Throughput forecast modelling over the Life-of-Mine

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ABSTRACT

Hatch has developed forecast models for predicting Life-of-Mine (LOM) circuit throughput for a number of operations worldwide. These models can be used to predict variations in future operating throughput arising from changes in ore characteristics, mine planning, blending strategies, and operating strategies, thereby improving process stability and helping to maximise profit over the LOM. In this paper, Hatch shares three case studies of throughput forecast modelling and discusses the main results, model precision, and associated challenges with the methodology, and provides a comparison of predicted plant performance with operational data.

Hatch's forecasting methodology considers the effect of ore characteristics and blast fragmentation on the entire feed particle size distribution (PSD) to the comminution circuits. Site-specific Morrell power-based models are also used to capture the key factors contributing to plant throughput. These include the proportion of each ore type in the feed blend, the characteristics of each ore type (hardness and breakage characteristics), product size targets, and equipment specifications.

Data is then collected (often during Mine-to-Mill (M2M) optimisation projects) and used to validate the power-based throughput forecast model against historical observed ore hardness and plant throughput. Outputs from site geological and geotechnical/geometallurgical block models, such as the distribution of the various ore types and their hardness, plus mine planning information are then used to predict the throughput on an annual basis over the LOM. The power-based equations that predict comminution circuit specific energy are also tuned to reflect the recommended mine and plant optimisation strategies, thus the model can reflect not only current practices, but also be used to investigate potential optimisation opportunities.

INTRODUCTION

In any operation, a certain level of variability in plant throughput is inevitable. Changes in the in-situ ore characteristics (strength and structure) associated with different ore types or domains yield different run-of-mine (ROM) PSDs under a given set of drill and blast parameters. Changes in the hardness and breakage characteristics provide an additional source of variability once the ore reaches the plant. Differences in mineralogy and liberation characteristics may also necessitate changes in the target grind size to maintain the performance of downstream separation processes, adding yet another layer of complexity. The ability to anticipate and control the resulting variation in throughput is critical to achieving consistent, stable operation, which is a necessary precondition for process optimisation and maximising profit over the LOM.

Members of Hatch's Mining and Minerals Processing group have developed throughput forecast models to predict LOM circuit throughput for several operations globally [see Bennet et al (2017), Burger et al. (2006), and Farmer et al (2021)] using a methodology based on established power-based approaches, and incorporating site-specific factors and constraints. These models consider the proportion of the different ore types present in the feed blend, and where available leverage detailed ROM fragmentation models to link the blend composition to the feed size seen by the plant. Combined with ore hardness data and inputs for available comminution power and target grind size, conventional power-based models can be applied to predict the LOM throughput. With many mining companies having invested significant effort in recent decades into the development of detailed geometallurgical models, which integrate geological, mining, and processing aspects (Alruiz et al., 2009), many of the required inputs can now be sourced from the one location.

Hatch's methodology is described in detail in the section that follows, with three case studies provided thereafter. While the use of similar models has been described elsewhere [Misle et al. (2013), and Farmer et al. (2021)], the case studies in this paper are intended to provide examples of the sort of challenges which can be encountered when applying this methodology – and the approaches needed to overcome them – as well as the flexibility of the methodology to consider future circuit changes.

METHDOLOGY OVERVIEW

At its core, Hatch's approach to throughput forecasting involves the application of power-based methods to determine the achievable throughput over the LOM, considering the available grinding power. The methodology for determining the total circuit specific energy, and the specific energy of the AG/SAG mill – proposed by Morrell (2004a and 2004b) and accepted as industry standard (Global Mining Guidelines Group, 2021) – is used to calculate the throughput over a given period, with the final forecast and the limiting grinding stage determined based on the lower of the two values. The key equations for total and SAG/AG specific energy are as follows:

$$Morrell\,Total\,Specific\,Energy\left(\frac{kWh}{t}\right) = 4M_{ia}\left(750^{f(750)} - F_{80}^{f(F_{80})}\right) + 4M_{ib}\left(P_{80}^{f(P_{80})} - 750^{f(750)}\right) \quad \textbf{– Eqn. 1}$$

$$SAG/AG\;Specific\,Energy\left(\frac{kWh}{t}\right) = K \times F_{80}{}^{a} \times DWi^{b} \quad \textbf{– Eqn. 2}$$

Where:

- Mia – coarse grinding work index (kWh/t)
- Mib – fine grinding work index (kWh/t)
- F80 – 80% passing size (µm) of the grinding circuit feed
- P80 – 80% passing size (µm) of the grinding circuit product
- f(x) – defined functions of F80 and P80, as per Morrell (2004)
- DWi – drop weight index (kWh/m^3) of the ore
- K, a & b – site-specific factors, calibrated to production data

Much of the value of Hatch's approach, however, comes from combining data from typically available sources (the LOM plan or geometallurgical model) and other models (blast fragmentation models and mechanistic process models) to best define the inputs to the power-based model, and to augment it where the impact of certain changes cannot be accurately captured by power-based approaches alone.

When developing a throughput forecast model, Hatch typically draws upon the LOM plan or geometallurgical model to provide the proportion of feed ore originating from the various ore sources or defined domains over time. The LOM plan or geometallurgical model will also contain data for the typical indicators of comminution characteristics (e.g. DWi, Axb, BBWi, Mia, Mib) for each of the ore sources, with the level of definition dependent on the maturity of the geometallurgical program at a particular site.

The proportion of the different ore types and DWi (or an equivalent parameter, from which DWi can be determined) in the LOM plan allows for a weighted average AG/SAG specific energy to be calculated for a given period. Similarly, the information within the LOM plan can be used to calculate the total specific energy via the Morrell method, provided a given feed size (F80) and product size (P80). While product size is a process target informed by the mineralogical and liberation characteristics of a given ore, feed size is often less well understood, particularly insofar as how it is influenced by drill & blast practices and in-situ ore characteristics. Defining the F80 is critical for any power-based throughput forecasting, and it is here where detailed ROM fragmentation modelling is particularly useful, such as that completed by Hatch during a M2M study.

