Mine-to-Mill optimisation at Mont Wright

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ABSTRACT

In 2019, ArcelorMittal Exploitation Minière (AMEM) and Hatch conducted a Mine-to-Mill (M2M) integration and optimisation project at Mont Wright (MW) iron ore complex in Canada. The aim was to increase production with little or no capital expenditure. In 2020 and 2021, the recommendations resulting from the M2M project were implemented by MW with assistance and refinement from Hatch.

Throughout the M2M project, site-specific models of the mine and plant (blast fragmentation, crushing, grinding, gravity separation) were developed and calibrated based on historical data, and audits and surveys carried out by MW and Hatch personnel. The models were integrated and used to simulate and determine optimised strategies across the entire value chain from the mine through to the plant, to increase production while minimising overall costs. Optimisation strategies were trialled and refined during implementation, accounting for the limitations encountered in the mine and plant.

During the project, ore domains were defined based on rock structure and strength, and blasting guidelines were developed for each to improve Run-of-mine (RoM) fragmentation for production blasts across multiple pits and reduce feed variability. Crushing and grinding simulations were conducted to assess the impact of finer RoM fragmentation and to optimise operating strategies for the finer feed. Simulations indicated an expected throughput increase of 7 to 26 per cent for the different grinding lines depending on the ore domain. One of the main recommendations in the plant was conversion of Mill 7 from Autogenous (AG) to Semi-Autogenous (SAG) grinding to fully utilise the available power, capitalising on the finer fragmentation from the mine and increasing throughput.

Implementation of the new operating strategies began in late 2020, including additional ore characterisation, refinement of domain definition, establishment of updated blasting guidelines to accommodate operational constraints, and conversion of Mill 7 to SAG (12 per cent ball charge). A composite (rubber/steel) mill liner design was also investigated to allow a higher ball charge in Mill 7. Throughput improvements of up to 10 per cent (overall, for all ore types) have been achieved to date and further benefits are expected when the refinements to blasting guidelines and all recommended M2M operating strategies are fully implemented.

INTRODUCTION

The AMEM MW iron ore complex is located in Quebec, Canada. The truck and shovel open pit mining across multiple pits feeds ore to a processing plant consisting of crushing, grinding, and gravity concentration. The processing plant currently consists of two gyratory crushers, six 32-foot AG mills and one 36-foot SAG mill in closed circuit with two stages of screening. The screen undersize is processed in three stages of spiral separation: rougher, cleaner, and re-cleaner.

In 2019, AMEM and Hatch conducted a M2M integration and optimisation project at MW, aiming to increase production with little or no capital expenditure. Hatch's approach to M2M integration and optimisation involves a structured methodology involving ore characterisation, detailed audits and surveys, model development, and integrated simulations to develop optimisation strategies (Valery, Duffy and Jankovic, 2019). All components are integrated to assess the impact of changes in each area across the entire value chain. Hatch specialists have implemented this structured approach to M2M at many sites around the world to improve production and minimise overall costs (Valery and Samuel, 2012; Valery *et al*, 2016, 2018a, 2018b, 2019; Valery, Duffy and Jankovic, 2019; Valle and Duffy*,* 2014; Tokarenko *et al*, 2017; Evangelista *et al*, 2021). This methodology is tailored to each operation, accounting for the specific conditions and limitations present.

Site-specific models of the mine and plant (blasting, crushing, grinding, and gravity separation) were developed and calibrated based on historical data and surveys carried out by MW and Hatch personnel. The models were integrated and used to assess impacts and benefits downstream in the plant from changes made in the mine and determine optimised strategies from mine to plant to increase production while minimising overall costs. Ore domains were defined based on the varying ore characteristics on-site, drill and blast guidelines were developed to account for these characteristics, and recommendations were provided for adjustments in plant operating strategies to maximise production. The recommendations from this project were implemented in 2020 and 2021, resulting in increased iron ore concentrate production.

METHODOLOGY

To successfully conduct the M2M project, the entire operation was investigated to form a strong understanding of the conditions, constraints, and any potential for improvement (Duffy and Valery, 2017; Valery, Duffy and Jankovic*,* 2019). *In situ* ore characteristics such as strength, structure, and mineralogy influence the performance of blasting and downstream processing. Therefore, a strong understanding of the ore characteristics is required to determine their impact on each stage of mining and processing, and the interactions between stages.

