Streamlining the Steps to Optimized Production: Project Process Modelling, Advanced Control, and Simulator Based Training for Optimized Operation – Case Studies

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Abstract

This paper describes the techniques used by two different mining projects to streamline the steps from pre-project to optimized production.

Prior to construction, the Newmont Conga project utilized a dynamic model of the process to help refine the P&IDs so that the process design was integrated with equipment and control design. Design deficiencies were flagged and corrected with the use of a dynamic process model.

The Antofagasta copper mine Minera Los Pelambres in Chile utilizes an advanced control loop system for optimized operation of the SAG mills, Ball mills and the Flotation area. Difficulties of traditional PID control are overcome by utilizing a model predictive controller with mining specific capabilities. Minera Los Pelambres also utilized the remote support capabilities of ANDRITZ to train process operators on difficult pipeline operations. Pipeline operators were trained to start up, shut down, react to various emergency scenarios, and operate the three pipelines using a replica of the pipeline control system connected to a dynamic pipeline model at the ANDRITZ remote support centre in Santiago.

Key words: Simulation, modelling, operator training, optimize, automation, control loops, SAG mill, pipeline, P&ID, virtual plant.

No one starts out on a project intending for loops to be on manual and the process to be struggling to make tonnage, so how then does it end up that way on many projects? Fundamental issues reside in the engineering design process, the adoption of advanced process control, and with the ability to train process operators on the latest technology in a uniform and measureable way. This paper briefly summarizes a phased approach that can help achieve a more optimized project design and commissioning process.

The issue: typical work flow to size and purchase a valve on a large project:
- The overall material balance is done by the process people using a typical steady state design tool. The valve may be identified, but not sized. At this point, the design is usually PFDs or preliminary P&IDs. The design is sent over the cubicle wall to the mechanical people.
- The mechanical people add ~5% contingency. Then they bring in 2D and 3D design tools, and other sizing tools to evolve the design, summarized in the P&IDs. They send out bid packages; the vendors add 5% contingency and send the bids back. Pipes, pumps, and major equipment are now all sized up with costs. The design is sent over the cubicle wall to the electrical people.
- The electrical people add ~5% contingency. They add the valves and the instruments and send out bid packages; the vendors add 5% contingency and send the bids back. The sum of all design buffers we call cascading contingencies.
- The controls people get involved try to test the controls before start-up, but usually are at site for months fighting fires, and keeping their heads low until the project is turned over to operations.

Cascading contingencies cause long-term operational issues: Each discipline did their job, but the final control element ended up oversized (relative to the original process design intent) and, in some cases, the loop ended up in manual. The project team then leaves, and operations has to deal with a design that needs tweaking for many years to come. Pump, pipe or other equipment could be inserted instead of valve in the above scenario.

Streamlining the steps to Optimized Production by Project Phase:
- Phase 1: P&ID/Design Validation
- Phase 2: Advanced Process Control
- Phase 3: Operator training

Using three case studies, this paper presents another view of what is possible on a typical project. Other industries are on the same path, some mining operational companies are leading the way, and we as an industry are ready for the next logical step: **the virtual plant**. What is the virtual plant? It is a dynamic model that contains the process/metallurgical, mechanical and electrical/control design information in one place. Engineers can still utilize their favorite design tool, but the results are communicated back to the overall virtual process model. This way oversizing is caught at the source, because all elements of the design can be seen by each other at the same time, instead of being isolated in a cubicle.

