MINE-TO-MILL OPTIMIZATION, PRODUCTION RELIABILITY ENHACEMENT AND EFFICIENT USE OF RESOURCES OVER THE LIFE-OF-MINE*

Walter Valery [1]
Rodrigo Hayashida [2]
Roberto Valle [3]
Erico Tabosa[4]
Kristy Duffy [5]
Lindon Pyle [6]

Resumo

A indústria global de mineração enfrenta desafios técnicos e financeiros crescentes e, com um crescente impulso para a sustentabilidade ambiental, tornou-se crítico que as operações mitiguem os riscos e otimizem as operações para garantir a máxima lucratividade e produtividade ao longo da vida útil da mina (LOM). As soluções integradas da Hatch abordam tais desafios para alcançar resultados de ponta. A otimização holística da mina à planta, em oposição às tentativas vãs de otimizar as operações unitárias isoladamente, garante que os processos interconectados operem em níveis que proporcionam a melhor eficiência global. Um programa inicial abrangente de caracterização mineral estabelece as bases para modelos mecanísticos de perfuração e desmonte e cominuição, que fornecem oportunidades de otimização no curto prazo para toda a operação. Sustentar a eficiência operacional maximizada que a metodologia Mine-to-Mill oferece requer um modelo de previsão de tonelagem apropriado que preveja o desempenho da planta em todo o LOM. A Hatch integra o planejamento de mina, geologia e alimentação de planta e especificações de equipamentos em um modelo geometalúrgico que forma a base de estratégias operacionais proativas. Depósitos de teores menores, particularmente, podem ser beneficiados pelas iniciativas de pré-concentração da Hatch. A remoção de estéril em um tamanho relativamente grosso nos estágios iniciais de processamento mineral tem o potencial de aumentar a produção e reduzir os custos de transporte, processamento, água e energia. As tecnologias que proporcionam tais benefícios às operações incluem pré-peneiramento, bulk ore sorting, separação por gravidade e magnética e flotação de partículas grossas. Este artigo fornece uma visão geral dos métodos das estratégias de otimização acima mencionadas, benefícios potenciais, desafios e estudos de caso com resultados reais.

Palavras-chave: Mine-to-Mill; Throughput Forecasting; Geometallurgy; Pre-concentration.

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Abstract

The global mining industry faces surmounting technical and financial challenges, and with a growing push for environmental sustainability, it has become more important than ever for operations to mitigate risks and optimize operations to ensure maximum profitability and productivity over the life-of-mine (LOM). Hatch's integrated efficiency solutions address difficult challenges to achieve high-end results. Holistic Mine-to-Mill optimization, as opposed to vain attempts to optimize unit operations in isolation, ensures interconnected processes operate at levels which provide the best overall

efficiency. An initial comprehensive ore characterization program lays the groundwork for mechanistic drill and blast and comminution models, which provide short-term optimization opportunities for the whole operation. Sustaining the maximized operational efficiency that the Mine-to-Mill methodology delivers requires an appropriate throughput forecast model which predicts plant performance throughout the LOM. Hatch integrates mine planning, geological, and plant feed and equipment specifications into a geometallurgical model which forms the basis of proactive operating strategies. Lower grade deposits particularly can be benefitted by Hatch's pre-concentration initiatives that promote an efficient use of resources. Removing coarse size waste in early mineral processing stages has the potential to increase production and reduce transport, processing, water, and energy costs. Technologies which provide such benefits to operations include pre-screening, bulk ore sorting, gravity and magnetic separation, and coarse particle flotation. This paper provides an overview of the aforementioned optimization strategies' methods, potential benefits, challenges and case studies with actual results.
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Keywords: Mine-to-Mill; Throughput Forecasting; Geometallurgy; Pre-concentration.

[1] *PhD, Global Director Consulting and Technology, Mining and Minerals Processing, Hatch Australia*
[2] *P. Eng, Sr. Consultant Drill and Blast, Consulting and Technology, Hatch Brasil*
[3] *MBA, P.Eng. Director Process Improvement, Consulting and Technology, Hatch Peru*
[4] *PhD, Sr. Minerals Process Engineer, Consulting and Technology, Hatch Australia*
[5] *P.Eng., Sr. Process Consultant, Consulting and Technology, Hatch Australia*
[6] *P.Eng., Minerals Process Engineer, Consulting and Technology, Hatch Australia*
[7] *.*

1 INTRODUCTION

Of all challenges the mining industry continues to face, declining grades in complex orebodies is certainly one of the most prominent. Such deposits have highly variable ore physical characteristics, which results in difficult extraction environments, and financially feasible operation is further limited by energy and water availability.
Mining companies, both existing and greenfield projects, face the need to be more profitable, productive, and sustainable, if they want to remain competitive. Potential for such productivity and efficiency gains are often available in numerous interconnected processes which comprise a mining operation. While these processes clearly affect the subsequent ones with close dependence, all have their own performance indicators such as productivity, unit cost and product quality, and often improvement is regularly considered in terms of each individual activity.
Mine-to-Mill projects conducted by Hatch provide a holistic optimization of operations with many documented successes. However, the term Mine-to-Mill has been commonly quoted in mines with an inaccurate and oversimplified approach; the most common being as simply increasing explosive consumption in blasting and expecting higher throughput in a processing plant from reduced feed size. For a full holistic optimization, blast energy needs to be adjusted with consideration for specific ore characteristics, circuit configuration and processing equipment to be optimized. This details a site-specific, structured, and integrated Mine-to-Mill method where efforts are placed in optimizing not just mining, but downstream comminution and separation processes as well.
As a result of the broad project scope, benefits can vary depending on specific targets and objectives but include:

- maximization of mine and plant throughput,
- reduction of unit costs,
- improvement of plant stabilization and consequently better process performance,
- reduction in specific energy, water consumption and generation of greenhouse gas emissions.