Existing ore characterisation, mining, and processing practices were reviewed, samples were collected for characterisation and breakage testing, audits were conducted of drill and blast operations, and a full plant survey was carried out. Surveys were conducted in the plant with ore fed from audited blast polygons to form a link between the ore properties and the resulting outcomes in terms of blast fragmentation and downstream processing performance. All the collected data was used in conjunction with the historical operating data and Hatch's extensive industrial database to develop the site-specific models, which were then used in simulations to evaluate opportunities for improvements in the mine and plant.

Ore domains were defined based on the range of rock strength and structure present across the multiple pits at MW. The Hatch blast fragmentation model was calibrated to the known conditions of an audited blast and used to define optimised blast designs for each of these ore domains to improve fragmentation for downstream processes (Valery *et al,* 2007, 2001; Isokangas *et al,* 2012; Bonfils *et al,* 2021). Integrated simulations were carried out with crushing and grinding models to assess the impacts of finer RoM fragmentation and to optimise operating strategies in the plant.

RESULTS AND DISCUSSION

Ore characterisation

The existing ore characterisation at MW focused on lithological descriptions of the rock mass and was being used to develop blasting criteria to provide sufficient size reduction for loading efficiency, equipment handling, and crusher feed constraints. However, the efficiency and throughput of downstream comminution circuits can be improved by producing an optimised particle size distribution in the mine for plant feed, which depends on the operating mode of the comminution circuit (AG or SAG). The optimised RoM fragmentation for the AG and SAG mills was investigated in the M2M project, accounting for the coarse fragmentation impacting load and haul and crushing (influenced by rock structure) and the fine fragmentation impacting grinding (influenced by rock strength).

A large amount of ore characterisation data was already available, including geotechnical test results on drill core samples, joint and discontinuity mapping using photogrammetry, Point Load Testing (PLT) data, and laboratory rock strength tests including Uniaxial Compressive Strength (UCS). In terms of comminution testing, only a limited number of JK Drop Weight Testing (DWT) results were available. These comminution breakage characterisation tests are used in developing the comminution models in integrated analysis with the blast fragmentation model to optimise fragmentation.

By understanding the ore properties considering the impact of hardness in terms of not only blast fragmentation, but also comminution energy requirements, the overall operation can be optimised in terms of production while minimising overall costs. More energy is applied in harder and more structurally massive ores to alleviate the energy requirements downstream, while less blasting energy is applied in softer or more naturally fractured domains where the energy is not required for downstream performance improvements.

To assess the current conditions on-site in terms of ore characteristics, as well as to measure the specific properties encountered during the audits and surveys in the mine and plant, additional samples were collected by Hatch for testing. This included PLT to determine the Point Load Index (PLi, Is50), SMC testing to determine Drop Weight Index (DWi) and the Axb parameter, and Bond Ball Mill testing to determine the Bond Ball Work Index (BBWi). Hatch recommended that additional ore characterisation was conducted to map the deposit spatially in terms of strength and structure, at a higher resolution to inform blast design. PLT was recommended to determine rock strength, as this is a fast, low-cost method to collect a large number of samples that can be tested on-site, and correlated with other hardness and breakage parameters such as UCS and Axb. In terms of rock structure, Hatch recommended the use of photogrammetry for structural analysis, which was already implemented on-site at MW for the purposes of geotechnical stability assessments. Photogrammetric methods enable a fine resolution of structural data to be analysed, at a local level that influences coarse blast fragmentation in addition to global structural conditions impacting wall conditions and stability.

Ore domains were initially defined during the M2M project based on the range of rock strength and structure present across all ore sources at MW. These were later refined during implementation as further characterisation was conducted by MW personnel. This provided an overview of the variability in strength and structure within each active pit on-site. Rock strength and structure both varied significantly depending on region or location across the multiple pits on-site. A summary of the refined ore domain definitions in terms of strength and structure is shown in Figure 1.

