OPERATOR TRAINING

Utilizing simulators in operator training

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ABSTRACT

Advances in desktop simulation software have improved the quality and benefits of simulator-based training. A real-time dynamic simulation was interfaced to a distributed control system and programmable logic controller for use in operator training and control system checkout.

Application:

Major projects utilizing sophisticated controls should incorporate a fully dynamic simulator as part of the training program.

BACKED BY A FINANCIAL COMMITment of US$ 400 million, Weyerhaeuser undertook a major modernization of its 64-year-old pulp and paper complex at Longview, WA. The complex (one of Weyerhaeuser's largest) has been a long-time producer of a variety of paper products, including bleached paperboard for milk and juice cartons, printing and writing papers, and containerboard medium for corrugated boxes.

Completed in 1995, the modernization replaced old pulping and bleaching systems with high-tech equipment necessary to meet customer and community demands and upcoming environmental regulations. The existing mill continued to operate during the project.

All new equipment, modernized controls, and a new work system required a sophisticated training program. The cornerstone of the training was the use of a dynamic high-fidelity simulation.

The new 1150 tons/day Fiberline consists of six basic segments:

- Two-vessel Kamyr continuous digester
- Brownstock washing, including knotting, screening, twin-press displacement washers, and O_2 delignification
- Three-stage atmospheric diffuser bleach stages: D1, Epo, D2
- High density bleach storage
- Chemetics ClO_2 plant
- Wet lap machine.

A simplified process flow is shown in **Fig. 1**. The fact that the mill is a single-line process for three wood species (hardwood, fir, and pine) is significant to the operations criteria. In addition to standard regulatory process controls, sophisticated supervisory controls were programmed into the distributed control system (DCS).

TRAINING OVERVIEW

Operators of the new Fiberline were trained from the basic process and equipment level through supervisory controls. Basic-level training was performed by peer operators and vendors in a classroom setting. The next level of training, that of the process control system, required the use of the simulator.

The training program goals, as developed by the operators themselves, indicated that they wanted a comprehensive system to develop operational confidence and safety. They also required a validation of acquired knowledge. Utilizing a simulator was recognized as a key tool in achieving these goals.

Operators received training according to their assigned functional area at startup. All operators received basic-level training in all areas. Control-system training was received in their operating area. A sample curriculum for a digester operator is shown in **Table I**.

LEVELS OF SIMULATION

Operator training for plants installing DCS requires some level of simulation in order to achieve success. There are two ways of categorizing these devices:

1. By level of sophistication required
2. By trainer types.

Levels of sophistication may be summarized as follows:

Level 1

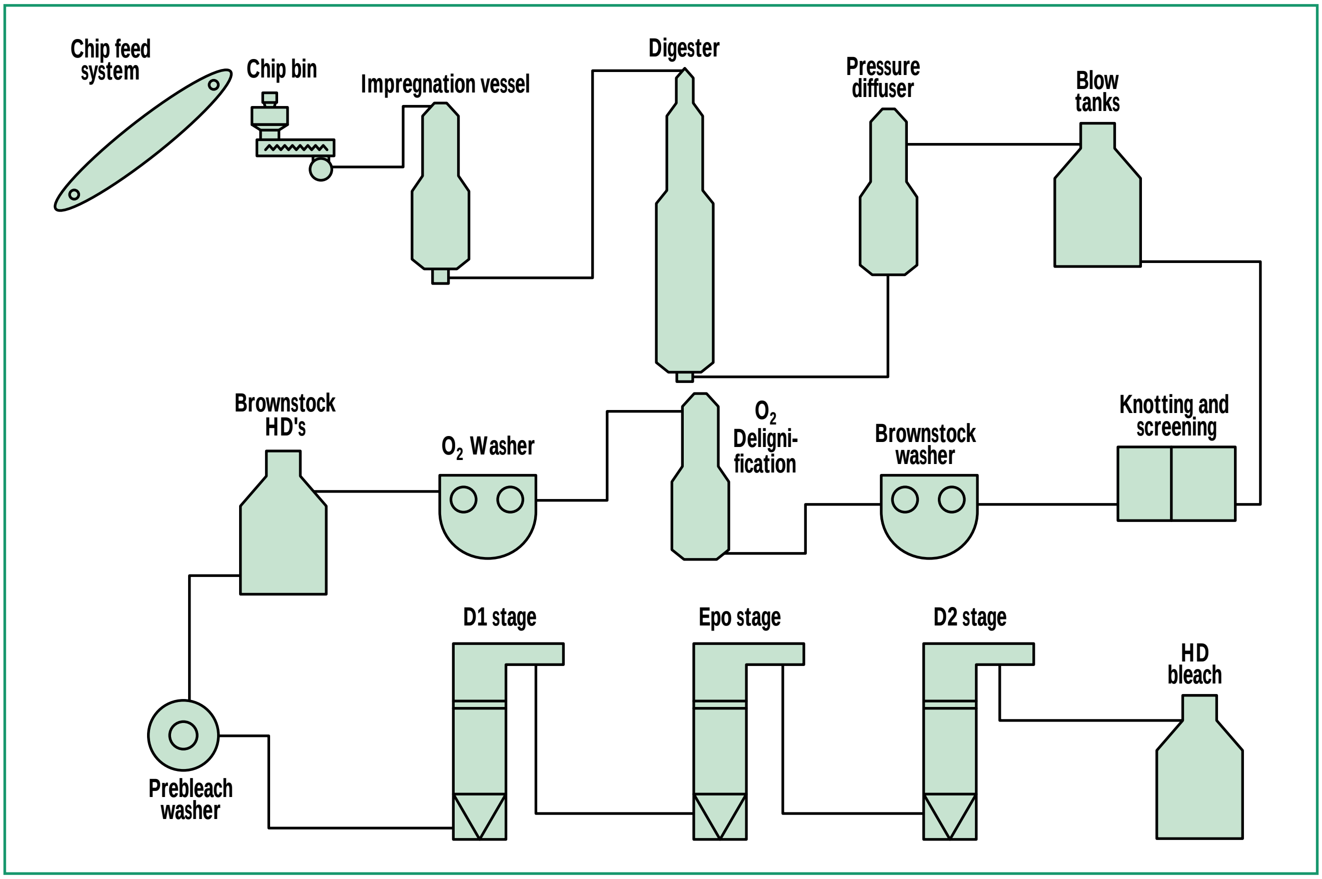
This simplest form utilizes a static process model or perhaps uses no model at all. Equipment may be a PC emulation of the operator's screen or the DCS operator console with the actual screens. No attempt is made to produce any process interaction. This is a control screen review only.

Level 2

Although similar to Level 1, some tie-back programming is done to allow ON/OFF states to be displayed. Furthermore, this level allows use of static operating data for display.

Level 3

This level uses a self-contained simulator on a PC, minicomputer, or on the DCS itself and incorporates DCS code. Programming is included to simulate interaction with field digital and analog I/O. Programming is static, and process interaction is limited. Loop logic and interlocks are "tied-back" such that the operator must at least perform a startup or shutdown in a specific sequence.



1. Simplified process flow of modernized operation

Level 4

Utilizing an external simulator engine on a PC or minicomputer with the actual DCS and PLC hardware and software, the operator can build algorithms to emulate process interaction. Emulation may not be truly real time, nor faithful to process dynamics. However, the user does get a feel for these dynamics.

Level 5

This is fully dynamic simulation in real time. The simulator engine is typically a PC (with today's equipment). The physical wiring and interaction of equipment (DCS, programmable logic controller, simulator) is identical to the actual system. This approach requires heavy involvement with mill/project controls personnel.

Trainer types include the following:

Type I

Trainer is embedded in the DCS and utilizes "tie-back" signals.

Type II

External PC or minicomputer drives control console using control logic.