All these benefits can be achieved with little to no capital investment from the business.
The mathematical models developed during the Mine-to-Mill project can be used as a basis to accurately predict the plant throughput over the Life-of-Mine (LOM) by understanding the ore variability in the feed and its characteristics, and how these will impact on blasting and processing. These models can be incorporated in the mine and resource block model, and optimum blending strategies can be defined accounting for different extraction, planning scenarios for the best outcome in revenue and ore delivery, thus enhancing production reliability.
Improvements in eco-efficiency and overall productivity can be achieved through the full optimization and integration from mine to plant, sustained in the LOM through accurate prediction of the throughput, and selecting preconcentration technologies that reduce haulage, downstream processing requirements and limited resources of water and energy.

2 METHODOLOGY

2.1 Mine-to-Mill Optimization

A Mine-to-Mill project is based on extensive surveys, measurements and auditing conducted on site, supported by thorough analysis of all collected data. Figure 1 summarizes the structured methodology developed by Hatch.

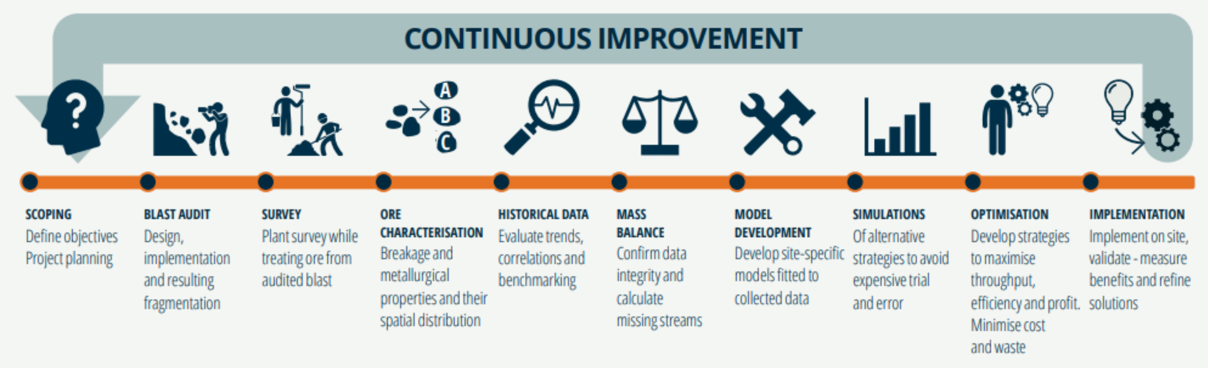

Figure 1. Mine-to-Mill and continuous improvement methodology from Hatch

Mine-to-Mill projects commence with an initial site visit and scoping study. The objective is to conduct a preliminary assessment in both mine and plant, to identify potential optimization opportunities and prepare a detailed project plan. This plan includes analysis of preliminary data collected and prioritization of initiatives to be conducted in accordance to project objectives. A full survey preparation and planning document is then issued, including sampling and auditing of current drill and blast practices and surveys of comminution and processing. The goal of the survey is to collect data to create a benchmark of the current performance of the overall operation which is critical to understanding the ore characteristics being treated. The performance in mining and mineral processing is influenced by the in-situ ore properties, therefore proper ore characterization is fundamental and completed early in the project. Ore domains are defined based on blast, comminution and metallurgical properties, and whenever possible the spatial distribution of these ores is mapped across the orebody.

With data collected from such audits in both mine and plant, for the different ore domains and types, mathematical models for each operation (drill and blast, crushing, grinding and separation) can be built and calibrated together with aid from historical operating data.

These site-specific models are then used to predict how the process will respond to changes in ore characteristics, operating practices and conditions in mine and plant without the need to conduct industrial trials, which are expensive and risky. Simulations are conducted applying such changes and different strategies are evaluated. These techniques, together with the industrial database of projects conducted in different ore types and commodities, and consulting experience of the personnel conducting such assessments, result in the identification of any opportunities for performance improvement.

Figure 2 shows example of models in drill and blast, crushing, grinding and separation processes used to conduct simulations and determine the optimal operating strategies.

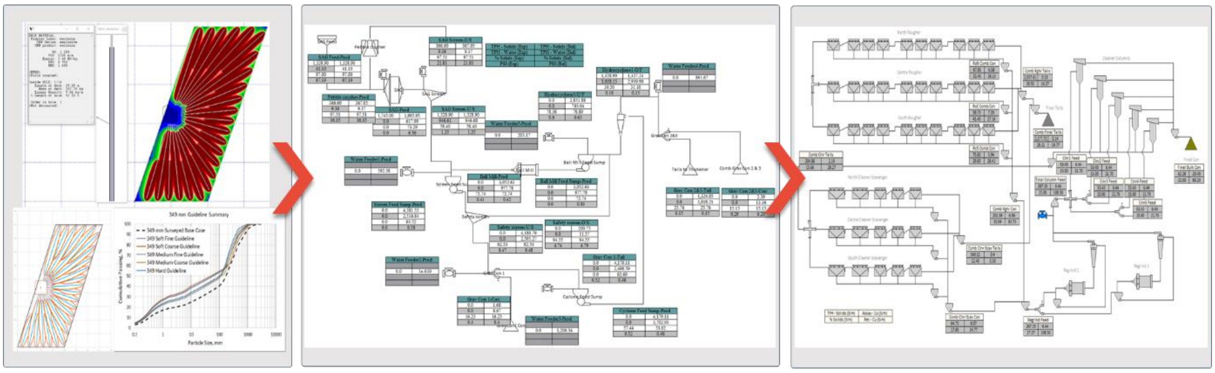

Figure 2. Example of integrated mathematical models

Hatch specialists have conducted hundreds of Mine-to-Mill optimization projects, one of them was carried out in a large Cu-Au operation in Latin America, which is used as a case study. The main objective was to maximize plant throughput with existing equipment while maintaining the product size of the comminution circuit. The project tasks included:

- Review of the available ore characterization data, which were bases for ore domain definition;
- Review of the drill and blast operating practices, mining and processing operations;
- In-depth data analysis of historical process variables;
- Planning and supervision of a full Mine-to-Mill survey;
- Rock characterization for the surveyed ore;
- Development of mathematical models for blasting and comminution.

The models were then used to conduct simulations suitable for the integrated optimization of drill and blast and comminution processes.

Ore domains were defined based on the site test work database and results from the full survey, with a combination of lithology classification, and corresponding rock strength and structure. Figure 3 shows an example of the domains defined according to the rock strength and structure characteristics. In addition, lithologies can be also incorporated in the background of the domain definition for easiness of application and nomenclature.

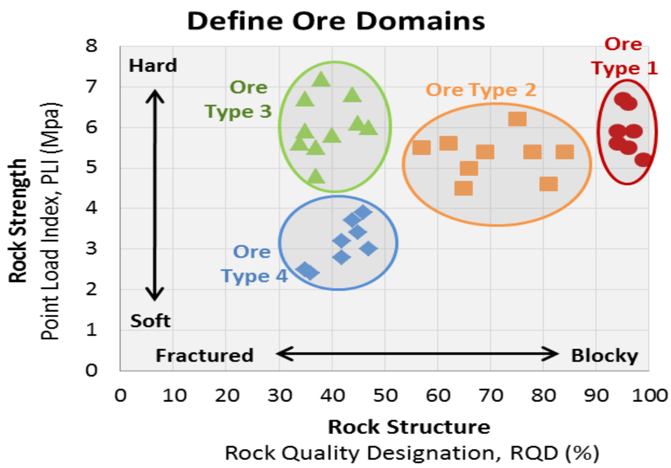

Figure 3. Example of ore domains definition based on rock strength and structure

Audits were conducted on different blast polygons in the open pit, collecting data such as polygon mark-out, hole drilling, charging, stemming, timing and initiation. After the blast, the Run-of-Mine (ROM) fragmentation was measured using image analysis of photos collected of both the blasted muckpile, and trucks hauling the ore and dumping at the primary crusher. Figure 4 gives an example of the images collected and processed in Split Desktop.

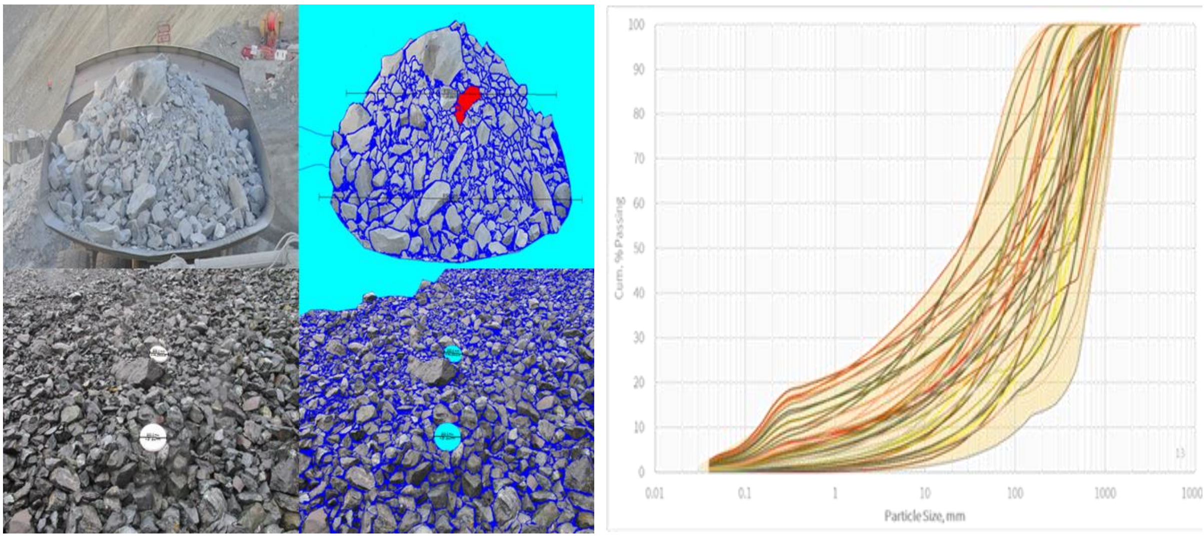

Figure 4. Example of image analysis for fragmentation analysis (before optimization)

Blast guidelines were then generated using the site-specific blast fragmentation model, which was calibrated with the measured ROM fragmentation and drill and charge conditions as inputs. The aim of the tailored guidelines according to ore characteristics was to produce the ROM size distribution that will maximize the throughput of the subsequent crushing and grinding operation. This means softer and more fractured ores were recommended for lower energy blasts, while harder and blockier domains warranted greater energy. This results in a more consistent crusher feed PSD across the varying domains, while not necessarily increasing overall explosive consumption and costs, as the relaxed and increased blasting guidelines balance out the overall use to some degree. Figure 5 provides example of blast guidelines.