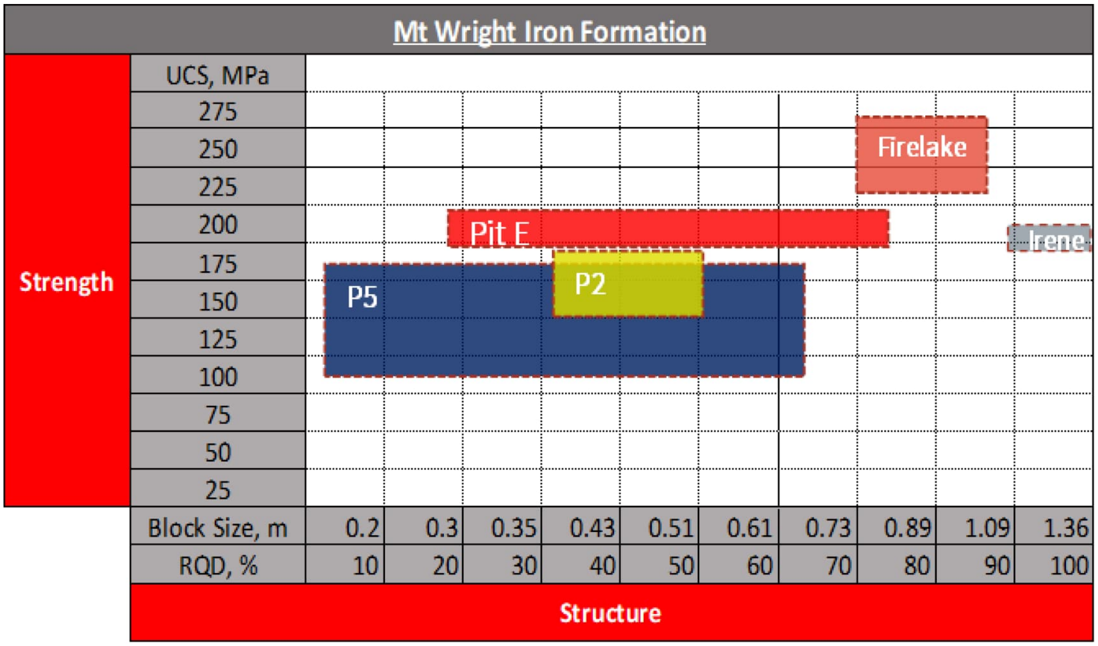

FIG 1 – Ore domain definition at Mont Wright.

Fragmentation and drill and blast optimisation

Optimisation of blasting requires accurate measurement of the resulting fragmentation. Blast fragmentation was measured using image analysis with SPLIT Desktop^{TM} (Split) of photos collected at post blast muck piles, as well as trucks dumping RoM ore to the primary crushers. All image analysis systems used for measuring fragmentation cannot accurately measure fines content (-10 mm), as this material is often below the surface of muck piles, and is too small to be defined accurately by software delineation in the analysis. To overcome this, Hatch and MW conducted a calibration of the fines using sieved material from a primary crusher product belt cut sample. As the primary crusher acts mostly on the coarse particles in the feed, the content of fines in the primary crusher product provides a good indication of the fines generated during blasting.

A large degree of blast fragmentation variability was observed across all MW pits from the calibrated fragmentation measurements. The mean fragmentation for the trucks dumping RoM ore to the primary crusher during the survey, as well as the envelope describing the variability in fragmentation for the audit is shown in Figure 2. This fragmentation analysis was conducted on a representative sample of trucks dumping to the crusher, however for this small subset of all trucks loaded from the audited blast polygon, variations in the blast 80 per cent passing size (P80) and fines content (-10 mm) of up to 300 mm and over 20 per cent respectively were observed. This indicated the potential to improve downstream performance and stability by tailoring the blast design to both the strength and structure of the ore. With the application of different blast intensities for each domain according to the *in situ* characteristics, the variation in resulting fragmentation can be minimised.

