NEW METHODOLOGY TO IMPROVE PRODUCTIVITY OF MINING OPERATIONS

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ABSTRACT: Metso Minerals Process Technology and Innovation (PTI) have been working with operations around the world to increase their efficiency through ‘Mine-to-Mill’ or Process Integration and Optimisation (PIO) methodology. These projects have delivered significant improvements in mine efficiency, mill throughput and reduced operating costs at mines around the world. The PIO methodology involves rock characterisation, site auditing, data collection, modelling/simulation and implementation of integrated operating and control strategies on site. This results in significant benefits to the operations – for example, increases in concentrator throughput of 5 to 20 percent have been measured at some operations. Typically, a PIO project starts with a site visit to perform blasting and process audits, collect high quality data including measurements of run-of-mine fragmentation and survey data around all crushing and grinding circuits. These measurements are combined with rock characterisation and the definition of strength and structure domains to model the complete production chain by developing site-specific models of the blast fragmentation, crushing, grinding and flotation processes.

This proven methodology has applications ranging from greenfield projects to operations with AG/SAG or conventional crushing and grinding circuits. Process improvements can be higher mining productivity, higher mill throughput, decreased overall operating costs and higher flotation or leach recovery. This paper presents a recent application of PIO methodology and emphasises the potential for increased productivity without capital spending.

INTRODUCTION

The Process Integration and Optimisation (PIO) methodology, developed by Metso (PTI), is a result of working with operations around the world over the past ten years to increase their efficiency. The PIO methodology includes optimization of the mining (drill and blast), comminution, flotation or other separation technologies, and dewatering processes, but each process is optimised with respect to the whole operation, not in isolation. PIO projects involve rock characterisation, site auditing, data collection, modelling, simulation and implementation of integrated operating and control strategies on site. The main objectives are to reduce operating costs, increase production rates and improve overall process, energy and water efficiency.

Implementation of the PIO methodology has delivered significant improvements in mine efficiency, mill throughput and reduced operating costs at mines around the world (Dance et al, 2006). For example, increases in mill throughput of 5 to 20 percent have been measured at some sites.

The PIO methodology is described in this paper, and a case study is presented demonstrating the application and benefits of the process. The case study discussed is a large open pit operation in South America, and preliminary results demonstrate a significant increase in concentrator throughput. A number of conditions present in this case study are common to many large mining operations, suggesting that there is potential for many sites to benefit from the application of the PIO methodology similarly to the site in the case study presented.

PIO METHODOLOGY

The key unit processes from the mine to the process plant may include drill & blast, crushing, milling, leaching and/or flotation or other separation technologies and dewatering. These individual process activities are considered within the context of the whole process in PIO projects, as shown in the Venn diagram provided in figure 1.
The basic principle of PIO is to optimise each process step in context of the whole operation, analysing the effect of changes in each part on the whole process. Changes in the early process steps (e.g. drill and blast) are simulated through downstream processes to determine the impact on the final product and throughput. For example, blasting is understood to be the most energy efficient and cheapest way of reducing particle size; therefore, the use of greater energy input in the blasting unit operation is less costly than expending more energy in downstream comminution circuits.

The PIO methodology involves a number of steps:

- Define project objectives
- Establish current operating practice and benchmarking
- Rock characterisation
- Audits/surveys of current conditions including material tracking where required
- Modelling/simulation to evaluate opportunities
- Implementation of recommendations
- Monitoring and measuring benefits

A PIO project is normally comprised of a number of site visits spaced over a few months. The first site visit is conducted to establish current operating practice, initiate rock characterisation and collect measurements of blast fragmentation and mill performance. This is followed by data analysis, modelling and simulation studies to determine how to exploit hidden inefficiencies. Recommendations are followed by further site visits to implement changes, monitor results and ensure improvements are maintained over time. The PIO methodology is demonstrated in Figure 2.