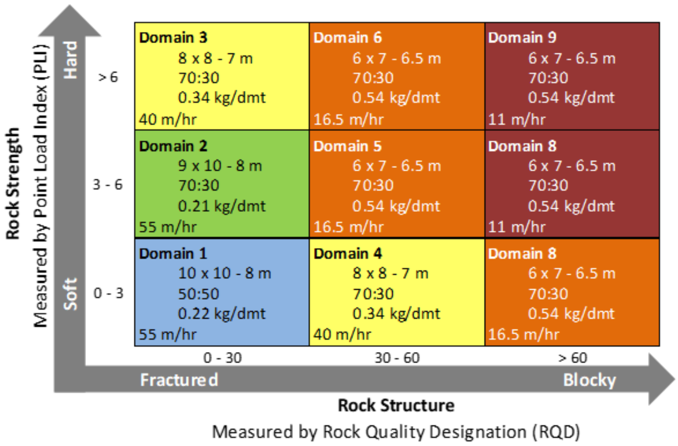

Figure 5. Example of blast guidelines for optimization

A full survey was conducted in the comminution circuit while treating ore from the audited blast polygons. This enabled comminution performance to be linked with the current blasting conditions, rock mass characteristics, blast and explosive properties, and the associated fragmentation results. The information also allowed the development and calibration of site-specific mathematical models for each unit in the

operation (primary crushing, SAG milling, pebble crushing, ball milling and classification).
As part of the survey, a belt cut sample was collected from SAG mill feed for particle size distribution (PSD) analysis. Crash-stops and grind-outs were also carried out in the SAG and ball mills. Charge measurements were taken, and the condition of the lifters/liners and ball size distributions were reviewed. In the SAG mill, the extent of pegging and penning of the grates, the capacity of the pulp lifters, and the presence of slurry pooling were also investigated.
Mathematical models of unit operations were calibrated using data analysis, rock characterization and survey results in conjunction with in-house modelling tools for Blast Fragmentation and JKSimMet model fitting and simulation software for comminution operations. The calibrated site-specific models allowed integrated simulations to be conducted with a holistic approach from mine to plant to develop optimized strategies considering the different ore domains and associated range of ore characteristics. Figure 6 shows example of potential improvements in mill throughput resulting from integrated simulations conducted.

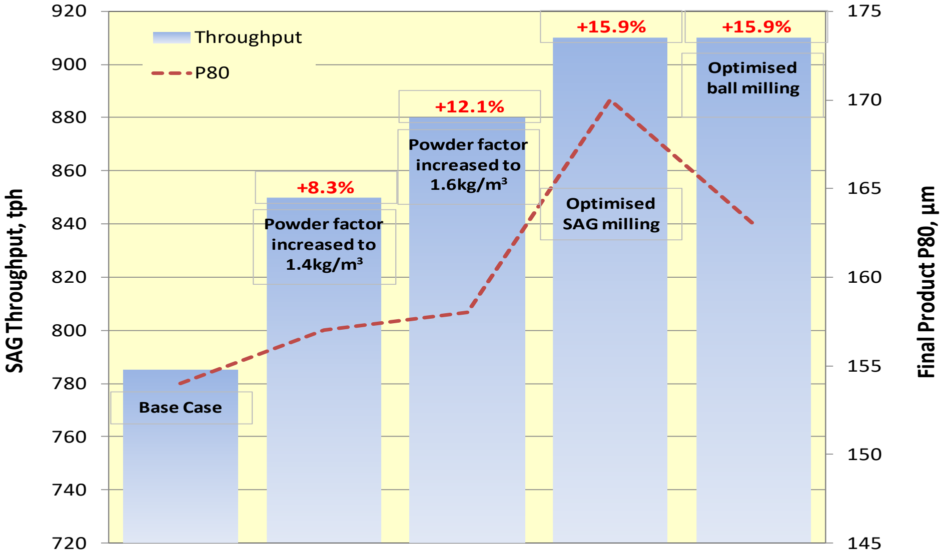

Figure 6. Example of improvements in SAG mill throughput (Diaz *et al.*, 2015)

The integrated simulation analysis indicated that plant throughput could be increased by 16 %, while maintaining the final product size to feed flotation below the target P80. The increase can be achieved with very limited capital expenditure.

2.2 Throughput Forecast and Geometallurgy

Mine-to-Mill optimization should not be considered solely for the short term. For an operation to remain sustainable, viable and competitive in the future, it requires strategic options to mitigate risks, ensuring high operational profitability over the LOM. The site-specific mathematical models developed in the Mine-to-Mill project have also been used as the basis for developing a Throughput Forecast Model for the LOM. These models were used in combination with the mine production plan and additional ore characterization data conducted by site to forecast plant throughput according to different ore properties, feed blends, drill and blast practices, circuit configurations, and

target product size. The model enables forecasting and planning to improve production reliability and assist with strategic LOM optimization.
To develop the throughput forecast model, Hatch applied a combination of Morrell power-based and mechanistic models, using the hardness/breakage properties and the proportion of each lithology/ore domain to predict a weighted average comminution Specific Energy for each domain.
Another critical parameter that impacts SAG mill throughput is the content of fines (% -10 mm) in the SAG mill feed. This is strongly influenced by ore properties and the drill and blast operations and is not typically included in power-based modeling which is based on F80 only in terms of feed size. However, Hatch developed a methodology to estimate the fines content of the feed and incorporate this in the power-based throughput model.
Figure 7 below shows the throughput forecast and concentrate production model concept diagram, which in turn provides the calculation steps diagrammatically.