Type III

External PC or minicomputer drives process-based interfaces to DCS and PLC hardware and software. This provides full process dynamics and operator interface.*

Process simulators used as trainers begin at Level 3. This is similar to the Type I reference. Note that the self-contained simulator remains highly static and therefore soon becomes a "video game." Level 4 simulators may be either Type II or Type III. The difference is the process dynamics and simulated field inputs.

Level 5 simulators are usually of Type III. These have use in both training and process control logic check-outs prior to startup.

*Baines, G., Gunseor, F., and Haynes, J., *Tappi J* 75(1): 133(1992).

SIMULATOR SPECIFICATIONS (RFP)

Specifications used in the Request for Proposal (RFP) for the simulator supply are summarized below.

General description

Supplier will provide all applicable hardware, software, interfacing requirements, and site support required to make the simulator system functional. Interfacing requirements for the simulator shall be to a Foxboro I/A DCS and Allen-Bradley PLC-5.

Simulator functional requirements

The operator interface will be a DCS vendor operator console. It is intended to provide realism and to allow operators to learn the mechanics of the control system, including display layout, control buttons, and process alarms. The simulator should be capable of running on three separate operator consoles simultaneously.

The simulated process should appear live to the operator.

- It should simulate routine operations and special situations, such as a boiler trip or chip storage variations. Various scenarios should occur at random.
- It should respond to control changes and start/stop requests as expected.
- It should exhibit process dynamics such as sensor noise, valve swings, motor trips, and breakdowns.
- It should simulate secondary process effects. For example, if the flow through a heater is increased, both the flow and the temperature should change accordingly.
- It should simulate response to situations external to the process. For example, if control of the high concentration NCG flow to the powerhouse was lost, the digester should shut down.
- It should use the actual safety and process interlocks.
- It should simulate the process chemistry.
- Lab test chemistry results should behave in accordance with process changes. For example, if the chlorine dioxide cells are running faster than the generator, the chlorate strength should increase.
- Changes to the process control logic should be integrated with the simulator.
- It should incorporate nonlinear mathematical models where appropriate.

The following specifications should apply to maintenance and upgrades:

- Additional process updates should be available at a reasonable cost.
- Mill personnel should be able to make minor process changes, such as changes in pump or heat exchanger sizes.
- Major process changes may be required of the supplier at a reasonable cost.
- Ongoing training should be available with a single operator on the system or with a "control" operator for process upsets.

The simulator should incorporate Weyerhaeuser's environmental permit limits. It should respond appropriately when an environmental discharge limit is reached.
These specs indicated that a Level 5, Type III, fully dynamic, interactive process simulator was required.

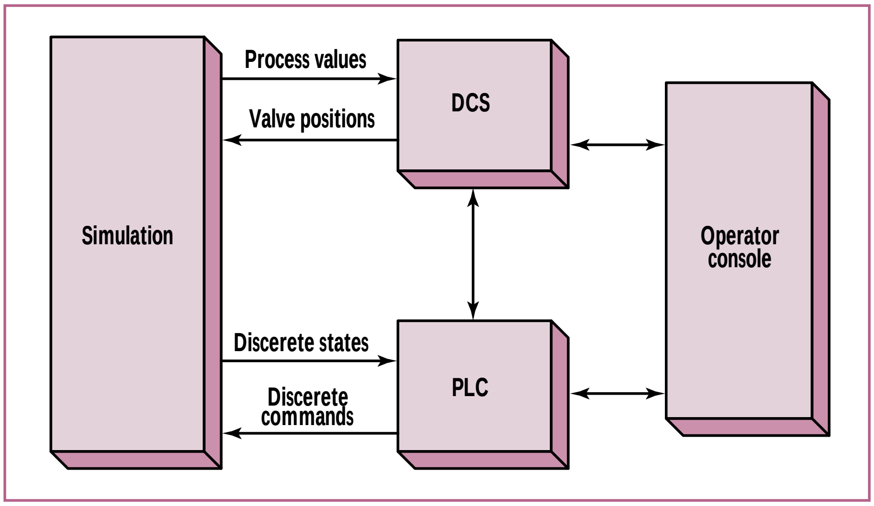
GENERAL CLASSES		
		Class hours
FL-001	Fiberline Overview	8
DIG-001	Digester Basic	24
BS-001	Brownstock Basic	16
BL-001	Bleach Plant Basic	16
C102-001 C102	Basic	4
WL-001	Wet Lap Basic	16
WL-002	Wet Lap Vendor	16
LAB-005	Wet Lap Lab Tests	8
FRKLIFT	Forklift Drv. Cert.	12
NCG-001 NCG	Overview	8
P&ID	P&ID Reading	8
PSM-001	Intro to Process Safety Mgmnt	4
SIM-001	Simulation & I/A Overview	8
EPSS-002	Review of EPSS System	2
	Windows—Beginning	6
	Windows—Intermediate	6
	Excel—Beginning	6
	Excel—Intermediate	6
DIGESTER OPERATOR CLASSES		
		Class hours
DIG-002	Study Group	
DIG-003	Digester Vendor	24
SIM-002	Simulator—Regulatory	80
LAB-001	Lab Testing—Digester	16
INST-003	Kajanni Instrumentation	8
NCG-002	Digester NCG Controls	6
LL-001	Line Labeling—Digester	
BL-005	HD Inventory Strategy	8
I/A-001	Digester Supervisory Ctrls	40
SIM-005	Simulation—Supervisory	40
	Commissioning	
OCS-002	OCS—Digester	

