last 12 years draws from the manufacturing industry (theory of constraints) and cost accounting (activity-based costing) as well as advanced mining techniques such as cut-off grade optimization and "skin analysis". The principles behind Enterprise Optimization accelerate cash flow through the business by applying a holistic planning approach over the whole business chain rather than conventional 'silo' based decision making. The EO methodology and techniques are underpinned by sophisticated in-house proprietary software and has proven to be an excellent strategic planning tool for mining businesses having consistently identified significant value uplifts to projects and operations alike.

This paper presents the findings from the EO Study for the Inca de Oro (IDO) Copper/Gold project located in the Atacama region of Chile. The Inca de Oro Project is a joint venture between PanAust Ltd of Australia and Codelco of Chile. The techniques and optimization mechanisms applied produced a 116.8 % overall increase in pre-tax NPV above the PanAust's best business case (referred to as the "base case").

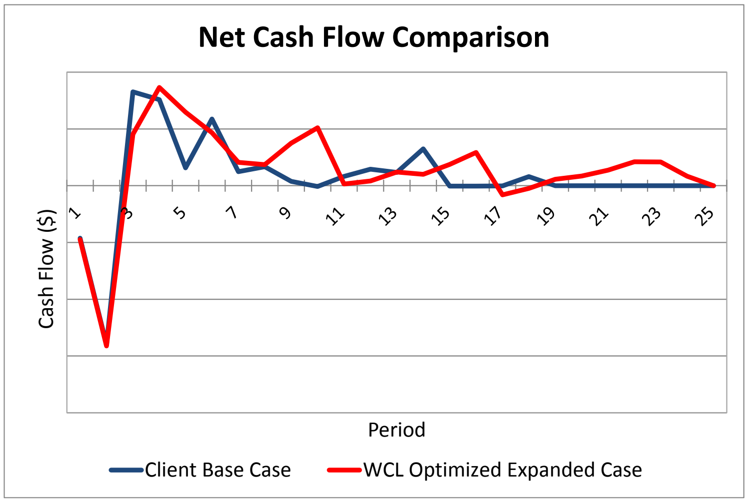


Figure 1 Net Cash Flow Comparison

INTRODUCTION

The IDO deposit is a porphyry-copper type ore body containing minor amounts of gold, silver and molybdenum. This is an open pit mine with a conventional process plant producing copper concentrate with gold and silver credits. The processing plant incorporates a SAG and ball mill preceded by secondary crushing. There also exists the potential to include external mineral resources from the Carmen deposit located 12 km southwest of IDO. The Carmen deposit is 100 % owned by PanAust and has similar geological and metallurgical characteristics to IDO. Dependent on the rate of production, Carmen ore will be either directly trucked to IDO or crushed on site and conveyed for processing at IDO.

The rim of the IDO open pit is within 500 metres of the nearest occupied building in the IDO township. Due to the proximity to the township, urban air quality criteria are applied to the operation which potentially limits production rates from the mine due to dust generation. Of the mine activities that generate dust, the largest contributor is in-pit haulage. A 46 Mtpa mining limit was applied as a proxy constraint in the initial study for limiting dust emissions. The Carmen deposit is regarded as a mineral source that could potentially keep the plant running at capacity whilst keeping dust emissions within regulatory limits since it is located at distance from the township. Blast intensity is also limited on the side of the pit closest to the township in order to maintain vibration below the environmental constraints.

Ore from both IDO and Carmen deposits have similar hardness and are energy intensive to process. Akin to other mines in the region, infrastructure challenges have contributed to relatively high capital and operating costs. Initial base case valuation indicated that IDO (not including Carmen) as a stand-alone project did not present an attractive investment case.

WCL was engaged to assist PanAust in realising the potential in this project and used EO as the tool to optimize the NPV. Specifically, WCL evaluated options around plant sizing, plant expansion timing, capital staging, scheduling, grind size selection, blasting intensity selection and the effect of including the Carmen deposit. The application of EO produced meaningful NPV improvements as presented in this paper.

