EXPERT CONTROL OF CRUSHING CIRCUITS AT BARRICK SOUTH AMERICA

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ABSTRACT

In 2008/2009, Barrick Gold Corporation in collaboration with the Advanced Systems Group at SGS implemented expert process control logic on three crushing circuits located in South America. The objective of each application was to improve throughput and stability by automating the steady-state ore crushing for 3 heap leaching operations. The implementation was carried out with the use of existing instrumentation and control logic, interfacing with MEC Crushing Expert technology. The MEC (MET Expert Console) platform was selected by Barrick due to its proven robust control capabilities, plus guaranteed technical support by the local SGS team of integrators with process and control expertise. A combined team of engineers from each of Barrick's operations and SGS designed and commissioned the expert systems. The logic structure used in all three experts was similar; with the lessons learned on one site passed onto the other sites. Each operation achieved its crushing performance goals with over 3% production gains. The capture of each site's operating practices was a key factor of the success.

INTRODUCTION

Barrick considers expert control as a tool for performance improvement of their operations. In 2008/2009, Barrick Gold Corporation, in collaboration with the Advanced Systems Group at SGS, implemented expert process control on three crushing circuits located in South America. The primary goals of each of these systems were to increase tonnage rates and improve the process stability.

Expert control was chosen because of the proven success in modeling and improving the performance of processes subjected to a high degree of variability. All crusher experts were designed with proven algorithms for responding to variations in ore types, configuration changes (running one or two crushers) and equipment wear conditions. In addition to these variations it was also required to handle multiple moving or temporary constraints within a circuit – such as bin levels, motor protection settings and idiosyncratic conditions such as frozen ore clumps in winter time or increased moisture during the summer. This paper will present in some detail the logic structure and algorithms utilized to address these in the three crushing circuits.

The paper also reports on the impact that the crushing experts had on the unit operations from the point of view of acceptance and added benefits. The projects were completed in a sequential manner in a relatively short period of time (less than 2 years).

The expert applications were built using SGS proprietary MEC (MET Expert Console) technology that runs on Gensym's G2 inference engine platform. Connectivity to the existing control systems was via OPC. The MET Expert Console provides a structure to easily interact with the control room operators and also, with the production process via the existing DCS or SCADA/PLC.

The crushing experts were deployed on the primary/secondary crushers' circuit of the Lagunas Norte, Peru; Veladero, Argentina and Zaldivar, Chile operations.

OPERATIONAL DESCRIPTION

Barrick Lagunas Norte

The Lagunas Norte Mine is located in the Alto Chicama Mining District in north-central Peru (Province of Santiago de Chuco, District of Quiruvilca, Department of the Libertad), 140 km east of the coastal city of Trujillo. The property is situated in the Peruvian Andes Mountains at an elevation of 4,200 meters above sea level.

Lagunas Norte's nominal tonnage is 62,000 TPD and it is comprised of an open pit mine, a primary and secondary crushing facilities, two waste rock storage areas, a geomembrane lined heap leaching facility, process and storm water pond systems, an acid rock drainage treatment plant, a barren solution treatment plant that uses the SO2 process, and a Merrill Crowe processing plant that recovers gold, silver and mercury as a by-product.

The open pit mine has been developed by conventional mining methods using trucks and loaders to extract gold-bearing ore. The waste is transported by trucks to either the west or east storage areas designed specifically for this purpose. Ore is placed on the heap leach facility by truck.

The primary crushing facility (Figure 1) is comprised of a single dump ROM bin, a 50x65" 500 HP gyratory crusher with a designed capacity of 3000 TPH, a rock breaker, a surge bin, and a 6'x23' 100 HP apron feeder loading material on a conveyor fitted with a weightometer. The rock breaker is operated manually and not controlled from the PLC. Additionally, ultrasonic sensors are installed at the dump ROM bin to monitor bin level and to detect truck presence and tipping.

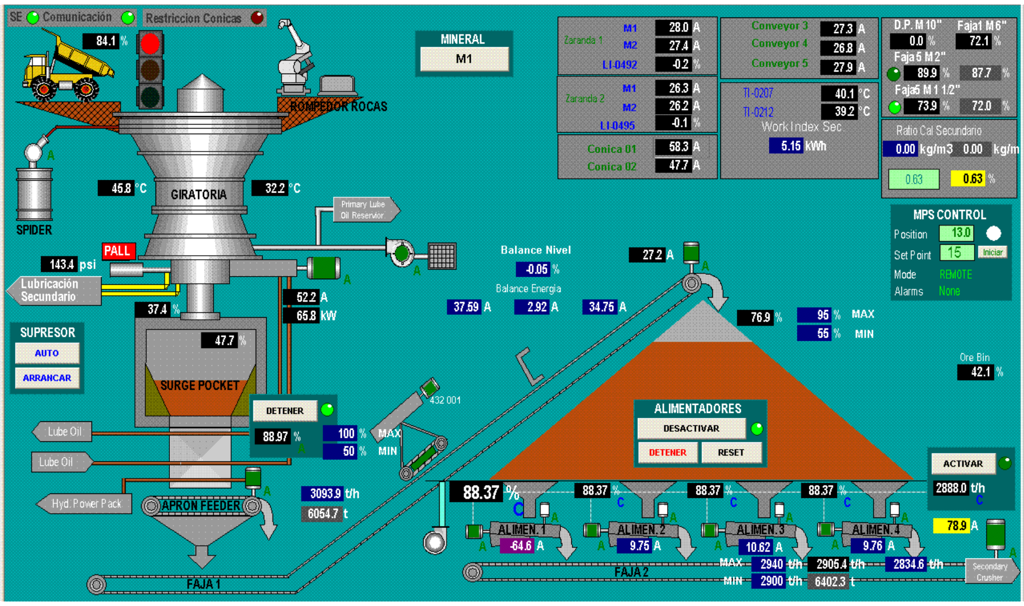

Figure 1 - Lagunas Norte's primary crushing facility

The secondary crushing facility (Figure 2) is comprised of four 5 HP vibratory feeders, a feed conveyor, two 800 HP Nordberg cone crushers, a load splitter and two 40 HP double deck vibratory screens under each secondary crusher. An ultrasonic level sensor is also installed at the top of each crusher to measure cavity level.