In a M2M study, blast domains are defined based on the in-situ characteristics of the ore, specifically its structure (typically measured in terms of in-situ block size) and strength (unconfined compressive strength, determined via point load testing). These two parameters respectively dictate the coarse and fine end of the ROM PSD under a given set of blast conditions. Defining these domains and conducting a controlled blast audit provides the basis for developing ROM fragmentation models, which are then used to establish drill & blast guidelines for each domain. The ultimate objective of these guidelines is to provide a ROM PSD which maximises plant throughput, while avoiding indiscriminate or unilateral increases in drill & blast cost. More energy is typically applied to harder and less naturally fractured domains, while less energy is applied in softer or more fractured domains where it is not required. The detailed fragmentation models and simulations used in a M2M study to identify the optimal blast design provide a link between ore characteristics, drill and blast practices, and ROM fragmentation, which can be captured and integrated into a forecast model. Within the forecast model this takes the form of a family of functions which together describe the ROM F80 in terms of drill diameter and powder factor for each of the different domains. The SAG/AG F80 can then be estimated in turn, based on tuned mechanistic models of the crushing stage.

Where a M2M project has not been completed, and no blast fragmentation model is therefore available, an alternative approach is required. In that scenario, data from online camera systems (e.g. *Ore3D*® or *Split Online*®) is often used to derive general relationships between SAG/AG feed F80 and blend composition.

Once the expected F80 is determined, the total and AG/SAG specific energy is then calculated, using Equations 1 and 2. Throughput is then calculated based on the AG/SAG and total specific energies, and the grinding power available in the AG/SAG mill and the overall circuit. By comparing the two throughput figures, a realistic estimate can be made, considering the “rate limiting step” in the grinding process. Extending this to a full LOM forecast, useful information is provided regarding not only throughput, but also how the limiting step may shift over time, which can assist in strategic planning for long-term plant expansions or upgrades.

For a throughput forecast prepared in conjunction with a M2M study, the same blast fragmentation models used to determine ROM F80 also provide details regarding the increase in fines generation associated with optimised blast conditions. Mechanistic models of the grinding circuit (such as those in *JKSimMet*) and analysis of historic operating data and surveys are used to estimate the throughput increase associated with these additional fines. Of course, the effect of these fines is not captured by the power-based approaches, whether that be the total specific energy method (which considers only F80 as a feed size indicator) or calculations of AG/SAG specific energy, which are tuned to historic data with the “pre-optimisation” blast conditions. When developing a throughput forecast model, Hatch incorporates the estimated impact of the added fines by applying a correction factor to the calculated throughput, linked to a toggle for the user to specify baseline or optimised blast conditions.

Where possible, validation of the increase in fines production associated with the M2M blast may help to further refine the blast model, as well as the throughput forecast. Caution should be applied, however, using online image analysis systems for this purpose, or integrating their output into the model directly. As noted by Contreras (2017), these systems are effective for measuring the F80 (at least when properly calibrated and maintained), however are often more prone to error at fine sizes.

Finally, an effective throughput forecast model needs to account for site specific factors or constraints, beyond those set by the feed conditions and installed power of the grinding circuit. Where such constraints are identified, Hatch's approach is to incorporate them into the model via "constraint ON/ OFF" toggle, allowing an immediate and flexible means by which to evaluate the benefit associated with relieving the issue or bottleneck. The case studies in this paper include an example where this approach has been applied.

CASE STUDY 1

Operation Description

The operation in Case Study 1 is an open pit copper/molybdenum operation, with the major ore minerals being chalcocite, chalcopyrite, and bornite. Ore at this site is classified into three hardness domains (soft, medium, and hard) according to Axb and BBWi values, and six geometallurgical units, referred to as UGM 1 through 6. The comminution circuit consists of three parallel grinding lines, fed by primary crushed ore. Two of the three lines feature identical SAG and secondary ball mill circuits. The third line features a larger SAG mill, with two secondary ball mills.

SAG trommel oversize from all three lines is classified over common pebble screens; undersize from those screens reports to the ball mills in the third line, while oversize is crushed. Crushed pebbles are distributed between the two smaller grinding lines in an 80/20 split, with none of the crushed pebbles reported to the larger grinding line.

Forecast Model

Hatch were engaged to complete a M2M optimisation project, and develop a throughput forecast model in parallel. Audited blasts and plant surveys were completed for the soft and medium ore types, allowing for the development of calibrated blast fragmentation models for these ores, as well as models of the crushing and grinding processes in JKSimMet. Hard ore was modelled based on the medium models, with adjustments made with reference to historical data. For the purposes of the blast fragmentation models, the soft domain was divided further into coarse and fine structural sub-domains, based on the variability in in-situ block size. Once the blast fragmentation models were developed, a range of drill and blast design conditions were simulated, with a view towards improving fragmentation in the medium and hard domains by increasing blasting intensity, while reducing operating costs and complexity in the soft domains by relaxing the blast. The prescribed blast guidelines were forecast to yield a 6% increase in fines generation in the soft fine domain, 4% in the medium domain, and 7% in the hard domain, as well as improvements at the coarse end (reduced P80 and top size). In the soft fine domain, only marginal improvement in terms of fines production was possible, however some reduction in ROM P80 was predicted. ROM fragmentation for the simulated base cases and guidelines is shown in Figure 1.