**Definition of Project Objectives**

Each project has different objectives, and therefore it is important to define the specific targets at the beginning of each project. Predominantly, the target is to maximise throughput, but there are also many cases requiring adjustment of product size, minimisation of costs, or changes to the amount of fines. For example, in a SAG mill circuit, normally the object is to increase the amount of fines in the feed to increase production, but in a heap leaching process fines should be reduced to increase the percolation of the chemical solutions in the piles. Cost and production are normally opposed, i.e. if the goal of an operation is to increase production it will also increase its total costs, but the cost per ton will probably decrease.
the crushing and grinding circuits provide the necessary data to model each stage of comminution. Operating practices such as stockpiling and blending of different ore types ahead of the concentrator are also reviewed with consideration of the expected variability in rock properties. Finally, the level of instrumentation and process control strategies are reviewed to ensure that the mill operating conditions are best suited to changing rock conditions.

Ore Tracking from Mine to Mill (SmartTag™)

In some cases, where material is blended before the concentrator or when sophisticated mine monitoring and dispatch systems are not in place, there is a need to monitor material movement from the mine to the concentrator. PTI routinely use passive Radio Frequency ID (RFID) tags to mark material and track its movement over time. Initially developed to assist in the PIO studies, PTI have commercialised this system under the name of SmartTag™.

The SmartTag™ system is an inexpensive and robust means of tracking parcels of ore from the blast, through ROM pads, crushers, intermediate stockpiles and finally into the concentrator. They are placed in the stemming of blast holes, on post blast muckpiles or ROM pads and travel with the ore through the process until they are consumed, generally in the grinding mill. They are detected by antenna placed above or below conveyor belts at various points in the process; for example, at the primary crusher and SAG feed conveyor belts. The use of such technology allows definitive correlations to be made between plant performance and plant feed characteristics. These could be intrinsic properties of the ore such as grade, chemical composition, strength and structure, or due to the application of external energy such as blasting or crushing. In conjunction with online image analysis systems, the impact of fragmentation from different rock domains on downstream crushing and grinding can be determined.

Figure 3 demonstrates application of SmartTag™ ore tracking for a typical flow of ore from a blast through to a concentrator. Other possible applications for SmartTag™ ore tracking include tracking material through an iron ore concentrator or coal preparation plant.

The SmartTag™ marker is based on an RFID tag encased in a shell to protect it from damage during blasting and its transit through crushers and stockpiles. The SmartTags come in three sizes, the super SmartTag (90mm Ø x 60mm), the standard (60mm Ø x 30mm) and the mini (20mm Ø x 10mm). Figure 4 shows the three tag types.
The mini tag is generally used for applications where screening or secondary crushing precludes the use of the larger tag. Mixtures of both the normal and standard tag can be used if necessary. The Super SmartTag™ has been developed to better allow survival in underground applications where long falls can be expected into ore passes.

**Rock Characterisation**

In-situ ore properties govern the ultimate performance that is achievable in all mineral processing operations. The first step in conducting any optimisation of the blasting, crushing or grinding circuits is to understand the material properties of the rock at site. Rock characterisation is a study that gives information on the strength and structure of the ore, which have a strong influence on all comminution processes.

The PTI methodology for rock characterisation utilizes simple and inexpensive measurements of rock strength and structure that can be performed by trained site personnel, and quite often these measurements are already being collected by the operation. The advantage of simple measurements is that a large amount of data can be collected in a very short timeframe, as samples do not need to be shipped to an outside laboratory. When attempting to characterise and map rock strength and structure of an entire ore body, density of data and their statistical significance are very important.

For rock characterisation, PTI use measurements of both rock strength and rock structure including:

**Rock Strength:**
- Point Load Index (PLI)
- Bond Work Index (BWi)
- Steve Morell’s Crushing Test (SMC)
- Drop Weight Test (DWT)
- Uniaxial Compressive Strength (UCS)

**Rock structure:**
- Rock Quality Designation (RQD)
- Scan line mapping
- Image analyses
- Fracture frequency

Rock strength (or competency) of the material is determined by physical testing through equipment such as the JK Drop Weight Test (DWT) for impact breakage, the Point load Test (PLT) for point compression breakage, the Unconfined Compressive Strength (UCS) system for surface compression breakage, and the Bond mill which is used to determine rod or ball work indices (BWi) for ore resistance to abrasion breakage. The various types of rock strength equipment are shown in Figure 5.