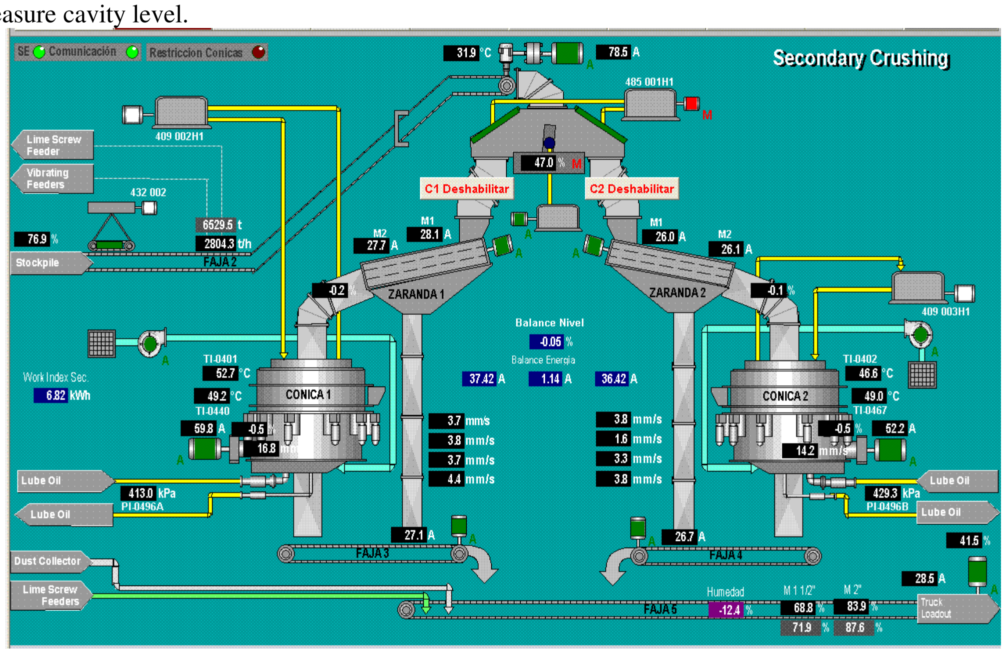

Figure 2 - Lagunas Norte's secondary crushing facility

Barrick Veladero

The Veladero high-sulphidation disseminated gold-silver deposit is located 375 km North West of the City of San Juan in Argentina. The mine life is estimated to be 13 years with proven resources of 6.8 million ounces.

Veladero's nominal tonnage is 60,000 TPD and it currently produces ore from two open pits with variable silica content (i.e. from 25% up to 95% silica content) which results in fairly variable ore hardness depending on the pool source of mineral. The operation uses hydraulic shovels, trucks, and drills. Ore is crushed by a two-stage crushing process, and is then transported by means of trucks to the leach pad area. Run-of-mine ore is trucked directly to the valley-fill leach-pad. Recovered gold is smelted on site and shipped to an outside refinery for processing into bullion.

The Primary crushing circuit (Figure 3) consists of a single 50"x75" METSO gyratory crusher with an installed capacity of 2,800 TPH. Material crushed in the primary crusher is then dumped into a temporary pocket. An apron feeder supplies material from the surge pocket to a primary belt conveyor, which finally dumps the crushed material onto the Primary stockpile.

