PREPARATION OF EFFECTIVE
COMPUTER-BASED TRAINING (CBT) PROGRAMS
FOR METALLURGICAL PLANT OPERATORS

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ABSTRACT

Effective plant-specific computer-based training (CBT) used in a formal training program can make the difference between a successful start-up and a failure. Or, in the case of an existing plant, it can make a huge difference in the effectiveness of operating results—particularly if turnover of experienced personnel is a factor. Once the plant process design and control strategies have been established, equipment has been ordered, and the plant is either operating or under construction, the only major variable affecting success is the capability of plant operating personnel. It is essential that the myriad details concerning plant operation are documented in a comprehensive CBT system suitable for training the non-technical personnel who will operate the plant. This paper describes the best approach for producing the CBT system and for conducting on-site pre-start-up operator training.

WHAT OPERATORS NEED TO KNOW

Performance Associates has been in the business of assisting worldwide mining companies to successfully start up new mineral processing plants for over 30 years. Based on this experience, it is obvious that certain key information must be known—and applied—by the operators and front-line supervisors during the start-up. Failure to impart this information, and to apply this knowledge during the commissioning phase, will likely result in either outright failure or a long, agonizing, and protracted effort to achieve design capacity—if design capacity can be achieved at all. This key information consists of several elements.

Process Unit Operations

It is essential that the operators have a conceptual understanding of the process and the principle of operation of each major unit operation in their area of responsibility. Conceptual knowledge allows for more effective reasoning when process upset conditions occur. Rather than attempting to provide a recipe covering any conceivable upset, the operator’s conceptual knowledge will allow for drawing the appropriate conclusions based on the situation at hand. Specifically, the following elements concern-
ing the functioning of individual unit operations should be documented and thoroughly understood by front-line supervisors and operators.

- **Objective:** Describes the purpose of the unit operation. For example, the objective of a ball mill circuit is to reduce the size distribution of feed material to allow for liberating minerals locked in the host rock.

- **Basic theory:** Describes the chemical, mechanical, thermodynamic, electrical, etc., methodology (e.g., magnetism, chemical reaction, mechanical action, differential density) used by the unit operation to effect the objective without reference to the physical layout of the equipment.

- **Principle of operation:** Describes the physical layout and how the basic theory is applied by the actual equipment being described. The inclusion of diagrams, photos, videos, animations, etc., to illustrate the important principles of operation is required.

- **Critical variables:** In any unit operation, the output quality is a function of certain critical variables. For example, cyclone feed density and pressure drop affect how effective a cyclone is at making a size differentiation of the feed slurry. This element identifies the important variables associated with each unit operation described.

**Safe Job Procedures**

To ensure that each employee works safely, information on the correct methods for performing potentially hazardous jobs must be learned. Each new plant operation will contain potential hazards that must be understood by every employee. These hazards include working with various reagents, such as sodium cyanide, caustic, sulfuric acid, etc. They also include working around various types of moving equipment.

**Process Control**

An operator must fully understand each control loop in his or her area of responsibility. This understanding includes the variable being controlled and the instruments and control strategy employed. An operator must also be able to recognize control problems when they occur and know the backup options available, as well as when it is appropriate to exercise those options. Distinguishing between process problems and process control problems is also important. This understanding has become more difficult over the recent past since control strategies have become increasingly complex with the advent of more and more powerful process control software.

**Interlocks**

In addition to the control loops, all interlocks must be thoroughly understood, including how interlock logic is affected by various operating parameters, such as remote operation, local operation, maintenance operation, etc. We have seen a very significant increase in the complexity of plant interlocks being designed into new plants.
Alarms

Once the process and its critical variables are understood, along with the controls and interlocks, the operator must then learn the fault, cause, and remedy associated with each alarm. This learning can be a tall order since many of today’s new plants have literally hundreds of programmed alarms in each plant area.