Table I. Sample curriculum for a digester operator

THE SELECTION PROCESS

A cross-functional group consisting of operators, team leaders, and technical support resources developed a set of requirements and specifications. Based on these requirements and specifications, the purchasing and technical staff wrote a Request for Quotation (RFQ), which was sent to suppliers.

A selection committee consisting of four operators, three technical resources, and one training resource narrowed the suppliers to three. The committee used a standardized evaluation and score sheet that was filled out based on the RFQ responses and calls to references.



2. Simulator information flow

Three finalists were invited for on-site presentations and discussions. Using another standardized evaluation sheet, the selection committee scored the presentations. Based on the compilation of the evaluation sheets and group discussion, Pacific Simulation was selected.

The final step in the process was the confirmation of this selection by the Fiberline Operations Design Team.

SIMULATOR DEVELOPMENT

This was the trainer development schedule:

- April: Offline simulation development
- May: Offline simulation development
- June: DCS hookup, online simulation development
- July: Brownstock simulation complete
- August: Bleach plant simulation complete
- September: Digester simulation complete
- October: Continued simulation tuning
- November: Began operator training.

DCS HARDWARE AND SOFTWARE

All trainer control hardware was identical to that used in the mill control system. The DCS included a rack with power supply, AW51 computer, WP51 display unit with mouse and keyboard, and three PL30 control processors. Communications between the DCS and the simulation PC required DCS vendor software. Analog inputs to the DCS (such as flow rate or temperature) were updated every 2.5 s using a secondary Ethernet port. **Figure 2** provides simulator information flow. During the trainer development, one operator console was used; during actual operator training, three operator consoles were used.

Three programmable logic controllers, including racks and power supplies, were used for the trainer, along with a gateway and cable to connect the PLCs to the DCS. Communication between the PC and the PLC required a serial communication card from the PLC vendor. A schematic of the hardware configuration is shown in **Fig. 3**.

Simulation hardware and software

The training simulation and trainer control display ran on a 90 MHZ Pentium PC in a Windows 3.11 operating system environment. The process simulation itself was handled by the WinGEMS version 2.1 modular simulator. Its speed, flexibility, and accuracy in pulp and paper calculations made it ideal for computing the complex mass and energy balances required for an entire Fiberline.

The first step in the development of the process model was to develop a steady-state model, then a dynamic model of the process. Process and control diagrams, functional descriptions of equipment, and finally input from mill personnel were used in constructing a first principles model of the mill. For this application, several custom modules were added to the WinGEMS simulator to model accurately specific elements of the process.