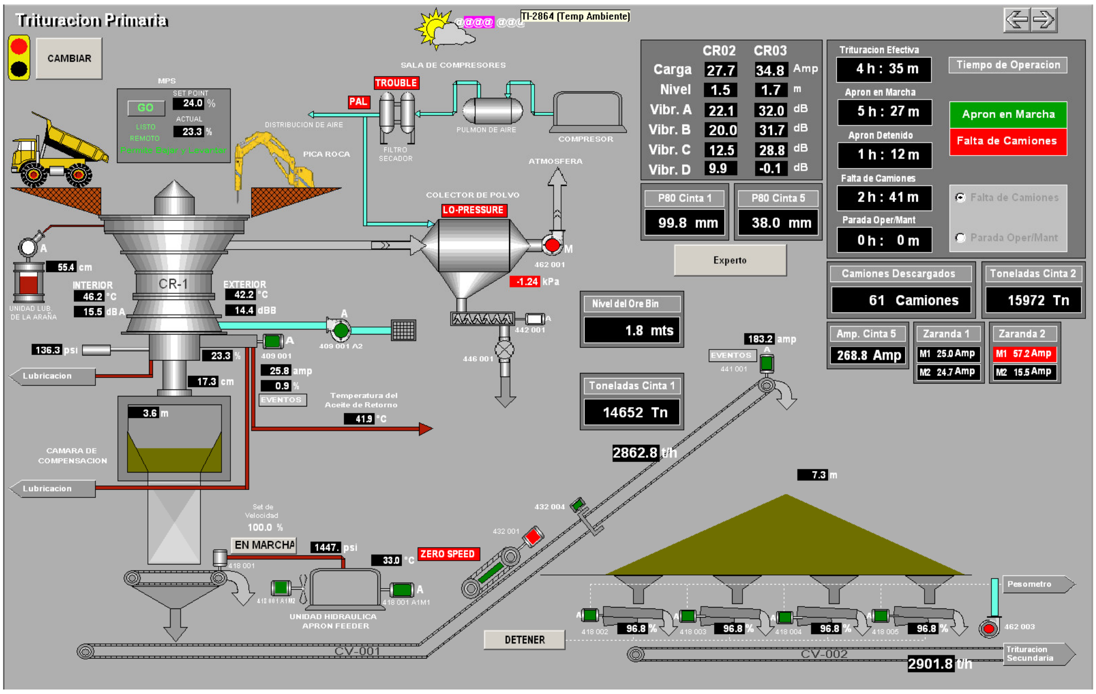

Figure 3 - Veladero's primary crushing facility

The design of the Lagunas Norte and Veladero's secondary crushing circuits are very similar. However, equipment differences are observed as each plant has a different processing capacity. The secondary Crushing circuit (Figure 4) has four 48"x100" LG vibratory feeders located underneath the Primary stockpile. The material fed through the feeders is transported to two 800 HP Metso cone crushers installed in parallel.

A moving splitter (i.e. load car) distributes load from one crusher to the other, depending on crusher power draw levels. A double deck vibratory screen is located under each secondary crusher with an installed capacity of 1200 TPH. The screen opening is 4".

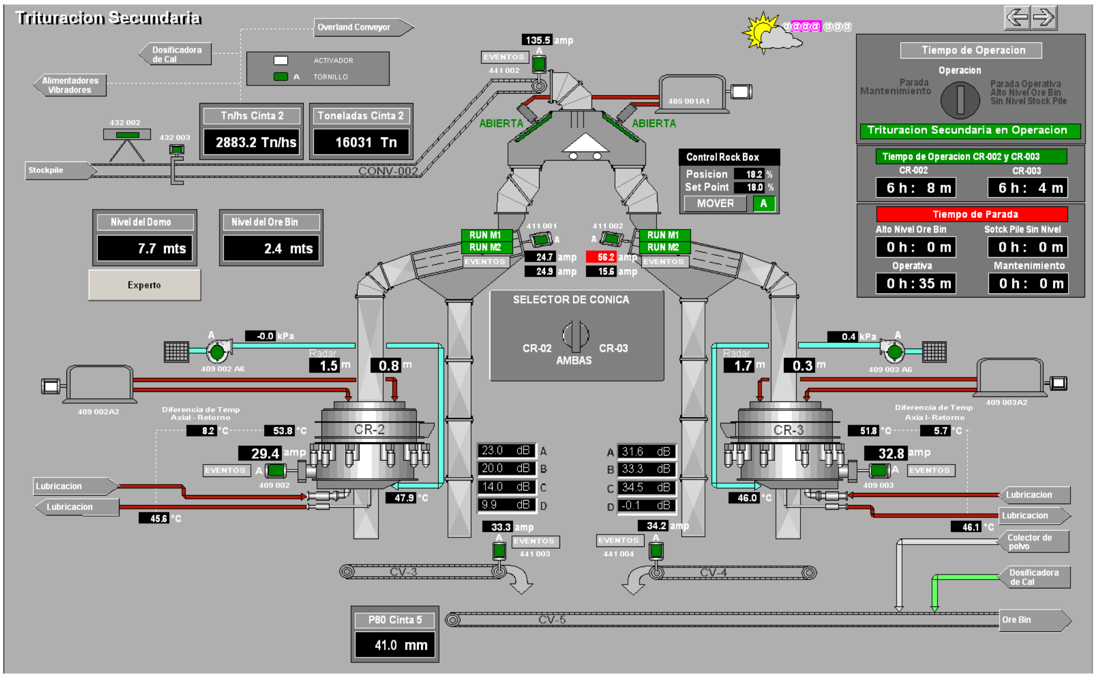

Figure 4 - Veladero's secondary crushing facility

Barrick Zaldivar

The Zaldívar copper deposit is located in northern Chile, approximately 1,400km north of Santiago and 180km east of the port of Antofagasta at an altitude of 3,300m. The main minerals are chalcocite, brochantite and mixed sulphide, and oxide copper minerals.

Zaldívar's nominal tonnage is 70,000 TPD and it uses conventional open-pit mining systems. The ore is hauled to the primary gyratory crusher and the discharge is fed to two secondary cone crushers and then, to a tertiary crushing stage. Final crushed ore is screened and sized to remove fines, which are effectively stacked on a leach pad.

The coarse crushed ore is transported by conveyor belts to a heap-leach operation to dissolve the copper using chemical and bacteriological agents. Copper is recovered from the oxides by sulphuric acid in the circulating leach solutions, and from sulphides by bio-leaching using bacteria naturally present in the ore.

A solvent extraction plant concentrates and purifies the dissolved copper in the leach solutions. The use of solvent extraction mixer-settlers recovers 90% of the copper from the pregnant leach solution. The remaining 10% is recycled to the heap leach. An electro-winning plant produces high-grade, high-quality cathode copper.

PROBLEM CONTEXT AND THE EXPERT SOLUTION

Barrick Lagunas Norte

Primary Crushing

The Lagunas Norte expert system was designed to improve the stability of both the primary and secondary crushing facilities. In the primary crusher, the expert achieves stability by monitoring the type of material, level of the surge pocket and the stockpile level. Here the application acts both as an advisor and to manipulate the primary stockpile feeder. The overall logic is shown in Figure 5.

