PAPER

EXPERT SYSTEMS IMPLEMENTATION AT PEÑOLES GROUP CONCENTRATORS

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ABSTRACT

SGS implemented two rules-based fuzzy logic expert applications on two grinding circuits operated by Peñoles Group in Mexico. Both expert systems are based on control strategies that push against process constraints to improve throughput. Based on proven methodologies, the projects also required some new approaches that led to permanent changes to the mill control strategy.

This paper provides descriptions of the implementation, operation and performance of both expert systems. It also reviews how improved production rates were achieved through the use of a common set of expert technology tools. An overview of the resulting control strategies implemented on the two circuits is presented. The paper also discusses the identification of the process constraints within each circuit and how these constraints are used within the expert systems.

INTRODUCTION

Mexico-based mining company Peñoles Group and the Advanced Systems group at SGS, formally known as MinnovEX Technologies Inc., collaborated on the implementation of two expert systems in two grinding plants, both located in Northern Mexico.

The primary objective of the expert systems was to increase throughput whilst still maintaining the cyclone overflow product size within an acceptable range. The secondary objective was to achieve a high level of utilisation of the expert technology.

In order to achieve these objectives, SGS proposed a proven methodology which leveraged the existing operating and technical expertise at site through the client's involvement in the design and implementation stages. The in-house operating and technical expertise of SGS was also brought to the project and implemented with the client's approval at all stages. At both sites the final acceptance was defined upon meeting both process and utilization parameters.

The development and deployment of rules-based fuzzy logic applications has matured as a technology and consequently, clear definition of process states and their place in the logic structure to control a given circuit are now transferable. The key to the robustness of the control logic depends on selection and tuning rules for maintaining stability and optimizing a given circuit. Application integrators need to have a standardized approach for timely integration and deployment; a critical component to avoid the common critiques that expert applications are idiosyncratic and difficult to maintain.

The paper also highlights the implementation of compensating techniques for addressing a very common situation in today's plants – deficiencies in instrument calibration and availability. It is often cited that a strong instrumentation base is required for a robust supervisory control scheme, a true statement; however validation techniques and use of software sensors can compensate for deficiencies. The SGS team employed an additional set of logic to validate and partially replace

measurements such as density gauges and particle size analyzers.

The state of today's expert systems technology was proven effective on small size operations as the two circuits described in this paper, which dispelled the notion that such technology only lends itself to large scale concentrators.

CIRCUITS DESCRIPTION

Primary Ball Mill Circuit

A flowsheet of the primary ball mill circuit is shown in Figure 1, indicating the various control loops and process measurements available to be utilized by an expert system.
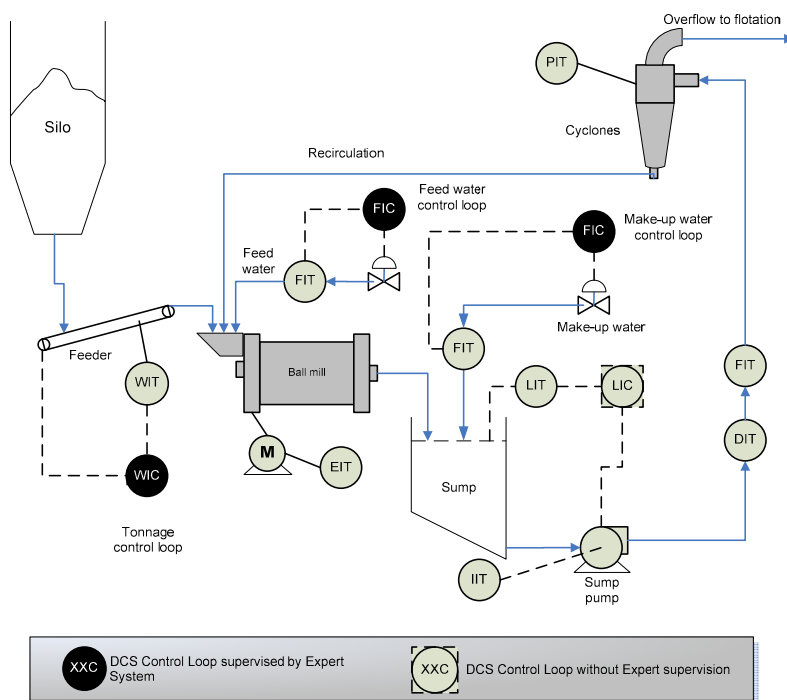