DEFINING THE BASE CASE

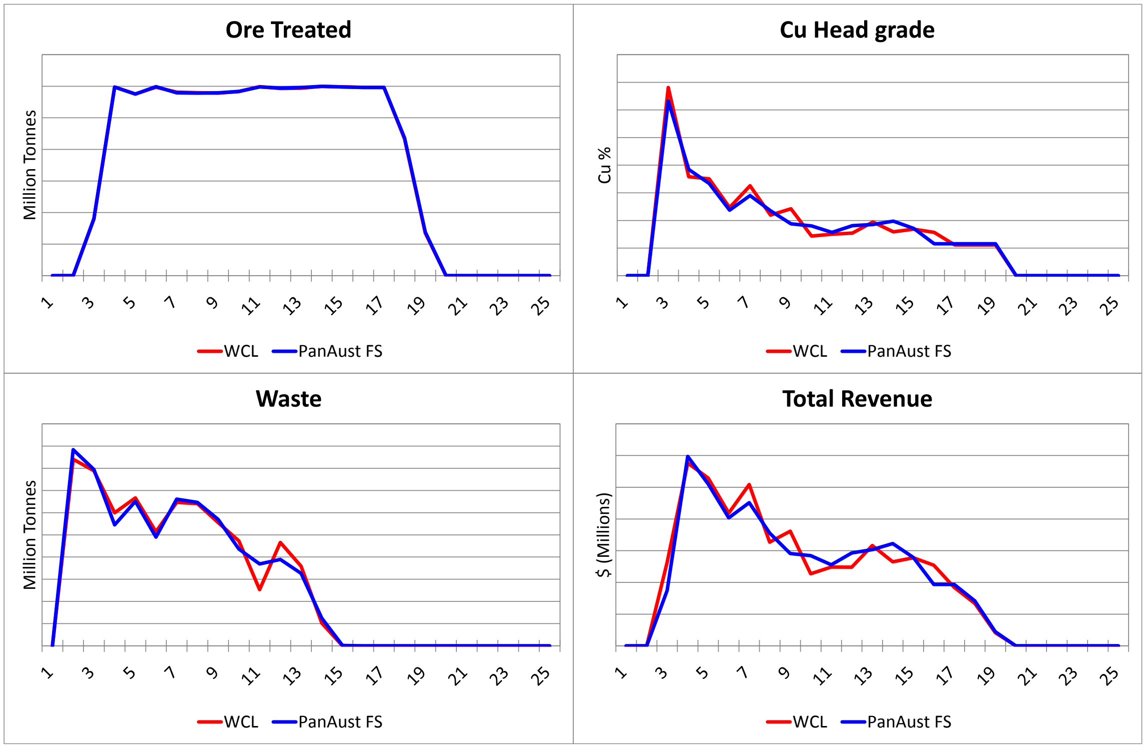


Figure 2 WCL Base Case versus PanAust FS

The first step in the EO methodology is to define a base case which is typically derived from an existing mine plan and financial model provided by the client. Based on this, WCL emulates this scenario in Prober. This step performs a key comparative and validation step and aligns WCL modelling with that of the client's before optimization mechanisms are incorporated.

The WCL base case was aligned with PanAust's existing Feasibility Study (FS) financial model using identical model inputs and system capacities. Figure 2 shows that the WCL case is closely aligned to PanAust's FS.

WHITTLE CONSULTING ENTERPRISE OPTIMIZATION METHODOLOGY

Fundamental to the EO methodology is activity-based costing (ABC) and the theory of constraints (ToC). Conventional cost modelling usually involves excessive averaging and allocation of costs only to production volume (tonnes), and simplistic, usually inadequate, distinction between fixed and variable costs. ABC involves a more detailed and responsive cost model which reflects more accurately the cause-and-effect relationship between activity costs and the cost drivers they are attributable to.

The ABC approach allocates variable costs to cost drivers that are truly variable, and can change or become a limitation to the rate at which a 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.

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 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. WCL has seen that about 30 % of variable costs are actually fixed costs that "keep the lights on".

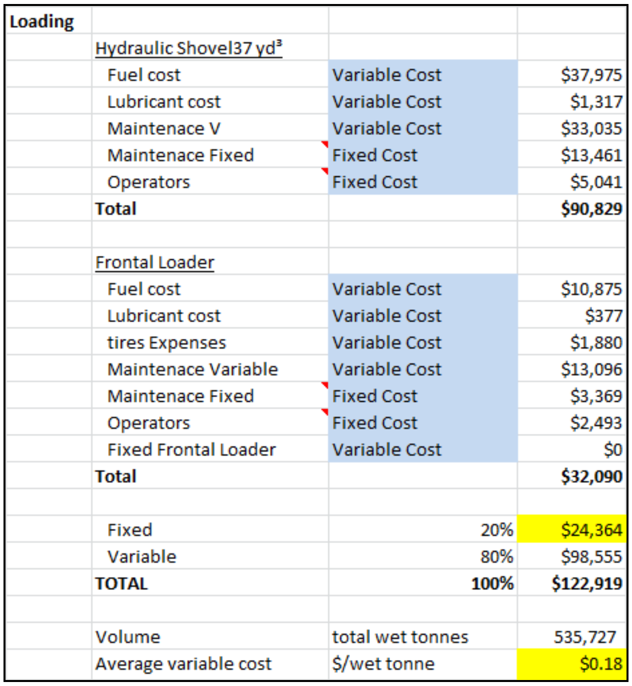
The period costs are used to penalize the constraint in the system, which forces the optimizer (Prober) to consider the effect of running the operation for one more period. This, in effect, is quantifying opportunity cost. This also has the effect of flat lining the period costs as the constraint in the system should always be at capacity, 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 are 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.