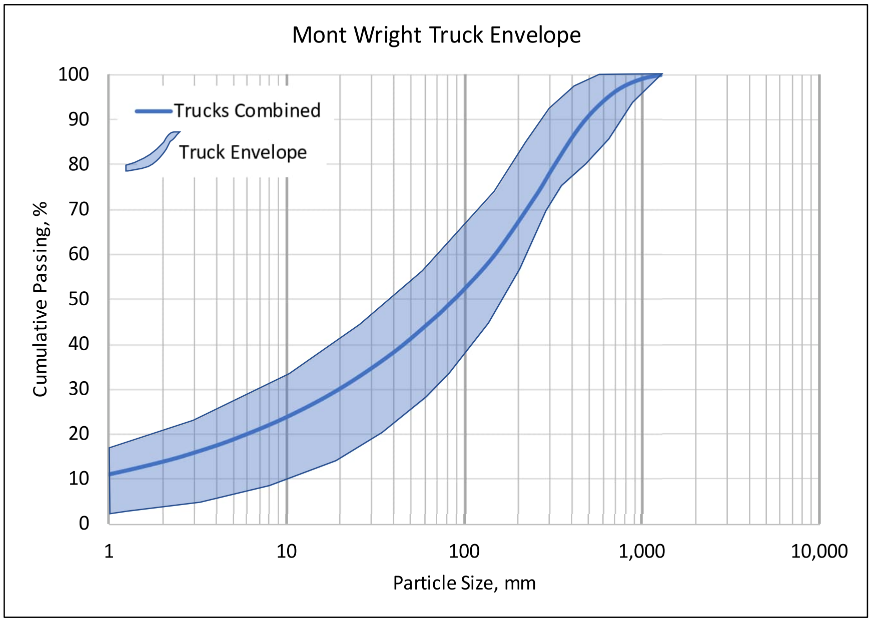

FIG 2 – Mean fragmentation and envelope of variability for trucks dumping to the primary crusher.

This measured fragmentation was used to calibrate the blast fragmentation model, alongside the measured ore characteristics and audited blast polygon conditions. The Hatch Blast Fragmentation Model is sensitive to the ore characteristics and their variability, explosive properties and performance, and blast design and implementation. Following model calibration, base cases were developed for each of the defined ore domains, based on the typical blasting practices on-site at the time. The blast fragmentation model was then used to simulate changes in blast design for each ore domain and determine optimum fragmentation for each of the different ore types.

The optimised blast guidelines developed and proposed for MW specify an appropriate level of blast energy for each ore type, with more energy applied in the harder and blockier domains, and less energy in the softer, more naturally jointed and fractured domains. A summary of the improved fragmentation from the initial blast guidelines for each domain in comparison to the audited base case RoM fragmentation is shown in Figure 3.

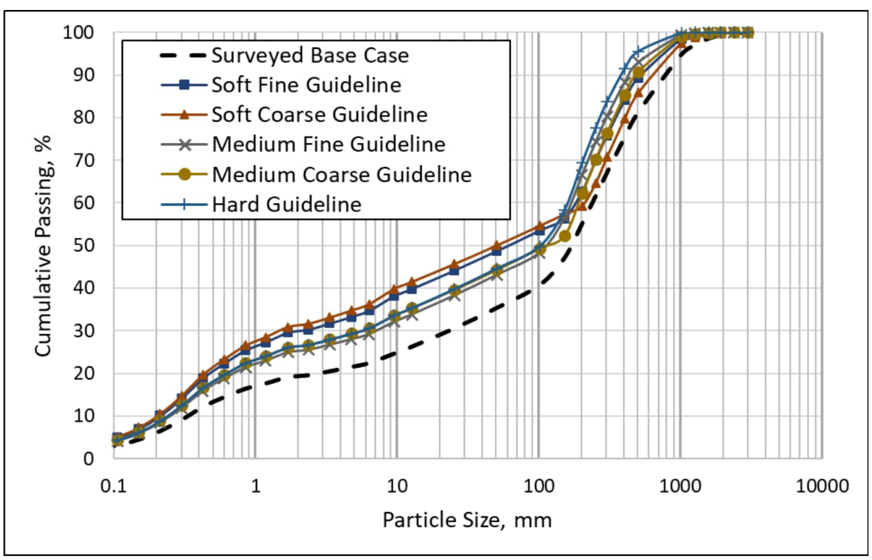

FIG 3 – Comparison of base case blast fragmentation with guideline blast fragmentation in each domain.

By applying the required blast energy to each domain, fragmentation variability can be reduced, and downstream processing performance improved. This can be carried out while avoiding excessive costs and potential damage in the mine that could occur by indiscriminately increasing blast intensity across the entire operation. Blast intensity was increased using a combination of increasing charge length with a reduction in stemming length, as well as tightening the drilling pattern.