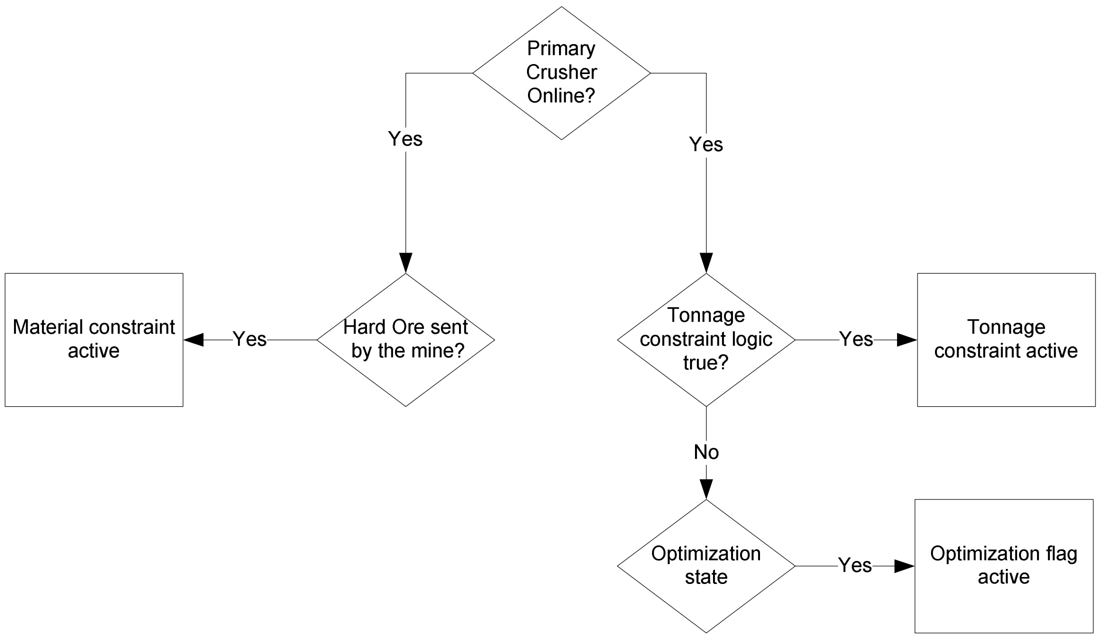

Figure 5 - Overall logic tier for Lagunas Norte's primary crusher

The left side of the overall logic diagram described above defines "hard" ore as either simultaneous high and increasing crusher power levels and coarsening crusher product size or simply coarse crusher product size. The crusher product size is determined by a SPLIT camera system located above the stockpile feed belt. Once ore is defined as "hard" the material size constraint is activated and a recommendation is passed to the Control Room Operator advising to adjust the primary crusher closed side setting.

The tonnage constraint logic (Figure 6) becomes active when the stockpile level is high and increasing, or when the surge pocket levels are high and increasing. Operational requirements state that the surge pocket level should always be kept within a given range. Levels above this range represent a risk of increased truck waiting times by overfilling the surge pocket, and levels below this range pose a risk of equipment damage due to material falling directly on the feeder.

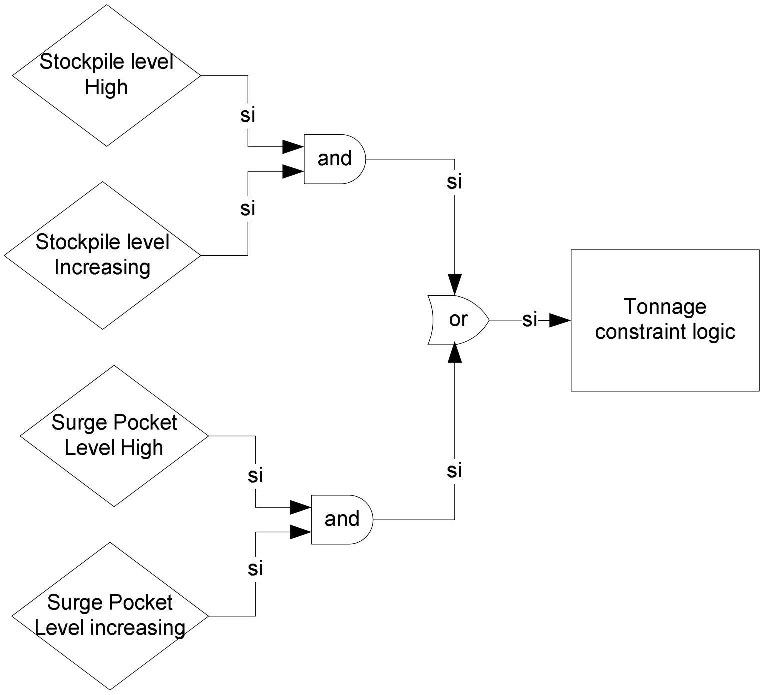

Figure 6 - Primary crusher's tonnage constraint logic

The optimization logic becomes active whenever the primary stockpile levels are within acceptable ranges and the surge pocket is either low or OK and not increasing. Once the optimization flag is active, the expert system will send messages to the DCS advising the control room operators to increase the frequency of hauled ore trucks coming from the mine pit.

There are also equipment protection rules to ensure critical equipment is maintained within acceptable operational limits; for instance, temperatures are continually monitored in the primary crusher and with any sudden temperature spikes, the expert system will send an advisory message to the control room operator requesting a review of the equipment and to increase the proportion of soft material in the mine blending.