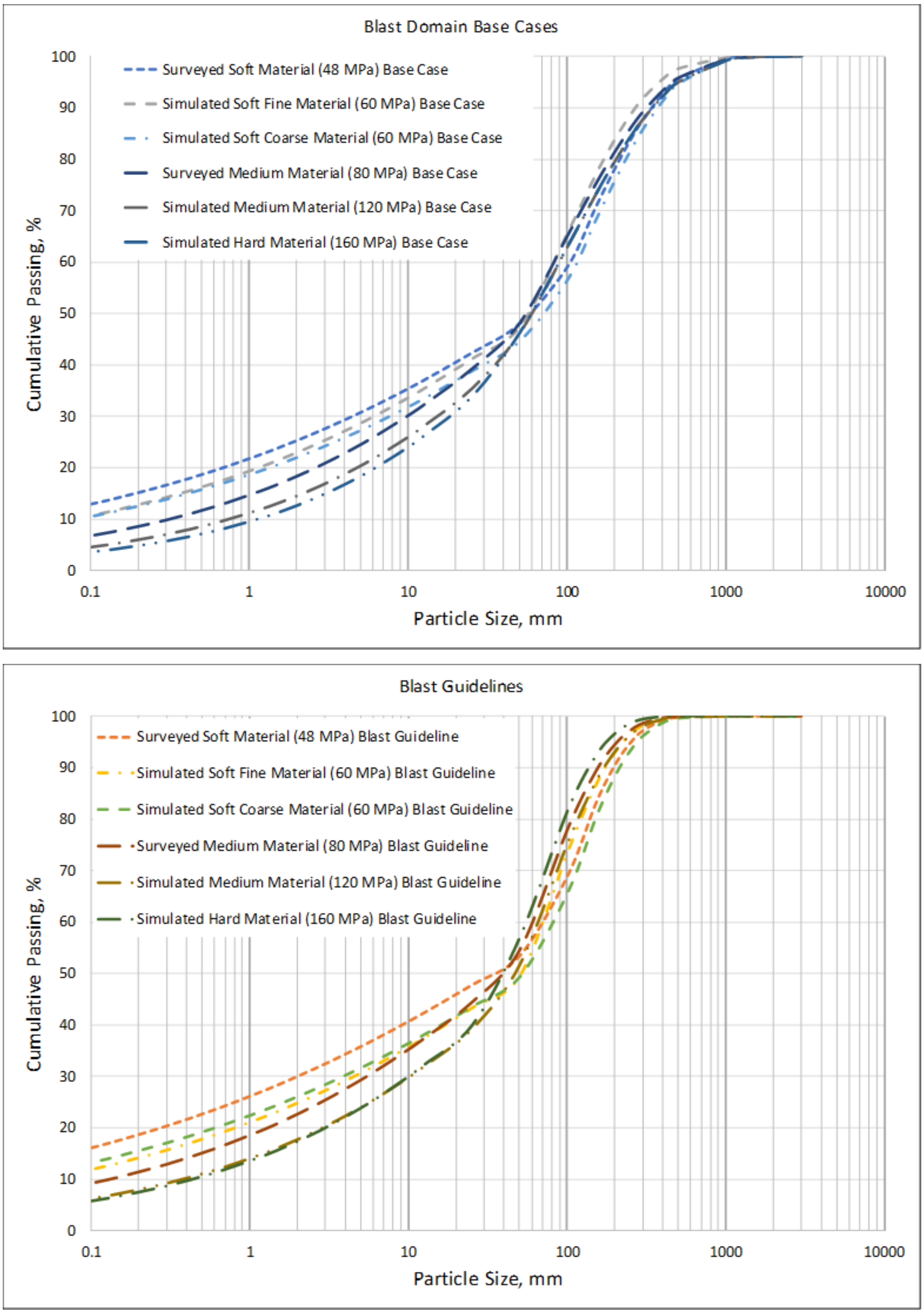

FIG 1 – ROM fragmentation for base case and optimised blast conditions in each of the blast domains defined as part of the M2M study.

Moving downstream, opportunities to optimise the crushing and grinding circuits were also identified. These included:

- improving power utilization in the two smaller SAG mills via increasing the mill speed and ball load,
- leveraging the finer ROM fragmentation from the optimised blast by tightening the primary crusher gap, thereby providing a finer SAG feed top size, and
- optimising the grate and pulp lifter designs to increase pebble production and better utilise the installed pebble crusher capacity, while simultaneously reducing the risk of slurry pooling.

The total throughput benefit of the optimised blast fragmentation and the changes in the process plant was forecast as between 10 and 12%, depending on ore type. A potential opportunity to reject barren pebbles by integrating the existing pebble screens into an ore sorting circuit – and thereby free up capacity in the milling circuit, while also improving the feed grade to the downstream separation process – was also identified for further review.

Along with the M2M study, a throughput forecast model was developed. Site had an existing model, based on the Morrell power-based equations, however an updated model was required to capture the impact of the improved blast fragmentation associated with the M2M recommendations. Input data required for the LOM forecast model was drawn from sites' existing geometallurgical model. Extensive ore characterisation – including Axb, DWi, BBWi, and UCS – sits within the geometallurgical model, allowing the development of a high-quality throughput forecast. Whereas the M2M study considered the three hardness classifications, the throughput forecast was based on the six previously mentioned geometallurgical units, which provided a higher level of definition. The modelled blasting behaviour (based on the hardness domains) was captured via a correlation between F80 and Axb, which could then be applied to the geometallurgical domains to estimate the F80 to the plant for a given blend. Figure 2 shows the annual average Axb values for each UGM over the LoM. A reasonable level of variation can be seen, with values varying between approximately 40 (moderately hard) and 100 (soft) for the most part for the period out to 2036. Testwork for ores to be processed beyond 2036 was not available at the time of the forecast being developed.