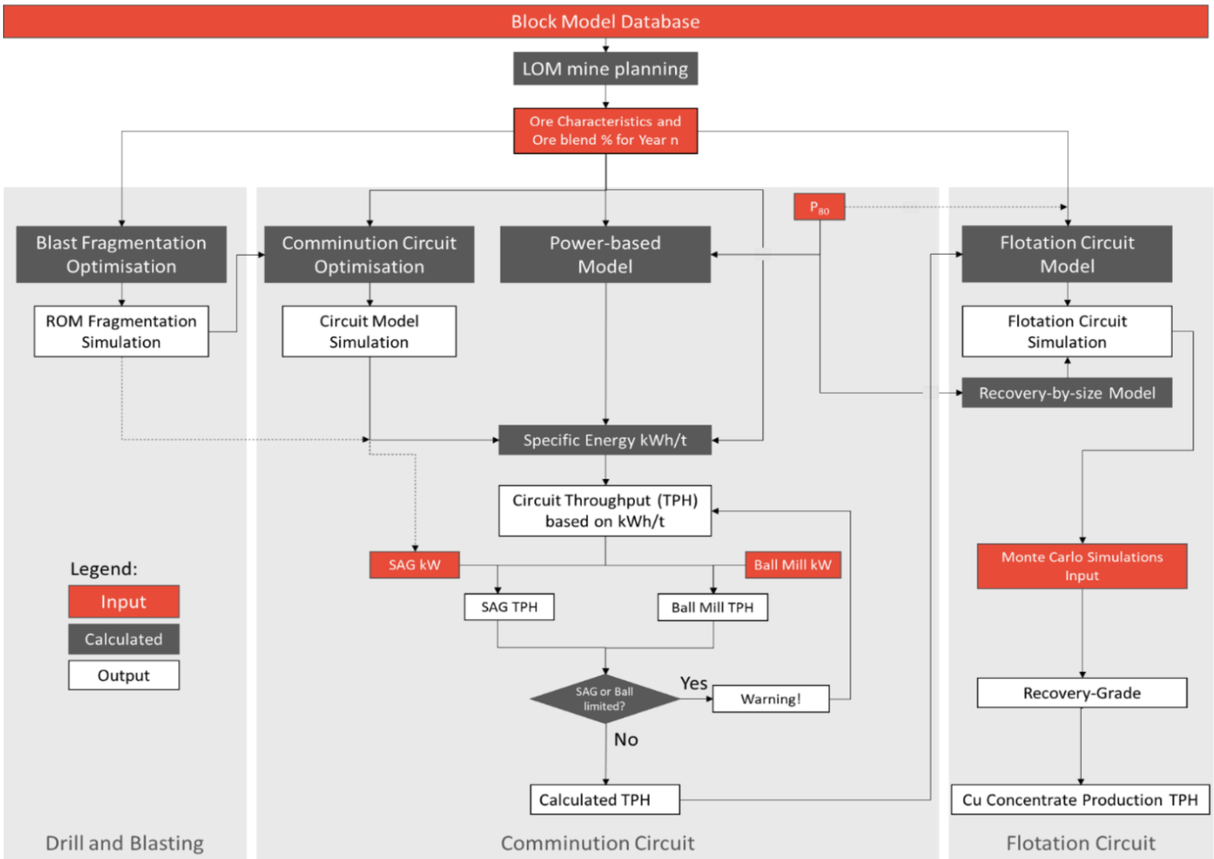

Figure 7. Conceptual Diagram for Geometallurgical Modelling and Concentrate Production Forecast

Very detailed historical ore characterization test work data were compiled to develop the database of ore characteristics which is the source of information for each domain in the throughput forecast model. This test work included including SAG Mill Comminution (SMC Test®), Bond Work Index (BWi), SAG Power Index (SPI), and Point Load Test (PLT).
Hatch also analyzed the recent data and information on the drill and blast, ore characterization and blend proportion for the lithologies. These were used to calculate weighted average blend of lithologies and corresponding blasting powder factors to correlate with the actual feed size to the plant.

Model validation consisted of comparing the throughput forecast model predictions with actual process throughput at various time scales (weekly, monthly, annually). The methodology used the actual feed blend proportions, provided by site, and the mill power from plant operating (PI) data to predict the actual throughput achieved. Appropriate filtering was applied to the PI data to exclude shutdowns and periods of maintenance activities. Figure 8 provides comparison between model output and actual plant throughput.