Figure 1: Primary Ball Mill Grinding Circuit

The circuit consists of two identical primary ball mills running in parallel with an overall processing capacity of 2500 TPD. Each ball mill has a single cyclone classification stage with the overflow product reporting to a downstream flotation circuit. A particle size analyzer is also installed on the cyclone overflow.

The different variables utilized by the Expert System as manipulated variables are indicated in Figure 1, which include the mill feedrate, feed and sump water addition. The reliability of some instrumentation installed on the circuit was found questionable, in particular the density measurement of the cyclone feed and the particle size measurement of the cyclone overflow.

SAG/BM Circuit

Flowsheets of the second grinding circuit are shown in figures 2 and 3, also indicating control loops and installed instrumentation.
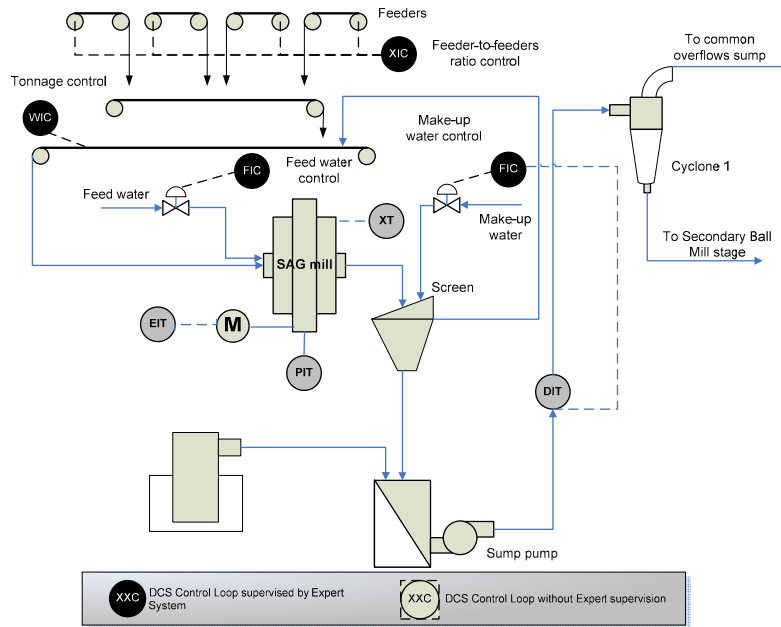

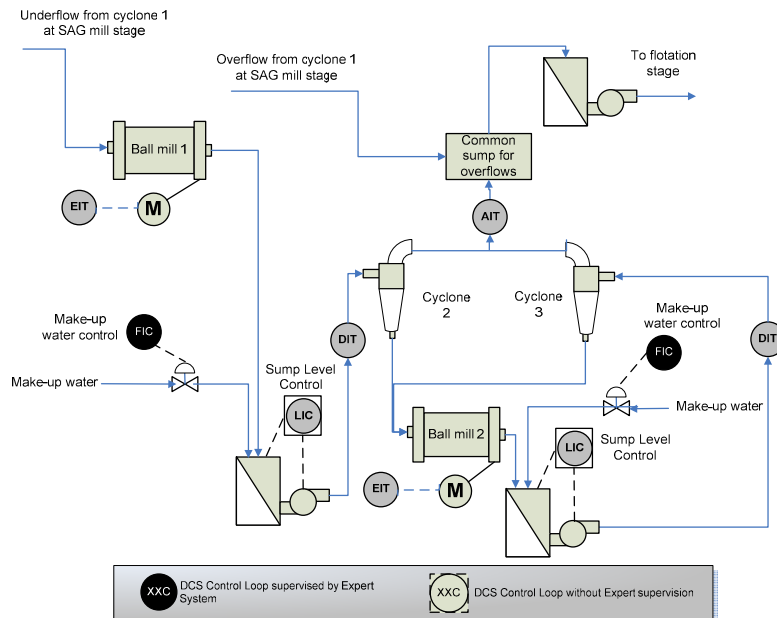**Figure 2: Primary SAG Mill – SAG/BM Circuit**

