INTEGRATED MINING AND PROCESSING STRATEGIES REDUCE COSTS AND MAXIMIZE PROFIT AT IRON ORE OPERATIONS*

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Abstract

Hatch's Mine to Process Optimization projects integrate mining and processing strategies, minimizing operating costs and maximizing overall profit. The methodology involves ore characterization, blast audits, plant surveys, analysis of historical data, and integrated modelling and simulation of mining and processing. Blast designs are tailored according to ore type and the downstream process is optimized for the changed feed. This approach has increased throughput and minimized costs for many operations worldwide. The implementation of this methodology at an iron ore operation that faced challenges with increasing mining strip ratio and ore body mineralogy changes is presented in this paper. The larger stripping ratio increased mining costs and constrained the run-of-mine (ROM) delivery to the process plant. Process performance was affected as the ore mineralogy shifted from predominantly hematite to include greater proportions of magnetite. The project objective was to minimize overall cost per ton mined and processed and maximize profit. Tailoring the blast designs according to ore type and process optimization increased the throughput of all process lines. This provided the potential to shut down one of the five processing line, aligning the mine and plant capacity and significantly reducing the processing costs.

Keywords: Mine-to-Mill; Integrated strategies; Iron ore.

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1 INTRODUCTION

Hatch's Mine to Process optimization projects have successfully been implemented in iron ore, base metals and gold operations.

Optimization projects add value regardless of fluctuations in commodity prices. To remain profitable in times of low commodity prices, mine sites need to operate more efficiently as well as identify opportunities for cost reduction per tonne of product.

The iron ore project described here cannot be named for commercial reasons, however, as a case study, it is a good example of the benefits that can be achieved through a Mine to Process optimization project when mine conditions and ore mineralogy worsens and profitability decreases. Before implementation, mine production could not meet plant capacity due to the high stripping ratio and the limited mining fleet available. The process plant faced difficulties in maintaining grade and recovery as the ore mineralogy changed from predominantly hematite to a higher magnetite content. Therefore, the focus of the project was to increase mine productivity, reduce costs in both mine and plant, and increase recovery as the ore properties changed whilst achieving product quality specifications.

2 METHODOLOGY

2.1 Mine to Process Optimization

The aim of a Mine to Process optimization concept is to optimize the entire operation, mine and plant, with respect to the overall business. Quite often the aim is to increase throughput, which can be achieved simply by optimizing blasting energy according to the different types of ore and downstream processes. This is well recognized within the industry. Unfortunately, the idea that increasing explosive consumption results in optimization of the entire value chain (mining and processing) is an over-simplification of the concept. This over-simplification is still often referred to as “Mine to Mill”. However, for true optimization, blast intensity is not necessarily increased, but is adjusted to best suit the different types of ores and the downstream processes, circuit flowsheet, types and sizes of comminution and classification equipment, installed power and final product specifications. It is a fully integrated effort involving optimization in the mine, comminution and separation processes tailored to the operation and key business drivers.

Mine to Process optimization projects usually commence with an initial site visit and scoping study. The purpose is to conduct a preliminary assessment to identify potential optimization opportunities and prepare a detailed project plan off site. The Hatch team then returns for the benchmarking and full mine and plant survey. Hatch and the client conduct audits of current drill and blast practices, surveys of comminution and processing in order to collect data regarding the performance of the overall operation.

Several drill and blast audits of ore and waste blast polygons are conducted, and samples are collected at various levels in the pit to determine rock strength for ore characterization. Photos of muck piles and exposed bench faces are taken to assess blast fragmentation and in-situ rock structure and a full plant survey is conducted. In the study case, this included primary crushing, grinding, medium and high intensity magnetic separation, the hematite and apatite flotation circuits. Additional samples were also collected for breakage characterization (SMC, drop weight tests, Bond work index and point load tests). Batch flotation tests which are required for model development were also completed.

Existing and newly collected ore characterization data are used to map the range of ore properties across the deposit and define domains for blastability. Site-specific models of blasting, comminution, and concentration are developed using all the audit and survey data, laboratory tests, historical operating data and Hatch's extensive database. These models are then used together to conduct simulations and develop integrated operating strategies according to project main objectives. For the case study magnetic separation and flotation models were developed, and operating strategies devised to increase production while minimizing cost and maximizing profitability of the overall operation (mine and plant).

The impact of different blast designs for each blasting domain and the subsequent impact on downstream processes is evaluated using simulations. Tailored blast designs are specified according to blast domain (defined by rock structure and strength). These blasting guidelines provide optimized Run-of-Mine (ROM) fragmentation for downstream processes while minimizing costs. More blasting energy is applied in harder and blockier domains, and less energy in softer and more fragmented domains. Simulations are also conducted to evaluate different operating strategies and conditions in the comminution, and downstream concentration stages taking into account the proposed changes to blasting. This is used in combination with trend and variability analysis of historical operating data, plant capacity test results, power calculations and benchmarking to determine the bottlenecks and constraints in the current circuits and identify opportunities for cost reduction.