The blast model was further validated and updated during implementation of recommendations and optimisation strategies in 2021. An example of the measured fragmentation for one of the audited trial blasts during implementation compared with the simulated fragmentation is provided in Figure 4. The validation blasts showed a good match between the simulated and measured fragmentation, however some inconsistency was observed in the coarse fragmentation and top-size. The measured fragmentation for some trial blasts was finer than the predicted fragmentation from the model simulations. This was most likely due to the very good implementation practices on-site, as well as more limited variability in rock structure than initially modelled.

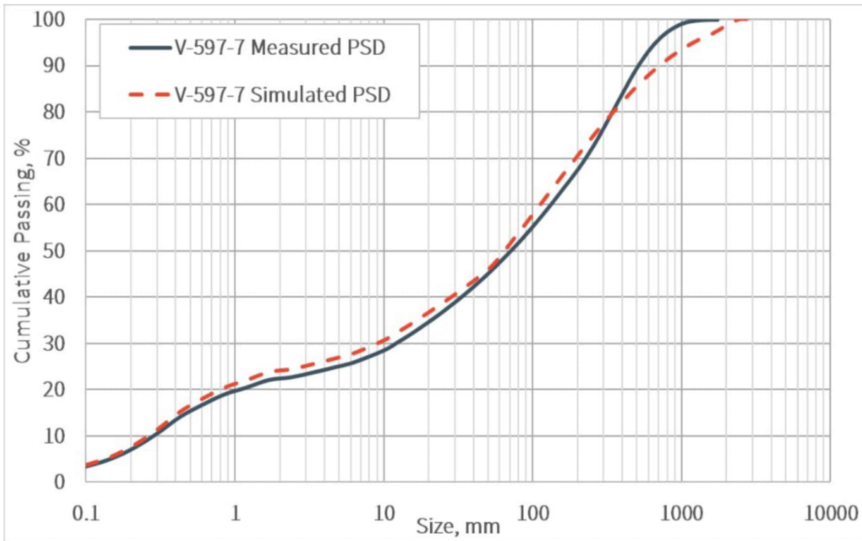

FIG 4 – Comparison of measured and simulated fragmentation for guideline trial blast.

During implementation, limitations in the mine were encountered, including minimum drilling spacing to enable safe and effective manoeuvring of drill rigs and explosive loading equipment. For each of the three typical drill diameters used on-site for production blasting (203 mm, 254 mm, 349 mm), a different limit in terms of burden and spacing was applicable. These constraints were accounted for in updated and refined blasting guidelines, and as a result, the blast intensity that could be implemented in each domain had to be adjusted.

During the M2M project, the base case blast intensity in terms of powder factor was approximately 1.0 kg/m^3. Following the initial M2M project, blast intensities varied across the defined ore domains in the range of around 1.0 to 2.2 kg/m^3 depending on the strength and structure of each domain. Following the trial blasts and identification of the drilling limitations, the updated guidelines for the refined ore domains had a range of powder factor between 1.1 and 1.8 kg/m^3. The limitations resulted in a decrease in the maximum blast intensity that was able to be safely and consistently implemented. However, following the validation trial blasts, it was found that significant improvements in fragmentation could still be gained with the refined blast guidelines.

Integration and process optimisation

For process optimisation, AG and SAG milling each benefit from a different feed size distribution, and so the ideal feed conditions will be dependent on the operation of the grinding circuits. However, both methods of comminution benefit from an increase in the content of -10 mm fine material. To determine the optimum feed size distribution for each mode of operation, site-specific models of crushing, grinding, and gravity concentration were developed from detailed plant surveys and historical data. JKSimMet was used to develop mechanistic models using machine parameters and ore properties, and calibrated to the measured survey data collected during the M2M project. These were integrated with the blast fragmentation model to identify opportunities for optimisation in the plant. Crushing and grinding simulations were carried out to assess the impacts of finer RoM fragmentation and to optimise operating strategies for this feed.

With the implementation of blasting guidelines and the finer RoM feed, throughput was simulated to increase in the range of 0–8 per cent depending on the ore domain, with greater benefits simulated in the harder and more structurally massive domains. The finer RoM fragmentation from the implementation of the blasting guidelines would also allow the primary crusher to be operated with a finer gap setting to provide a finer mill feed, further increasing mill throughput. Simulations indicated the finer mill feed would further increase throughput by about 2–5 per cent. The increase in throughput is dependent on which ore domain is being fed, and to which grinding line/mill. The plant during the M2M project was arranged in seven parallel lines, with Lines 1 to 6 each consisting of a 32-foot AG mill in closed circuit with two stages of screening, treating around 1200 t/h of primary crusher product. Line 7 consists of a 36-foot AG mill with the same screening arrangement, treating around 2800–3200 t/h.