Figure 3: Secondary Ball Milling Stage – SAG/BM Circuit

The overall SAG/BM circuit consists of a SAG milling circuit, followed by a secondary and tertiary grinding stage utilizing two ball mills.

The SAG/Ball Mill Circuit has an overall processing capacity of 2300 TPD. A 20.0 ft x 7.5 ft, 1500 HP fixed speed SAG Mill is fed with ore coming from four feeders. As a result of the natural size segregation occurring on the feed stockpile, the feeders can be utilized by the expert system to manipulate the ratio of coarse to fine ore.

The secondary grinding stage consists of a ball mill fed with material coming from the SAG circuit. Finally, a tertiary grinding stage consisting of a ball mill in closed circuit is fed from the secondary grinding stage. The secondary and tertiary ball mills have individual classification stages where the cyclone overflow reports to a common overflow sump before being pumped to the flotation stage.

DESIGN, DEVELOPMENT AND DEPLOYMENT OF EXPERT SYSEMS

The methodology for the implementation of both expert systems was inclusive, progressive and combined the technical expertise of SGS with the client's operational knowledge to ensure the sustainability and longevity of the systems. The full life-cycle of the expert system implementation is based on the following three steps:

Knowledge Capture

This is the design stage where the circuit's process states are identified and the rules that will be implemented in the control strategy are defined. The ability of the field instrumentation in achieving the stated objectives of the control strategy are also critically reviewed, in particular the reliability of measured variables utilized in the expert system.

The knowledge capturing process is initiated with an interview process in which the SGS team meet with operations personnel (e.g. superintendents, control room operators, shift supervisors, electricians, senior metallurgists) to review and discuss their current operating practices and propose alternative strategies. Critical variables such as mill power draw, mill discharge density, cyclone feed density, cyclone pump amps, etc are analyzed and a consensus on their use to define process states is carried out.

The main deliverable at the end of the interview process is a complete set of logic for both expert systems, as well as a functional specification for interfacing with the sites' control systems. A clear and concise documentation of the rules must be approved and is then reviewed to identify each component within the coded application.

During this stage all critical measurements are validated – on this project it was noted that the density on the ball mill cyclone feed and the particle size of the overflows were often noted to be unreliable. An analysis of the data showed that these readings could be validated and modeled using other process variables. State of the art expert technology includes data validation

techniques as standard and must allow for easy deployment of models. With the client's approval these compensating techniques became part of the final design.

Installation of Application – Set up of interface and initial tuning

Once the client has set up the interface as per the functional specification, the connectivity is tested and consequently, the manipulated and measured variables are checked for proper validation and filtering so as to provide inputs to the logic. After completion of these commissioning checks, the application tuning can commence.

During tuning, site feedback was a key factor to confirm all logic. The initial collaboration with the site personnel with a "live" application often uncovers additional opportunities for improvement. Often these opportunities involve secondary readings such as sound measurements of a SAG mill; new constraints may become apparent as tonnages are increased beyond the typical comfort zone.

The tuning of the SAG logic provided a clear advantage for stability with automation as the maximum tonnage limit was raised by 20% above that typically considered "safe" during manual operation.

Training of the operators and administrators starts during this visit. Operators are shown how to interact via the regulatory control system and administrators, with SGS in the control room, assist in the tuning of the application. At the end of this stage the application will run with the on-site assistance of the administrators and a period of testing begins.

Final tuning of Application

The third and final stage in the process is to finalize the tuning and complete the training. The expert operating trends and data are reviewed and the logic is analyzed for possible "holes" – the latter is a statistical analysis that can indicate that some operating states were not properly accounted for in the logic.

