TRAINING OPERATORS FOR TODAY’S CONCENTRATOR

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ABSTRACT

The control room in a mineral processing plant has become increasingly complicated with complex unit operations coupled with rapidly evolving systems of sensors and control. Even with significant automation, human intervention is required to counter various scenarios that play out every day. A typical control room operator must monitor over 300 individual points of data in order to ensure the safe and efficient operation of the plant. At the same time, the experience of the workforce is decreasing as operators retire and the new generation enters the concentrators. Global competition for skilled operators continues to be strong and the opportunity to apprentice has diminished. The challenge is to provide a skill foundation for the operators so that they can be effective in the concentrator in a timely and safe manner. Progressively, the industry is turning to dynamic simulation tied into the control system. The simulator environment operates behind the control system to emulate the plant operation, reacting as the plant would when a change is made. The operator drives the process, with realistic feedback, which enables learning in a safe environment. This paper will take the reader through a green-field case study and discuss the effectiveness of integrating an operator training simulator (OTS) on the operator’s learning curve.

KEYWORDS

Modeling, Simulation, Operator Training Simulator (OTS), Comminution, Crusher, Screen
INTRODUCTION

Most of the primary industries have seen significant innovation and advancement in automation systems in recent years, mainly to reduce costs without sacrificing quality and safety. The mining and mineral industry has also been seeking ways to counter rising costs while achieving similar quality and safety goals. This has required the mining sector to adopt new approaches in doing business by embracing innovation in all its forms. The implementation of process automation and control systems during different stages of operations has helped to narrow the gaps and accomplish these goals.

Globally, newly commissioned green-field mining projects have implemented sophisticated control strategies in their mineral processing, hydro- and pyro-metallurgical operations with an objective of optimizing the recovery of valuable minerals without compromising the quality of the concentrates sent to the extraction plants. Mineral processing plants have been through numerous technological developments in both equipment and control. The new larger capacity equipment requires the older analog controls to be replaced by a central control system, i.e. distributed control system (DCS) or programmable logic controller (PLC) that interfaces between the operating machines and sensors. Even the old concentrators are embracing the change and are continuously evaluating avenues to implement new technologies. A recent cross-industry survey reported that as much as 75% of the total physical assets in the world are now under process control (Li, 2012). It is safe to extrapolate this data to the mineral processing operations as well.

The implementation of process automation system has increased safety and optimized plant performance by addressing known and easily predictable upset events. Computers can run the entire process autonomously assuming a largely stable world. They continue to run their pre-scripted programs even if the actions are inappropriate. In mineral processing plants, these upset conditions are associated with dynamic feed characteristics like grade, hardness, particle size distribution and tonnage etc. Therefore, even with complex automation, the operators still take actions to offset any unseen and unpredicted upset condition. The operators are already under pressure as the process is running at equipment capacity following automation and technology improvements. To control the dynamic process, the operators are therefore required to do more, in less time, in more complex ways, and in less and less favorable conditions.

Over the years, the mining industry has been successful in finding technical or hardware solutions but has largely failed to address the concerns involving human performance (Munro et al., 2009). As the mineral processing operations do not pose the same hazard level as nuclear power and petrochemical industries, the human operation has not been considered critical in safety sense and has not received the required attention. However, Li et al. (2011) listed human factors along with engineering and technological aspects as attributes of a successful process control and automation system that puts the focus on training the operators.

The increased human-machine interaction in a mineral processing control room is one of the leading sources of error. The control room has become quite complex with diverse information about the process being displayed on multiple screens on the central console to increase situational awareness of the operator. The typical information displayed on the screens includes overviews, trends, online stream analysis and alarms etc. The operators are required to continuously monitor at least 300 individual data points at a given point in time. If this isn’t overwhelming, they are also required to communicate with the field operators, shift supervisors, and metallurgists while monitoring the dynamic process. Thus they are often subjected to data overload including visual and auditory alarms that compete for operator’s attention causing the operators to miss critical pieces of information. Another simple error is “mode error” where the operator takes actions following a decision making process based on a particular mode, only to realize that the control loop was actually operating in a different mode. With improvements in automation, one can only expect that the operators will be operating at operational limits which will require the operator to correctly comprehend the dynamics of the process. Therefore operators need to be trained continuously so that they are always on top of their game.