Secondary Crushing

The Secondary Crushing plant logic (Figure 7) strives for balanced loading of the two secondary cone crushers by monitoring crusher power draw, crusher vibration and double deck screen current draw, and vibration.

An online calculation of the difference in secondary crushers amps draw provides the main indication of load distribution. The rate of change of the difference in amps drives a fuzzy logic load distribution controller that sets the position of the feed splitter.

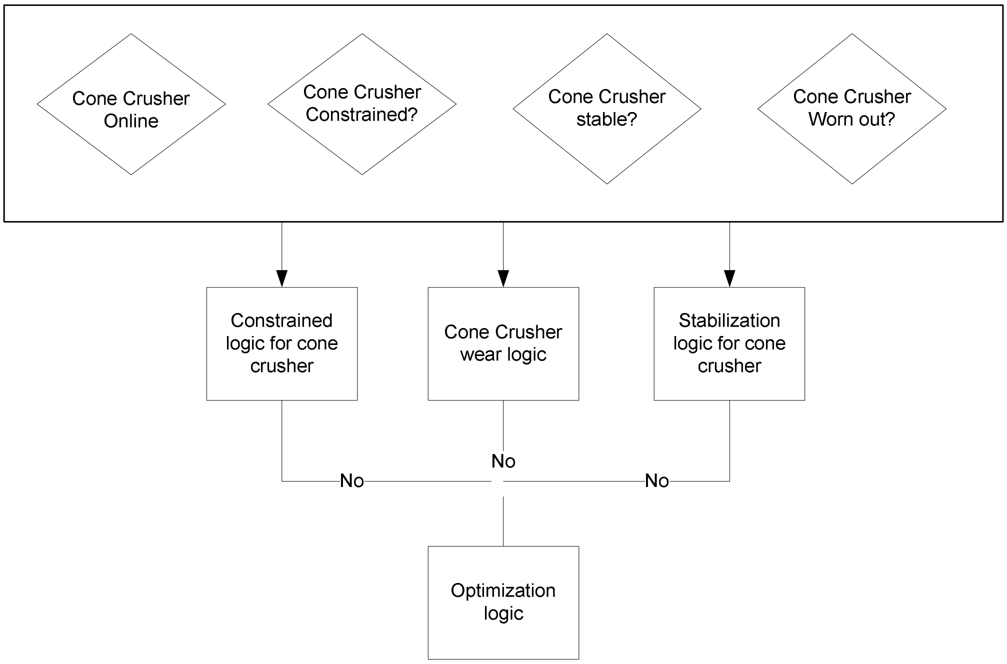

Figure 7 - Secondary crushing plant's cone crusher logic

This logic works with a multi-state manager function that can vary the magnitude of its actions depending on the wear of a crusher's mantle. Operators indicate via a selector in the DCS screens when a crusher mantle is worn. With one worn crusher selected, the tuning parameters will favor the healthier crusher through the positioning of the splitter also the magnitude of the tonnage step changes will be reduced. With two worn crushers, the expert tuning parameters change so as to act sooner and more aggressively to indications of overload conditions.

During normal operation the expert may flag a crusher as "constrained" – see Figure 8. The constrained crusher state indicates that at least one of the following is "high and increasing": crusher power, thermal capacity, crusher bowl level, motor vibration or screen amps. With constrained crushers the expert may trigger overload logic – this is a non linear response to avoid stoppages. The splitter diverts load to the unconstrained crusher or, if both crushers become constrained, the tonnage is reduced quickly. As the constraint flag(s) are cleared then overload recovery logic takes control – this logic looks at recent operating history to calculate a tonnage that can quickly recover steady state. Stability logic then becomes active again to maintain a balanced load split so that optimizing conditions can be achieved.

The optimization logic is active when the secondary crushers' amps difference is small (OK) and crusher feed bowl levels are low or OK. This logic will increase throughput unless there are downstream constraints active. These constraints are: a high level in the product ore bin, and coarse product. Product size measurements are provided by a SPLIT camera system.

