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# OPERATOR TRAINING SIMULATOR SYSTEMS

## The Simulator System for Profertil's Fertilizer Plant


**Authors**:

**Regina Meloni -** **Snamprogetti S.p.A.**
Viale de Gasperi, 16
20097 San Donato
Milanese, ITALY

**Paolo Gaffuri -** **APC Tech, srl**
Via Durando, 38
20158 Milano
ITALY
Web: www.apctech.it

**David Pathe -** **Trident Computer Resources, Inc.**
151 Industrial Way East
Eatontown, New Jersey, USA
Tel: (732)-544-9333
Fax: (732)-544-1511
Email: simulation.sales@tridentusa.com
Web: www.tridentusa.com



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Regina Meloni - Snamprogetti S.p.A., Italy
Paolo Gaffuri - APC Tech, srl, Italy
David Pathe - Trident Computer Resources, USA

## Introduction

PROFERTIL's S.A. Fertilizer Complex in Bahia Blanca, Argentina is a Fertilizer Plant designed to produce 2050 MTPD of ammonia and 3250 MTPD of urea. The ammonia process technology is licensed by Haldor Topsoe, while the urea unit is the world's largest single train urea plant, licensed by Snamprogetti. The complex includes a granulation unit, with two trains (production capacity of 610,500 MT per year, each).

The construction of the Complex was awarded by Profertil, a Repsol YPF and Agrium J.V. to **Snamprogetti & Techint**, in a turn-key contract with Snamprogetti as Main Contractor. PROFERTIL's complex, covering 64 Ha, is located in Bahía Blanca, a city in the Province of Buenos Aires, on the Atlantic Coast of Argentina, approximately 700 Km to the South of the city of Buenos Aires.

The particular size and location of this new, grassroots complex suggested a significant investment in terms of training because most of the operators and local engineers had little or no experience with these complex processes and control system technologies.

Classroom and in-the-field training in similar plants in Canada were carried out under the lead of Snamprogetti and Agrium engineers, but a large portion of the training was conducted on an Operator Training Simulator (OTS) developed by **Trident Computer Resources Inc**. located in Eatontown, New Jersey, USA and their Italian partner **APC Tech srl** in Milan. The OTS was commissioned and installed at Profertil's site before the commissioning of the real plant, so that it was possible to train operators and engineers before the actual plant start-up.

## Background

OTS's have long been recognized as the best method of training in the airline, nuclear power, aerospace and military industries. Other than governmental regulations, an important factor in using OTS's is the ability to safely train on unusual situations and emergency scenarios that are seldom encountered in real life. Since the mid-1970's, the Hydrocarbon Process Industries (HPI) have used OTS's starting with part-scope analog panel board simulators and digital simulators in the early 1980's. Accident prevention was a major focus in the HPI during this period, and recent data indicates that overall losses are being reduced (figure 1).

OTS's are now viewed as an important, if not critical training tool for grassroots plants and process units being revamped or re-instrumented. As the computer power vs. cost ratio has dramatically improved, there are fewer limitations for developing full-scope, high-fidelity training models which are now capable of being utilized for engineering applications prior to training of operators. More and more, OTS's justified for "training" are now paying for themselves in engineering benefits prior to operator training. Training budgets and capital investment costs continue to be the "limiting factor" in determining the extent of the simulation scope, but there have been some advances in recent years which have reduced overall OTS costs yet have maintained the fidelity for training of operators.

On-the-Job training is also an important component of the overall training program, but has many limitations in training or testing operators on critical or emergency scenarios, use of ESD/Interlock systems, etc. Site visits to similar process plants have similar limitations and could also have differences in the control system and equipment configuration. Several studies have shown that an OTS will give operators the equivalent of 6 years of on-the-job training and that periodic training, especially on emergency scenarios, will bring operator skill levels to their highest values (figures 2 and 3).

Real-time dynamic simulators are recognized as the ultimate training tool because they allow experiencing in a "hands-on manner" virtually every type of operating condition which can be encountered including startup, shutdown, normal and emergency / unusual operating scenarios, etc. In addition, there are now tools for the instructor to develop standard exercises for testing and evaluating each student's performance as well as documenting the training session results.