![Figure 5: Rock Strength Testing Equipment](image)

Point Load Tests (PLT) can be performed quickly and easily on drill core or irregularly shaped samples of material collected from blasted muckpiles or stockpiles. Bond Work Index and Drop Weight Tests are more difficult to test requiring more sample, resources and time. However, the PLI value (Is50 in MPa) can be correlated to the Drop Weight test parameters (A & b) and the Bond Work Index (BW). The Drop Weight and Bond Work Index parameters are required to model the crushing and grinding circuits. Therefore, the use of the Point Load Index allows sites to characterise their rock properties quickly and easily while still making use of the sophisticated grinding models that are available.

The PLI data can also be converted to a UCS estimate using either known factors for each rock type or, if not known, a factor of 24. For example, an Is50 of 5MPa would correspond to a UCS of 24 x 5 or 120MPa.

Rock Quality Designation (RQD) is a measure of rock structure which reflects the fracture frequency present in the drill core. RQD measurements are collected on intervals of diamond drill core. This measurement is routinely taken for geotechnical purposes but has also proven to be very useful in blast fragmentation modelling in the absence of detailed rock mass structure mapping.

Once the PLI and RQD data are available, the range of rock properties can be mapped out on the mine plan and domains defined. Within each domain, the material will behave similarly in blasting, crushing and grinding processes while all of the domains cover the complete range of rock properties that are present. An example of defined domains is provided in Figure 6; three ore types originally classified by the operation based on lithology and grade have been mapped according to their rock strength and structure domains. Ore type A shows variable rock strength with a limited range in rock structure. Ore type B is the reverse: variable structure with more consistent strength. Ore type C is the most consistent overall with medium strength and very blocky in structure. Under the same blasting conditions, all three ore types will result in different fragmentation.
Modelling and Simulation

Rock characterisation measurements are used, along with data from site audits and surveys, to calibrate the blast fragmentation, crushing and grinding circuit models. Using these calibrated models, operating conditions such as throughput, power consumption and final grind size can be predicted based on estimates of future ore reserves and ore characterization measures, PLI ($I_{50}$) and RQD. Geotechnical drill core with measurements of $I_{50}$ and RQD can be used to populate the geological block model with estimates of mill throughput using the PTI methodology. This forms the basis for the throughput-forecasting model.

The blasting and comminution models calibrated to site operating conditions and ore characteristics are linked to model the complete blasting and comminution process. The models can simulate the performance of the process and predict key outcomes (like throughput and product size). Alternative operating strategies and conditions can be simulated and the outcomes compared to each other and the current situation to evaluate various strategies with minimal impact on the operation.

Customised blast patterns can be developed to optimise both crushing and grinding performance. For each domain, blast designs are defined to generate the optimal fragmentation size for downstream processes. This may involve an increase or decrease in energy (powder factor in the blast), depending on the rock characteristics of each domain.

The objective of any modified blast design is to minimise the overall cost for the entire process by distributing the energy required to fragment the rock mass, sensibly and effectively. Near-field vibration measurements and models are used to confirm that pit wall stability, damage and dilution issues are considered in the blast designs. In addition, the crushing and grinding models allow the impact of operational and control strategies to be investigated and optimised.

CASE STUDY: LARGE OPEN PIT OPERATION IN SOUTH AMERICA

PTI was recently involved in a PIO study at a large open pit operation in South America. Recommendations on blast design, crushing and grinding changes were implemented and preliminary results indicated a significant increase in concentrator throughput. A review of the current operating practices at this particular site revealed a number of sub-optimal conditions that are common to most operations of this size:

- An ore type classification based on assay and not rock properties resulting poorly defined rock classifications;
- Unmeasured variation in underlying rock conditions and lithologies resulting in variable concentrator performance;
- Use of a single blast design for all ore types;
- A significant change in blasting energy was required to demonstrate the effect on mill throughput.