Once training is completed, the process of project handover begins. The rules were reviewed with the client against the original design, redlining changes. With the application contents confirmed and the fine tuning completed the expert system is ready for acceptance testing. Following the final site visit, testing begins based on the acceptance criteria such as Key Performance Indicators (KPIs) as agreed to with site personnel.

OVERVIEW OF EXPERT STRATEGY

Primary Ball Mill Circuit

The control strategy implemented on the circuit utilizes a hierarchical structure to ascertain the current operating state of the process. Control actions are then executed by the system based on

the currently identified state, thereby ensuring that conditions of highest priority are corrected earlier. A schematic representation of this process is shown in Figure 4.
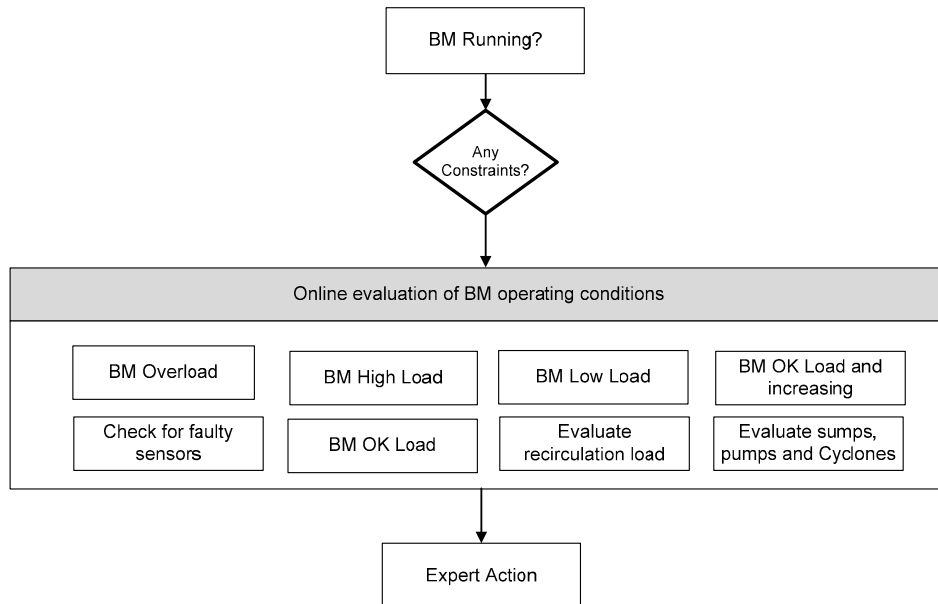

Figure 4: Primary Ball Mill Expert Logic Overview

The first state in the hierarchy is used to confirm whether the ball mills are operational and available, and no control action is taken if this state is false. If this state is true, the control system will continue to evaluate downstream operational states, and any associated control actions will be implemented whenever a true result is achieved.

 For the ball mill circuit, several measurements are considered when defining the process states:

- Power draw
- Mass flow to cyclone
- Sump level
- Mill discharge % solids
- Cyclone feed %solids
- Cyclone overflow particle size

The state of the ball mill load is determined using these process variables in a rules based evaluation hierarchy. For example, a high mass rate to the cyclone can imply a high load but if the overflow particle size is on target then less weighting is given to the high mass situation. This means that the expert fuzzy logic response will be mitigated by the presence of an on target, validated, overflow particle size.

The control actions associated with each process state are also designed to be implemented in a hierarchical structure. The system does not only utilize absolute process values in determining the appropriate control action to apply, but also considers the rate of change of important process

variables. Therefore, an upward trend in mill load can first be addressed by manipulating water flows before reducing the mill feed tonnage. This ability to prioritize control actions based on a variety of operating conditions makes the expert system flexible enough to provide appropriate actions for different operating scenarios as identified in the hierarchy.

During "overload" situations, the expert system will implement control actions based on the current power draw, circulating load levels and rates of change values. The control actions range from a partial flushing without a feed tonnage decrease, to a feed tonnage reduction with a full mill flushing. The use of multiple actions ensures that the appropriate control action is taken in relation to the severity of the condition.