The technology combination that allows the unification of engineering disciplines is three-fold: first, the ability to create and embed knowledge into precompiled objects that represent common mining/milling equipment; second, to have design decisions communicated to all engineering disciplines through a database; and third, the ability to communicate via OPC (OLE for Process Control) to any control system. The virtual plant is therefore not just a metallurgical and engineering tool; it is a method to help utilize and unify the design information, to test the controls prior to start-up, and to be able to train operators. Figure 1 shows an example of a grinding area virtual plant.
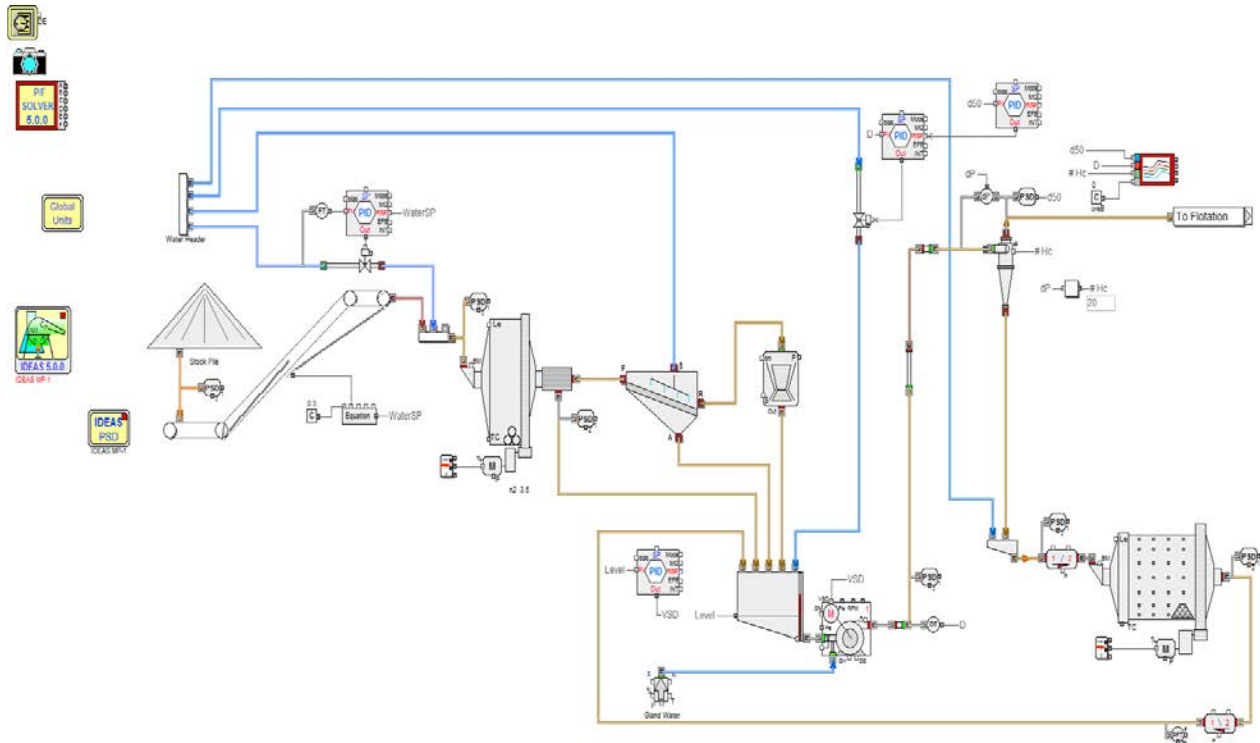
Figure 1: Grinding Area Virtual Plant using IDEAS Software

The design process is now no longer separated by cubicle walls, but projected onto a wall in a conference room, with the virtual plant changed by all parties and the results seen at once. Design decisions are fed into a project database and changes documented on traditional P&IDs. Just as the 3D plant walk-through changed drafting, the virtual plant has now changed how the process is designed. Engineers can still use traditional design programs, but the unification of final design data inside the virtual plant is the check on assumptions, and a method to view how those assumptions interact between disciplines. To follow through on the valve example given earlier, in the virtual plant concept, the valve cannot be oversized because the same data was seen and used by each discipline, so no artificial contingencies are added.
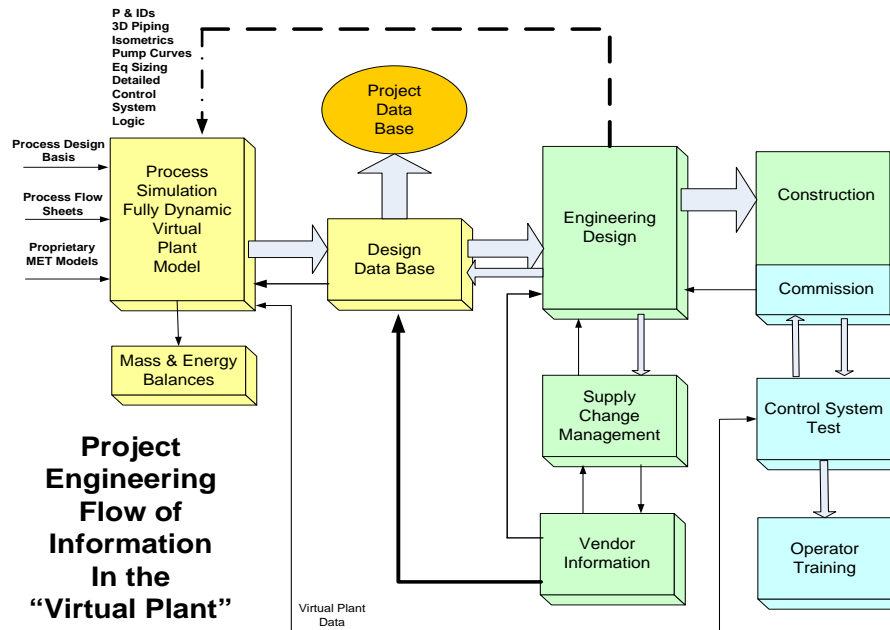
Figure 2: Virtual Plant Information Flow