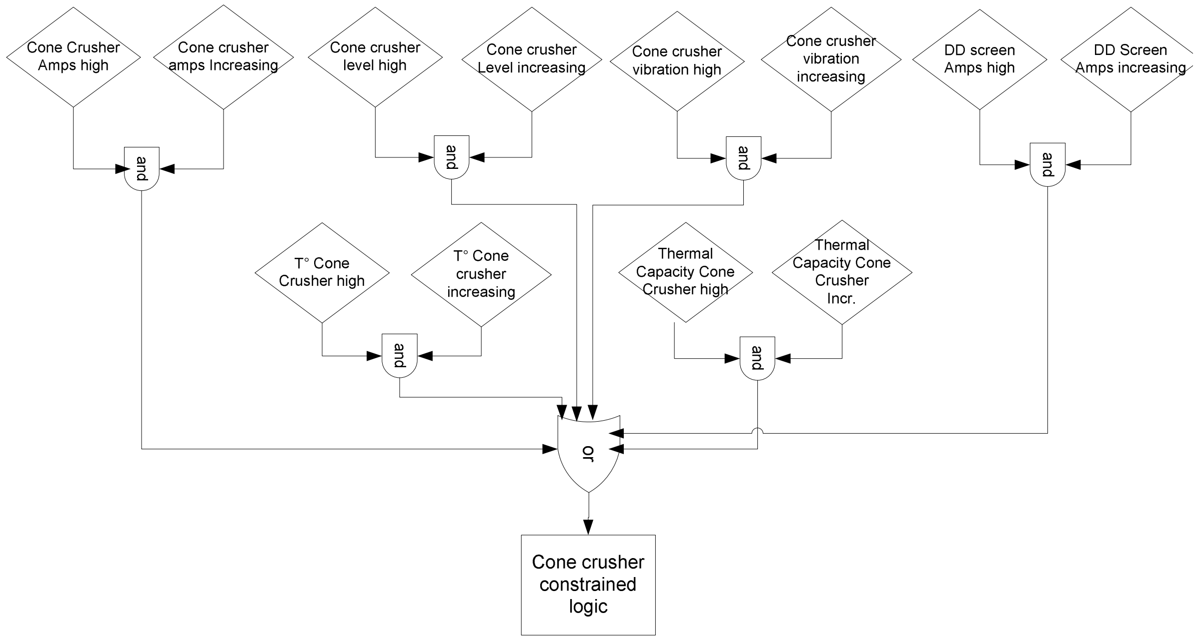

Figure 8 Cone crusher's constraint logic

Operator Interface

Operators are provided with an "expert system screen" in the DCS where they can set the Expert System's operational limits (Figure 9) such as maximum and minimum setpoints or process variables' high and low values. The expert was designed to allow Control Room Operators to change the limits according to their day-to-day operations, which required comprehensive training for the people on site.

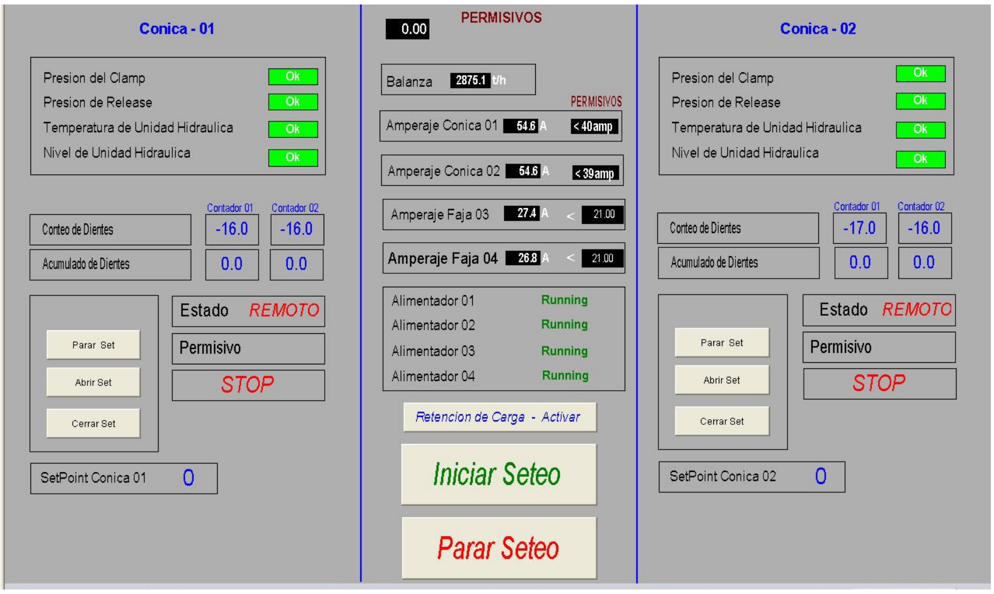

Figure 9 - HMI screen for high and low operational limits

Barrick Veladero

Overall the control philosophy of the Veladero crusher circuit is comparable to that just described for Lagunas Norte however some differences exist and are described in this section.

Primary Crushing

The primary crusher expert system operates in advisory mode only. The system provides advisory messages to the control room operators but does not take any control actions– see Table 1.

Table 1 - Operator messages – Primary crusher

Primary Stockpile Level	Material size distribution (P80)	Surge Pocket level	Operator message
High	High	High	Reduce truck loading frequency and adjust crusher setting.
High	High	Ok Or Low	Slow down truck dumping and adjust settings
High	Ok Or Low	High	Reduce truck loading frequency
High	Ok Or Low	Ok Or Low	No message
Ok Or Low	High	High	Slow down truck dumping and adjust settings
Ok Or Low	Ok Or Low	High	Slow down truck dumping and adjust settings
Ok Or Low	Ok Or Low	Ok Or Low	Increase truck dumping
Ok Or Low	High	Ok Or Low	Increase truck dumping and adjust crusher setting

Secondary Crushing

The Veladero secondary crushing logic hierarchy is based on bin levels, stockpile levels, crusher power draw and crusher vibration as shown in Figure 10. Five operating states are considered:

1. Crusher operation running
    a. Stockpile vibratory feeders and at least one of the crushers running
2. Downstream Crusher Constraint
    a. Out-of-range product particle size
    b. high product bin level
3. Upstream Crusher Constraint
    a. high crusher vibration levels
    b. high crusher bowl levels
    c. high crusher ampere levels.
4. Crusher load low
5. Crusher optimization

As at Lagunas Norte the logic will maintain an even loading of the secondary crushers to maximize throughput and maintain product quality. At Veladero a multi-state function is also utilized for worn secondary crusher mantle(s).