As a result, this project provides a good case study in how many operations could benefit from application of the PIO methodology.

Process Conditions

As per normal PIO procedure, the current blasting practices and processing conditions were reviewed during the site visit phase of the PIO study. A typical ore blast was monitored including an audit of the blast design implementation (hole location, hole length, loading practices, tie-in, etc.) and ore tracking from the muckpile through the stockpiles and to the concentrator feed using the SmartTag™ system.

This operation exhibited very different blast fragmentation distributions for different ore types, and as a result, a high degree of variability in concentrator tonnages through the SAG mill circuit. The range of
fragmentation generated by the same blast design is illustrated in Figure 7 (one metre scales shown at bottom of photos). The material on the left fragmented very well – with an abundance of fines and little oversize to be crushed by the primary gyratory. This material was tracked using the SmartTag™ system and processed through the concentrator at between 4,000 and 5,000 tph. The material on the right exhibited poor fragmentation, and despite the primary crusher operating with a tighter gap, resulted in concentrator throughputs between 2,000 and 3,000 tph or almost half the rate of the finer material.

It is interesting to point out that despite the primary crusher operating with a tighter gap, the amount of fines generated in the blast still had a dramatic effect on SAG mill performance. That is, despite controlling the SAG mill feed top size, the distribution of feed in the finer fractions (especially in the size smaller than the mill discharge grate size) has a significant impact on mill performance.

The fragmentation shown in Figure 7 illustrates the effect of adopting a single blast pattern (or relatively similar blast patterns) that does not take into account varying rock properties. The first step in optimising blast fragmentation for mill performance is to understand the material properties and how they affect blast fragmentation and thus the Run-of-Mine size distribution. The second step is understanding how feed size affects mill throughput and how to modify blast design, crushing and mill operating practices to achieve optimal process performance. The third step is to ensure the integrated and optimised operating strategies are correctly implemented and maintained so that the true effect of blast design, crushing and grinding changes are revealed in the concentrator performance.

**Rock Characterisation**

The operation reviewed here defined ore types based on assay differences alone. In Figure 7 above, the material on the left had a different metal assay compared with the material on the right, Which at this site dictated that material would be processed differently, but blasting conditions are consistent regardless of ore type. The key issue here was the inability to predict how the material would fragment based on ore type or metal assays prior to actually drilling the pattern. Designing the blast pattern based on metal assay rather than rock properties resulted in a highly variable fragmentation size and mill throughput.

A review of the different ore types defined by metal assay and their associated rock lithologies revealed an interesting pattern represented in Figure 8. In this figure, the eight defined ore types were ranked (in general) from left to right from finer to coarser fragmentation (and higher to lower mill throughput). Of the eight ore types, A and F represented almost three-quarters of the expected mill feed, with the remaining six types making up the other quarter. (In Figure 7 above, the left photo was of ore type A and the right photo was of ore type F.)
Of the main lithological groups, Endoskarn and Exoskarn made up the majority of mill feed material. It was found that the finer fragmenting ore types (like A) were found predominantly in Endoskarn while coarser fragmenting ore types (like F) were found in Exoskarn. It is likely that the presence of these two lithological groups (and sub-categories within each group) is a better indicator or predictor of blast fragmentation than ore type (or metal grade) as they relate to the rock strength and structure which can be measured.

To investigate this further, drill core measurements of rock strength ($I_{50}$ or Point Load Index) and structure (RQD) were reviewed. Unfortunately, there is not an extensive set of $I_{50}$ and RQD measurements along with rock type/lithology and ore type. Figure 9 summarises the currently available data.

![Rock Strength & Structure Map for Main Lithological Groups](image)

It can be seen that the Exoskarn lithology exhibited (in general) both higher $I_{50}$ and larger RQD values.

Due to the complexity of the ore body, it is likely that each blast will contain a number of blast domains. When this occurs, there are three options to base the blast design on:

- The average rock strength and structure
- The highest rock strength and structure
- Adjust the pattern with localised rock strength and structure data.