Start-Up and Shutdown Procedures

Each operator must also learn the correct steps to start up and shut down the plant under various conditions. These conditions normally include start-up from complete shutdown, start-up from standby shutdown, start-up from emergency shutdown, and start-up from power failure. Additionally, each operator must know how to manipulate the distributed control system (DCS) to determine what is happening in the process, to take control of a particular controller, to adjust set points, etc. Operators must also know how to take control using any local control panels in the plant. These panels are typically used for packaged boilers, samplers, and solution heaters. The new complexity of metallurgical plants makes all of these procedures much more involved than they used to be.

Operator Tasks

Each operator must learn other operating procedures associated with optimizing the plant. These procedures include such tasks as checking pulp density, optimizing flotation cell performance, tapping a furnace, taking solution samples, conducting routine inspections, and ensuring that the plant operates within permit requirements.

Conclusion

Operators having any limitations in the knowledge described above will cost the company during the start-up and subsequent initial operation—the more the knowledge gap, the more it will cost.

In plant start-up situations where very little of this knowledge has been transmitted to operators, the start-up can be disastrous. In a typical start-up scenario, personnel react inappropriately to process upset conditions, causing further upsets. These upsets result in a new series of inappropriate reactions, sometimes including physical plant changes. Many times a never-ending cycle occurs: operator reactions cause problems, resulting in different reactions that cause more and more serious problems. Once this cycle has started, it can quickly get out of hand. Just getting back to the base plant design conditions can be virtually impossible.

To add to these problems, once the plant actually starts and problems develop, there is no time left to train the operators. The problems begin to multiply; since everyone is working extra hours to deal with the problems, there is no chance to catch up. Operators are left to absorb the necessary information by trial and error while dealing with the start-up problems. In some cases, more complex plants never do successfully start up. Simpler plants may eventually operate at production capacities approaching design, but only after long, arduous start-up periods.
Generally, operators of plants started under these conditions all have their own pet methods for controlling the operation. We have observed many plants where critical variables are controlled with entirely different home-grown strategies on each shift. In some cases, even the target values are different.

**AN ALTERNATIVE APPROACH**

**Introduction**

Few people would dispute the necessity of transmitting literally thousands of critical pieces of information about the new plant to the operator. In fact, there is really only one way to do it. We have found that writing a series of custom plant operating manuals migrated to a web-based interface, specifically designed for an education level of the target employee pool, is the correct approach. This CBT system is then used in a formal classroom training program, complete with integrated workbooks and tests in a learning management system. For a new start-up, the training must occur prior to mechanical completion. Ideally, the trained operators complete the class and field training and then assist with the final stages of preoperational testing. Only then are they ready to introduce feed and perform their normal operating functions. For an existing plant, scheduling training is more challenging, but the results can be dramatic.

Figure 1 illustrates an example of the results that can be expected from implementing such a computer-based start-up training program for a new start-up.

**FIGURE 1**

TYPICAL RESULTS OF A PRE-START-UP CBT PROGRAM
We have found that the following CBT components work well, both for training and as a continuing reference.

**Training Content**

**Introduction:** This section describes the purpose of the plant area and identifies those areas that comprise the entire plant.

**Safe job procedures:** This section provides formal written procedures, including any special equipment required, to be followed by the operator when performing potentially hazardous job functions.

**Process description:** This section provides a written description, complete with schematic diagrams and illustrations, including flowsheets, describing the process. Refer to Figure 2.

**FIGURE 2**

**TYPICAL PROCESS DESCRIPTION**

![Typical Process Description Diagram](image)
This section also includes principles of operation for all of the major process unit operations. Refer to Figure 3 for a typical illustration. In this case, the principle of operation of a shell-and-tube heat exchanger is described. Unit operations such as vacuum pumps, flotation cells, furnaces, dryers, filters, etc., are described as principles of operation. It is essential that the operator is provided with the necessary information so he or she can describe the key operating principles.