3 MINING

3.1 Optimizing Blast Design

Mining costs at the site being described have escalated due to a significant increase in stripping ratio, but the comminution equipment was underutilized. Decreasing blasting intensity in waste blasts, and in ore blasts with softer and more fragmented ore types to reduce drill and blasting costs and increase mine production rates was considered a potential solution.

Blasting performance (fragmentation) is impacted by geotechnical properties (rock structure and strength) as well as blast design parameters. The Hatch blast fragmentation model is sensitive to both rock mass and design properties and can be used to optimize the blast design for different ore types.

The model was calibrated using the rock mass characterization data, blast design parameters and measured fragmentation (using image analysis) from the audited blasts. The calibrated model was validated with the audit conditions for the full particle size distribution (coarse, intermediate and fines).

To optimize blast design and energy according to ore types, it is necessary to understand the geotechnical properties of the rock mass and how they are distributed through the deposit. Energy and gases from blasting tend to detach the rock along natural fractures. Thus, the in-situ rock structure generally controls the coarse end of the blast fragmentation size distribution. The rock strength (hardness of the rock matrix) affects the generation of fines in blasting.

Rock strength and structure data already existed at site from their structural and geotechnical testing program. However, the available data was oriented to pit wall stability and risk assessment for possible faults and slides. Consequently, the focus was on the larger fractures and discontinuities that affect stability. Inevitably, this scale overlooks smaller discontinuities of relevance to blast fragmentation. Hatch conducted additional rock structure and strength measurements to complement the existing data.

Rock strength is a measure of the hardness of the rock matrix and can be measured with laboratory tests such as Point Load Index (PLI), JK Drop Weight test parameters

(A, b, ta), and SMC Drop Weight Index (DWi). The Unconfined Compressive Strength (UCS) is a common measure of strength and can be estimated from PLI to reduce laboratory testing costs. Rock structure is determined by the in-situ joints and fractures and can be estimated with rock quality designation (RQD), fracture frequency, and joint mapping.

Samples were collected for point load testing to estimate UCS for rock strength, and stereo photos were taken in the pit for SirovisionTM analysis of rock structure. The SirovisionTM system uses the photo pairs and survey data to create 3D images of the face. Hatch specialists use these images to map structures on the bench face. The dip, dip direction, length and spacing of the joint sets are outputs of the analysis. Joint sets are identified and a distribution spacing is calculated for each joint set. This analysis quantifies the joint spacing and discontinuities in the rock face and can be used to estimate in-situ block size. Figure 1 shows an example of the bench face image before and after mapping the joints and fractures. The associated Stereonet plot and set spacing distribution is also included in Figure 1.