Historical operating data was provided for analysis during the M2M project, and the typical power draw for Mill 7 for the period from October 2018 to February 2019 is shown in Figure 5. It can be seen that the installed power (14.9 MW) was being reached less than 1 per cent of the time. At the time, all mills were operating fully autogenously, and mill power was not being fully utilised in Line 7 and Line 4.

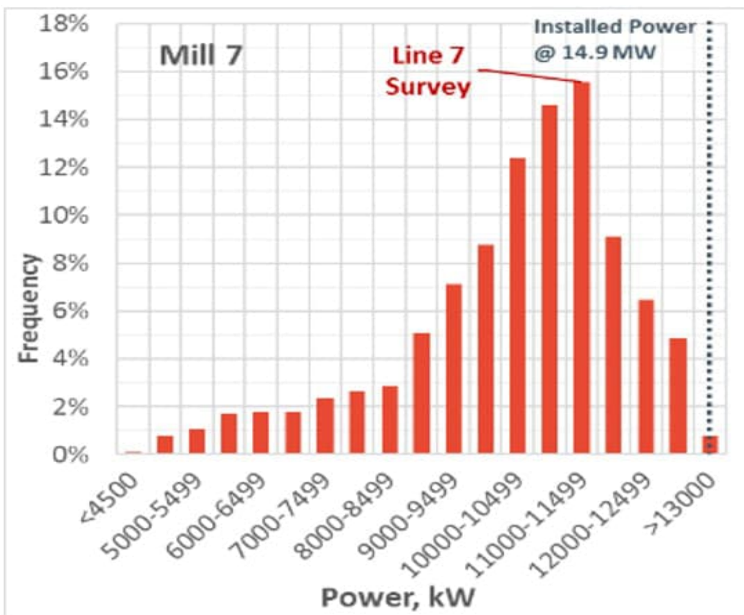

FIG 5 – Power draw in Mill 7 (AG) for October 2018 to February 2019.

The grinding lines were near the limit of achievable power consumption in AG operation, and to utilise the available power, grinding media was required. To achieve greater increases in throughput without significant capital expenditure, Hatch recommended that AMEM convert the current AG mills with available power to SAG mill operation to fully utilise the available power. Power calculations indicated that 15 per cent balls could be added to Mill 7, and 10 per cent added to Mill 4, based on the available installed power. Additionally, it is critical sized material (in the size range of 40–60 mm) that builds up in the mill load and limits the throughput in SAG and AG mills. For MW, further size reduction of this critical size material was best achieved by means introducing steel grinding media.

While AG mills require a different feed size distribution to SAG mills to maximise throughput, both modes of operation benefit from the increased production of fines (-10 mm) by the drill and blast optimisation and recommended drill and blast guidelines (Kanchibotla *et al,* 1998; Kanchibotla, Valery Jnr and Morrell, 1999; Grundstrom *et al*, 2001; Valery *et al*, 2007: Valery, Duffy and Jankovic, 2019). Following the update of the blasting guidelines, integrated blasting, crushing, and grinding simulations estimated throughput increases of 7 to 26 per cent for the different grinding lines depending on the different ore types. A summary of the simulated increase in throughput for Line 7 for each domain, depending on the implementation of recommendations in shown in Figure 6.