PHASE 1: P&ID/design validation - Newmont Conga Project (Nees and Gamarano, 2011)

Newmont reasons for utilizing the virtual plant concept on the Conga project:
1) Project risk mitigation
2) Improve business readiness
3) Mining lags behind other industries in utilization of advanced engineering tools
4) Lack of industry experience and engineering talent
5) Delayed start-ups
6) Control system problems
7) Mechanical design issues
8) Lack of trained operators

Newmont justification: (as presented at the CDI Users Exchange 2011, Control Dynamics*)
- Time to Market, Reduce Start-Up Time: $100 – 500k per day*
- Operating Cost, Reduce Unscheduled Downtime: $5 – 50k per hour*
- Reduce Risk, Reduce Unknown Failures and Incidents: $50k - $1MM per incident*

Conga Project Results Utilizing the Virtual Plant in Phase I: (Schug et al, 2012)
- Investigation Report SAG Mill 20110414 – An investigation into the SAG Mill's peak on the power versus loading curve.
- Investigation Report Conveyor 20110428 – Discovery of under-designed pebble crusher discharge conveyor, and other conveyors and feeders under-designed when considering process design criteria surplus factors.
- Investigation Report Launder and Slurry Pipes 20110509 – Discovery of high launder slurry velocities under all conditions. Discovery of high pipe slurry velocities under design conditions.

Discovery of some sanding conditions (slurry velocity < deposition velocity) at minimum flow conditions.

- Investigation Report Filtration Conveyor 20110511 – Presented discoveries regarding excess concentrate conveyor capacity, the need for a variable speed drive, and expected sampling difficulties related to discrete presence of concentrate on the conveyor.
- Investigation Report Flotation Dart Valves 20110705 – Investigation into the dynamic behaviour of the dart valves and their ability to maintain operation within the desired operating range of 40% to 70% open for both the Intermediate and Discharge Box dart valves.
- Investigation Report Ball Mill Limiting 20110929 – Illustrates the dynamic behaviour of the Conga comminution circuit for different ore types and transitions. This report also produced comparison between alternative control strategies at the cyclone feed area.
- Investigation Report Flotation Dynamics 20120104 – Illustrate the dynamic behaviour of the flotation area following the sudden removal from service of one of the three rougher and rougher scavenger flotation cell trains.

Summary Virtual Plant P&ID/Design Validation:

The Newmont Conga project utilized the virtual plant concept during the design phase. The Conga virtual plant incorporated all aspects of the design: the metallurgy, the engineering, and the control. The combined talents of Newmont, Fluor, and ANDRITZ AUTOMATION working together allowed the Conga project to:

- Evaluate effects of various ore types in plant feed
- Evaluate process and mechanical design issues
- Evaluate various operating scenarios
- Evaluate competing control strategy alternatives

PHASE 2: Advanced Process Control – Minera Los Pelambres

Mineral processing operations present many challenges for automatic process control due to variations in unmeasured ore properties, material transport delays, and nonlinear response characteristics. Expert systems are a popular approach to manage the control of these difficult processes. In some cases, the expert system may control the actuators directly using a rule-based approach but, typically, the expert system relies on conventional Proportional-Integral-Derivative (PID) loop controllers to perform the underlying regulatory control of the process.