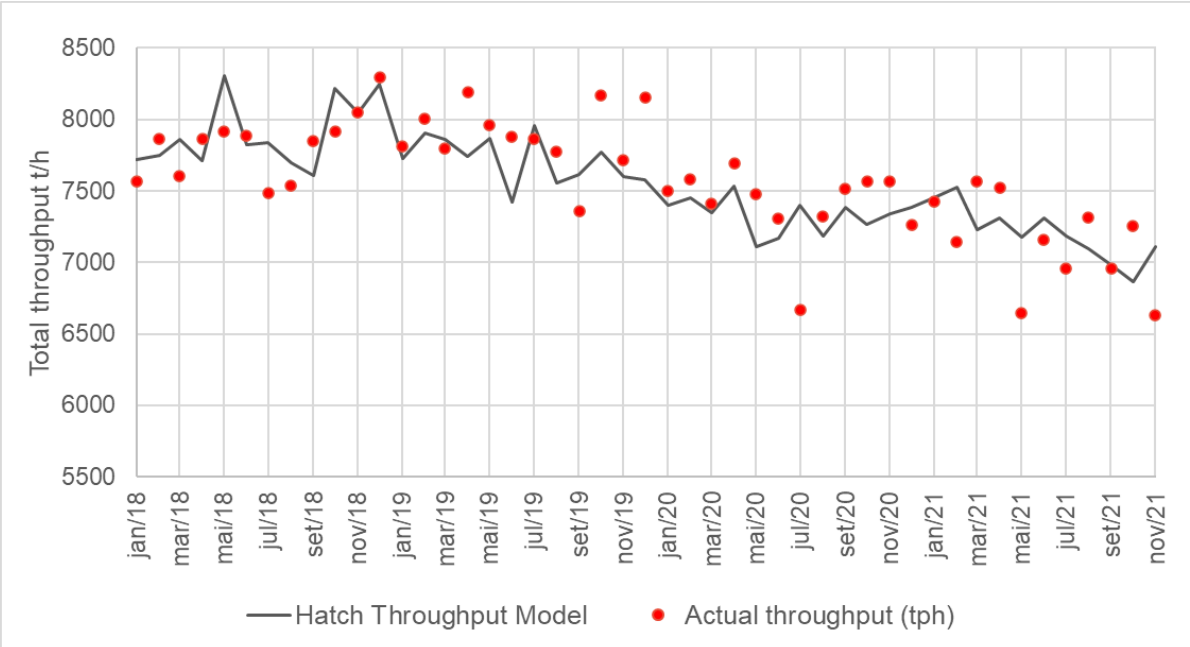

Figure 8. Comparison between Actual vs Calculated throughput (Abbot *et al*, 2022)

The estimated model throughput is compared with the actual plant throughput, and the standard error of the model is calculated based on the number of observations at different time scales. The relative standard error (%) was compared to the average throughput with a confidence interval of 90 %. The model predicts quite well on a yearly basis (error of 1.4 %) and in an appropriate range on a monthly basis (+/- 3 %) for the same period.

Table 1. Model prediction error in different time scales

90% prediction interval		**Daily error**	**Weekly error**	**Monthly error**	**Annual error**
Throughput Model Standard Error	+/- %	6.2 %	4.5 %	3.0 %	1.4 %

2.3 Pre-Concentration

In the face of technical challenges in declining grade, rising operating costs, water and energy supply, evaluation of different technologies in the pre-concentration of ore are a necessity to mining companies. Pre-concentration can prevent gangue minerals from entering the high energy intensity and costly process route of comminution and separation. Furthermore, implementation of pre-concentration as close as possible to the mining extraction point creates opportunity to exploit the natural heterogeneity of the ore deposit, which could be tremendously beneficial.

However, successful pre-concentration must be site specific and dependent on ore mineralogy, and physicochemical characteristics. These characteristics will determine if the ore body is amenable for the pre-concentration technology and process. Additionally, costs such as equipment, for preparation, handling and separation, must also prove to be economically favorable.
Understanding of a deposit's inherent grade variability and gangue liberation size is also of equal importance. Simply sending ore samples to a sensor or equipment vendor to determine if separation is possible at a given size is insufficient. Mines attempting to assess pre-concentration viability with this method could likely obtain misleading results.
The use of proper geostatistical methods is a far more reliable approach. Geostatistical methods can provide superior understanding of variability and performance of pre-concentration technologies in separation processes.
There are numerous options for pre-concentration, and evaluations comparing these options should proceed as follows: selective mining, selective blasting, pre-screening, sorting (either particle or bulk), coarse gravity separation (jigging, dense media separation), coarse particle flotation and magnetic separation. Performance and benefits for each are dependent on ore characteristics and heterogeneity, which dictates the grade upgrades and ore losses from the pre-concentration, as well as mine design, transport and downstream processing requirements and costs.

Figure 9. Pre-Concentration Technologies (Pyle *et al*, 2022)

Examples of the pre-concentration options are:

Pre-Screening

Ore and valuable minerals are frequently concentrated in fine size fractions. This is due to mineralization being associated with fracture planes and valuable minerals commonly exhibiting softer and more friable characteristics than gangue. Upgrading may be achieved by screening the material, either directly after blasting or pre-crushing.
A copper operation used pre-screening where certain ore types are screened at 32 mm, the oversize is discarded as waste and undersize is sent as ore to the plant. Though the technique is well-known and simple, implementation of pre-screening must be done with caution as it is heavily ore dependent. While the general technology is well established, ore specific factors that affect the performance of the technology is not always comprehensively covered by literature.

Ore Sorting

Material sorting is widely used in other industries such as recycling and agriculture and is becoming increasingly popular in the mineral industry in the form of pre-concentration. Sensors are used to measure a differentiable property between ore and gangue components, which is followed by an accept or reject mechanism of the material. The mechanism then forms two streams, product, and waste. Many different sensors are available, and the most suitable is heavily dependent on ore characteristics. Two types of sorting can be used:

- Particle or individual sorting
- Batches or intervals of material i.e., on a loaded conveyor belt, a shovel or truck load.

Particle sorting measures the different property of individual rock fragments, and the separation is achieved through some physical mechanism. Throughput is by in large determined by the chosen mechanism e.g., air ejection. Bulk sorting is however simpler, cheaper, and more productive, but usually is not able to achieve the same efficiency in separation, as a larger batch of material is separated instead of individual rock fragments.
A trade-off between the better separation performance, lower productivity and higher capital cost from particle sorting compared to higher throughput and lower efficiency in upgrade from bulk sorting needs to be considered.

Coarse Gravity Concentration

Differences in density between the valuable and the gangue minerals present an opportunity to implement gravity separation. However due to the coarse particle size required for pre-concentration, only jigging and dense medium separation (DMS) are viable.
Jigging has the key advantage of low operating costs; however, the valuable and waste minerals need to hold a distinct difference in density, and there can be very little material of intermediate density.
DMS is a robust and proven technology that can treat particles from around 300 mm to 0.5 mm range. The separation process is simple and effective, but it is the necessary accompanying feed preparation and medium recovery process which has the potential to add to the overall costs and complexity.