A trainer control display was created, allowing easy startup and shutdown of the simulation, the ability to initiate training exercises or overload specific pumps and motors, and also allowing the creation of a training history file for individual operators.

Review process

An important part of simulator development was operator checkout and review. After the initial trainer configuration was completed but before simulator training began, substantial time was allocated with operators to verify the trainer response. In addition, this time provided an opportunity for the operators to give input on the operator display itself and to further define some of the exercises desired for training.

Training exercises

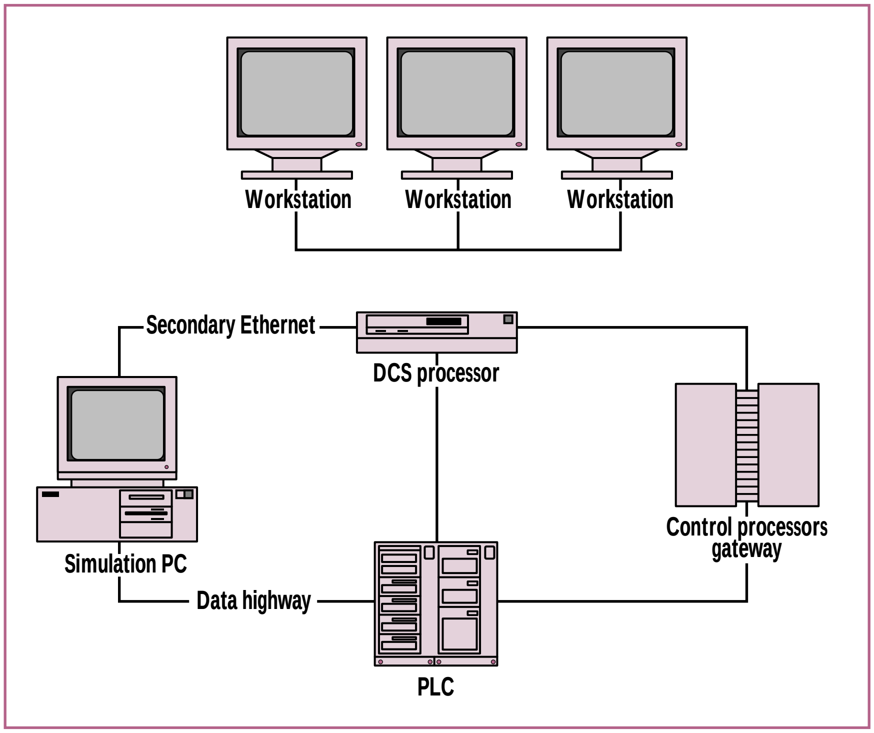
Exercises were constructed to provide training in a specific process situation. These exercises were initiated from the trainer control display and could be set to begin at a specific time or in a certain order. They required varying levels of operator knowledge and skill in coping with the problem. Furthermore, they were constructed with operator input and based upon first principles. The exercises for the digester operators are shown in **Table II**.

Maintenance and upgrades

Ongoing maintenance is necessary as the control system and the process change. The control system is altered to tune control parameters,

1. Plugged relief line screen on steaming vessel.
2. Chip chute circulation pump overload and shutdown.
3. Top separator on IV plugged.
4. Cold blow pump failure.
5. Bottom circulation liquor heater No. 1 plugged.
6. Digester outlet plugged due to high consistency.
7. Emergency stop on chip conveyor.
8. Pressure diffuser extraction screen plugged.

Table II. Digester training exercises



3. Schematic of hardware configuration used in simulation

to reflect process changes, or to change the look of the operator display. The process itself may change as instruments are added or valves resized. Therefore, the trainer must be periodically updated in order to give the correct look and feel to an operator.

THE TRAINING PROCESS

Simulation training involves more than merely navigating around the control screens and attempting to operate the PC simulator. The training exercises must also "simulate" real-life environments to the extent possible. Operators were required to have complete basic and vendor courses prior to beginning the simulation training. Therefore, field exercises were placed within the program. Also, since the final control room configuration would include operators for all three parts of the Fiberline, the simulator training room was set up in a like manner. Operators were trained in sets of two for each functional station. Written exercises were assigned, and adhoc scenarios were given by the instructor. Generally, two instructors were at each session. A few operators who had been through the complete simulation training program were used as assistant trainers. Training was conducted using two shifts (days and swing).