Through consultation with PanAust, WCL carried out ABC on processing and mining costs. Each cost item was scrutinized line by line to determine if it was fixed or variable or if it needed to be split into fixed and variable. Evaluation of fixed and variable cost was broadly based on:

- Type of cost
- Forecasted cost profile
- Cost driver
- Client consultation

For example (Figure 3), loading costs were split into fixed and variable costs by review of each cost item. The total fixed cost was then determined and applied annually to the optimization runs. In this instance, the average cost was calculated based on $/wet tonne:



Loading			
	Hydraulic Shovel37 yd³		
	Fuel cost	Variable Cost	$37,975
	Lubricant cost	Variable Cost	$1,317
	Maintenace V	Variable Cost	$33,035
	Maintenace Fixed	Fixed Cost	$13,461
	Operators	Fixed Cost	$5,041
	Total		**$90,829**
	Frontal Loader		
	Fuel cost	Variable Cost	$10,875
	Lubricant cost	Variable Cost	$377
	tires Expenses	Variable Cost	$1,880
	Maintenace Variable	Variable Cost	$13,096
	Maintenace Fixed	Fixed Cost	$3,369
	Operators	Fixed Cost	$2,493
	Fixed Frontal Loader	Variable Cost	$0
	Total		**$32,090**
	Fixed	20%	$24,364
	Variable	80%	$98,555
	TOTAL	**100%**	**$122,919**
	Volume	total wet tonnes	535,727
	Average variable cost	$/wet tonne	$0.18

Figure 3 Example of ABC on Mining Cost

MINING MODEL, DUST EMISSIONS MODEL AND ENVIRONMENTAL CONSTRAINTS

To begin with, PanAust had a separate detailed mining cost model and a dust emissions model. The dust emissions calculations were based on the FS mine schedule. WCL helped to integrate both models through a process of calibration, reconciliation and consultation. The result was an optimization model that could simultaneously capture dynamic variables like distance, depth and dust emissions.

Mining Cost Model

The mining cost model used in PanAust's pit optimization was based on a flat $/tonne base cost for material mined and an incremental $/tonne depth cost. This captured high level average costs but ignored cost differentials between blasting ore and waste. For instance, WCL was told that different rock types were to be blasted at different intensities. This was subsequently built into the EO model:

Table 1 Blast Intensity by Rock Type

Rock Type	Blast Intensity (kg/bcm)
Gravel & Leached	0.37
Oxides	0.69
Mix, Sup, Pri, Car	1.20

It also ignored the cost variation in in-pit haul distances. Keeping depth constant, the cost of hauling material from one end of the pit should be substantially different from hauling material from the opposite end. Using a blanket average cost over these variations destroys value as it does not present options for Prober to choose the most cost-effective cause of action. This had to be captured in the EO model.

PanAust provided a detailed mining cost model with cost details for all mining activities and areas. With this information, WCL was able to derive a mining cost model based on the ABC approach. Two cost drivers were identified that would adequately capture the cost variation in mining:

Table 2 Mining Cost Drivers

Cost Driver	Activity
$/tonne cost that varies based on blast intensity and rock type	Drill & Blast Cost
$/tonne.km	Hauling/ Earthmoving Equipment

The cost drivers for hauling and earthmoving equipment required a distance component (km) which was not available in the resource model. With specific site distances provided by PanAust, WCL worked out the in-pit and ex-pit haul distance for each block. The in-pit haul distance was estimated given the pit exit point by assuming the greater value of either:

- the horizontal distance to the exit point or;
- 10 times the vertical distance to the exit point

This method was validated and calibrated by reconciling WCL figures with the total in-pit tonne.km calculated by PanAust from an earlier model.