Once the evaluation reaches the "OK Load" state, the expert system will attempt to optimize and increase tonnage with solid confidence that the recirculation load is not increasing. The expert will simultaneously verify that other key variables such as power draw, sump pump amps, cyclone feed density, etc are stable. In scenarios where densities are out of range, the expert system will correct the situation by modifying the water addition at the ball mill feed end or cyclone feed sump and also; verifying in parallel the stability of variables such as cyclone O/F particle size, recirculation load, sump levels and pump amps.

Finally, the "Low Load" state considers high ball mill power draw. In this state, the feed tonnage increase applied by the expert system is more aggressive when compared to the "OK Load" state since the Expert is 100% certain that the circuit is underloaded.

A "secondary" set of logic was created to validate cyclone feed density and cyclone O/F particle size by automatically detecting instrumentation problems and reacting appropriately to the problem. The secondary logic uses a combination of variables such as pump current, sump level and ball mill power draw to estimate density and particle size on a relative basis under scenarios where the actual instrumentation is unreliable.

SAG/BM Circuit

The SAG mill expert strategy was defined using a set of mutually exclusive power/load state definitions arranged in a matrix for the entire set of SAG operating conditions. This matrix is schematically depicted in Figure 5. The matrix considers the state (high, ok, low) and the trend (increasing, stable, and decreasing) of both the mill power and pressure. This approach created around forty rules. Each rule first considers the state of the sag mill solids and the possible presence of downstream constraints (flotation constraints or ball milling constraints) before implementing a control action.

The use of a dashboard view (Figure 6) easily allowed the identification of the process state and the rules that would be implemented next – this visibility is critical to properly tune the SAG rule base.
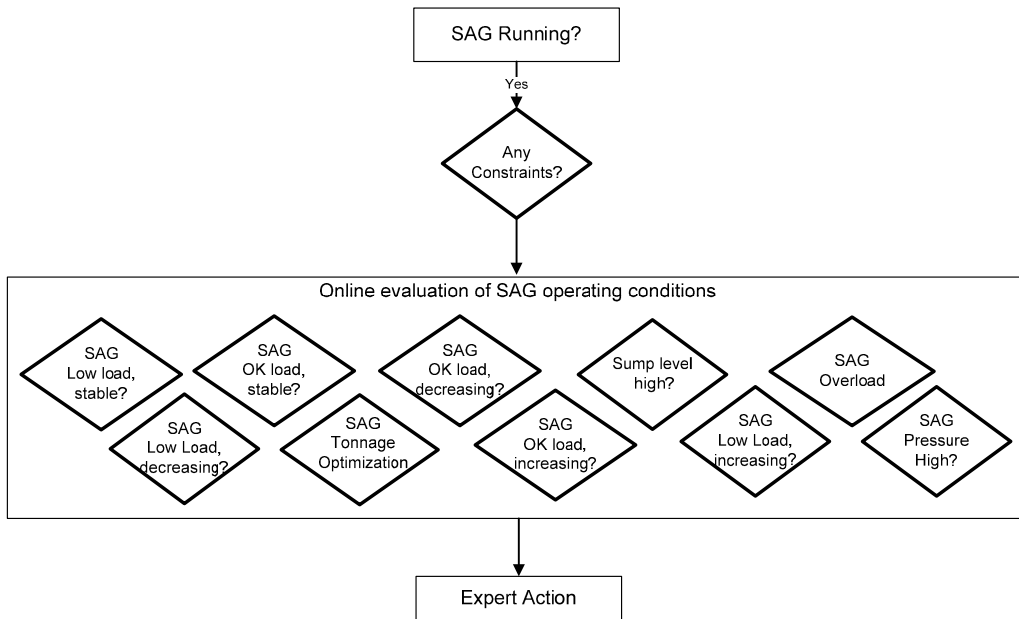
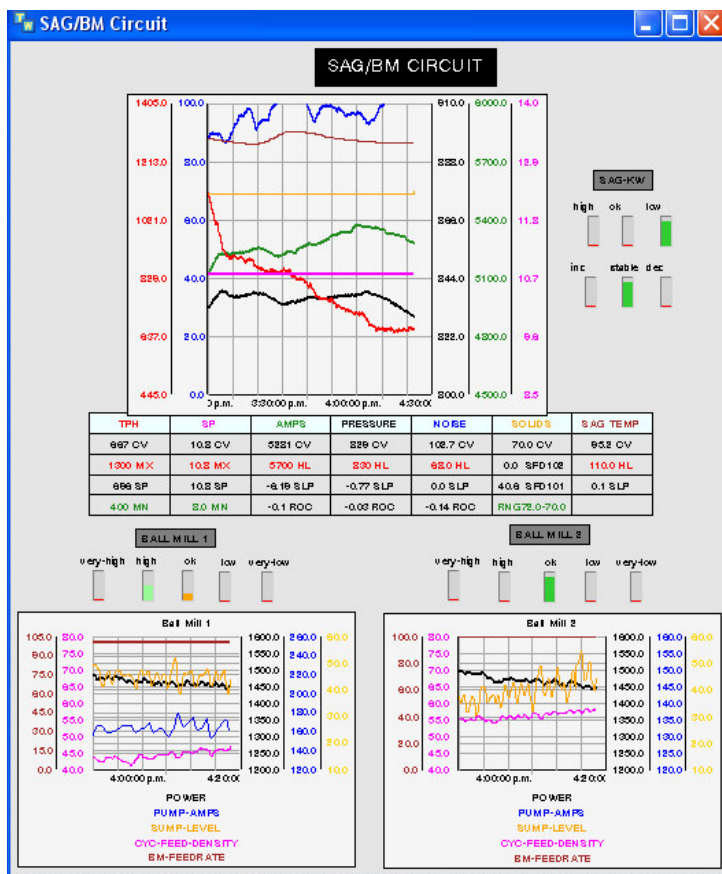**Figure 5: SAG/BM Circuit Expert Logic Overview**