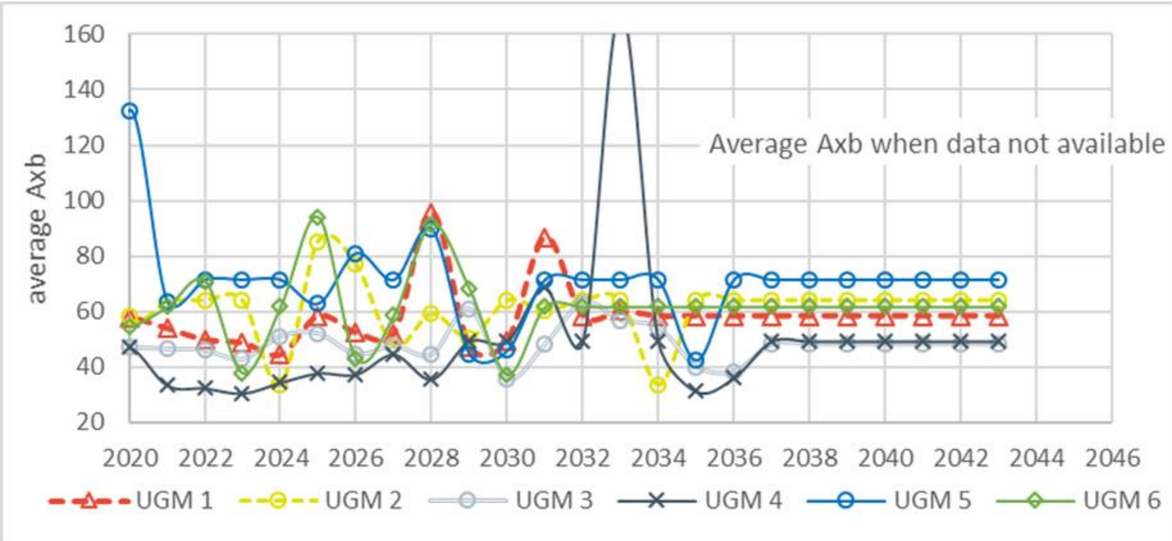

FIG 2 – Axb of the various UGMs from Case Study 1.

These data, along with the BBWi data also in the geometallurgical model, are used to calculate the Mia and Mib indices used in the Morrell specific energy calculations. Together with the estimated F80, and the user-specified grind size target, this allows the calculation of the specific energy for each UGM. It is important to note that the specific energies used for the final throughput calculations are based on a weighted average specific energy, derived from the individual specific energies calculated for each UGM. This allows for the differing F80 associated with each UGM to be accurately accounted for and avoids incorrectly averaging the non-additive Axb values. Once the weighted average specific energy is calculated, throughput is calculated based on the available grinding power in each line, and the final estimate calculated by comparison against the throughput calculated based on SAG specific energy. Calibration factors were also applied to account for differences between the lines, specifically the consistent trend of lower specific energy in Lines 1 and 2, compared with Line 3.

Finally, the model features optionality allowing the user to predict ROM fragmentation for different drill and blast scenarios, being either the base case "as is" blast design, or under conditions in line with the recommendations of the M2M study. Calculated throughput in the M2M cases is adjusted by reducing the specific energy in inverse proportion to the expected throughput gain determined from the detailed process modelling. The overall model structure is shown in Figure 3.

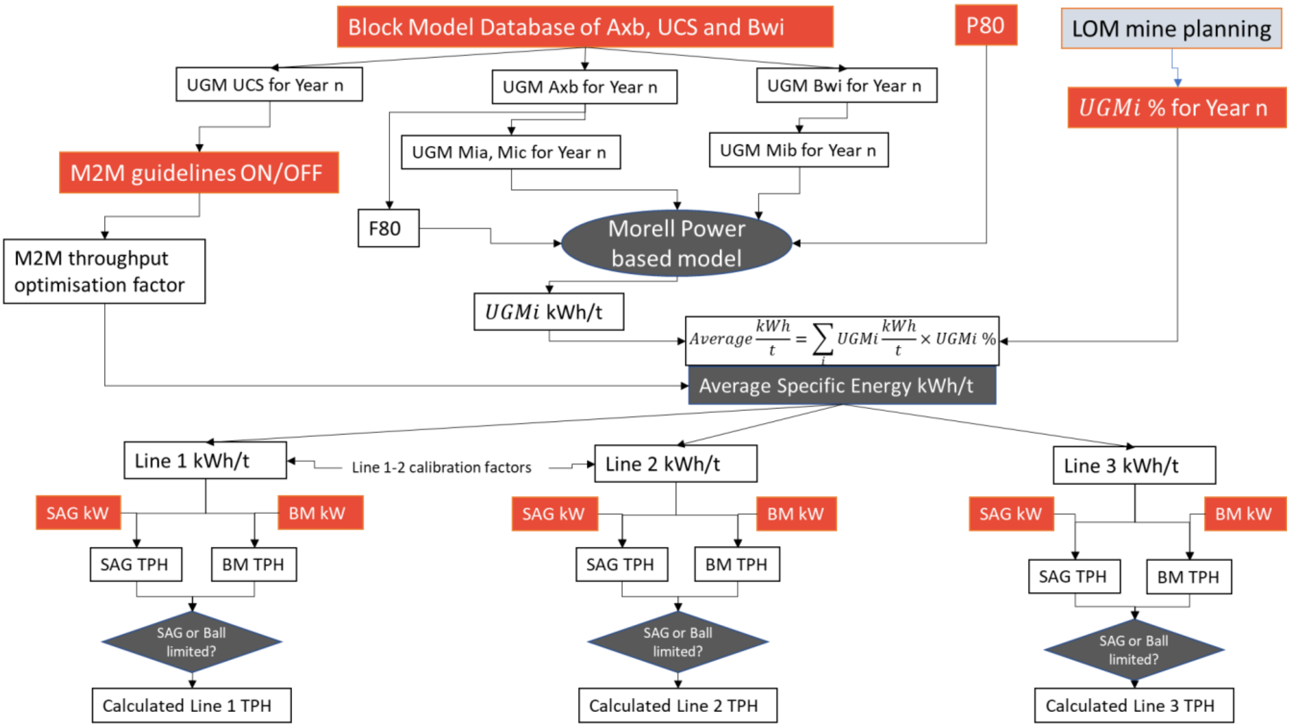

FIG 3 – Overall forecast model structure for Case Study 1. Note the on/off toggle available to the user for the M2M guidelines.

The model was validated against one years' worth of production data, covering the 2018 calendar year. Recorded power and product size were used as inputs, and the model predicted throughput was compared against the actual throughput. Model standard error equated to 9.8% of the average total throughput (Line 1 + Line 2 + Line 3) on a monthly basis. Standard error for each individual line equated to 9.3%, 5.8%, and 11.2% of the average, corresponding to confidence intervals of between 12 – 25% of the line average throughput at a 95% confidence level.

CASE STUDY 2

Operation Description

Case Study 2 takes places at another large open pit copper/molybdenum operation. Copper mineralisation occurs primarily in the form of chalcopyrite and chalcocite. Recovery is via two flotation stages, with the bulk Cu-Mo concentrate from the first stage reporting to the molybdenum circuit, with the molybdenum concentrate subject to hydrometallurgical treatment also on-site. Minor silver content provides an additional by-product credit.