Environmental Constraint – Dust Emissions

PanAust's existing dust emissions model derived dust values based on operational activity which was in turn, calculated through methods prescribed by the environmental regulatory body. Each activity had a specific equation to work out dust emissions and the equation input variables were based on the FS schedule. As mentioned previously, instead of constraining mining based on dust emission from mine site activities, a proxy constraint of 46Mtpa on mining was used. This figure was estimated based on past dust calculations which showed annual dust emitted from in-pit and ex-pit haulage consistently made up approximately 70 % of all dust emissions. Whilst functional, this is not accurate and might unfairly limit the level of production, particularly if the second deposit (Carmen) were to come into play. Dust generation from Carmen mining activities are not limited in the same way as it is situated 12 km away from the Township. Based on PanAust's dust model, the main activities and proportion of dust emissions in the highest emissions year are:

Table 3 Emissions Proportions

Activity	Proportion of Emissions
In-pit haulage - waste	19 %
In-pit haulage – ore	20 %
Ex pit haulage – waste	33 %

Ex pit haulage – ore	4 %
Primary crusher	6 %
Secondary crushers	9 %
TSF construction	2 %
Other – unclassified	6 %
Total	**100 %**

The regulatory method used to calculate dust emissions were very detailed and certain variables were specific to each activity. In its current form, it was difficult to calculate dust emissions dynamically. In order for the EO model to include dynamic dust calculations, WCL had to identify drivers which were closely correlated to the level of dust emissions. The sensible drivers for each activity were discussed and presented below:

Table 4 Activity-Based Dust Emission Drivers

Activity	WCL Dust Emission Drivers
In-pit haulage - waste	kg of dust emissions/ tonne.km
In-pit haulage – ore	kg of dust emissions/ tonne.km
Ex pit haulage – waste	kg of dust emissions/ tonne.km
Ex pit haulage – ore	kg of dust emissions/ tonne.km
Primary crusher	kg of dust emissions/ tonne
Secondary crushers	kg of dust emissions/ tonne
TSF construction	kg of dust emissions/ tonne
Other – unclassified	kg of dust emissions/ tonne

Utilising information from a range of sources, it was possible to derive dust emission factors for each activity based on PanAust's existing dust emissions calculations. This was then carefully calibrated to produce sensible results. A series of test optimization runs were done - the proportion of dust emitted from mine activities and total dust emissions were consistent with the PanAust's expectations. This was further validated by comparing calculated dust emissions from both methods – the WCL method versus the prescribed method. A more conservative approach was taken by calibrating the model to the year with the highest dust emissions as calculated by PanAust. The figure below shows how the optimization model is set up and the text in brown indicates dust generation points.