Model Predictive Control (MPC) provides an additional tool to improve the control of critical processes where PID or rule based expert control is not well suited to the application. MPC is often able to reduce process variability beyond the best performance that could be obtained with PID or expert system control methods. MPC is able to manage applications where there are delays in the process response to actuator changes or multiple interactions between process variables. In particular, MPC is able to optimize the control of processes that exhibit an integrating type response in combination with transport delays or variable interaction. This type of response is particularly difficult to control, and it is common in mineral processing for many different processes including level control of flotation cells and crushers, and SAG mill weight control.

The patented ANDRITZ AUTOMATION MPC (BrainWave®) has been successfully applied to many of the critical processes at Minera Los Pelambres including SAG mill control (Silva and Tapia, 2009), Ball Mill control, and Rougher Flotation control. In each case, the MPC was used to enhance or replace

elements of the existing advanced control system. MPC consistently demonstrated the ability to provide reduced process variability and increased stability compared to PID or expert system based control. Details of each application are presented in the following sections.
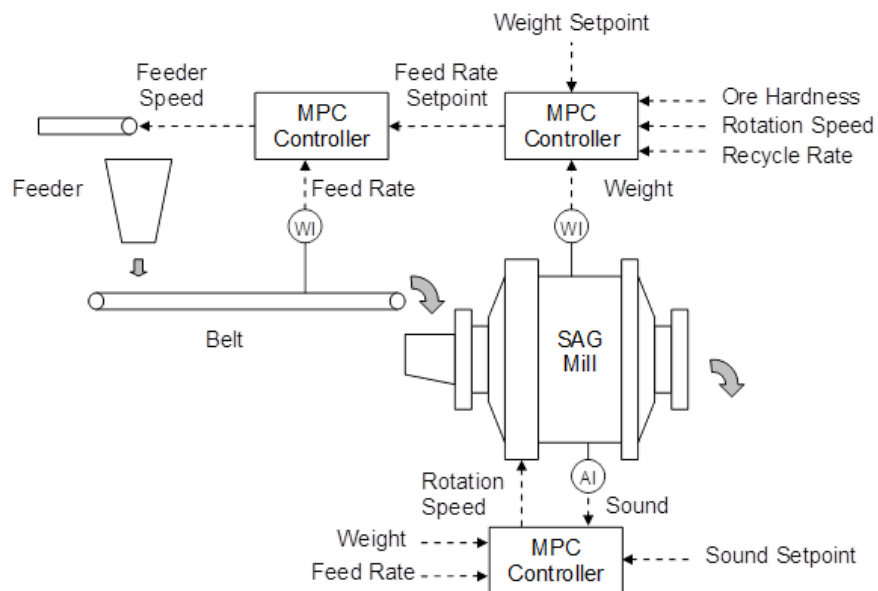
SAG Mill Control

SAG mills can be optimized for maximum ore throughput or maximum grinding energy efficiency. In both cases, precise control of the mill filling percentage is critical (Wills and Napier-Munn, 2006). Maintaining constant mill weight, as indicated by bearing pressure, is one approach to stabilize the mill filling percentage.

Mill weight is difficult to control as the dynamic response changes as the mill approaches maximum capacity. Near maximum capacity, the weight response exhibits integrating behaviour, and the mill can overload quickly. This situation is complicated by the transport delays in the feed system, so it is important that the control system can detect the imminent overload and adjust the feed rate quickly to prevent an overload. The maximum capacity and throughput of the mill changes as ore hardness changes, and this is a difficult property to measure online for use in the control system so the controller must rely on feedback of the mill weight to correct for many of the variations in ore properties.

A rule-based exert system was used to control the feed rate to the mill. The system was able to detect the rapid increase in mill weight and anticipate an imminent overload; however, it tended to reduce the feed rate more than necessary in some situations, and required time to return the feed rate to maximum levels.

An MPC controller was installed to control the mill weight, the belt weight in the ore feed system, and the mill sound emissions. Figure 3 shows a diagram of the control strategy.