Coarse Particle Flotation

Conventional flotation returns optimum results when it is conducted to recover particles in a limited size range of around 10 to 150 µm. Finer and coarser particles outside this range typically presents poorer recoveries, and are dependent on degree of liberation of ore, oxidation of particle surfaces, hydrophobicity, and density. If the particle size that can be effectively recovered could be increased, so could be the grinding product size, which results in energy saving in the upstream comminution processes.
If coarser particles could be floated, a possibility to pre-concentrate with flotation stage recovering these particles containing valuable minerals exists. The much smaller amount of material required to regrind to a final suitable size for conventional flotation would significantly reduce costs and energy consumption.
This could be achieved by modifications in design or operation of conventional flotation cells, that allows coarse particle flotation. This is limited by the machine hydrodynamics, such as poor coarse particle suspension and probability of particle-bubble separation due to high turbulence environment. Work has been published on coarse particle separation, suggesting that the upper limit of flotation may be extended up to one millimeter for sulphide ores.

However, the effect of mineral liberation on the effectiveness of these new coarse particle flotation technologies is a key area which demands attention.

Hatch conducted a conceptual study for a greenfield porphyry copper project, to investigate pre-concentration options and economic returns. Copper occurred predominantly as disseminated covellite and pyrite-covellite veinlets in the deposit. The mining method was block caving, feeding a conventional SABC circuit followed by flotation producing separate copper and pyrite concentrates.
At first, the bulk ore sorting alternative for pre-concentration appeared as highly attractive as the low selectivity mining method would introduce large volume of barren and low-grade material in the plant feed. Significant CAPEX savings were projected due to potential rejection of a large portion of the feed, reducing the size of the concentrator.
For a block caving operation, grade control in mining can be very challenging and limited. Material flowing through draw points will include internal dilution and dilution from cave walls and roofs. The bulk ore sorter may be the only way for a caving operation to have some control in implementing a cut-off grade.
In this case study, the disseminated nature of the ore within the body would limit the ability of BOS to properly reject barren batches of material. In addition, combining crushed ore underground from many draw points and ore passes onto a single surface transfer conveyor would significantly reduce the in-situ heterogeneity. Hatch evaluated the BOS alongside different pre-concentration technologies such as screening, DMS, particle sorting and coarse particle flotation to determine viability of options.
A summary of the performance of the pre-concentration routes assessed during the study is presented in Figure 10 on a mass-metal recovery curve comparison.

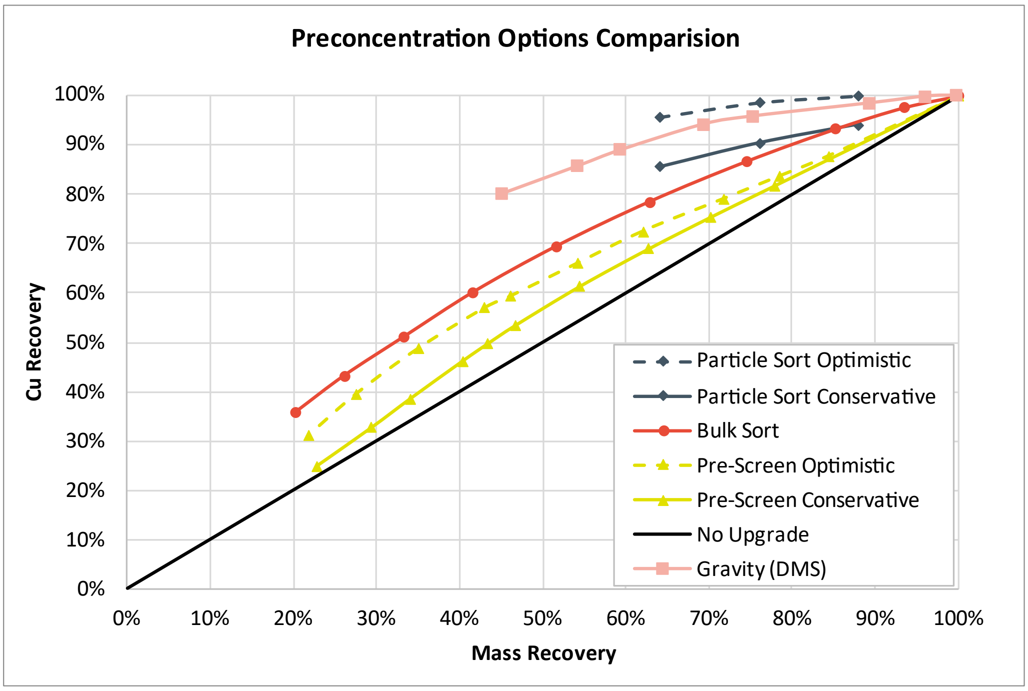

Figure 10. Comparison of Pre-Concentration Options (Pyle *et al*, 2022)

This low-grade porphyry deposit is a good target for pre-concentration due to its large size and thus large volumes of barren dilution material which could potentially be rejected prior to downstream processing. However, the ore may be finely disseminated and experience significant mixing during mining, limiting the upgrade potential of BOS

which separates large batches of material. By considering all pre-concentration options, alternative opportunities such as gravity concentration via DMS were defined that would not have been apparent if BOS was the exclusive focus.
However, while DMS, particle sorting and jigging presents the best separation and upgrade performance compared to BOS and screening, it presents the highest complexity in material preparation, handling and high capital costs. This analysis was conducted and schematically shown in Figure 11.