In addition to the above advantages, simulator training is also one of the most cost-effective tools for operator training. An OTS allows the student to experience more operating situations in a relatively short period of training time, usually just before the plant is commissioned. An OTS thus represents the best method for conducting carefully supervised training exercises that will help to reduce personnel errors, and consequently maximize plant availability and, thus, increase plant productivity and improve product quality. Training sessions can be easily repeated to monitor and prove operator improvements.

In recent years, high fidelity simulators used for operator training, plant design and control strategy evaluation have become less expensive. This is due in part to improved computer price/performance ratios but some of the biggest savings are achieved by using "software emulation" of the operator station and control systems. In today's OTS, the most expensive hardware component is usually the DCS operator stations, the interface to the simulation computer, and associated control equipment. High-fidelity simulated or "Emulated" operator stations can significantly reduce the overall OTS cost without sacrificing realism at the operator station, while at the same time, greatly increasing the training capabilities of the system. These will be discussed later in this paper.

Lastly, the engineering labor needed for the development of detailed dynamic simulations has been streamlined by the advent of user-friendly model development languages and tools. Other benefits from development of the OTS and dynamic process models during the Project Engineering Phase will be highlighted later.

**Profertil Training Goals and Simulator Justification**

The key justifications for Profertil's OTS investment included the following:

- To have Safer Plant Operations
- To avoid Unnecessary Plant Trips
- To have Better Plant Performance and Maximizing Urea Production.

These are some of the foremost concerns due to the limited experience of the operators combined with the complexity of the process, controls, and ESD, plus the relative newness of the DCS. Additional justification included Profertil's awareness of possible plant pollution problems; justifications that are difficult to quantify but must be considered in the OTS benefit calculations

Profertil had a total of about 40 operators to train using a variety of methods, including classroom and site visits to similar Agrium plants in Canada. Direct costs as well as travel and living costs for Operator Training in Canada were also considered for the initial OTS investment.

Time and schedule constraints were also a factor as there were a large number of candidates to be trained in a relatively short period of time prior to the plant commissioning.

At the beginning of the OTS project, Profertil did not quantify their expectations for achieving specific training goals, however, their intention was that the OTS would be one of, if not the most important tool used in the overall operator training program.

In addition to training, there were some known engineering benefits / justifications which Profertil expected to achieve. Since the OTS would be the first tool to integrate the plant design in a dynamic process model, the plant controls, the ESD system and the DCS configurations into one system which could be operated over a wide range of conditions, there were expectations that certain engineering benefits would be achieved.

During the OTS Factory Acceptance Test the simulator system was used by Snamprogetti engineering personnel to evaluate and verify plant operating procedures, process controls, ESD Interlocks, and DCS configurations / graphics. The functionality of the graphic pages was thoroughly tested and checked before the commissioning of the DCS by performing all of the start-up and shut down procedures and also by testing some process malfunctions and equipment failures. As a result, Snamprogetti engineers suggested modifications to the original DCS displays in order to improve the functionality of the system. Also the DCS database was tested before commissioning and again corrections were suggested and performed. Specifically, some mistakes were discovered for configurations of split-range control loops which were resolved prior to the OTS being delivered to site.

The Advanced Process Control (APC) and logic were considered in the OTS as simplified algorithms for Operator familiarization and training. As a result, the APC Operator interface in the DCS was also improved.

Using the OTS in this manner saved time and money since it was possible to make changes to the DCS and test other parts of the control system well before the DCS was commissioned at Profertil's site.

**Snamprogetti Support for OTS development**

Snamprogetti, as Process Licensor and Main Contractor, was fully involved in the OTS development, primarily during the plant model definition and during the OTS Factory Acceptance Test (FAT). Snamprogetti discussed the details of the project and process model definition with Trident/ApcTech and fully verified the simulation results as part of the FAT. The Licensor's process know-how and involvement at the key stages in the project improved the quality of the mathematical model, resulting in a higher level of fidelity in the OTS.