Comminution at the site takes place in a conventional SAG-ball-crusher (SABC) flowsheet. Primary crushed material feeds a large SAG mill in primary grinding duty. Discharge from the SAG mill is classified via a trommel and incline screen, with the circuit closed with two cone crushers. Product from the SAG circuit feeds the secondary grinding stage, consisting of two parallel ball mills, each of which is closed by two cyclone clusters. A second grinding line had been recently commissioned and was in the process of ramp-up at the time the throughput forecast model was being developed. While not the focus of this discussion, a preliminary forecast model for the new grinding line was also provided, based on the assumption that it would operate in the same manner as the existing line.

Throughput Forecast Model

The throughput forecast model for this operation had a similar overall structure to that described in Case Study 1, however with some key differences. As was the case in the earlier example, the LOM planning (covering the period from 2020 out to 2044) was drawn upon to define the proportion of the various ore types in the feed blend. Here, the LOM plan defined six different lithologies, five of which occurred in significant proportion over the LOM, with the sixth being present in the plant feed in only a handful of years, and in very small proportion. The model therefore considered the five main lithologies as its basis. The proportion of the different lithologies in the plant feed over the LOM is shown in Figure 4.

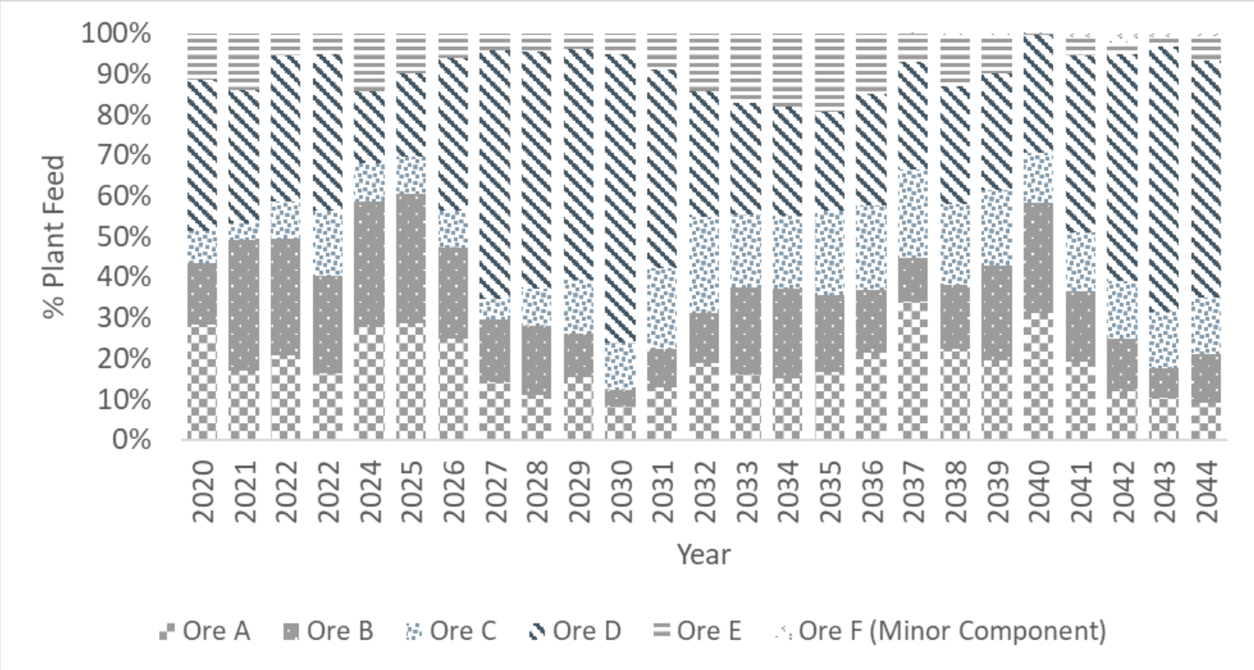

FIG 4 – Bar chart showing the proportion of each of the different lithologies in the feed blend, on an annual basis.

Where the site covered in Case Study 1 had a detailed geometallurgical model, the extent of the testwork conducted at the site in Case Study 2 was much more modest. Some Macon crushability index and BBWi data was available, however the number of samples was quite limited. Based on this, a single impact hardness (DWi) and grinding hardness (BBWi) value was assigned to each lithology, with the model assuming the characteristics of the ore from each lithology will not change in future, only the proportion of the feed drawn from each. Considering this, the model was configured to allow the user to adjust the ore hardness inputs in the future, when additional test work becomes available and the variation in the hardness of each lithology is better understood. The assigned values are shown in Table 1.

Ore Type	Estimated Axb	BBWi (kWh/t)
Ore A	36.7	15.28
Ore B	70.2	9.74
Ore C	50.1	13.62
Ore D	37.4	15.07
Ore E	34.7	17.60

TABLE 1 – Assigned ore characterisation data for each of the lithologies in Case Study 2.

In this case, Hatch did not have the benefit of having already completed a full M2M project for this operation. Calibrated drill and blast models to define the ROM fragmentation were therefore not available. Fortunately, the SAG feed belt at the site is equipped with an image analysis system (*Split Online).* Data from the image analysis system was cross referenced with daily production records, which provided the proportion of each ore type in the feed. Multi-linear regression was carried out, and an equation to predict F80 as a function of the feed blend composition type was derived. The equation took the following form, where a, b, c, d, and e are fixed coefficients:

$$F80 = (a \times \%\, Ore\ A) + (b \times \%\, Ore\ B) + (c \times \%\, Ore\ C) + (d \times \%\, Ore\ D) + (e \times \%\, Ore\ E) + Constant$$ **– Eqn. 3**

While analysis of variance (ANOVA) indicated there was a statistical significance to each of the coefficients, and that the overall regression was significant, there is a degree of scatter in the data due to operational variability and error associated with the image analysis. This is reflected in Figures and Figure 6 below.