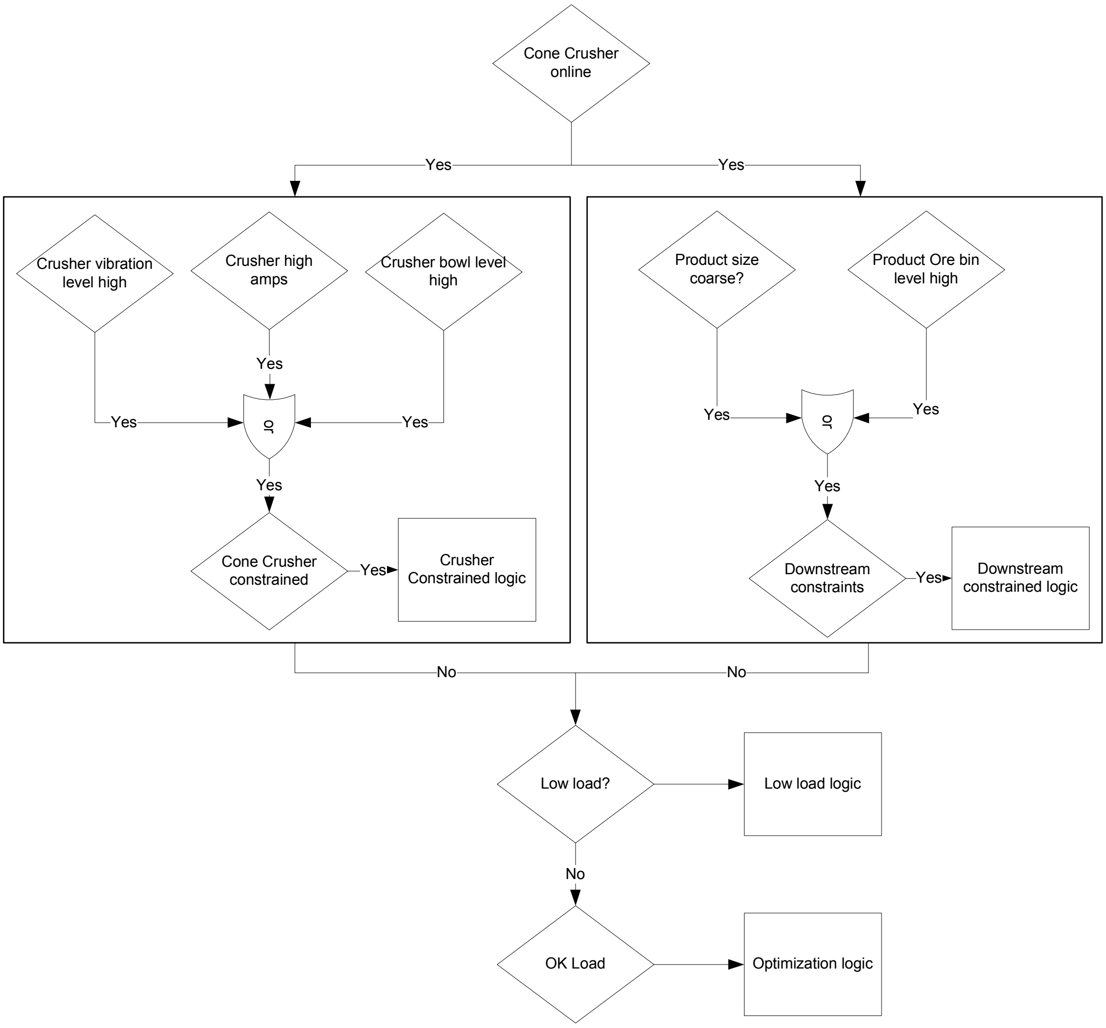

Figure 10 - Overall logic hierarchy for secondary crushers.

In the Veladero logic a predictive model was created to address a unique situation in the secondary crushers. The crusher feed bowl level sensor range is small and very close to the conveyor discharge. This means that in general the crusher bowl is operated close to its high limit so as to have a level measurement to maintain stability. Some events however may occur that can result in a plugged screen discharge as the feed builds up. To avoid these stoppages, a model was created to predict if the crusher bowl level was about to spike and cause stoppages in the screen discharge. Admittedly a repositioning of the feed bowl level sensor will make the model obsolete but in the meantime this model provides valuable enhanced stability.

Barrick Zaldivar

This project was oriented to upgrade Zaldivar's expert platform and also additional fine-tuning of their expert system. Similar to the Lagunas Norte and Veladero mines, this expert system controls the primary and secondary crushing circuits.

As background, Zaldivar's expert system was fully commissioned in 2001. In 2008, Zaldivar contacted SGS to upgrade their application to the latest version of the expert system platform offered by SGS. The expert system at Zaldivar was designed to control both, primary and secondary crushers as shown in Picture 11.