Figure 6: SAG/BM Circuit Expert Dashboard

The expert logic was designed to implement multiple actions based on different operating scenarios. For instance, when the SAG power draw is increasing and high, the first option considered by the expert would be to change the coarse-to-fine ratio of material coming through the feeders. The second option would be to adjust the feed water and the third and final option would be to reduce tonnage in a timely manner.

The expert logic used for the SAG/BM circuit considers downstream and upstream constraints. These constraints interact directly with other logic states to prioritize expert actions when one of the constraints is activated. All constraints considered during the expert design are the direct result of previously identified operational requirements.

The overall structure for the states of the first and second ball mill is comparable to that of the Primary Ball Mill Circuit (Figure 4). However the first ball mill is an open circuit and its control was closely associated with the SAG mill load state to ensure responses to changes in the feed solids and rate so as to stabilize as much as possible the slurry density in this mill. The second ball mill contains a circulating load and subsequently its actions had to respond to the SAG load states as well as eventual high solids loading of the closed loop.

RESULTS

A summary table (Table 1) shows a substantial throughput increase in both plants with 6.3% and 5.0% for the Primary BM circuit and the SAG/BM circuit respectively. The system utilisation in both circuits was also higher than 90% of the time the grinding circuits were available for advanced control operation.

Table 1: Results for both plants

Circuit	TPH Without Expert	TPH With Expert	% Increase throughput	% Usage
Primary BM Circuit	99.3	105.6	6.3%	>90%
SAG/BM Circuit	93.0	97.5	5.0%	>90%

The high utilisation percentage is a direct result of two key elements, the hands-on training provided to operations personnel and the performance of the expert logic when controlling both circuits. The training component allowed operations personnel to understand the expert logic and its functionality; consequently, operations personnel became aware of the inherent capabilities of the expert system and were also able to understand its decision-making criteria.