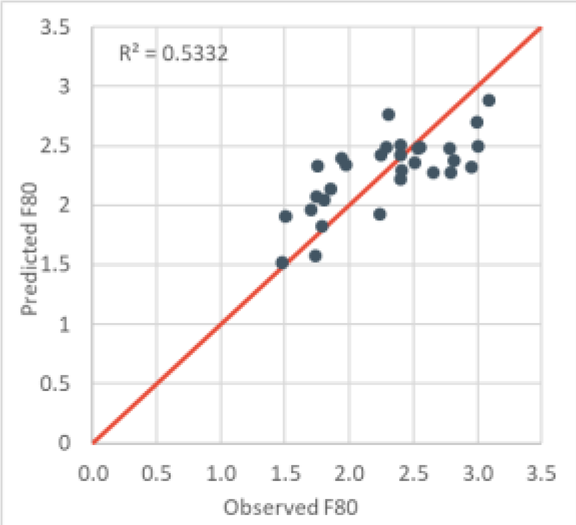

FIG 5 – Parity chart of predicted and observed (online camera) SAG feed F80.

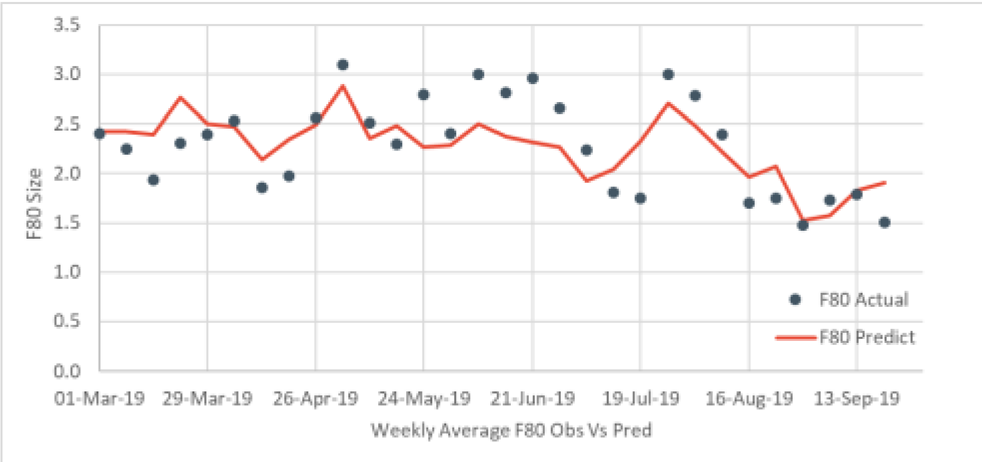

FIG 6 – Timeseries plot of predict and observed SAG feed F80 (weekly average).

Finally, the model development was complicated further by specific conditions which occurred when Ore B was present in high amounts. Being the softest of the five main ore types, the power-based model was predicting a reduction in the required specific energy as the proportion of Ore B increased, with a corresponding increase in the predicted throughput. The initial model, however, was shown to be systematically overestimating during these periods. Based on this, it became evident that there was an operational/practical factor at play, which was not being captured in the model.

Discussions with site indicated that this ore, along with Ore C, had been causing issues in the downstream thickener. These issues compelled the operators to manually reduce throughput when these ores were present in significant amounts. In the case of Ore B, the particularly soft nature of the ore meant that the SAG mill struggled to maintain a rock charge once the operator reduced the throughput, leading to a reduced power draw. The relationship between the proportion of Ore B in the feed and SAG mill power draw is shown in Figures 7 and 8. This relationship was incorporated into the throughput forecast model to capture the “reduced SAG mill power” operating state, with the option to disable this function once the thickener issues are resolved.

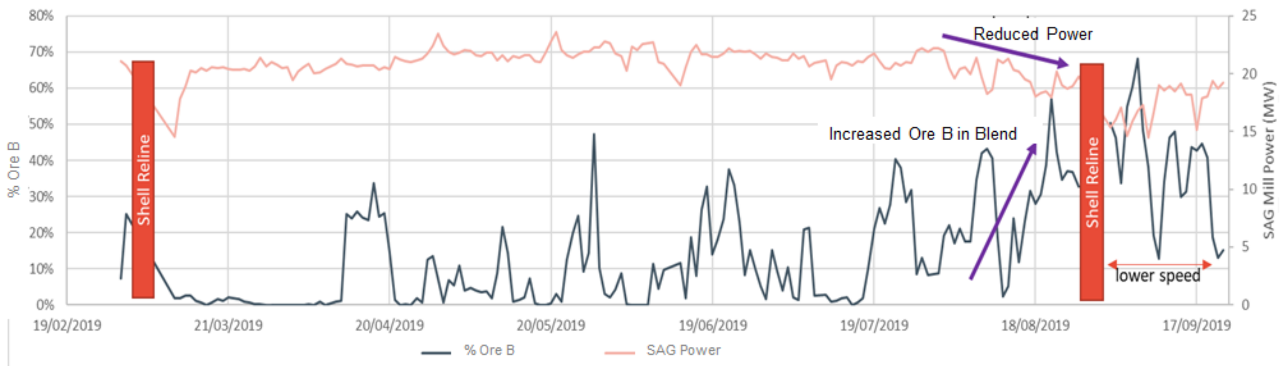

FIG 7 – Timeseries plot of SAG power alongside the proportion of Ore B in the feed blend.

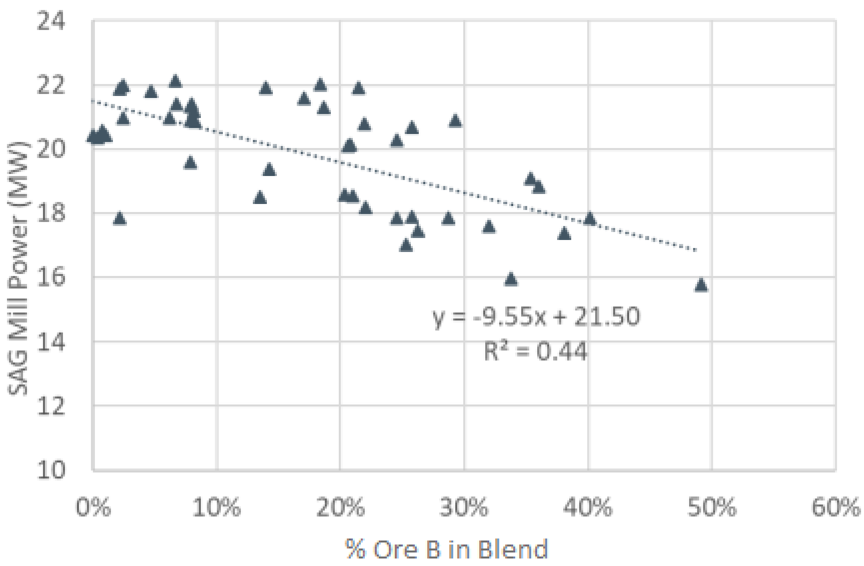

FIG 8 – Regression of SAG mill power as a function of the proportion of Ore B in the feed.