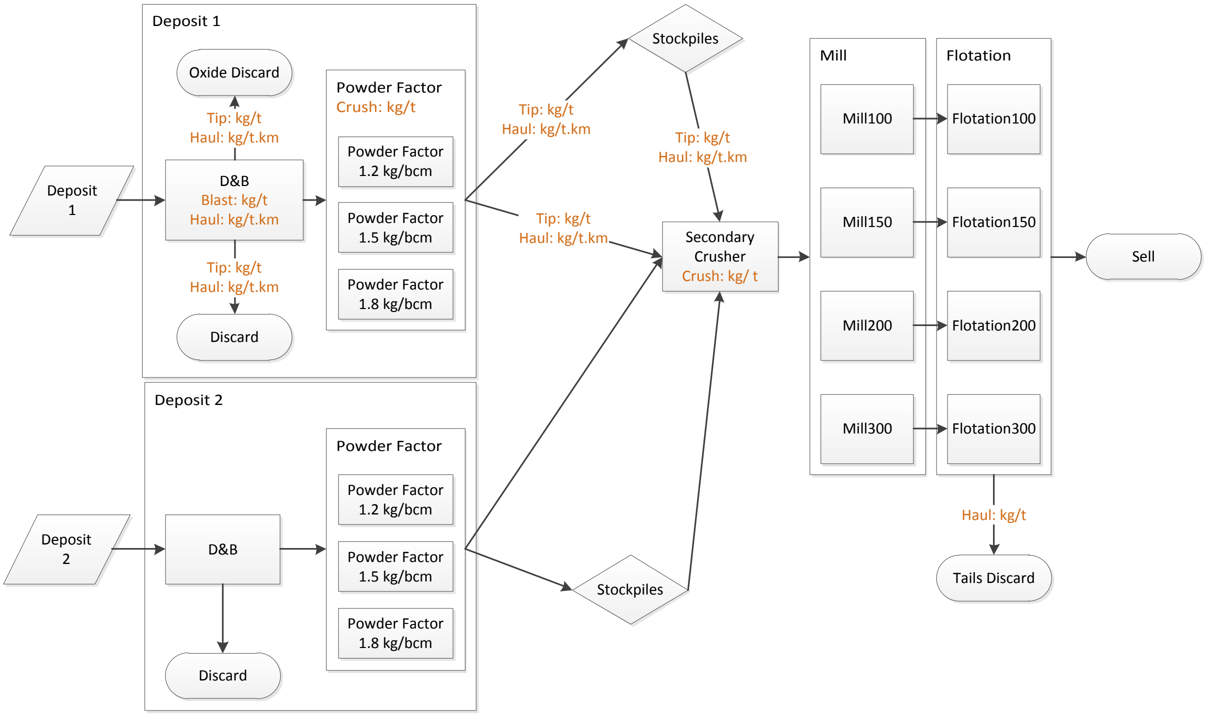


Figure 4 Dust Generation Points

Since the mining model now includes a distance component (t.km) for each block, dust emissions are easily calculated for haulage activities. Dust from non-haulage activities are based on quantities (tonne). This allows the overall dust emissions to be easily calculated replacing the mining proxy constraint for dust. This is a more realistic representation of the mining operation.

Environmental Constraint: Blast Intensity

Another environmental constraint was on limiting the blast intensity in certain areas of the pit because it was within close proximity to the town cemetery and water tank. A prior study was done assessing the restrictions around blasting in these areas. This translated to a blast intensity limit on blocks provided by PanAust. As seen in the figure below, the pink blocks were restricted from being blasted at an intensity of higher than 0.69 kg/bcm.

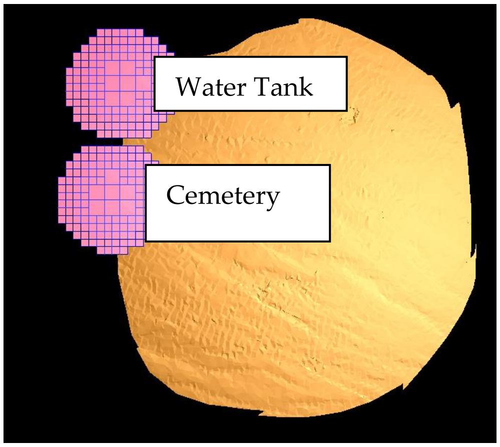


Figure 5 Blasting Restrictions

THROUGHPUT OPTIMIZATION

Applying a flat constraint on throughput tonnes is not accurate because ore type and thus, the hardness of the mill feed is variable through the life of mine. Mill throughput varies with ore hardness which is in turn dependent on available power for processing – processing harder ore types consumes more power and results in a lower throughput. In most conventional open pit gold/copper mines, mill power is and should be the bottleneck in the system because it is the most capital intensive part of the operation. Therefore, the constraint on the mill should be on power consumption rather than tonnes throughput.

Throughput optimization was done using two EO mechanisms:

1. Determining the optimal blast intensity
2. Determining the optimal grind size

Collectively, finding the optimal blast intensity and grind size contributed a value uplift of 63.1 %. Throughput optimization was subject to the following constraints in the system:

- Dust emissions limit
- Material handling limit
- Mill power consumption limit
- Water supply limit

Throughput Optimization – Blast Intensity

In the base case, all ore is blasted at a powder factor (PF) of 1.2 kg/bcm, and all gravel and leached rock is blasted at a PF of 0.35 kg/bcm. With the help of PanAust, detailed blasting data was obtained and applied to later scenarios:

Table 5 Blast Intensity by Rock Type

Rock type	Blast Intensity (kg/bcm)

Gravel & Leached	0.37
Oxides	0.69
Ore	Option of 1.20, 1.50 or 1.80

Optimizing the blast intensity is based on incorporating two mechanisms into the model:

1. Cost differentials between different blast intensities
2. Downstream plant energy savings.

Prober can make the decision to either blast at a lower intensity for less cost but at the expense of using more grinding power downstream or, blast at a higher intensity for a higher cost to save power consumption. In short, the effect of higher blast intensity is greater plant throughput since less downstream power is required for ore processing. As indicated above, three blast intensities were considered: 1.2 kg/bcm, 1.5 kg/bcm and 1.8 kg/bcm.