TRAINING SEQUENCE

Simulation training outline

Simulation training was split into three sections:

1. Introduction to the DCS
2. Regulatory control
3. Supervisory or advanced control.

The introduction to the DCS involved familiarization with the control screens and color convention used. A few simple exercises were performed.

It was essential that operators became proficient at operating the new mill under regulatory control to lay a strong foundation towards understanding supervisory control and how to operate during emergencies. Therefore, the first portion of simulation training was concerned only with regulatory control.

The objective of simulation training is to approximate real life conditions as closely as possible. As part of troubleshooting, the system administrator caused upset conditions that required corrective action from the team. During this process, one operator was designated as the field hand, while the other served as the control room operator. They switched places after a few hours. The field hand went into the mill and actually identified and observed the errant piece of equipment and reported back to the control room operator. Since the mill wasn't actually operational, the field hand had to role-play when he talked, for example, about the failure of a piece of equipment. For realism, the operator contacted role- playing support personnel such as electricians or mechanics. In this case, the system administrator acted as "support personnel." This was one of the most crucial portions of training, and it provided realistic upset conditions and reaction times.

The sequence for Parts 1 and 2 and the time involved in each sequence were the following:

I/A Review, 8 h

- Turn valves and motors ON/OFF
- Review color conventions
- Change set points, etc.

Exercises, 32 h

- Small process changes
- Control material flows to set points
- Fill/empty tanks
- Understand interlocks.

DIGESTER SIMULATION VERIFICATION

Trainee: ______________________________

Completion Date, All Units: ______________________________

Instructor: ______________________________

Initial each unit box when completed: ______________________________

1. Regulatory Control Simulation	**Yes**	**No**	**Int.**
Identify a control valve.	❑	❑	❑
Identify a control valve that has interlocks that are active.	❑	❑	❑
Demonstrate how to bring up an overlay screen and explain features.	❑	❑	❑
Demonstrate how to bring up a trend.	❑	❑	❑
Demonstrate how to change the set point on a control valve.	❑	❑	❑
Bring up the alarm page. Describe its use.	❑	❑	❑
NCG concentration goes high: Identify interlocks.	❑	❑	❑
Identify the digester level measurements.	❑	❑	❑
Perform cold startup	❑	❑	❑
Discuss the relationship between chip meter and high pressure feeder.	❑	❑	❑

2. Supervisory Control Simulation	**Yes**	**No**	**Int.**
Describe how DPV18 and PV14 are related to the differential pressure.	❑	❑	❑
Send 10% of the total white liquor to the bottom circulation flow.	❑	❑	❑
How is chip meter speed related to production?	❑	❑	❑
What is H-factor?	❑	❑	❑
What is the dilution factor and the extraction factor?	❑	❑	❑
Demonstrate a Kappa change of +5.	❑	❑	❑
Decrease production rate by 10 tons/hr. Discuss system changes.	❑	❑	❑

3. Process			
How would you determine the production rate?	❑	❑	❑
How is washing accomplished in the digester?	❑	❑	❑
How does the vertical differential pressure control the hydraulics in the pressure diffuser?	❑	❑	❑

4. Digester simulation verification form used in validation

Normal procedures, 40 h

- Startup
- Shutdown (normal)
- Shutdown (emergency)
- Troubleshooting
- Stabilize the process after administrator-induced upsets.

KEYWORDS

Control systems, distributed control, education, equipment, modernization, personnel, simulation, training equipment, utilization.

Validation

- Consisting of planned exercises only.

Supervisory (advanced controls)

Prior to working on the simulation using the supervisory controls, each operating group (digester, brownstock, and bleach plant) attended a 40-h classroom session explaining the advanced control system. The simulator was connected to the mill network to allow the classroom session to be held in the mill training center.