Li et al. (2011) went further with their investigation inside the control room to conclude that the default operator behavior is reactive i.e. they do not prefer to touch the control system unless things go wrong and more than often than not, their actions are too late. They also realized that the operators lacked sufficient insight into the process dynamics and its impact on control objectives. It was also clear from the survey that operators lacked adequate knowledge about the control system. For example, only 6 out of 20 operators surveyed were using the
trends displayed to understand process performance over time. As perception, attention and decision making differs from person to person, competence for a process also varies with the operator.

It has been a challenge to bring the competence level of all the operators at site to a similar level through operator training across the board. Li et al. (2011), in the plant operators’ survey, found that most of the operators reported that their key process control system knowledge came from hands-on-training while working with experienced operators even though a formal operator training program was structured. This typical human work-related learning behavior for is illustrated in Figure (1) that is a representation of the learning pyramid (NTL Institute for Applied Behavioral Science).

Even though, the mining industry is predicted to meet the demand for engineers over the next decade, the study forecasts a shrinking labour pool for key mineral and metal processing roles including operators (MiHR, 2013). These “trades and production” occupations have been historically trained on the job by experienced operators. According to Canada’s Mining Industry Human Resources Council, approximately 40% of the resource extraction industry’s workforce is at least 50 years old, and one-third is expected to retire by 2022 (MiHR, 2013). With experienced workforce retiring, the younger generation of operators is more likely to learn by trial and error while on the job. This training is unrealistic and economically unfeasible for high throughput mineral processing operations. This is because it involves significant risk (personnel and equipment), is expensive (loss in productivity), and is time consuming to experiment with real-life situations (Gustafsson et al., 1982; Robinson, 1994; Mardan, 2012).

A practical approach to train operators needs to be developed that provides reliable hands-on experience without any associated risks of compromising productivity and safety. This can be achieved using real time on-line dynamic simulators specifically designated as operator training simulators (OTS). Compared to a steady state simulator that have been long established in mining and mineral processing industry, dynamic simulators are fairly unfamiliar. However, dynamic simulators integrated with the distributed control system (DCS) have been used in the oil and gas industry for quite some time now to address an ever-widening gap of required and available operator skills. OTS allows operators to control and drive the virtual plant using implemented control systems and HMI graphic screens without stresses associated with controlling the actual plant. OTS promotes a learning-by-doing approach, illustrating cause-effects and action-reactions interconnections within the dynamic environment of the virtual plant.

OTS coupled with other learning approaches improves the operators’ cognitive readiness by enhancing their situation awareness by addressing the following components (Manca et al., 2013)

a. Experiencing the plant and its components including the control system, sensors and associated data
b. Understanding the underlying purpose of various data points or process information which allows better situational awareness
c. Learning to project to a near-future process state by analyzing the current process state which promotes a proactive approach rather than the default human nature of being passive and reactive

Operator training is therefore of utmost importance throughout North America, more so in Canada, as most operations are trying desperately and exploring different ways to retain and transfer the knowledge of aging and retiring workforce of experienced operators, while simultaneously increasing automation. This paper discusses a strategic training approach implemented to develop required competence level in operators by providing a virtual crushing plant and control system of a green-field concentrator. The simulator forms an integral part of operators to get trained on the crushing plant even before the plant itself is commissioned.
CRUSHING PLANT SIMULATOR