Keeping the grind size consistent with the base case (150 microns), Prober chooses a mix of blast intensities:

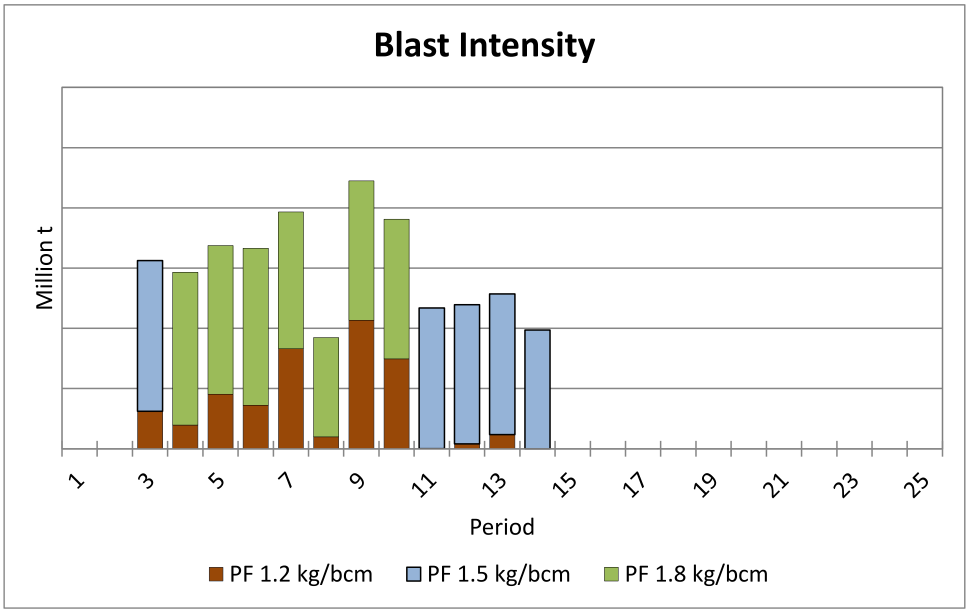


Figure 6 Powder factor vs Tonnes blasted

This mechanism adds 14.9 % to the NPV. A notable observation is that blasting at higher intensities has allowed the material handling limit to be filled closer to capacity whilst keeping mill power consumption at capacity i.e. fully utilising the bottleneck of the system.

Throughput Optimization – Grind Size

All ore is processed at a grind size of 150 microns in the base case. For the grind size optimization, PanAust defined 5 different rock types (Porphyry, Mixed, Supergene, Andesite and Carmen) along with 4 grind size options for each rock type (100 microns, 150 microns, 200 microns and 300 microns). These options were presented to Prober. Each rock type at each grind size has a different power consumption and metal recovery:

Table 6 Grinding Circuit Work Index vs Grind Size

Grind Size:	**100um**	**150um**	**200um**	**300um**
SAG Mill Work Index (kWh/t)				
IDO-Por/Mix/Sup	11.39	8.70	7.47	5.71
IDO-And	12.23	9.34	8.02	6.13
Carmen	12.17	9.30	7.99	6.10
Ball Mill Work Index (kWh/t)				
IDO-Por/Mix/Sup	12.17	7.30	7.98	6.10
IDO-And	13.06	9.00	8.57	6.54
Carmen	13.00	11.53	8.53	6.51
Total Grind Circuit Work index (kWh/t)				
IDO-Por/Mix/Sup	23.56	16.00	15.46	11.80
IDO-And	25.29	18.34	16.59	12.67
Carmen	25.17	20.82	16.52	12.61

Table 7 Recovery per Rock Type vs Grind Size

Rock type:	**Mixed**	**Super**	**Porphyry**	**Andesite**	**Carmen**
100 microns					
Cu recovery	50.0 %	82.0 %	92.0 %	92.0 %	89.8 %
Au recovery	50.0 %	67.0 %	71.1 %	71.2 %	76.6 %
Ag recovery	50.0 %	64.0 %	63.0 %	53.0 %	77.0 %
Mo recovery	50.0 %	74.0 %	90.0 %	57.0 %	77.0 %
150 microns					
Cu recovery	50.0 %	82.0 %	89.5 %	89.5 %	89.5 %
Au recovery	50.0 %	67.0 %	67.0 %	67.0 %	77.0 %
Ag recovery	50.0 %	64.0 %	63.0 %	53.0 %	77.0 %
Mo recovery	50.0 %	74.0 %	90.0 %	57.0 %	77.0 %
200 microns					
Cu recovery	50.0 %	82.0 %	86.7 %	86.7 %	87.3 %
Au recovery	50.0 %	67.0 %	62.3 %	62.2 %	72.0 %
Ag recovery	50.0 %	64.0 %	63.0 %	53.0 %	77.0 %
Mo recovery	50.0 %	74.0 %	90.0 %	57.0 %	77.0 %
300 microns					
Cu recovery	50.0 %	82.0 %	81.1 %	81.0 %	83.0 %
Au recovery	50.0 %	67.0 %	52.9 %	52.7 %	62.1 %