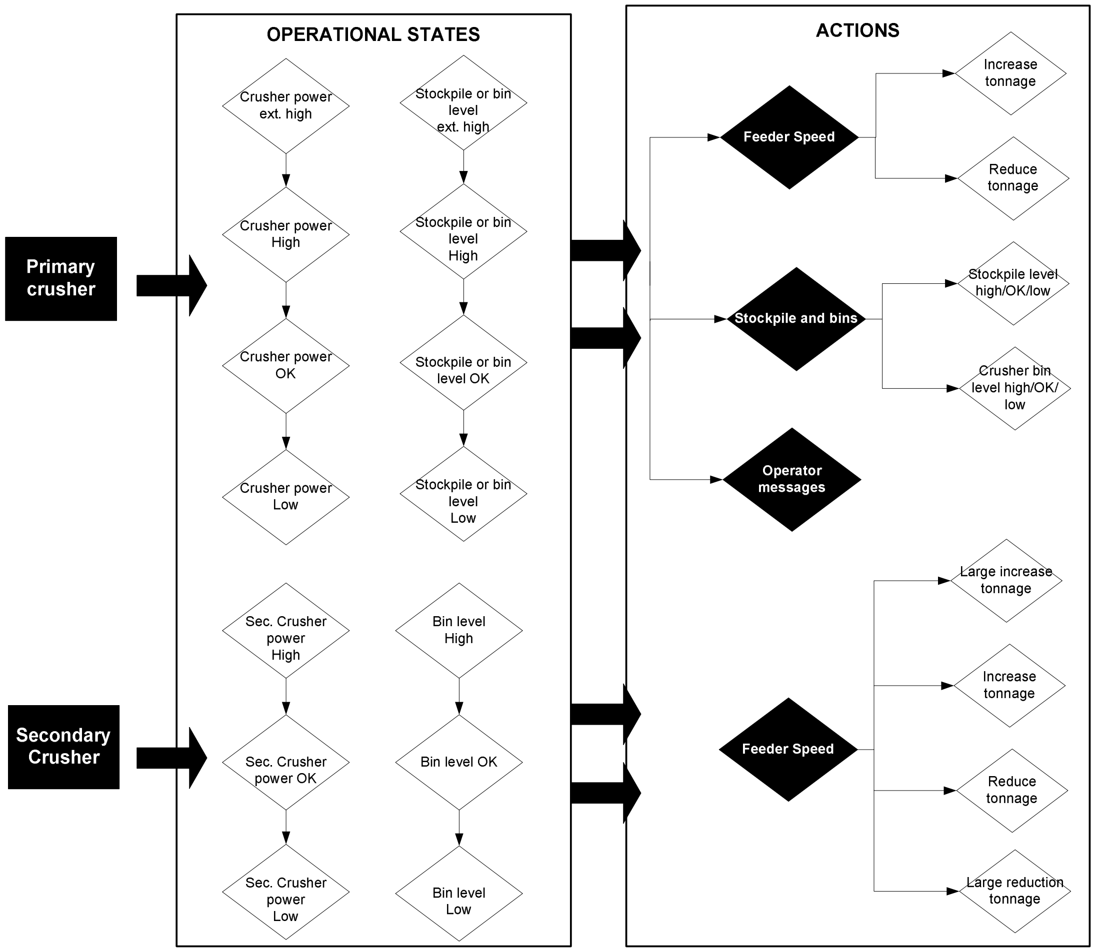

Figure 11 - Overall structure for Zaldivar's expert system

The Zaldivar circuit differs from the Veladero and Lagunas Norte due to its lack of a stockpile ahead of the secondary crushers. Without a stockpile, it was found that the secondary crusher stability was best achieved via a fuzzy controller that acted directly on the output to the crushed product bin feeders. The stabilizing impact of this controller greatly improved the acceptance of the expert by the operators.

RESULTS

Barrick Lagunas Norte

A one month Site Acceptance Test (SAT) was performed at the Lagunas Norte Mine to quantify the benefits of the Crushing Expert System. Data was collected from the Expert System and from the site historian for analysis. With the testing in both the primary and secondary crushing plants, Lagunas Norte's increase in throughput was calculated at 3%. Additionally, the expert system brought more stability to the system that resulted in a reduced tonnage standard deviation of close to 48% as shown in Table 2.

Table 2 - Barrick Lagunas Norte Site Acceptance Test (SAT) results

Secondary Crushers Variables	Expert System Status		%Difference
	Online	Offline	
Feed Rate (TPH)	2,829	2,748	+3%
Feed Rate Standard Deviation	182	353	-48%
Expert System Utilization	98.6%	NA	NA

The utilization statistic means that the expert was left in control for 98.6% of the circuit operation time.

Barrick Veladero

The site acceptance test for Barrick Veladero was conducted from July-September 2008. The overall percent usage of the expert system improved over time, as time was spent to improve operator acceptance. The benefits attributable to the expert increased in direct proportion to increasing levels of utilization and acceptance – see results shown in Table 3.

Table 3 - Barrick Veladero final results

Month	TPH		Increased Throughput (%)	Time Usage (%)
	Expert Online	Expert Offline		
Jul-08	2,699	2,562	5.4%	57.3
Aug-08	2,716	2,440	11.3%	84.1
Sep-08	2,478	2,289	8.3%	91.1

Barrick Zaldivar

For Barrick Zaldivar, no acceptance test was required since the upgraded expert system fulfilled their operational requirements. The upgraded system provided higher throughput as a result of improved circuit stability.

A statistical analysis based on 4 months of data was done by SGS to quantify the benefits of having the upgraded expert system installed at Zaldivar and the results showed an increase of 4% in throughput along with a reduction in specific energy consumption (kwh/ton processed) close to 6%. The power draw standard deviation was reduced by 16% in the primary crusher and 40% in the secondary crusher.

CONCLUSIONS

Based on the results and lessons learned from these projects, we can draw the following conclusions:

- Crushing Expert Systems provide a higher degree of stability and consequently, greater throughput to crushing operations.
- The implementation of Expert technology resulted in greater than 3% throughput increases in each circuit.
- Knowledge gained and lessons learned on one site were successfully applied to improve the newer systems.
- A greater degree of client involvement has resulted in a wider Operator acceptance of Expert technology.
- By capturing best operating practices within the expert system, continuity of operation can be maintained among different operators and the effects of modifications to operating strategy can be measured with greater certainty.

FUTURE OPPORTUNITIES

- Improved bowl level sensing should permit the inclusion of logic to run at least one secondary crusher with choke feed. This may require some changes to the feed bin structure.
- Incorporate Merrill Crowe and leaching in expert system

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