**FIGURE 3**

**TYPICAL PRINCIPLE OF OPERATION**
**Process control:** This section provides a table identifying each critical process variable, such as temperatures, flows, pressures, densities, etc. It also summarizes their target values, methods of control, and their impact on the process. Each control loop is also described using text, a simple block diagram, and a simple loop diagram extracted from the piping and instrument diagram (P&ID). Each method of control, such as automatic remote set point, automatic local set point, ratio, and manual is discussed, as applicable. Refer to Figure 4 for an example.

**FIGURE 4**

**TYPICAL ILLUSTRATION OF A PROCESS CONTROL LOOP**
**Interlocks:** This section provides tables identifying all interlocks and permissives for each motor and affected instrument, along with cause-and-effect diagrams. The diagrams cover the same information as the tables and are used to complement the tables. The interlock tables and diagrams are organized by logical process system. Refer to Figure 5 for an example.

**FIGURE 5**
TYPICAL ILLUSTRATION OF A GROUP OF INTERLOCKS
Alarms: This section illustrates each alarm in the process area. It is in a tabular format and includes the affected equipment, the fault, the potential causes, and the steps to take to remedy the alarm. Refer to Figure 6 for an example.

FIGURE 6
TYPICAL ILLUSTRATION OF ALARMS
**Operating procedures:** This section is divided into three sections: Start-Up, Shutdown, and Operator Tasks. Start-up describes the detailed procedures necessary to start up the plant from a complete shutdown, from a standby shutdown, from an emergency shutdown, and from a power failure. Shutdown describes the procedures necessary for a complete shutdown, a standby shutdown, and an emergency shutdown. It also describes the effect of a power failure and any specific procedures the operator should perform. Operator tasks describe additional standard operating procedures (SOPs) required to operate the plant. These procedures always include preoperational inspections necessary to set up the plant for start-up. They also include procedures necessary for the operator to perform his or her job function. They may also include any steps the operator must take to manually control key process variables.

Typical operator tasks for various job functions are:

- Routine inspections.
- Measuring pH.
- Preparing a batch of flocculant.
- Furnace tapping.

An operator task procedure is important whenever consistency is critical. Refer to Figure 7.

**FIGURE 7**

*EXAMPLE VALVE SEQUENCE FOR A STRIPPING OPERATION*
DEVELOPING THE CBT SYSTEM
Writing each manual that will be migrated to the web interface is a tedious and involved process. The following source material is needed:

- Process flow diagrams.
- Piping and instrument diagrams.
- Equipment operating and maintenance instructions.
- Functional descriptions.
- Motor control schematics.
- Control valve specification sheets.
- Design criteria.
- Equipment list.
- Alarm list.

This material is used to develop each of the sections previously described. Ideally, writers are engineers with experience in plant operation. This is often an elusive combination that is difficult to find. Typically, a few months must be dedicated to writing and editing each process area manual. In many cases, engineering changes continue to occur as the manuals are being prepared; this adds to the complexity.

Once the manuals are completed in Microsoft Word, the drafts are reviewed by client operations management and engineering personnel. Additionally, if the materials must be translated into another language, the drafts are sent to a translator. Once comments are received, they are incorporated, and the final version is migrated to the web interface. Videos, animations, etc., are linked as necessary.

LEARNING OBJECTIVES AND WORKBOOK
Learning Objectives
The learning objectives identify what the trainee should be able to do once the training in the process area is complete. The learning objectives focus on behavior. That is, the trainee must demonstrate he or she has mastered the objective by doing something, such as explain, describe, perform, identify, etc.
Workbooks

Workbook questions form an integral part of the CBT interface. The workbook is designed to reinforce learning; it is not a validation device. Following a component of classroom training, the trainees are asked to complete a portion of the workbooks. The trainees access the workbooks using toggle buttons at the top of the computer screen. Refer to Figure 8.