While production data covering the period from March 2019 to September 2019 was used to calibrate the forecast model (specifically, the calibration constants for SAG specific energy), data for the subsequent six months was used to validate the model predictions. Blend composition data over that period was averaged at daily, weekly, and monthly intervals, and provided as the input to the model. Figures 9 – 11 shows the comparison of the actual and predicted plant throughput at each time scale, with the red line separating the calibration and validation periods.

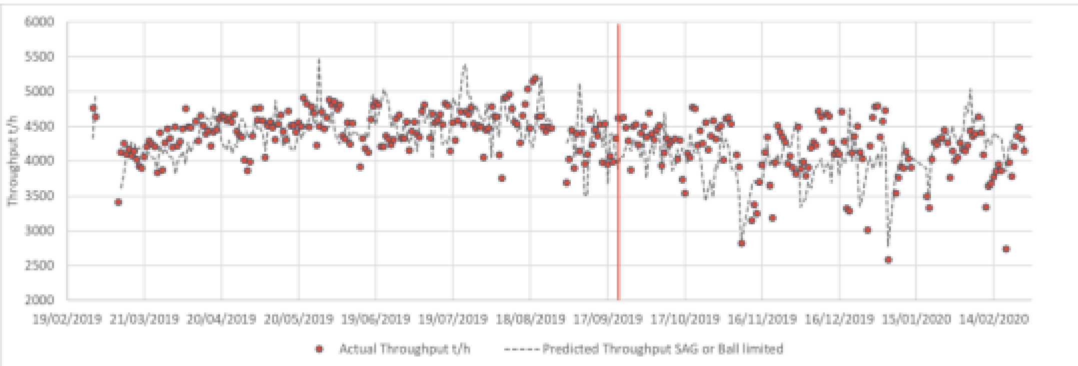

FIG 9 – Timeseries plot showing actual and predicted model throughput, on a daily timescale. Area to the left of the red line is the data used for calibration, area to the right is the validation period.

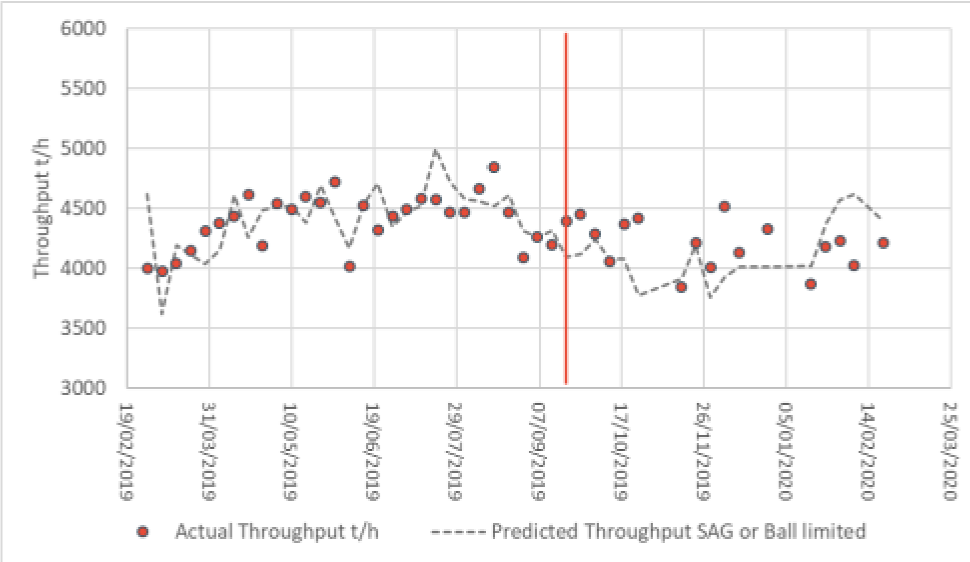

FIG 10 – Timeseries plot showing actual and predicted model throughput, on a weekly timescale.

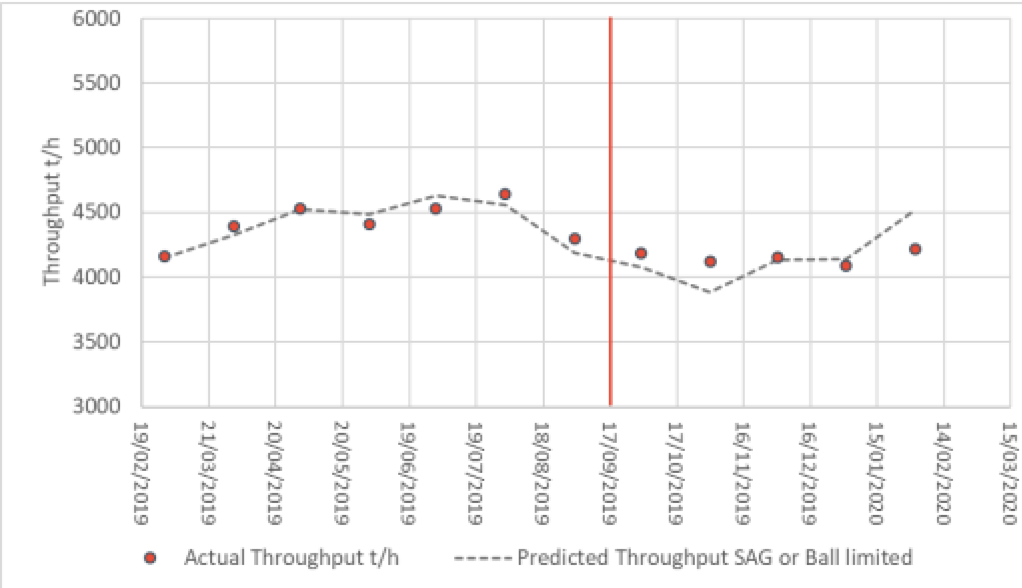

FIG 11 – Timeseries plot showing actual and predicted model throughput, on a monthly timescale.