Figure 3: SAG Mill MPC Control Strategy

The MPC weight controller includes measured disturbance variables such as pebble recycle and ore size distribution as feed forward inputs to improve control of the mill weight when changes to these variables occur. The MPC control is able to maintain mill weight on target with less variability and avoid overloads without making excessive reductions to the ore feed rate. This performance improvement, together with reduced variability in the mill weight and fill percentage, enables the mill to operate closer to optimum grinding conditions, resulting in an average improvement of mill production of 1.64%.
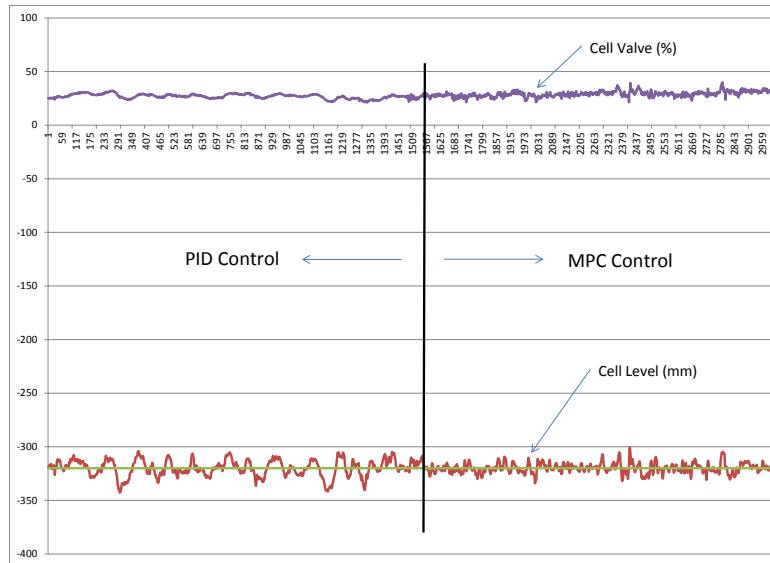
Flotation Cell Level Control

Optimal performance of the flotation process requires stable control of the froth depth in each flotation cell. If the froth level can be maintained, a stable froth layer is formed without excessive bubble breakage, and there is a steady overflow of froth over the lip of the flotation cells. A well-chosen froth depth allows time for some 'drainage' of entrained water and gangue particles before the froth overflows the cell; however, greater froth depths can result in lower recovery and increased use of expensive frother chemicals (Powell et al, 2009). An expert system monitors the froth flow with cameras and adjusts the set point for the cell level PID controllers, which adjust the flow control valves at the outlet of each cell.

The inflow to the flotation line is typically not measured, and these variations can cause significant disturbances to the cell levels. As the cells are arranged in series, the control actions of the upstream cells cause disturbances to the downstream cells, so the effects of a single feed rate change can cause level swings to persist in the flotation line for several minutes. The existing PID controllers include a feed forward decoupling scheme based on the flow control valve position of the upstream cell to minimize the effects of control actions made by the upstream cells.

The froth level is measured using a mechanical float that detects the liquid-froth interface level. The process environment causes frequent fouling of the float mechanism, resulting in discontinuous level measurement signals as the probe binds and releases from time to time. This problem can lead to unnecessary changes to the cell level control valve that disturb the downstream cell levels, so it is important that each cell level controller can manage the level disturbances effectively. New level probes with no moving parts are currently under test to help reduce these disturbances, but results were not yet available at the time of writing.

An MPC controller was installed on the Rougher Flotation cells (4 lines, 5 cell level controllers per line, for a total of 20 controllers). The MPC uses the cell levels and cell valve positions to estimate the flow between the cells. These flow estimates are used as feed forward inputs to the MPC controller to improve the rejection of level disturbances caused by the actions of the upstream controllers. Figure 4 shows a chart of the cell level control performance of the existing PID controller and the MPC controller over a period of about 3 hours. The MPC controller reduced the standard deviation of the cell level by 29% in this example. The average reduction in cell level standard deviation for all 20 of the flotation cells was 24.1% with the MPC compared to PID control.