**FIGURE 8**
ACCESSING THE WORKBOOK VIA THE TOGGLE BUTTON

The trainees can toggle between the workbook screen and the training content screen using the buttons at the top of the screen.

Learning Management System (LMS)

Performance Associates uses its proprietary LMS, *PTracker Pro*, to allow trainees to take knowledge assessment tests online. Refer to Figure 9. Trainees can be grouped into areas and groups based on the job function and area of responsibility. *PTracker Pro* can also track certifications and performance of field assessments. *PTracker Pro* is also used to set up training schedules and track trainee performance through each trainee’s customized curriculum.
Training Content: Learning Management

Training Learning Center
The Trainee Learning Center is the one-stop shop for users to launch and view progress on their assigned training content modules, electronic tests, and trainer/course evaluations. They can also view completed and outstanding certifications and practical assessments. This allows them to progress through an instructor-led curriculum or learn independently.

Electronic Tests
Electronic tests assess the user’s knowledge of the training content. Questions can be text-only or also incorporate images, animations, and other visual aids. As with training content, PAI can develop all assessment materials.

Learning Reinforcement
After taking an electronic test, the user can view wrong answer reports containing only the questions answered incorrectly and the reference location in the training content. Users can then research the information for themselves before retaking the test.
CLASSROOM AND IN-PLANT TRAINING

It is important to use credible personnel with previous experience in plant operations for training instruction. Ideally, the personnel who have prepared the CBT system should carry out the classroom instruction. In many cases, we use our personnel to conduct train-the-trainer classroom sessions for the client’s trainers, and then they, in turn, train their plant operators. We have found this approach very successful.

The formal training consists of four main components:

- Classroom lecture.
- Trainee completion of workbooks.
- Site visits to observe the plant equipment and instrumentation.
- Completion of knowledge assessment tests and field assessments.

The lecture, workbook, and site visits work best when they are distributed throughout the training day. Too much time in the classroom can dull the learning process.

During the classroom phase, it is important to get the trainees involved. Trainee participation results in better retention and makes for a more interesting experience. Near the end of training on a process area, simulation drills can be held. These drills require that the group be split into teams. Each team then attempts to determine the cause of hypothetical process upsets postulated by other teams or by the instructor. The simulation drills require knowledge of the full breadth of information contained in the CBT for the process.

Once the formal classroom training sessions are completed, additional time can be spent in the field tracing pipelines, identifying every control valve and instrumentation element, and generally marking up P&IDs as instruments, equipment, and pipelines are identified.

For a new plant start-up, the final phase of training is trainee participation in preoperational testing prior to introduction of feed. Operators, having completed training, are extremely knowledgeable about the new plant. They make ideal personnel to walk the plant and prepare punch lists of discrepancies. When functional testing of completed plant systems occurs, operators can also participate in that testing. Ideally, the new operators can use the DCS or local programmable logic controller (PLC) to operate the equipment necessary under the direction of appropriately qualified engineering personnel. As problems are identified during the testing phase, the new operators and supervisors can participate in problem-solving teams investigating the problems.

We have found that there is no substitute for highly trained operating personnel during the testing and start-up phase of any new plant and for the effective operation of an existing plant. The training program described above will provide those highly trained operators and supervisors. We know of no other satisfactory method for ensuring that personnel are ready to operate the new plant.
CONCLUSIONS

There are literally thousands of specifics that must be learned by each operator involved in a plant. In addition to facts concerning the plant, operators must also learn principles and theory associated with the new equipment, controls, and methods. No matter how carefully a new plant has been designed, or how well the new equipment works, the start-up will not be a success until the operator has completed this learning. With respect to an existing plant, a lack of effective training represents an opportunity cost.

There are only two ways for operators to learn the material necessary. They can learn it in a controlled classroom environment as has been discussed in this paper. Alternatively, they can learn it by trial and error as they are attempting to operate the plant. The cost of the former approach, while certainly not inexpensive, is very low compared to the lost production and damage usually associated with the latter approach.