Snamprogetti has extensive experience in fertilizer plants so, for the Profertil Project, the OTS didn't provide any new process feedback to Snamprogetti, however it served to confirm and verify the correctness of start-up/shut-down procedures and the operability of the plant during malfunction and emergency scenarios.

However, in other situations (mainly for new or unproven types of process plants), dynamic simulation is an important tool for identifying plant deficiencies and troubleshooting the design (e.g. bottlenecks, control problems, etc.). The identification of problems in the engineering / design phase of the project allows early problem resolution, thus minimizing the cost and the impact on the project design schedule and also during the plant commissioning phase.

In general, these engineering benefits are difficult to predict and quantify, but considering the potential delay and consequent cost due to design mistakes encountered during commissioning and start-up period, the cost of the dynamic simulator is more than justified.

**Brief Process Description**

An ammonia / urea process represents a very complex combination of sophisticated process equipment, controls, ESD/Interlock logic as well as extreme operating conditions (1000 degF to –30 degF) in addition to interesting process interactions (figure 3).

Ammonia is produced from a mixture of hydrogen and nitrogen. The source of hydrogen is the process steam and the hydrocarbons in the feed natural gas and the source of nitrogen is the atmospheric air.

The natural gas is desulphurized and then is reformed with steam and air into the raw synthesis gas. The gas contains mainly hydrogen, nitrogen, carbon monoxide, carbon dioxide and steam. In the gas purification section CO is converted to CO2 and H2 with steam (shift reaction) in order to increase the H2 yield. Then CO2 is removed in the CO2 removal section. The remaining CO and CO2 are converted into methane by reaction with H2 (methanation)