Primary Ball Mill Circuit

In terms of the achieved benefits in this circuit, Figure 7 shows the differences in throughput for the on-line and off-line periods:

- **On-line** throughput: **40%** of the time > 110 TPH
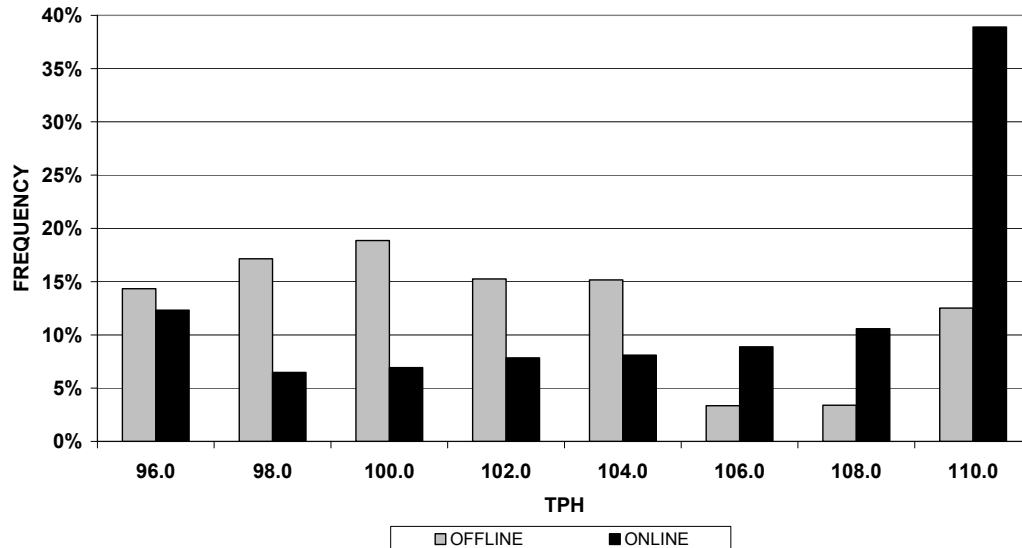- Off-line throughput: 12% of the time > 110 TPH.

Figure 7: Expert On-line vs. Expert Off-line (Primary Ball Mill Circuit)

As seen in Figure 7, off-line throughput was considerably lower and with greater variability. On the other hand, on-line periods show a more consistent and higher production rate being achieved by the process.

The data used for the analysis of this circuit was collected over a period of three months. It should be also highlighted that differences in Ore Hardness between the OFF and ON periods were marginal.

SAG/BM Circuit

Figure 8 shows the results based on four months worth of data, which was collected during the testing period of the expert system with the following results:
- **On-line** throughput: ranging between 66 to **150** TPH, **30%** of the time > 106 TPH.
- Off-line throughput: ranging between 66 to 125 TPH, 9% of the time > 106 TPH.
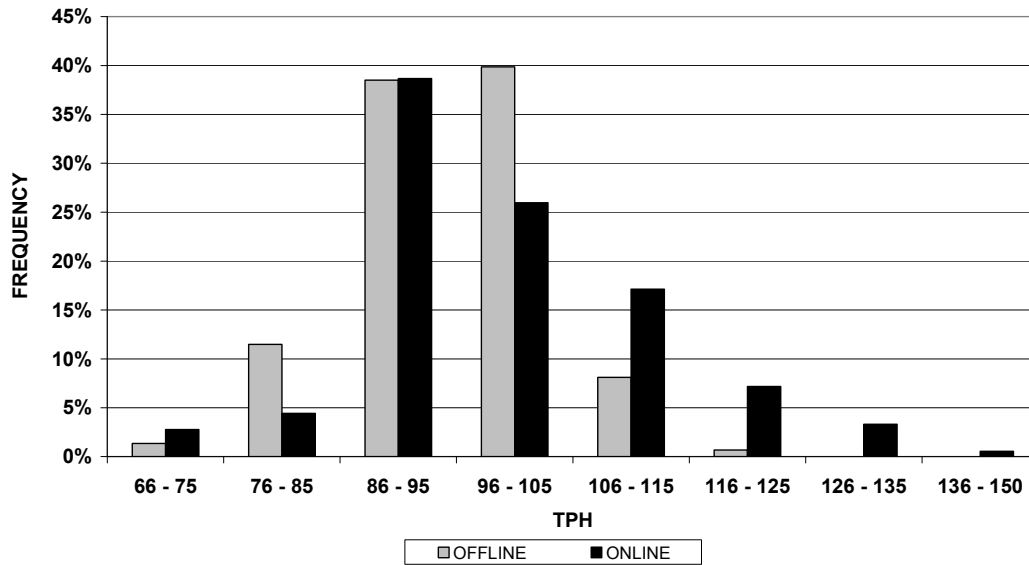
Figure 8: Expert On-line vs. Expert Off-line (SAG/BM Circuit)