Ag recovery	50.0 %	64.0 %	63.0 %	53.0 %	77.0 %
Mo recovery	50.0 %	74.0 %	90.0 %	57.0 %	77.0 %

With the flexibility of blasting at different intensities and processing at different grind sizes, Prober is now able to use both the power limit and material handling limit to capacity - throughput is maximized. All the activities have been maximized to meet the dust emissions limit in almost every year of operation:

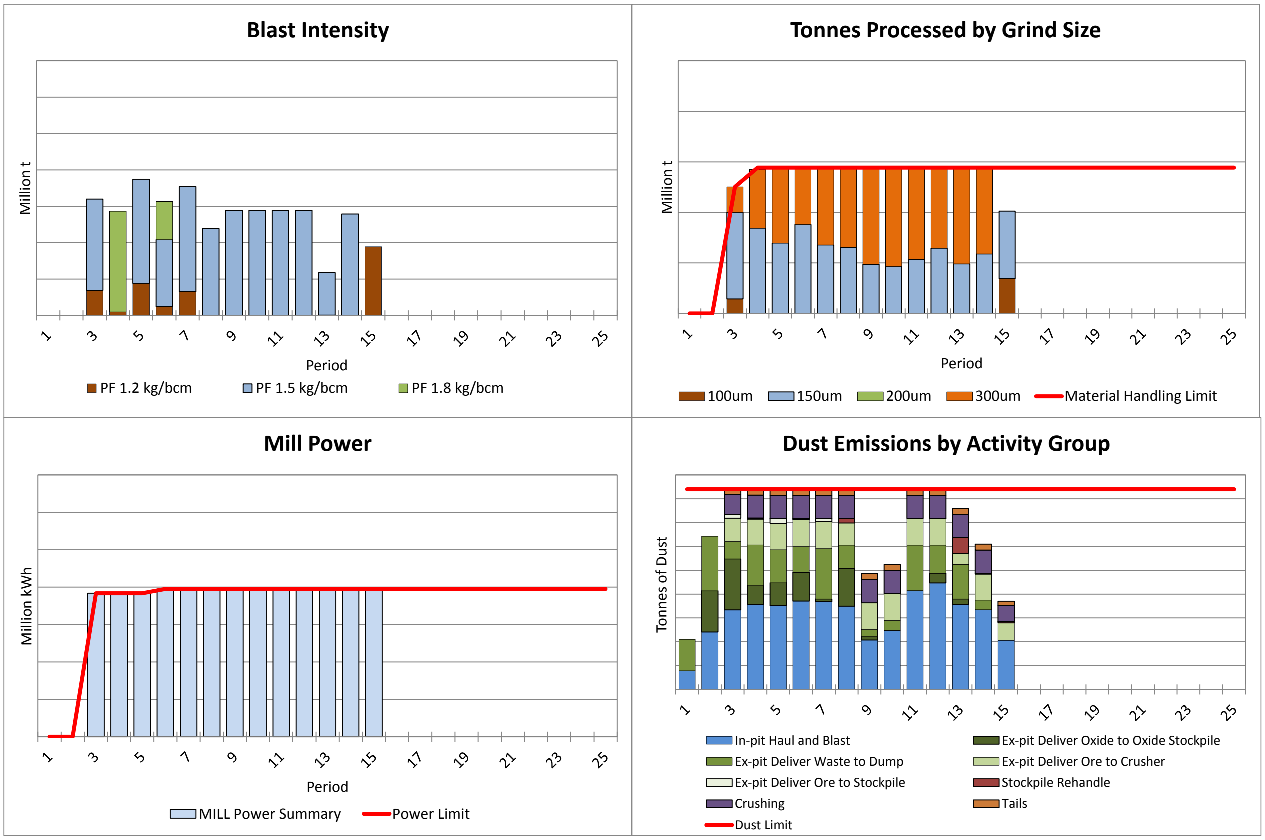


Figure 7 Blast and Grind Options Subject to System Constraints

Switching on the grind size mechanism together with blast intensity mechanism produces the largest gain – an additional uplift of 48.2 % above the blast intensity optimization scenario with and 63.1 % over the base case.

OTHER SCENARIOS CONSIDERED

Other scenarios considered in this EO project were:

- Different plant sizes including and excluding the Carmen resource
- Staging of development expenditure through two plant modules
- Capital expenditure timing

- Scenarios moderating blasting and grind size strategies

This provided PanAust with a range of practical mine plans and revealed the sensitivity of "flexing" certain variables.