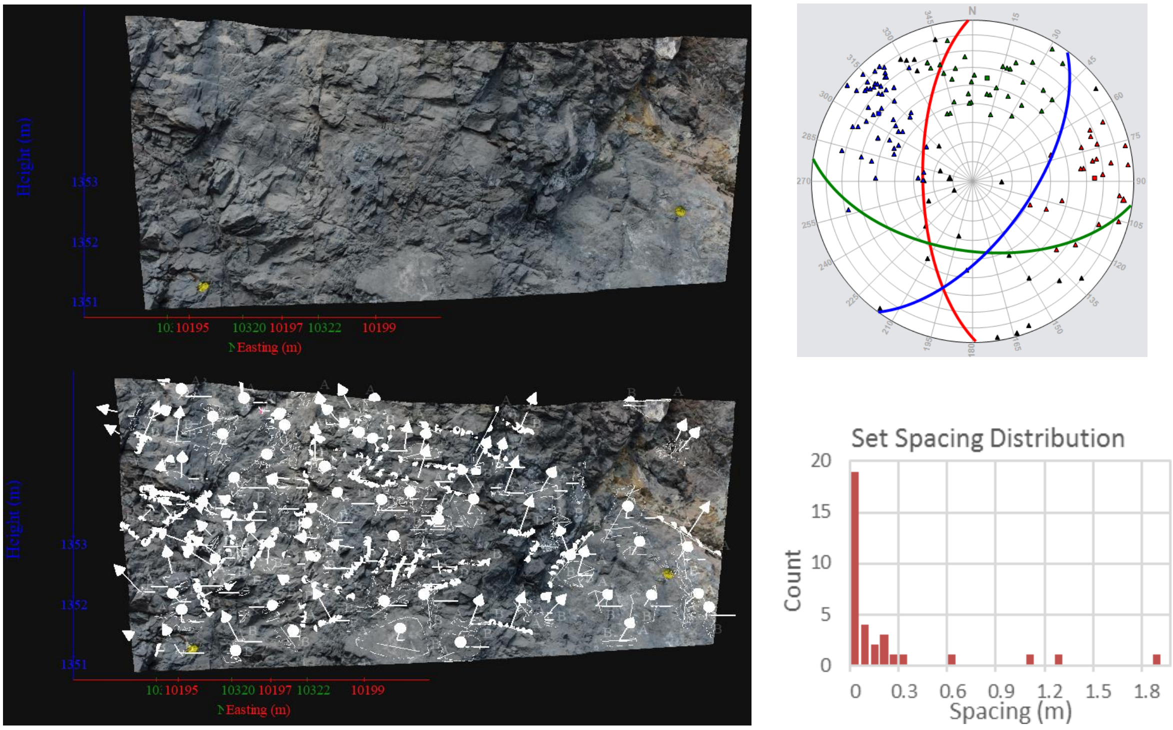


Figure 1. Analysis of Rock Structure

Ore domains were defined based on existing data plus the additional rock strength and structure measurements. Waste domains were also defined for cost reduction purposes. They have a similar structure to the ore domains but with lower values for strength categories. Both ore and waste domains are shown in Figure 2.

Simulations were conducted using the calibrated Hatch blast fragmentation model to determine the effect of changes to blast design parameters (including burden, spacing, stemming length, sub-drill, explosive type and drill diameter) on ROM fragmentation. Additional simulations were then conducted to customize the blast design for the characteristics of each ore and waste domain.

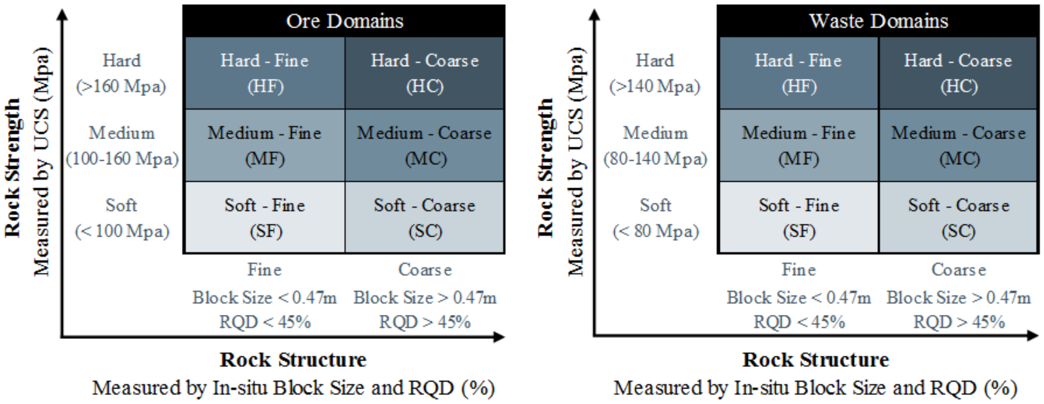
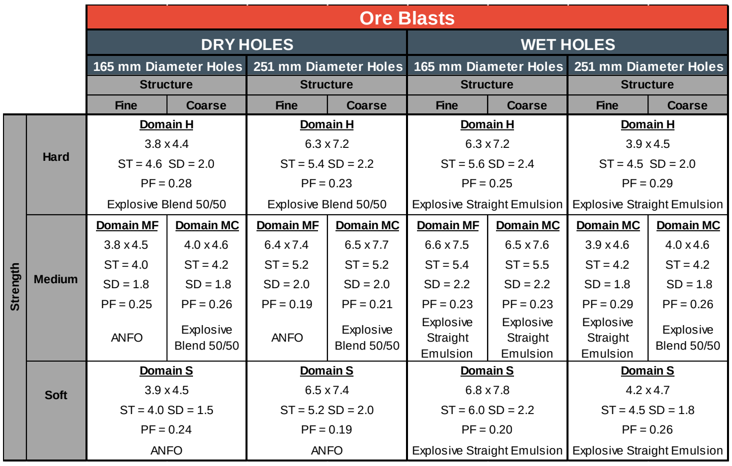


Figure 2. Definition of Ore and Waste Domains

The objective of the drill and blast assessment was to increase mine production, reduce costs and utilize the available comminution capacity better. Therefore, the blast pattern was adjusted to reduce blast intensity where possible, while still producing adequate fragmentation results. The reduction in drill and blast costs should help counter the high stripping ratio required for the remaining life of mine. Most of the proposed blast designs have reduced powder factors compared to the previous blast designs. In these cases, the sub-drill and stemming lengths were decreased for cost reduction and improved fragmentation in the top collar area. All explosives available onsite were evaluated, and appropriate explosives chosen in each case according to rock mass characteristics and conditions. The recommended blasting guidelines for ore domains for each drill diameter and for wet and dry holes are shown in Figure 3, and an example of the predicted ROM size distributions for each domain is shown in Figure 4. Some domains were grouped where blasting outcomes were similar and thus the same design could be employed.