Project Objectives

A simulator is an imitation of an operation accomplished by mathematical models representing part or all of a given unit processes within the operation. By interfacing with the facility's DCS, the process model can be configured using detailed, real-time engineering and control data. The simulation program then uses this data, in conjunction with the control algorithms used by the plant's process controllers, to create a model that reflects the actual, dynamic behavior of the process. The overall objective of this operator training simulator project for greenfield operations was to develop an operator training simulator (OTS) suitable for simulation for normal and emergency operations of a crushing plant that can be used for control room operator training. This objective was accomplished by keeping the following points in mind-

a. Develop simulation capabilities necessary for process operator training
b. Develop a practical yet reliable and robust simulator that provides close to real life process dynamics
c. Develop improved trainer capabilities to interact during the training session
d. Demonstrate and evaluate the simulator with the client’s project team before system delivery

Simulator

The crushing process simulator was developed in partnership with Portage Technologies Inc. and Mynah Technologies using MiMiC simulation software package that provides real time dynamic process and I/O simulation solution for operator training and automation system testing. MiMiC offers selective fidelity on different unit processes and equipment based on specific requirements. A low fidelity simulated model is utilized for part of the process where precise material and energy balances are not deemed necessary. These usually are basic analog tiebacks that are set to constants of reasonable value that are directionally correct for the given unit process. On the other hand, high fidelity models use rigorous first principles to track material and energy. It is accomplished using advanced modeling blocks that provide detailed functionality of the unit process while standard blocks are used to optionally utilize empirical relationships. A high fidelity model therefore provides real life functionality with largely accurate results over a wide range of operating conditions. The different models are executed using sequential and iterative solutions to simulate the process.
The crushing plant was modelled based on the end-user feedback on the required fidelity for various unit processes. For example, to save time and cost, it was decided to have low fidelity on the dust collection system as this was not a critical unit process within the crushing plant. However, the rest of the equipment required modelling with medium to high fidelity. The equipment models for various crushing unit processes were developed in-house based on previously established first principle mathematical models and metallurgists feedback from Portage Technologies Inc. The configurable properties and equipment specific empirical relationships within these advanced models enable the simulation engineers to tune the virtual plant as needed. These models include, but are not limited to bins, conveyors, feeders, jaw crushers, cone crushers, screens, etc.

All the above mentioned unit processes are linked together to create a dynamic “virtual process” that behaves like a real crushing plant during operator training exercises, within the established training boundaries. For the project, it was decided to have a simulation cycle time of one second corresponding to the field controllers scan time. DeltaV Simulate suite was used to provide the “virtual control” system in a standalone PC environment. Any auxiliary equipment such as a lubrication system is simulated using discreet tieback connections. The simulated control system is flexible and easy to manage after product delivery as future changes in DCS configuration can be easily merged with the virtual control system.

The virtual plant and virtual control system are then integrated using client-server architecture to provide a simulated control room with the dynamics of the actual plant as illustrated in Figure (2). The actual DCS database integration ensures that operators interact with the same control modules, logic, advanced control and HMI as the actual plan system. This highly integrated simulated crushing plant and the virtual control system enables real time response to controller outputs based on operator actions. In addition, it is possible to allow multiple operators to be trained on the system using multiple consoles as required. A screenshot of the HMI as seen on operator screen is shown in Figure (3).

The OTS provides the instructor with tools for training purposes and for evaluating trainee performance through a separate console. The controls that are available for the trainer on his screen are shown in Figure (4) and Figure (5). Using the independent console, the instructors can select specific operating conditions, set training exercises, specify malfunctions, and monitor operator performance. The trainer has the ability to change the boundary conditions of feed i.e. hardness, feed rate and particle size distribution of the run-of-mine (ROM) ore that are the main causes for dynamic process conditions in a crushing plant. The trainer can also change the equipment performance on the fly, including forced equipment breakdown and decreased operating efficiency. A screenshot of different equipment controls at the disposal of trainer are shown in Figure (6). The trainer can also observe the state of the simulated process at any given time using specific graphics on trainer screen. This information includes data from the samples from different streams that are sent to the metallurgical laboratory. Figure (7) shows real-time particle size distribution at various sampling points during crushing.