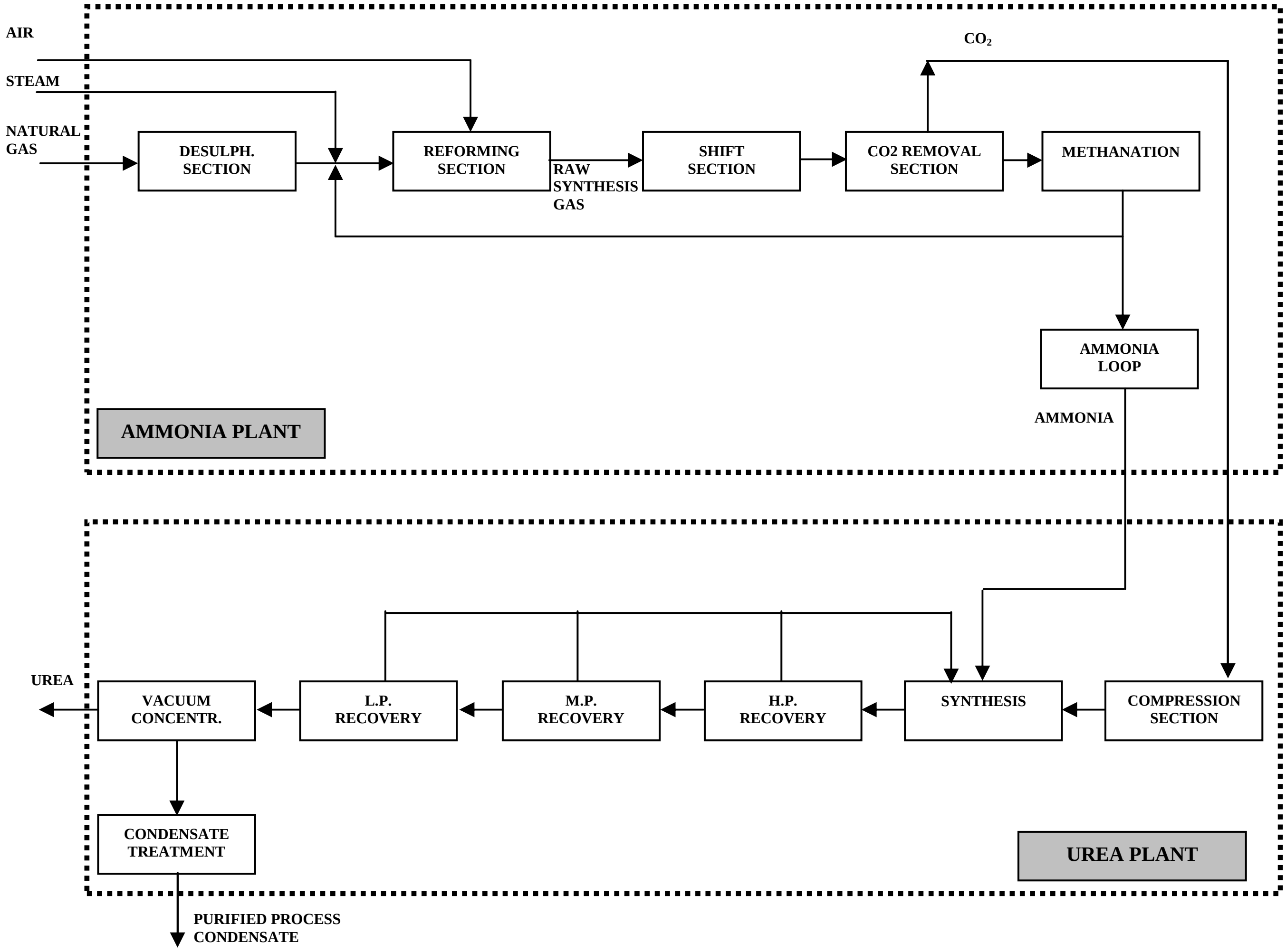


**Figure 4 – Overall Ammonia and Urea Process Areas**

before the synthesis gas is sent to the ammonia synthesis loop where it is converted into ammonia. The CO2 separated in the CO2 removal section is sent to the compression section of the urea plant and then to the synthesis reactor together with ammonia. Downstream the urea synthesis, the decomposition and relevant recovery of unconverted chemical reagents is carried out in three subsequent steps: High Pressure Decomposition, Medium Pressure Decomposition, and Low Pressure Decomposition. Urea is then concentrated in the Vacuum Concentration section before being fed to the granulation unit. The process condensate is treated in the waste water treatment section and is sent to battery limit.

What is important to consider for operator training is that the process contains many fast-moving unit operations (ie compressors) coupled with interactions between the process and the steam which is generated from the excess heat of the process. Every action taken by the operator will have multiple effects in different parts of the process. Some equipment failures, such as an air compressor trip, can be recovered by quick operator action, thus saving a plant trip and a much greater amount of lost production.

**System Architecture**

The Profertil OTS consists of the following major components (figure 5):

- Simulation Computer
- Dynamic Process Models
- Instructor Station
- Emulated Operator Stations
- Field Operator Station

The hardware consists of a Simulation Computer (Compaq Workstation) and Instructor Station (monitor, keyboard, mouse), while the Emulated Operator Stations, and Field Operator Station are standard PC's networked to the Simulation Computer. A printer provides hardcopy documentation of the training session with various printouts such as files from instructor sessions with process reports, alarms logging, and a log of events that occurred during the training session, both instructor and operator actions.

The Compaq Simulation Computer is the heart of the system where the simulation executive, simulation models, instructor's software, and the operator station interface or emulation runs.

The instructor can control the session, monitor all the process variables, insert malfunctions, override instrument signals, change battery limit conditions, measure the student's performance, and record the results of the training session. A user-friendly interface minimizes the need of instructor's computer knowledge and allows the instructor to be focused only on the training session. In addition the instructor can change the time scale from 0.1 times to 10 times the real time. With this training feature the instructor can run faster operations that have been already examined or operations that need long time (filling of tanks, heating and pressurizing phases) or he can run the process slower than the real time to allow the student to carefully observe critical situations. More sophisticated instructor functions include creation of training scenarios, sending text or audio or video files to the student, and management of the student's training. Some typical windows and menus of the instructor station are shown in figure 6.