The decreased powder factor and expanded patterns in the proposed blasting guidelines are compensated for with different explosives and combinations of different energy levels, sub-drill, and stemming length. All of these have been considered in estimating the impact of the proposed changes on overall drill and blast implementation and costs. The variation in powder factor for each domain (compared to previous practice) is shown in Figure 5. Overall, the powder factor is reduced by about 10 % and this should reduce drill and blast costs by about 12 % for ore and 6 % for waste (8 % overall).



		Ore Blasts							
		DRY HOLES				WET HOLES			
		165 mm Diameter Holes		251 mm Diameter Holes		165 mm Diameter Holes		251 mm Diameter Holes	
		Structure		Structure		Structure		Structure	
		Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse
Strength	Hard	**Domain H** 3.8 x 4.4 ST = 4.6 SD = 2.0 PF = 0.28 Explosive Blend 50/50		**Domain H** 6.3 x 7.2 ST = 5.4 SD = 2.2 PF = 0.23 Explosive Blend 50/50		**Domain H** 6.3 x 7.2 ST = 5.6 SD = 2.4 PF = 0.25 Explosive Straight Emulsion		**Domain H** 3.9 x 4.5 ST = 4.5 SD = 2.0 PF = 0.29 Explosive Straight Emulsion	
	Medium	**Domain MF** 3.8 x 4.5 ST = 4.0 SD = 1.8 PF = 0.25 ANFO	**Domain MC** 4.0 x 4.6 ST = 4.2 SD = 1.8 PF = 0.26 Explosive Blend 50/50	**Domain MF** 6.4 x 7.4 ST = 5.2 SD = 2.0 PF = 0.19 ANFO	**Domain MC** 6.5 x 7.7 ST = 5.2 SD = 2.0 PF = 0.21 Explosive Blend 50/50	**Domain MF** 6.6 x 7.5 ST = 5.4 SD = 2.2 PF = 0.23 Explosive Straight Emulsion	**Domain MC** 6.5 x 7.6 ST = 5.5 SD = 2.2 PF = 0.23 Explosive Straight Emulsion	**Domain MC** 3.9 x 4.6 ST = 4.2 SD = 1.8 PF = 0.29 Explosive Straight Emulsion	**Domain MC** 4.0 x 4.6 ST = 4.2 SD = 1.8 PF = 0.26 Explosive Blend 50/50
	Soft	**Domain S** 3.9 x 4.5 ST = 4.0 SD = 1.5 PF = 0.24 ANFO		**Domain S** 6.5 x 7.4 ST = 5.2 SD = 2.0 PF = 0.19 ANFO		**Domain S** 6.8 x 7.8 ST = 6.0 SD = 2.2 PF = 0.20 Explosive Straight Emulsion		**Domain S** 4.2 x 4.7 ST = 4.5 SD = 1.8 PF = 0.26 Explosive Straight Emulsion	

Figure 3. Blasting Guidelines for Ore Blasts

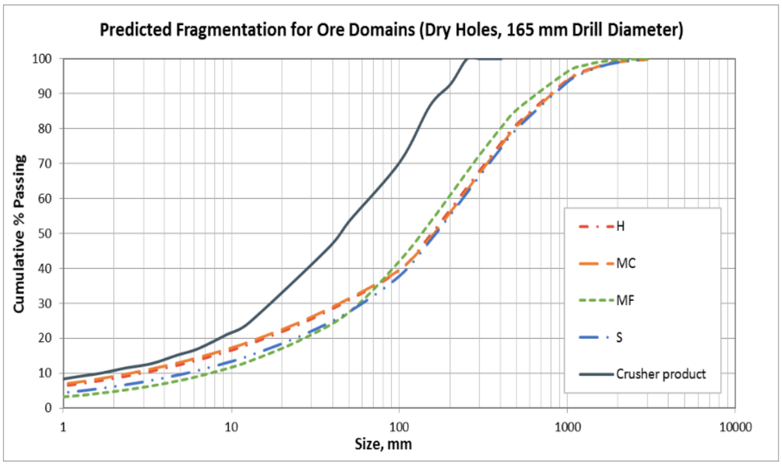


Figure 4: Predicted Fragmentation by Ore Domain for Dry Holes with 165 mm Diameter Holes