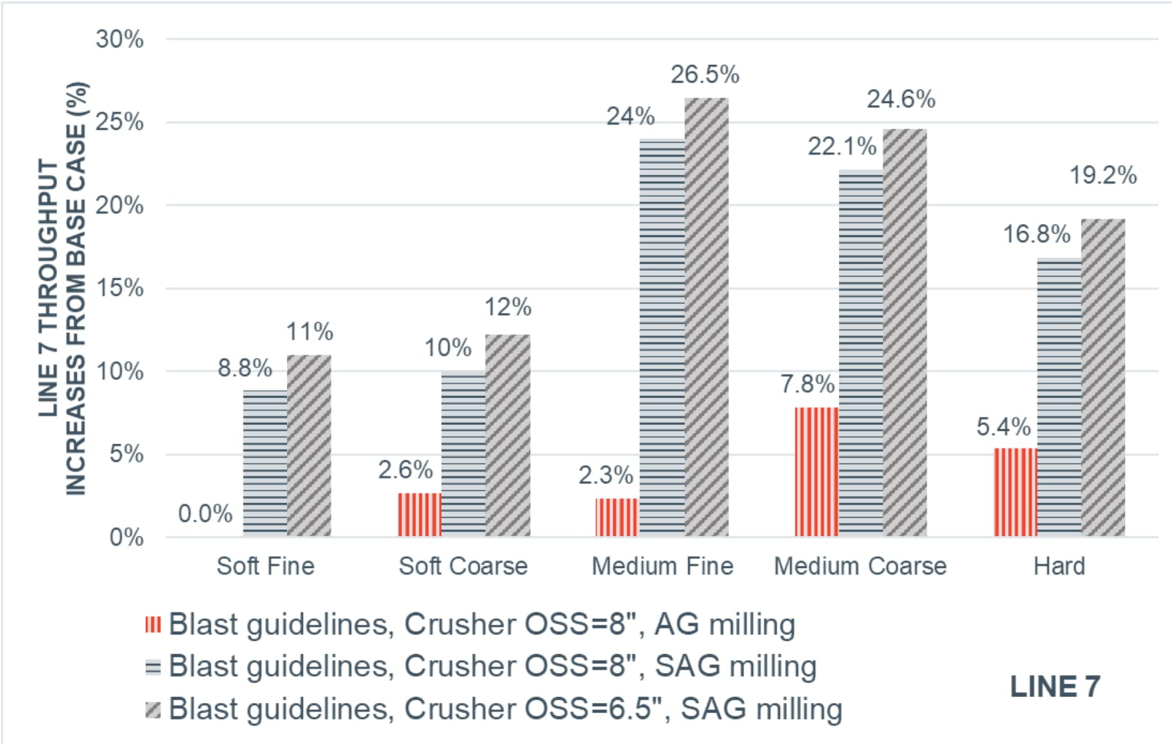

FIG 6 – Simulated increase in throughput for Line 7 depending on ore domain and change in operation.

Throughput improvements for each line were calculated on a weighted average basis, accounting for the proportion of feed in each of the defined ore domains. For Lines 1–6, a throughput increase of almost 5 per cent was simulated for the finer mill feed resulting from implementation of blasting guidelines and tighter primary crusher gap. For Line 7, the finer mill feed should increase throughput by about 6 per cent, with AG to SAG conversion providing an additional 14 per cent increase in throughput.

In late 2020, Line 7 was successfully converted to SAG milling with 12 per cent ball charge resulting in an increase in throughput of about 10 per cent. A higher ball charge of 15 per cent was originally recommended but could not be achieved due to the mill weight causing the bearing pressure limitation to be exceeded. Therefore, an alternative composite liner design has been investigated for Line 7 to reduce the mass of the liners compared to existing steel liners. The reduction in liner weight will enable ball charge to be increased to the recommended 15 per cent making use of available power without exceeding bearing pressure constraints and further increasing throughput.

Line 4 is currently still operating as an AG mill but will be converted to SAG milling in 2022 following adjustment of the liner design to suit SAG mill mode of operation.

CONCLUSIONS AND ONGOING WORK

The M2M optimisation project identified integrated strategies in the mine and plant to increase throughput by 7 to 26 per cent (depending on the processing lines and ore types) with minimal capital expenditure. Implementation of the recommended operating strategies started in late 2020, including further ore characterisation, refinement of ore characterisation and definition of domains, adjustment of blasting guidelines, and conversion of Line 7 to SAG (with 12 per cent ball charge). Throughput increases of up to 10 per cent overall, for all ore types, have been achieved to date and further benefits are expected when the refined blasting guidelines and all recommended operating strategies are fully implemented.

As an extension of the M2M optimisation, a throughput forecast has also been developed, integrating the ore properties, mine plan and schedule, blast fragmentation and comminution models. This model will be used to accurately predict future throughput, provide advance notice of the impact of changes in ore characteristics, and assist with strategic long-term planning.

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