ENTERPISE OPTIMIZATION RESULTS

A net value uplift of 80.8 % was identified in the optimized case over the base case through the EO process. The notable EO mechanisms that contributed value as seen in Figure 8 were:

- Blast options - allows the optimizer to modify blasting options with regard to powder factor and grid pattern
- Blast + Grind options – in addition to blast options, this scenario allows the optimizer to simultaneously modify product grinding scenarios and provide variable grind size depending on feed material
- Pits/Phases - considers WCL designed pits and phases

WCL did a series of scenario testing to ascertain the highest value configuration and mine schedule, subject to additional capital requirements. This added a further 36 % of value above the base case, bringing the total value uplift to 116.8 % for the "expanded case". The waterfall diagram shown below provides an indication of the impact of this approach.

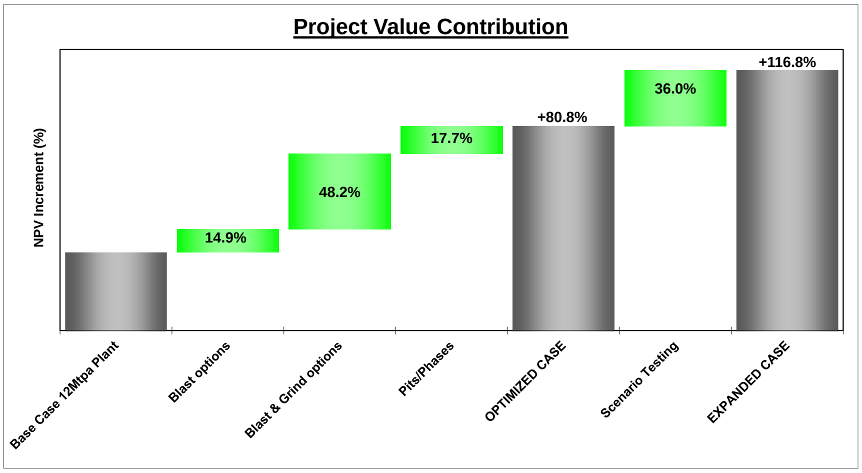


Figure 8 Example Waterfall Diagram of Value Contribution

This EO study has unified all the available information into a single holistic strategic business model to identify value opportunities for IDO. The model can provide ongoing support for future strategic planning as updated model inputs including operational pit and phases can easily be incorporated to generate a new mine and production plan profiled to maximize business value. Practical strategic limitations on mining, plant and dust have been overlaid to ensure the results are robust. Through application of ABC and the ToC, combined with a focus on NPV and bringing cash flows forward, the WCL solution has unlocked hidden value and increased the economic appeal of this project as observed in Figure 9. The resultant schedule is an outcome based on WCL's philosophy, methodology and techniques that maximizes the flow of cash through the whole business.

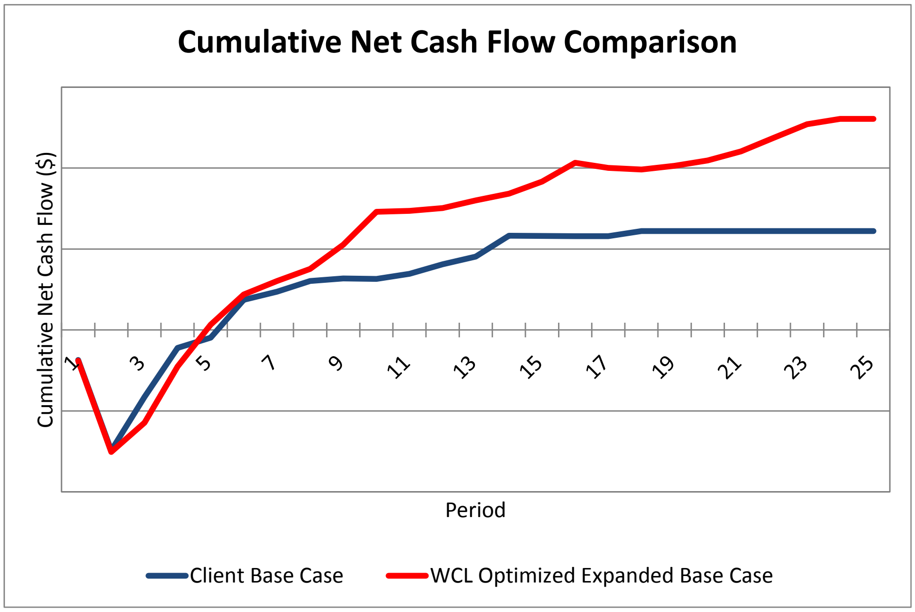


Figure 9 Cumulative Net Cash Flow Comparison

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