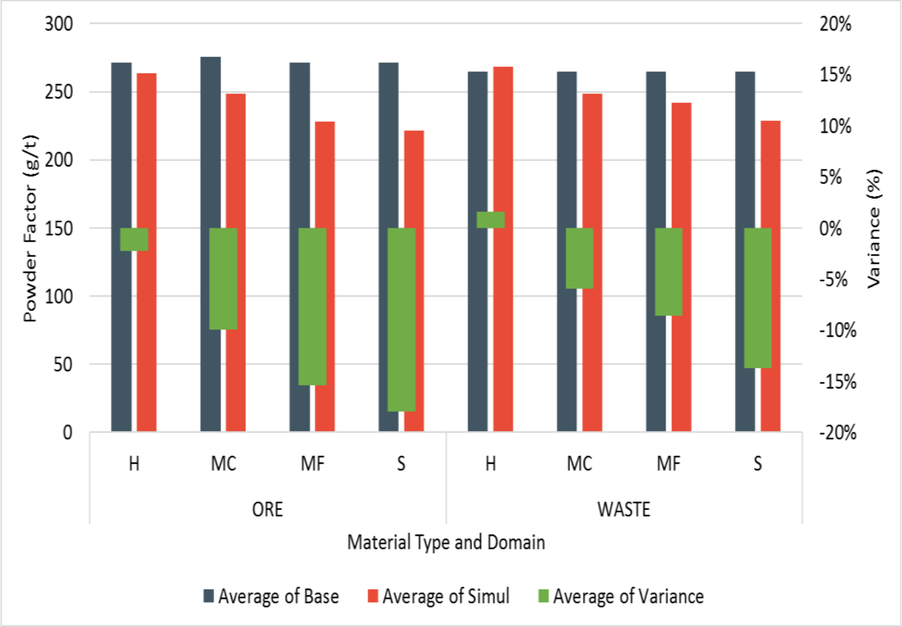


Figure 5. Variance of Powder Factor by Domain

3.2 Drill and Blast Implementation

A good blast design is only effective if accurately implemented. To be effective, Mine to Process optimization must also consider how well the optimised design is implemented.

Hatch's recommendations included appropriate drill diameter and explosive product according to the ore type and hole conditions. It was recommended that the drill bits and tools should be constantly monitored for wear, as a minor difference in drill hole diameter will drastically affect the explosive charge in the hole, and consequently will affect powder factor and the resulting fragmentation. In the case of variation in hole diameter, the explosive charge and blast geometries should be corrected to achieve the design powder factor. Explosive pumping should also commence from the bottom of the hole and the hose should be kept below the level of the explosive to prevent voids or water gaps. Hole depth and water check measurements should be performed, and the actual explosive charge should be recorded in blast reports. Periodic quality control should be performed for the VOD, viscosities, temperatures, and densities for explosive products. Any out of specification issues should be addressed with the supplier as variance in explosive properties can cause significant disturbance to the blasting fragmentation result.

The drill cuttings previously used for stemming did not provide the necessary retaining properties to confine explosive gases. Hatch recommended the use of crushed aggregate rock with a top size of about 10 – 15 % of the blast hole diameter for stemming. Stemming length can be reduced significantly if effective stemming material is used, resulting in better explosive distribution and improved fragmentation. It was also seen that the stemming did not always reach the top of the collar, which can result in flyrock, unconfinement and consequently poor fragmentation. It was recommended that when using straight emulsion, the charged holes are monitored for explosive sensitization for at least 30 minutes.

Hatch also recommended using electronic detonators for delay timing for production blasting, to take advantage of the creation of free faces in regular holes detonation sequence. Timing should be planned to provide enough burden relief for rock movement, resulting in optimum fragmentation by the creation of free faces for holes detonating in adequate sequence.

3.3 Load and Haul

Typically, load and haul are one of the most expensive activities of mining operation. An improvement in fleet performance can have a significant impact on profitability. Given the increased stripping ratio and mine production limitation, improving the load and haul productivity could have significant benefits. An important indicator of productivity is the volume or weight of material removed per unit of time. The higher the productivity, the cheaper the operation, as the use of the same equipment and resources is maximized.

Truck payload was not being measured, and trucks were observed operating with very low fill factor, where fill factor is the volume of the material occupying the tray relative to the volumetric capacity of the tray. Operating with low fill factor and consequently low truck payload reduces the load and haul productivity. The high specific gravity of the ore may contribute to this; however, it may also be because the payment for load and haul activities is based on the number of cycles completed, not the tonnes of material delivered. If this is the case, operator behaviour is focussed on delivering more cycles rather than more tonnes. More cycles can be delivered if trucks are loaded with less tonnes (shorter dig and load time, faster truck speed / cycle time, etc.) decreasing the overall tonnes delivered in a day. Therefore, Hatch strongly recommended that the payment for load and haul activities be based on the tonnes of ore and waste delivered, to encourage more productive behaviour. Delivering more tonnes per cycle and day would reduce the load and haul cost per tonne.