In a real life scenario, the control room operator has to continuously receive critical feedback from other field operators. For the simulation purposes, the trainer assumes the role of other field operators. Thus, the instructor also has the controls for field controllers, operators of downstream operations, and operators of neighbouring utilities. The trainer also has access to pre-defined training scenarios that trigger events leading up to an upset condition. The trainer builds structured, measurable, recordable operator training sessions by combination of the tools available that are used to provide feedback to the trainee operator.

Typical training routines include start-up, normal and upset operation, routine and emergency shutdowns, and procedures for process optimization. These are useful for the operators to understand the dynamics of the process. As attaining a desired process state is a time consuming process, the trainer has the ability to create and restore snapshots of the process state. These snapshots thus provide a mechanism for saving different states of the simulated process and control system.

The trainee operator works on the trainee console while the operator sets-up various training conditions on the instructor console. The trainee is unaware of the changes being introduced by the trainer which gives a real-life dimension to the training exercise. The operator acts on the set of guidelines and procedures established by the operations team to drive the system. The operator looks at relevant sensor and transmitter data points on the HMI screen for e.g. power draw, bin levels, and alarms etc. to take appropriate action to operate the plant at maximum availability and performance. The operator might periodically be provided with results from the laboratory (data
from trainer screen) confirming the effect of his actions. If however, the operator fails to take required actions to bring the system to a stable state, a series of equipment might trip due to inbuilt safety mechanism (interlocks and permissive) as defined within the DCS.

**SIMULATOR TRAINING FOR OPERATOR**

**Crushing Circuit**

A simplified flow sheet of the crushing plant that adopted for the simulation is shown in Figure (8). The crushing plant gets feed from two sources: (i) production shaft from a system of conveyors and feeders, and (ii) reclaimed ore/waste which is periodically dumped into the hopper by haul trucks. The plant equipment was designed for a F<sub>80</sub> of 450mm at ore hardness, defined by Crushing Work index (CW<sub>i</sub>), of 14 at 8500tpd to provide a consistent feed for the ball mill (100% passing 12mm). This is achieved in three stages of crushing by a jaw crusher (primary), a cone crusher (secondary) and two short head cone crushers (tertiary).

The DCS was configured in DeltaV which was imported in DeltaV Simulate to provide the virtual control system for the crushing plant. Various sensors and controllers installed on different equipment continuously provided data to the DCS that is displayed on HMI for operators.

The geology of the ore mined from different zones provided the boundary conditions for hardness which varied from a value of 9 to 15 (Crushing Work Index, CW<sub>i</sub>). The data provided for the simulation included the live capacities of hopper/bins, and design specifications for crushers, screens, conveyors and feeders. The dynamic simulation was based on the steady state simulation results at design conditions. In the absence of accurate results for different ore types, the assumed behaviour of the equipment for hardest and softest ore was confirmed with the project managers and metallurgists. This provided an expected behaviour of circuit at different feed conditions.

![Figure 2 - A “virtual” plant integrated with “virtual” control system to create the desired operator training simulator (OTS) that is configured to provide consoles for trainee operator and instructor](image-url)
Figure 3 - HMI screen as seen by trainee operator who is controlling the crushing “virtual” plant. This screenshot depicts secondary and tertiary crushers along with conveyor system and surge bins.

Figure 4 - Trainer screen with options to change boundary conditions i.e. feed rate, ore hardness and PSD from two different sources.
Figure 5 - Trainer screen with mass flows and equipment performance indicator (current and power draw) for primary crusher

Figure 6 (a)

Figure 6 (b)

Figure 6 (c)