In this session, the functional description of the area was reviewed. The simulator was used to illustrate the concepts.

These sessions discussed reaction profiles, storage constraints, flow, and quality parameters in the context of the process control system. Then the specific supervisory controls employed by the system were discussed by functional area. Operators needed to be familiar with system reactions to changes in production rates, residence time, kappa controls, temperature, and other control variables.

After the classroom session, operators worked on the simulator with the advanced control system fully functional. They were again set up in teams of two and scheduled in two shifts. This session was 40 h.

Simulator exercises

Certain training exercises were developed and programmed within the simulator. Each operating area had unique scenarios built in. These exercises required that the simulator be set to a certain operating state within the DCS, PLC, and simulator process. This included various tank levels, flow and production rates, and production conditions. These exercises could be set up to activate at a given time.

Also incorporated in the simulation was a "couple" or "uncouple" function. The various sections of the Fiberline would operate as a single line or as discrete units. During regulatory training, the Fiberline was "uncoupled." During supervisory control training, the entire system was "coupled." In this case, if the digester operators produced a "hard cook," the brownstock and bleach operators would see that condition (in real time).

Trainer selected scenarios

Each trainer, following the lesson plan, would set a state within the simulator. These states could be upset at the trainer's discretion. Motor failures, tank leakage, overflow, or valve position changes, even a complete power failure, were initiated and controlled by the trainer. Any of the exercises could be activated on demand, at a specific time, or in a specific sequence.

VALIDATION

The new work design system required that each operator validate his knowledge at each point in the training program. Each operator took the same validation based on his operating area. The predesigned scenarios in the simulator were a key component of consistent validation.

A sample portion of the validation is shown in **Fig. 4**.

ANCILLARY USES OF SIMULATOR

Aside from direct use in training, the simulator was used in checking out and pre-tuning the process control system. Many control errors were found or changes tried on the simulator prior to implementing the control on the actual mill system. It was also found that during simulation, social interaction and work systems were accurately portrayed. Operators were able to experience working in a central control room under the new work design.

After startup, the simulator was used to test control optimization and tuning changes prior to use on the real system. Since the simulation hardware was identical to the actual mill hardware, different cards or hardware configurations could be tried in the PLC or DCS to test their capabilities. "What-if" uses of a simulator are a valuable ongoing operation.

SUMMARY OF LESSONS LEARNED

Full use of a simulator means looking beyond startup training requirements to its continued utilization. The simulator is a "live" part of the mill. It needs to be modified and kept current with the process and process control system. The network architecture of the system should facilitate updates. Resources need to be authorized for this.

A seamless interface requires coordination with mill information systems and process control personnel. As process changes take place, a log or other device should be maintained to track changes. Periodic changes to the simulator should be made in the log.

During initial development of the simulator, adequate operator and process resources must be provided. Adequate mill resources need to be available, and all hardware and software should be purchased and delivered in a timely manner.

Simulator and simulation should be developed to incorporate all aspects of the new work system and physical layout. Operators should visit the mill to emphasize the relationship between the control screens and actual equipment.

MANAGEMENT COMMITMENT

Undertaking a complete simulator-based training program requires not only funding but commitment. It must be recognized that utilizing a simulator as a training tool requires resources for development and maintenance. Weyerhaeuser determined that the successful startup of the Fiberline would be contingent upon well-trained personnel. To that end, both internal and external resources were assigned to the task. However, the depth of commitment required at the early stages was not fully recognized. Certainly, one of the key things learned from this project was the necessity to fully integrate the resources of the process control department, training, operations, and mill information systems department in the development of a full simulator. This is especially true if it is to be used to its full potential in an ongoing training environment.

SUMMARY

The modernization project enjoyed a successful startup. This was in no small part due to the use of simulation in the training program. Operators became highly familiar and comfortable with the control screens, their use, and the dynamics of the system. Any major project utilizing sophisticated controls should incorporate a fully dynamic simulator as part of the training program. **TJ**

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