4 PROCESSING

Historical operating data and comprehensive surveys of comminution, magnetic separation and flotation circuits were used to evaluate their performance, identify opportunities to reduce costs, and improve efficiency. Historical data provides an indication of the range of operating variables and trends over time, whereas survey data provides more detailed information, but is a snapshot in time.

Survey data was mass balanced to identify any errors or inconsistencies in the data and calculate values of any streams that could not be sampled. The mass balance demonstrated sufficient quality for evaluation of circuit performance and development of site-specific models of the unit operations and overall process. Models were developed for each processing unit including primary crushing, grinding, magnetic separation, hematite flotation and the associated classification stages.

Primary crushing and AG mill circuit mass balance data were fitted to semi-mechanistic models in JKSimMet. These models have predictive capabilities with regards to throughput and product size distributions. Therefore, they were used to evaluate the impact of the ROM size distributions expected from the proposed changes to blasting on crushing and AG milling. They were also used to evaluate the impact of increasing throughput for each line.

Whilst JKSimMet is suitable for predicting size and throughput for comminution and classification operations, it cannot track different minerals or elements through a separation process. Limn (a Microsoft Excel add-in) was used to create an overall model for one processing line. This overall model includes water and solids flow rates, size distributions, and assay by size for Fe, FeO and P for each stream. The Limn simulation was used to evaluate the impact of blasting changes (using the results from the JKSimMet primary crusher and AG mill models) on downstream processing. Further simulations were also conducted with to evaluate opportunities to improve the performance and reduce costs.

4.1 Grinding

All the grinding mills were operating well below the installed power, suggesting excess grinding capacity is available. Similarly, both the magnetite and hematite ball mills in each line have available grinding capacity, typically operating at about 60 % of their installed power. If feed rate increases, the required grinding product size could be achieved by increasing the ball load.

4.2 Magnetic Separation

The survey showed that magnetic separators were performing well with high recoveries of Fe and FeO. In the cobbing stage, phosphorus recovery was high for coarse particles, possibly due to insufficient liberation. Each magnetic separation stage was investigated and the phosphorus recovery to iron concentrated was tracked. In the medium intensity cleaner magnetic separators, concentrate mass pull (solids and water) was very high resulting in very little upgrading. In these units, the recovery of phosphorus was over 90 % possibly due to entrainment due to high feed pulp density. It was recommended that the operators investigate increasing the dilution water to reduce the feed pulp density.

4.3 Hematite Flotation

The hematite reverse flotation circuit was also performing well, with excellent grades and recoveries seen during the survey. The main iron losses occurred in fine particles which suggests that the principal loss mechanism is by entrainment to the silicates/apatite concentrate. The rejection of phosphorus was effective, particularly in the 15 – 75 µm size range. The finer phosphorus particles were not rejected as well, possibly due to low probability of collision, while composite particles may be the cause for lower rejection in coarser particles.

Analysis of the hematite flotation kinetics indicated much lower residence time than the surveyed estimated residence time in the rougher stage to maintain high rejection of phosphorus and high recovery of iron bearing minerals for the current ore types. This suggests that the rougher stage currently has plenty of extra capacity.

4.4 Apatite Flotation

The performance of the apatite flotation circuit during the survey was poor, however, apatite recovery is not the main objective at this site. Apatite is a by-product and is only produced when apatite feed grades are high enough to produce a final concentrate containing greater than 33 % P2O5.

Batch flotation tests indicated that the flotation kinetics in the apatite flotation circuit are slow, and more phosphorus may be recovered given additional flotation time. The tests also indicated poor selectivity against iron bearing minerals. The estimated residence time for the apatite rougher stage given the survey conditions is was similar to that of the batch flotation tests and implies the rougher stage of the apatite circuit is under capacity.

5 MINE TO PROCESS INTEGRATION

5.1 Impact of Blasting Optimization on Processing

The Run-of-Mine (ROM) size distribution resulting from the proposed blasting changes is expected to be slightly coarser, but more consistent than historically observed from the current practices. Modelling of the comminution processes and analysis of historical operating data indicated that the downstream crushing and grinding circuits have plenty of installed power to treat the coarser ROM. Some examples of the comminution simulation results for different ore domains and drill hole diameters are presented in Table 1. The simulations demonstrate that there is sufficient AG mill power to treat coarser feed with only a slight coarsening of the product (AG screen undersize) 80 % passing size, T80.