Figure 9 shows cyclone overflow particle size during the on-line and off-line periods. The target size was specified by the client to be between 60% and 75%. Results show a marginal difference between ON and OFF periods and at the same time, the particle size standard deviation was lower when the expert system was controlling the circuit. Additionally, enhanced cyclone management was achieved by having more stable cyclone feed.
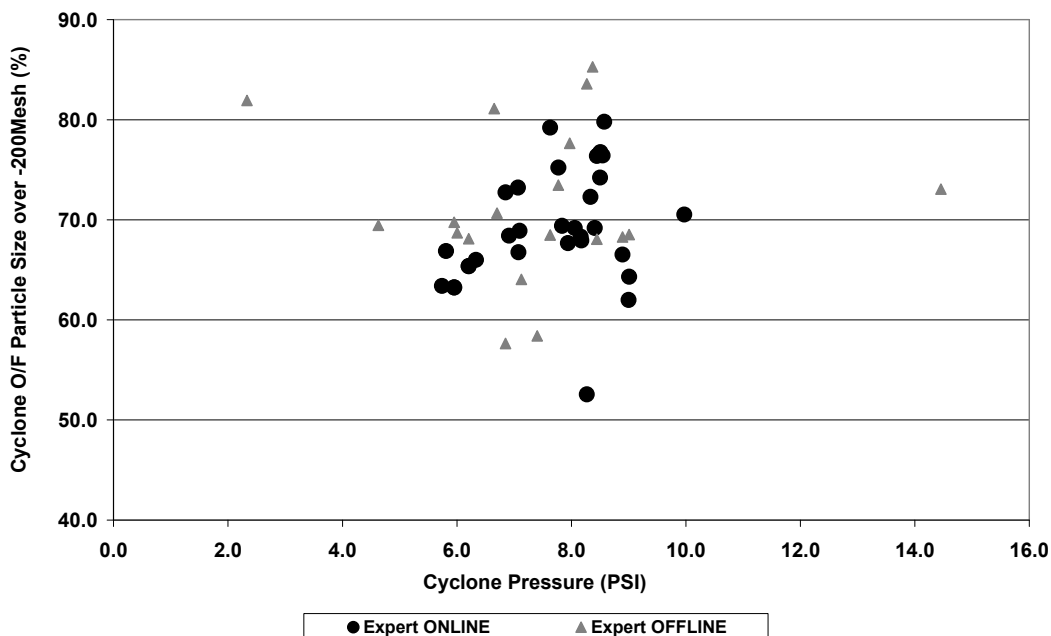

Figure 9: Grinding Product Size – Expert On-line vs. Off-line

CONCLUSIONS

- On-line versus off-line periods showed an average improvement in throughput of 6.3% and 5.0% for the Primary BM and SAG/BM circuit respectively.
- The expert system was able to achieve greater throughput by keeping grinding product within specified size ranges and consequently no negative effects on flotation recovery were realized or reported.
- The proposed expert control strategy provided a standardized process for the operation of both grinding circuits and consequently assisted in the reduction/elimination of inconsistencies in operating practices between shifts.
- Site training led to an enhanced understanding of the expert structure by site personnel, resulting in a greater degree of acceptance by operational personnel at all levels (e.g. >90% utilisation).
- The proposed methodology of working closely with the client at all levels during the design of the expert system led to an effective implementation.

ACKNOWLEDGENENTS

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