Figure 4: Flotation Cell Level Control Performance Comparison - PID vs. MPC

Ball Mill Control

The Ball Mill control system objectives are to maintain stable operation of the process while minimizing the variations in the particle size distribution (PSD or P80) of the pulp that is passed to the flotation cells. The discharge of the Ball Mill is pumped from a sump to a battery of cyclones that separate the ore particles so that fines are passed to the flotation cells and coarse material is recycled to the Ball Mill. Cyclones are opened or closed to keep the cyclone pressure in an acceptable range depending on production rate. Cyclone pressure is an important factor to maintain stable performance of the cyclones. However, many control strategies adjust the Ball Mill sump pump speed to maintain the sump level at the expense of increased variability in the cyclone pressure and increased cyclone open or close operations.

The new control strategy adjusts the pump speed to maintain stable cyclone pressure. The Ball Mill sump level is allowed to change over a specified range so that minor variations in production rate are managed in the sump. This approach avoids unnecessary changes to the cyclone pressure or the number of cyclones in service, resulting in increased stability of the cyclone pressure and the P80 to the flotation cells. Dilution water to the sump is adjusted to maintain pulp density to the cyclone, which is also an important factor in stabilizing cyclone performance. Figure 5 shows the control strategy.
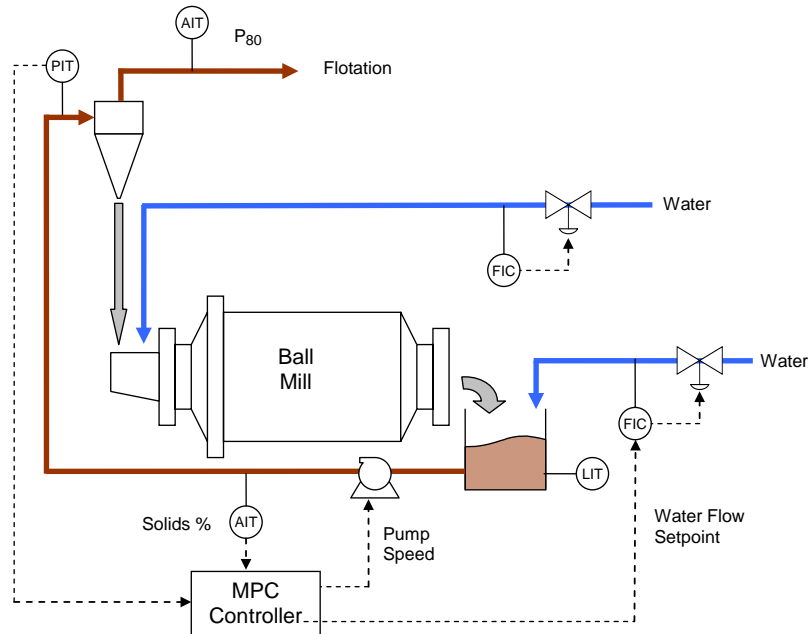
Figure 5: Ball Mill Control strategy Diagram

An MPC controller is used to control the cyclone feed pressure and cyclone feed density by adjusting sump pump speed and dilution water flow. A rule-based expert system is used together with the MPC to control the sump level by adjusting the number of cyclones in service. The expert system also adjusts the cyclone pressure set point over a small, specified range to assist with the sump level control for the purpose of minimizing the number of cyclone openings or closings. This strategy transfers disturbances caused by production rate variations to the sump level instead of disturbing the cyclone pressure. Cyclone pressure variations were 6 to 14 psi with the existing controls and were reduced to 9 to 11 psi with the new controls. The improved cyclone pressure control results in less fouling of the Flotation Cells due to transfer of oversize material from the cyclones and also reduces unnecessary recirculation of fine material to the Ball Mill.

PHASE 3: Pipeline Operator Training at Minera Los Pelambres

Minera Los Pelambres (MLP) is one of the lowest cost producers of copper in the world. They achieve results by adopting the right technology, and have a culture of training their operators to achieve results. The pipeline did have an existing leak detection system, but many false positives desensitized the operators, so when a real leak did occur they did not detect it in a timely manner. ANDRITZ AUTOMATION was contracted to design a training system that would enable pipeline operators to correctly detect when a leak occurred in future. ANDRITZ replicated the MLP control room in the ANDRITZ Santiago office and supervised the training of all operators to be able to detect and correct pipeline abnormal operations. To accurately simulate two tailings 50 km pipelines (28-inch and 36-inch) with five 370 hp pumps and one 8-inch 120 km concentrate pipeline with four displacement pumps, a combination of operations expertise, control understanding, and the ability to correctly model the transient behaviour of high density slurries in real time was required. The details of the modelling techniques were presented at the SME in Salt Lake City in February 2014 (Cristoffanini et al, 2014). Once the modelling of the pipelines was accomplished, the IDEAS virtual pipeline model was used to