Model standard error at each time scale was determined, along with the 95% confidence interval. Standard error equated to 7.6%, 5.4%, and 1.4% on a daily, weekly, and monthly basis, corresponding to confidence intervals of 7.6%, 5.4%, and 1.4% respectively. While some apparent outliers can be seen in the graphs in Figures 9 – 11, these confidence intervals represent a good level of accuracy, particularly at a weekly and monthly timescale.

CASE STUDY 3

Operation Description

Case Study 3 concerns an open pit polymetallic operation. Ore at the site is sourced from three pits, with ROM material processed first through two parallel crushing lines. The first crushing line consists of a jaw crusher receiving feed scalped over a grizzly, while the second consists of an in-pit gyratory crusher, product from which is scalped over another grizzly, with oversize reporting to a mineral sizer. Primary grinding takes place in a 34' SAG mill, which operates in closed circuit with two pebble crushers. Undersize from the SAG screen reports to a cluster of primary cyclones for pre-classification ahead of the secondary ball mill circuit. Undersize from those cyclones feeds directly into the 24' ball mill, along with undersize from the ball mill closing cyclones. Overflow from the two cyclone stages reports to flotation, which produces a bulk concentrate, which is sold without further selective flotation.

Forecast Model

Hatch, in conjunction with the site's explosive supplier, completed a M2M optimisation project at the site from December 2019, which concluded with the delivery of the final report and recommendations in July 2020. The M2M project identified several opportunities – including improved drill and blast practices, and optimised operating parameters of the primary and pebble crushers, SAG and ball mills, and cyclones – which were predicted to provide a 13 – 22% uplift in throughput if implemented in full, while maintaining the product size to flotation. While the implementation of the M2M recommendations was underway, Hatch were engaged to support site in the development of a geometallurgical and throughput forecasting model.

Historically, there had been a small number of comminution tests conducted for the main lithologies in each of the three pits on site. The testwork program included impact testing conducted by external groups, and point load testing (PLT) conducted by the site geology department. A campaign of full Drop Weight (DWi and Axb) and BBWi testing was also completed shortly prior to Hatch's engagement with site, with the same samples also subject to testing using the Hardness Index Tester (HIT) breakage device. At the time of delivering the model, a campaign of HIT tests on exploration drill core samples was underway, with the intent of further improving orebody definition and the understanding of hardness variability. HIT results representing ores to be processed in 2021 and 2022 were used to predict the throughput for those and subsequent years, with the data for later years to be updated once additional test results become available.

The model itself was based on the general structure described earlier. As in Case Study 1, a site-specific feature was incorporated to capture the impact of the increased fines (- 10 mm) in the plant feed associated with the recommended M2M blasting conditions. Once again, this correction involved reducing the calculated specific energy in inverse proportion to the throughput increase predicted for the relevant domain in the M2M study.

A site-specific adjustment was also added to accommodate a proposed partial pre-crushing circuit. The model treats the pre-crushed material as a separate component in the feed with its own required specific energy in the grinding circuit, similar to how each of the different ore types are treated. To calculate the contribution of this stream to the required grinding specific energy, and therefore the overall throughput, an estimate of the pre-crushing circuit throughput and usability is required.

Model validation was completed using process data from 2020 and 2021, which was compared with the throughput forecast model predictions on daily, weekly, monthly, and annual timescales.

Partway through the period of data considered in the model validation, a change to the SAG mill internals occurred, which saw a bi-directional liner design and radial pulp lifters installed, replacing the single-direction configuration which had been in place at the time of the M2M survey. The bi-directional liners and pulp lifters were later removed. The total period for which they had been installed amounted to around 4 months, from a total of 18 months in the validation dataset. While changes to SAG mill internals, and particularly the discharge assembly (grates and pulp lifters) can have an impact on mill performance, the model appears to be robust during this period. This is not entirely unsurprising, given details of these components are not inputs into the specific energy calculation. Where care would need to be taken, however, would be in a scenario where significant changes to the grate design are planned, for example to build a larger rock charge to promote fine grinding in the SAG mill and relieve the secondary circuit. In this scenario, drawn power may differ from expectations, while the calibration factors used to estimate SAG specific energy may need to be re-established under the new conditions. Alternatively, where changes are needed to alleviate slurry pooling issues, the subsequent increase in power draw may impact the assumed power draw used for forecasting, as well as the overall grinding efficiency and SAG specific energy relationship.

A second period in the validation dataset saw the circuit operated under single-stage SAG conditions. The model was not designed to predict the throughput in this mode of operation and would need to be adjusted to do so. This period was therefore excluded from the validation process.

Those considerations aside, the model predictions showed good agreement with the observed throughput. The relative standard error was approximately 11.2% of the average value on a daily basis, 8.8% on a weekly basis, and 4.9% on a monthly basis. These figures correspond to confidence intervals of 19.3%, 13.5%, and 10.4% respectively, at a 95% confidence level.

CONCLUSION

This paper has presented three case studies from recent throughput forecast projects completed by Hatch. The forecast models described provide the respective sites with a powerful tool for both short- and long-term planning, which can ultimately assist in maximising operational efficiency and profits over the Life-of-Mine. Hatch's methodology combines detailed drill & blast modelling (when available) with widely accepted power-based methodologies for grinding circuit throughput estimation, to provide a model with the flexibility required to assess trade-offs along the full value chain. While not covered here, these models also lend themselves to use alongside models of the downstream separation processes, giving an insight into the impact of changes in the drill & blast or the installation of additional comminution capacity on the overall economics of the operation.

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