Figure 6 - Trainer graphics with trainer system controls (a) Control to change plugging rate of screens thereby decreasing efficiency, controls for providing field action of shovelling/clearing secondary crusher surge bin, and controls for changing closed-side setting of cone crushers (b) Controls for changing upper and lower deck screen efficiencies, controls for providing split of feed to secondary crusher surge bin, and control for changing crusher efficiencies (c) Manual overwrite switches to provide the ability to plug chutes
The crushing plant operator training simulator allows the operator to get trained on different training scenarios. These scenarios familiarize the operators with the dynamics of the plant and its components including DCS and HMI. A few scenarios were developed to train the crushing plant operators prior to commissioning of the plant are discussed below:

a. Scheduled start-up and shut-down

The simulator familiarizes the trainee with the actual control system as it uses identical controller’s response and HMI. The control system appears to be completely identical to the real plant operations and alarm events. With dynamic process simulator, the control system requires identical attention from the operator as in real life which makes it a very useful training tool prior to commissioning.

The scheduled start-up and shut-down of the crushing circuit requires the operators to accurately follow a standard operating procedure. This is usually configured within the DCS to ensure process and equipment safety. The OTS provides a real life start up experience for the new untrained operators of green-field operations to learn and follow the procedure for safe star-ups and shut-downs. The operators also get familiarized with the various operator control tools available in the DCS and the display on HMI to interact with the process. With proper trainer inputs, the OTS can also benefit the operations by preparing the operators to anticipate and handle unplanned incidents during start-up. This improves the operational readiness and reduces start-up time during commissioning phase while still operating close to the maximum operational efficiency.

The OTS has also provided opportunity to review and improve the HMI design to make it easier for the operator to comprehend the information and better control the process. The simulator has also helped in creating and reviewing standard operating procedures during the pre-commissioning phase by uncovering design flaws that could have delayed project start-up. OTS has also allowed the automation engineers to test the DCS configuration prior to commissioning which is expected to reduce delays in project start-up.

b. Normal circuit operation during life of mine

Even though it is expected that the mined ore will have variable characteristics during the life of mine, it is still important for the operators to experience normal crushing circuit operation. The high fidelity models used for dynamic process simulation let the operator recognize the steady state operations of the crushing circuit. This allows the operator to visualize the steady state conditions for different types of ore and operating conditions. This is an integral part of training as it helps the operator to differentiate the steady state and upset conditions.

c. Upset conditions
The next step in operator training involves the operator to recognize expected changes in operation due to dynamic process behaviour that arise from changes in ore characteristics. During operations, the operator also has to frequently deal with varying equipment efficiencies and in the worst case, equipment failure. As mentioned earlier, the trainer has tools in the OTS to adjust the breakage efficiency of crushers, the efficiency of screens, equipment state to failure mode, and plug the chutes. These tools provide the trainer with the flexibility to create a wide range of training scenarios consisting of single or multiple events. This phase of training challenges the operator to recognize different upset conditions and develop skills to predict the current state of the process.

Once the process state has been identified, the operator needs to take corrective actions to restore back to a steady state. The operator has the flexibility in the simulator to take multiple control actions to address the situation. The simulator gives operator the cushion to make mistakes and learn from them in a safe and controlled environment. This eventually leads to a change in the operator’s behaviour from passive to proactive as s/he is able to judge the future process state based on current conditions and the actions.

For example, an increase in ore hardness will usually lead to an increase in recirculating load for the tertiary crushers. With proper training the operator can visually recognize this scenario on the HMI screen at first by an increase in current draw of the secondary cone crusher. This will be followed by a steadily increasing tertiary crusher surge bin level and ultimately lead to an increase in current draw for the tertiary crushers. The operator therefore learns to correlate the distributed information on the HMI screens to the process state that leads to an increase in situational awareness.

Benefits

The OTS aims at improving the operators’ understanding of the crushing plant dynamics and the integrated control system. The trained operators gain valuable operating experience, and familiarize themselves with the HMI screen and the control philosophy of the plant. With a comprehensive training program, the operator is able to correctly identify the difference between the steady state and upset conditions in real life. The training program also develops the operator’s situational awareness and a streamlined thinking process to identify the cause of the changed process behaviour. Once the cause is identified, the operator can then prioritize and take necessary actions to restore the process to a steady state in the shortest possible time. The operators execute the process specific standard operating procedures (SOPs) within the simulated environment, decreasing the likelihood of errors and unsafe operating practices in the field. The operators also demonstrate the ability to recover from various upsets and malfunctions encountered during the course of regular operations. The OTS can also be used to cross train the operators that increases the operational flexibility and migration of skill set.