While adjusting the pattern blast to suit local conditions is optimal for minimising cost and fragmentation purposes, it requires an accurate prediction of rock characteristics. If the rock characteristics are known prior to drilling, then a variable burden and spacing can be designed to account for harder/softer zones within the blast. If harder zones are identified during the drilling process using either a drill-monitoring system output or drill operator's logs, then the formulation and amount of explosive can be varied. In most cases, this is not very practical and instead, it is recommended to design the blast for the 'worst conditions' present.

Following definition of ore domains, specific blast patterns can be recommended to optimise both fragmentation size and overall cost for the entire operation. The set of standard blasting patterns are designed to maintain a consistent fragmentation size and therefore a consistent mill throughput. Some modified blast designs may involve an increase in powder factor while others may warrant a reduction.

**Modified Blast Designs**

At this stage of the project, blast domains are still to be defined for this operation. However, using the modelling and simulations tools available, PTI recommended a modified blast design for the expected “difficult to blast areas” of the pit as illustrated by the right photo of Figure 7. Table 1 summarises the current (or historical) blast pattern along with the modified pattern recommended for difficult zones to improve fragmentation. With a tightening of the pattern, the powder factor increased by 41% and the drill and blast cost per tonne increased by 40%. Fragmentation modelling and simulations predict a finer 80% passing size (P80) of 175mm compared with 401mm and an increase in the –25mm fraction of 14%.

**Preliminary Blast Trial Results**

Following PTI's recommendations, the operation is currently trialling the modified blast design in the recognised difficult zones.
Figure 10 shows two images of the muckpiles resulting from the modified blast (with one metre scales). These images can be compared with historical results shown in the right hand photo of Figure 7. The photos clearly demonstrate the effect of the higher powder factor along with some changes in stemming length and explosive formulation. Measurements of the fragmentation using image analysis confirmed the model-predicted P80 of 175 mm and the mine reported a significant increase in shovel productivity.

![Figure 10. Resulting Fragmentation from Modified Blast](image)

This material was stockpiled, tracked and processed separately through the concentrator with impressive results. Figure 11 shows a trend of SAG mill tonnage over time before, during and after this modified blast material was processed. For the entire period shown, the ore type was the same and was mined from a similar area of the pit. The values in Figure 11 show the mill tonnage increased from 3,500 to 4,000 tph before to around 5,000 tph for the modified blast material. With the stockpile depleted and normally blasted material sent to the concentrator, tonnage returned to below 4,000 tph.

The increase in mill throughput was 25 to 40%, exceeding all expectations and more than compensated for the 8c/tonne higher blasting costs.

![Figure 11. Trend of Concentrator Tonnage During Modified Blast Trial](image)
SUMMARY

The PIO methodology developed by PTI has been applied at a large open pit operation in South America. This PIO study revealed that rock lithology was closely associated with rock strength and structure, and therefore also with blast fragmentation and consequently concentrator throughput.

An ore characterisation study is ongoing to collect drill core measurements of rock strength and structure for different rock types and further refinement of rock domains. The results of this study will allow a series of standard blast patterns to be designed for each strength/structure or blasting domain. The set of standard blasting patterns will be designed to maintain a consistent fragmentation size and therefore a consistent mill throughput. Some modified blast designs may involve an increase in powder factor while others may warrant a reduction.

Until the ore characterisation program and subsequent blast patterns are designed, a modified blast pattern has been designed and implemented for “difficult” ore zones. Implementation of the modified blast design and improvements to the operation of crushing and grinding circuits have resulted a significant increase in concentrator throughput. The trial of the modified blasting pattern resulted in an increase in mill throughput of 25 to 40% for the material found to be more difficult to fragment and process. This tonnage increase more than compensated for the higher blasting costs.

A number of conditions present in this case study are common to many large mining operations:

- An ore type classification based on assay and not rock properties;
- Variation in underlying rock conditions and lithologies resulting in variable concentrator performance;
- Use of a single blast design for all ore types;
- A significant change in blasting energy is required to demonstrate the effect on mill throughput.

This suggests that there is potential for many sites to benefit from the application of the PIO methodology similarly to the site in the case study presented.

REFERENCES