connect to an offline version of the Emerson control system and the leak detection system. Once the process model was connected to the offline control system, the IDEAS Instructor software was added to introduce process upsets and measure operator responses. Twenty operators were trained on normal, specific scenarios and traceability conditions (Figure 7). Training proceeded with pipeline operators until they were able to correctly identify specific fault conditions, and is repeated yearly to recertify. When a similar leak occurred a year after initial training certification, instead of taking multiple hours to respond, operators were able to detect and correct the error in a few minutes.

Figure 6: Santiago Remote Support and Training Centre

This result was achieved by having an accurate model of the pipeline, connected to the same graphics and logic used in the real plant, and a training system that was able to simulate a leak, and measure whether the operators could tell the difference in pressure response between normal and abnormal operation.
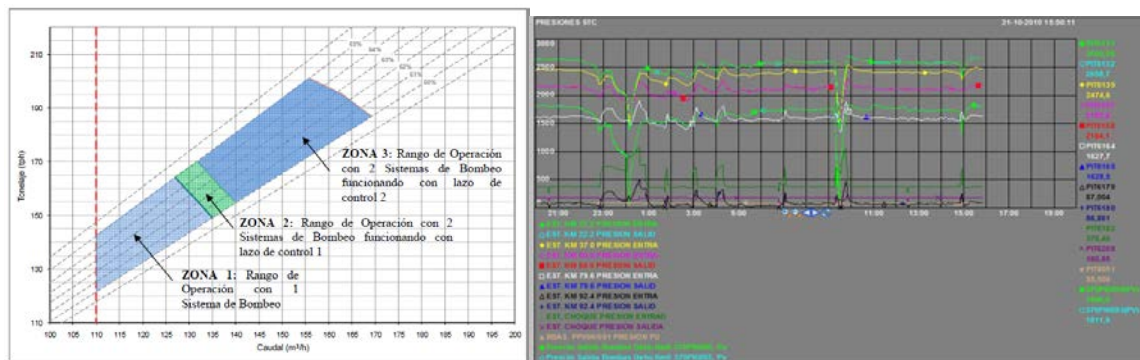
Figure 7: Operating Guidelines and Control System Pressure Trends

The success of this approach has led to several companies adopting the same methodology for complete copper concentrators and encapsulating the entire remote support and training facility inside an air-conditioned container that can be placed at site or anywhere the operating company decides. With the advent of remote access to virtual computers, all support can be done in Santiago, and the field training only requires a high-speed internet connection to achieve the same realism as if the computers were residing in the same location. This approach has saved cost, support time, and is a much more flexible and scalable training option (Figure 8).

Figure 8: Site Remote Support and Training Centre

Future Direction

A large copper concentrator under construction and commissioning in 2014 will utilize the Virtual Plant concept to test whether the circulating load and hardness of ore can be accommodated with the chosen equipment. If additional production is required after start-up, the simulator has pinpointed where to change the control and equipment to achieve it. Advanced process control will also be tested against the virtual plant prior to start-up. This means a more automated way to run the concentrator will be in place at start-up because the system has been tested against the virtual plant and operators are trained in both standard and Advanced Process Control from day one. In addition to Simulator Based Training (SBT), many mining companies are adopting Web Based Training (WBT). WBT includes, sound, graphics, P&IDs and a 3D interactive environment that provides a virtual walk-though that accelerates understanding.

Summary

The virtual plant concept unites the engineering disciplines and enables process and control designs to be tested prior to start-up. Model Predictive Control has been shown to provide additional production and improved operability. Operator training can utilize the virtual plant prior to or after start-up, and the advent of high-speed internet with virtual computers operating remotely has lowered the cost and increased the effectiveness of training. The combined result is a plant built with operations in mind, a workforce continuously trained, and an operation that is more optimal from the start of production and into the future.

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