According to the data available from oil and gas operations (Winter, 1996), it has been reported that after training the Conoco unit operators on OTS, the unit start-up times after scheduled shutdowns were reduced by as much as 70%. At other sites, the use of OTS for Conoco unit operations has significantly decreased the time for operator training. The operator training program integrated with OTS has also significantly reduced the time for operators to assume full responsibility from 12-18 months to only 6 months.

Apart from developing the operators cognitive skills, the OTS can also be used to test different sections of the distributed control system (DCS) like motor start/stop logic, validate the permissive logic and check the graphics on HMI screens.

The result from the study conducted by ARC Advisory Group to identify measurable benefits of incorporating technology at early stages of a project is summarized in Figure (9). The findings reported that integrating OTS for operator training offers significant measurable benefits to justify the implementation of an OTS. The OTS also offers tangible advantages such as such as energy efficient operation, consistent feed to grinding circuit, improved process operability, improved process safety, and less human errors in operation due to better process understanding.

CONCLUSION

This paper discussed the implementation of OTS as a tool to train crushing plant operators. The strategy can also be extended to other metallurgical processes like grinding, flotation, leaching and autoclaves. The ultimate
goal of such an OTS is to improve operator’s readiness to perform satisfactorily under different process conditions. The integration of control system with the dynamic process enhances the capability of the operator to recognize the process state, understand the root cause leading to the upset condition and react accordingly in a shortest possible time. The trained operator also prioritizes the numerous data points available on the HMI screens focusing on the critical performance indicators. The operators understand the significance of field operators as well as the information received from upstream and downstream process operators. The proposed training approach is not only beneficial to educate the novice operators but also keeps the skills of the experienced operators consistent over time, especially after significant plant modifications including changes in equipment or control philosophy.

REFERENCES

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NTL Institute for Applied Behavioral Science, 300 N. Lee Street, Suite 300, Alexandria, VA 22314.


Figure (8) – Simplified process flow diagram for the crushing circuit

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<thead>
<tr>
<th>Operations readiness - source of savings</th>
<th>Typical startup savings</th>
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<tr>
<td>Process technology training</td>
<td>5 days</td>
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<td>Simulator based training</td>
<td>5 days</td>
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<td>Procedural training for operators</td>
<td>2 days</td>
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<td>Licensor prepared scenarios</td>
<td>2 days</td>
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<td>Licensor specified process models</td>
<td>1 day</td>
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<td>Operating procedure validation/optimization on simulator</td>
<td>5 days</td>
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<td>Controls check/verification on simulator</td>
<td>5 days</td>
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<td>Safety shutdown system verification on simulator</td>
<td>5 days</td>
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<td>Better initial controller tuning from simulator</td>
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<tr>
<td>Faster start-up from operations readiness</td>
<td>26 days US$26M</td>
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<tr>
<th>Operations effectiveness</th>
<th>Startup Savings</th>
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<td>Procedural operations</td>
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<td>ASM Graphics</td>
<td>1 day</td>
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<tr>
<td>Mishap avoidance from operation effectiveness</td>
<td>4 days US$4M</td>
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<tr>
<td><strong>PRODUCTION OPTIMIZATION</strong></td>
<td><strong>Improved Performance</strong></td>
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<tr>
<td>APC delivered sooner through simulation program</td>
<td>6 months early US$19M</td>
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<tr>
<td><strong>TOTAL BENEFITS</strong></td>
<td>~US$49M</td>
</tr>
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Figure (9) – Reduction in costs for a green-field project associated with the early incorporation of advanced technologies such as simulation and advanced process control. (ARC Advisory Group, 2009)