Table 1 - Impact of Blasting Changes on Comminution - Simulation Results

Parameter	Survey	Simulation			
	Base Case	**MC Domain 251 drill ∅**	**SF Domain 251 drill ∅**	**MC Domain 165 drill ∅**	**MF Domain 165 drill ∅**
ROM P80 (mm)	367	424	435	486	501
Primary Crusher P80 (mm)	151.9	124.9	124.9	135.9	134.5
AG mill Load (%)	15.2	16.9	17.8	17.4	19.2
AG mill Power (kW)	3772	4025	4155	4099	4333
AG Screen Undersize T80 (mm)	0.220	0.235	0.251	0.246	0.264

5.2 Operating one less Processing Line

The option of shutting down one of the five processing lines and increasing throughput to the others for the same mine production rate was investigated and confirmed to be possible. This would provide a significant cost reduction compared to operating all five lines; labor, maintenance and power costs would be reduced.

Simulations were carried out to assess the effect of increased feed rate on AG mill performance. The typical operating range of mill filling, and power draw is illustrated in Figure 6 and compared to the survey conditions and historical data. The expected AG mill power draw at higher throughput necessary to process current mine production rate is still well below installed mill power and the filling is within the typical range for AG mills. This suggests there is sufficient AG mill capacity to treat increased throughput rates per line for ores similar to those encountered during this project.

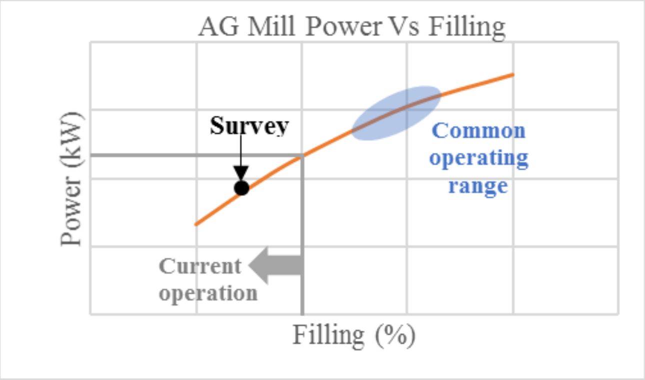


Figure 6 – AG Mill Power vs Filling

To understand the impact of increasing throughput per line on downstream processes, plant capacity tests were conducted to identify any plant bottlenecks or operating issues at throughput rates above the current values. The tests were conducted over a two-day period in one processing line at four different plant throughputs. Tests I to IV represent respectively 5 %, 10 %, 18 % and 25 % increase in the current throughput. A summary of the operating conditions and performance is provided in Table 2 and Figure 7. The phosphorus feed grade during the plant capacity tests was very high, adversely affecting the ability of the process to meet the product phosphorus specification.

Table 2 - Operating Conditions and Plant Performance During Capacity Tests

Parameter	**Installed or Target**	**Capacity Test Throughput (t/h)**				
		I	**II**	**III**	**IV**	**IV' (2nd test)**
AG Mill Power (max), MW	8	4.5	4.4	4.8	5.1	5.3
Magnetite Ball Mill Power (max), MW	4	2.2	2.2	2.4	2.1	2.4
Hematite Ball Mill Power (max), MW	0.75	0.47	0.45	0.50	0.44	0.50
AG Mill Water Addition, m^3/h		130	140	145	160	160
Fe Recovery %			82.8	83.4	83.3	
Fe Grade %	≥ 67	67.4	67.8	68.0	67.8	66.8
P Grade %	≤ 0.07	0.10	0.11	0.11	0.11	0.14

The recoveries (Fe, FeO and Magnetite) were similar in all the capacity tests; there may be a slight deterioration of product quality at highest throughput rates without some process modifications. Improvement of the process control system and adjustment of operating practices would facilitate high performance at increased throughput rates. Some pumps and launders may also need upgrading. The sump/pump which combines HGMS product and a proportion of the magnetite concentrate to feed the hematite flotation circuit could not handle the increased flow rate. Thus, a lower proportion of magnetite concentrate was treated by hematite flotation. Consequently, the final P grade increased slightly, and Fe grade decreased. It may be possible to either gravity feed some of the flow and/or upgrade the pump to allow an increased proportion of magnetite concentrate to be treated in the hematite flotation circuit at higher throughput rates. The hematite flotation has sufficient residence time, but some of the concentrate launders may need wash water addition to prevent overflowing.