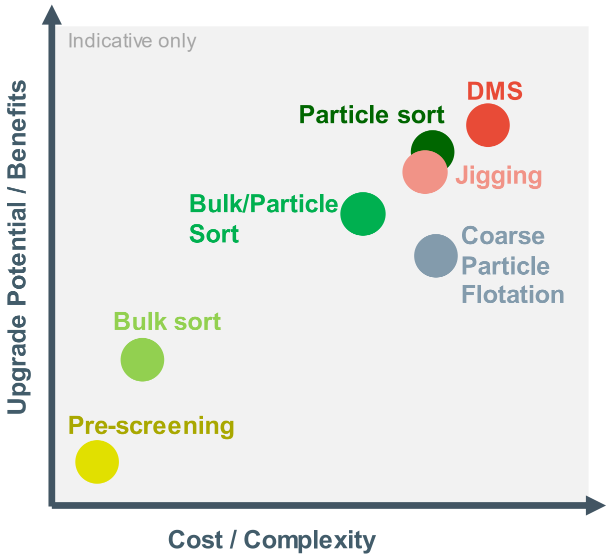

Figure 11. Analysis of cost/complexity vs. potential benefits of pre-concentration alternatives

3 CONCLUSION

This paper presented a summary and overview of relevant offerings methods that can be conducted by Hatch, including potential benefits, challenges, and case studies with actual results.
Mine-to-Mill has proven to be extremely successful when implemented properly, using a structured methodology and supported by extensive data collection and analysis. Benefits include increased throughput, reduction in specific energy consumption and reduced unit costs, which have all been achieved for numerous operations globally.
In the example case study described, analysis indicated that plant throughput could be increased by 16 %, while maintaining the final product size to feed flotation below the target P80. The increase can be achieved with very limited capital expenditure.
Mine-to-Mill benefits can be sustained over the LOM when the operation incorporates the outcome recommendations as site practices, procedures, and training.
Table 2 below shows a list of Mine-to-Mill projects with the respective benefits achieved for a better reference.

Table 2. Benefits derived from Mine-to-Mill Projects (Valery *et al,* 2017)

Operation	Commodity	Country	Benefits	Author
Newcrest Cadia	Cu/Au	Australia	12% increase in mill throughput	Kanchibotla et al., 1999
Porgera Joint Venture	Au	PNG	25% throughput increase	Grundstorm et al., 2001
Hamersley Iron Marandoo	Fe	Australia	8% increase in lump production, improved lump/fines ratio	Valery et al., 2001
KCGM Fimiston	Au	Australia	8-12% throughput increase 1-1.4kWh/t l specific energy (simulated)	Valery et al., 2001
AngloGold Ashanti Iduapriem	Au	Ghana	21-32% increase throughput 0.5 - 1% increase in leach recovery	Renner et al., 2006
Newmont PTNNT Batu Hijau	Cu/Au	Indonesia	10-15% mill throughput increase (hard ore)	Burger et al., 2006
Kinross Rio Paracatu Mineração (RPM)	Au	Brazil	10% increase ball mill capacity (sim) Finer blast product	Tondo et al., 2006
Anglo American Los Bronces	Cu/Mo	Chile	Capacity increase 15-20% (simulated)	Powell et al., 2006
Freeport McMoRan Candelaria	Cu/Au	Chile	Increased tonnage 10-20% (actual)	Munoz et al., 2008
Newmont Boddington	Au	Australia	Steady improvement over time	Hart et al., 2011
Minera Yanacocha	Au	Peru	Reduction of ROM fragmentation and SAG mill steel consumption	Burger et al., 2011
Newmont Ahafo	Au	Ghana	Reduced SAG mill power 8% total throughput increase 20% decrease SAG specific energy 30% primary ore throughput increase	Dance et al., 2011
Compania Minera Antamina	Cu/Zn	Peru	Throughput increase from 2750tph to 4400tph (hard ores), 23% decrease SAG specific energy	Rybinski et al., 2011; Valery et al., 2012
PanAust Phu Kham	Cu/Au	Laos	8% production increase (simulated) Forecast model developed for LOM	Bennett et al., 2014
Goldfields Cerro Corona	Cu/Au	Peru	Throughput increase 15% hard ore, 6% overall, 18% increase in SAG fines 9.2% decrease SAG specific energy	Diaz et al., 2015

Lundin Mining Chapada	Cu/Au	Brazil	Throughput increase 13 – 22 % with same P80	Evangelista et al., 2021

To mitigate risks and ensure the highest operational profitability is sustained, it is necessary to accurately predict future performance of processing and interaction with mining practices, based on ore characteristics.
Geometallurgical modelling provides a link between the physical properties of the ore, and performance of mining and processing operations. Integration of the ore characterization, domain mapping, and site-specific models of each operation in the value chain (blasting, comminution, separation) with the mine production plan in a geometallurgical model, provides a production forecast of the plant operation over the LOM. This facilitates strategic planning and optimization, considering the various ore characteristics feeding the plant to maximize profitability.
In the example case study, for the period of year 2021 the prediction standard error in average was 1.4 % only.
Examining the application of different pre-concentration alternatives instead of simply focusing on Bulk ore sorting is also important. Novel application of existing or adapted technologies and tailored solutions based on understanding of the process interactions and ore types provides an opportunity to develop solutions that are more efficient and profitable for the overall operation, considering cost and complexity of implementation or operation, and the potential benefits and efficiency in separation. The selection of the optimum pre-concentration route needs to be evaluated considering the deposit characteristics and in an integrated analysis with mining and downstream processing.

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