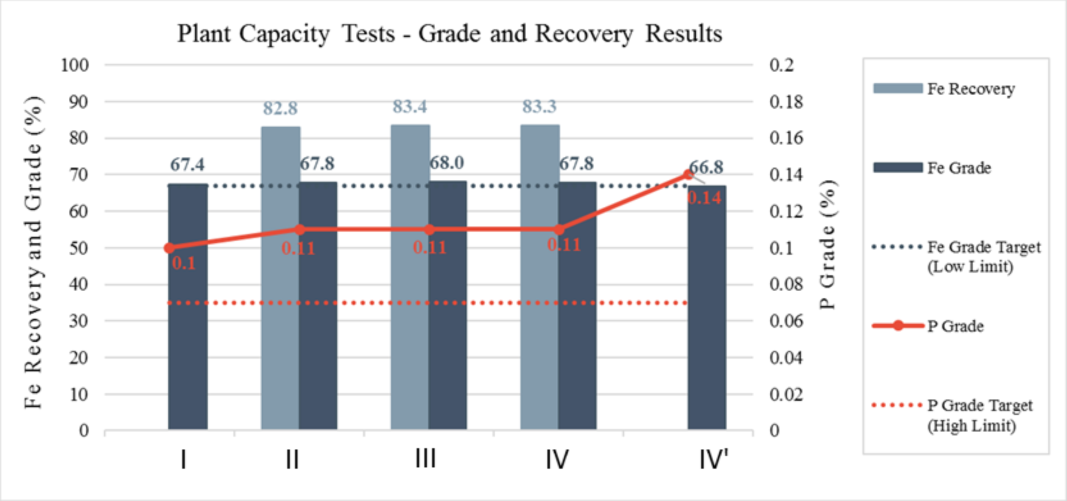


Figure 7 – Grade and Recovery Results for Plant Capacity Tests

Capacity tests indicated that current throughput could be increased 18 % per line (Test III) with only very minor issues with volumetric flows. Throughputs of up to 25 % higher than current throughput (i.e. the range investigated) could be achieved with minor modifications (better water balance control in the circuit and pulp-level control in the hematite flotation circuit).

Simulations were also conducted at increased feed rates of Tests II to IV using the Limn process model (which describes the full circuit after AG milling). The Limn model tracks assay by size for Fe, FeO and P throughout the circuit. However, the process models do not have built in capacity limitations, nor do the interconnecting streams, and hence any feed tonnage can be simulated, however large. Nevertheless, the simulation results are useful in that they indicate the likely flows of solids and water in all parts of the circuit. This information can be used for capacity calculations, such as for pump sizes, as well as for assisting in establishing the water balance. Simulations indicated that the Fe grade meets specification for throughput rates up to 25 % increase on base case throughput, but the phosphorus grade exceeds the 0.07 % limit. However, phosphorus feed grade used for these simulations (from plant capacity tests) were 0.2 % greater than that observed during the detailed survey and used for the base case simulation. This higher phosphorus feed grade for the tests at higher capacity contributed to the high P grade in the concentrate.

Historical operating and survey data, plant capacity tests and process modelling and simulations all confirmed that the phosphorus grade in the final concentrate is strongly correlated to the phosphorus feed grade. The site blends the feed to reduce instances of high P grade and this should be continued. The success of blending is limited by the ore sources available, and other strategies are required to ensure product specifications are met when there is no low phosphorus feed material available.

Options to reduce phosphorus in the concentrate were investigated by simulation. The phosphorus is mostly contained in finer particles, so increasing the amount of material treated by hematite flotation is the preferable solution as this provides effective removal of fine phosphorus. This would require upgrade of the hematite flotation feed pump and/or a gravity bypass, but the hematite flotation circuit has enough capacity.

6 CONCLUSIONS

At the iron ore mine and processing plant discussed in this paper, the aim of the Mine to Process optimization project was to reduce mining cost and increase mine productivity so as to meet installed plant capacity. Effective utilization of the overall system (mine and plant) enabled profitability to increase.

The blasting intensity was reduced in some waste and ore blasts, particularly those with softer and more fragmented ores, to reduce costs. There is sufficient comminution capacity to handle coarser feed. Thus, the tailored blast designs use expanded patterns and lower powder factor in the appropriate domains (based on rock structure and strength). Overall, the powder factor was reduced by about 10 % reducing drill and blast costs by about 12 % for ore and 6 % for waste (8 % overall). To fully maximize the benefit of these changes required accurate implementation of blast designs and definition of ore domains from ore characterization. There is also further potential to increase mine production rates and reduce operating costs by increasing the payload in haul trucks, which were observed operating with very low fill factor.

Mine production before the project was being fed to five parallel processing lines. Through the process modelling and optimization, Hatch concluded that four parallel process lines were able to handle the ore delivered by the mine at higher throughput. The labor, maintenance and power costs would be significantly reduced by the shutdown of one line. While on site, plant capacity tests were conducted by Hatch and confirmed that processing lines could be operated at recommended higher throughput for an extended period with only minor operational issues that could be easily addressed.

The structured mine to process optimization methodology identified significant opportunities to align mine and plant capacity, reduce costs and improve operating efficiency and stability to ensure product quality specifications are achieved.

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