The Emulated Operator Stations closely resemble the Foxboro I/A Series DCS including monitors, keyboards, and touchscreen / pointing devices. The actual keyboards can be used as well as console cabinetry to maximize "control room realism". The man-machine-interface is faithfully represented for all operator related activities including operating groups, trends, alarms, graphics, keyboard functions, touch-targets, etc.  The graphic displays are exactly duplicated by using a translator which uses the actual Foxboro configurations and integrates them into the Emulated Foxboro I/A format with all the functional features such as windows, control targets, etc. In addition, a significant part of the emulator includes simulation of the many and various control algorithms and functions available in the Foxboro Control Processor (CP). Lastly, the emulation software includes a set of utilities which permits the client to change the DCS configurations and control soft-wiring in a similar manner to how they are changed using the engineering configuration tools at the real DCS.

The overall result is a very high-fidelity representation of the operator station found in the control room. This product allows both the operator training to occur with maximum realism as well as engineering applications since the control algorithms are simulated in detail. The cost savings from using this approach are significant, both in the initial cost for the OTS as well as for the ongoing maintenance of the system. Figures 7a thru 7c show emulated operator stations used for several different OTS projects, and it is difficult if not impossible to discern which are emulated and which are interfaced to actual DCS. More information about specific benefits are contained later in this paper.

The Field Operator Station (FOS) was configured to include the remote or field operated equipment not available from the main DCS operator station and also the ESD/Interlock functions using graphics instead of the hardwired panel displays in the control room. Field equipment includes block and bypass valves, motor starters, local relay and switch controls and other types of digital and analog devices. The FOS was physically located near the Emulated Foxboro I/A operator stations to provide the operator more complete control of the simulated plant. Since the FOS is a subset of the instructor station the same functionality is also available at the instructor station so that the presence of a field operator is not necessary to conduct a training session.

**Process Model Overview**

The single most important component in an OTS is the mathematical model that should accurately simulate the dynamic behavior of the process.. The overall fidelity of the model should ensure that operators can be trained to observe and respond correctly to a variety of operating conditions.

The “high fidelity” model should be enough accurate to reproduce not only plant responses due to disturbances around the normal operating conditions, but also the dynamic behavior for non-design operations including cold start-up, process upsets and emergency conditions.

Models are derived from the First Principles of Chemical Engineering (conservation of mass and energy), thermodynamic properties, and equipment performance/design data to ensure accurate responses in all the possible conditions. Differential and algebraic (linear and non-linear) equations are developed for all plant equipment, which ensures that individual unit responses as well as complex unit interactions are preserved. Process models are constructed using the algorithm library of equipment modules. Modules that simulate unit operations include compressors, distillation sections, drivers, heat exchangers, pumps, valves, and vessels. Distillation sections available in the simulator are trayed sections and draw trays. These modules perform VLE calculations on feed streams to determine the distribution of the components in the vapor and liquid streams exiting each tray. Other modules provide instrumentation and logic functionality such as control processors, level transmitter and compressor surge controller. Reactors or specific units, for instance where a reaction can occur or there are special mass-transfers occuring, are modeled with custom algorithms and the kinetic equations are sometimes rewritten to satisfy the need for faster than real-time computation.

TRIDENT's unit operation algorithm library, developed over many years and projects, has nearly every kind of equipment necessary for developing a custom process model.

For Profertil's OTS project, the urea and ammonia process and the steam network sections were simulated rigorously and in detail, while other auxiliary systems such as lube & seal oil systems, cooling water and regeneration of catalyst were simulated in less detail since these areas were not the major focus of operator training.

Malfunctions and their effects were included in the model such as heat exchanger fouling, plugging, pump failure, electric power failure, cooling water supply failure, steam supply failure, natural gas supply to primary reformer failure, air to secondary reformer supply failure. All battery limit conditions such as ambient temperature, cooling water temperature, fuel gas heating value as well as catalyst activity can be modified by the instructor to enhance the training session.

The main functionality and effects of multivariable process control implemented in the real plant have been included in the model although in less detail. The goal was to provide realistic scenarios for building operator confidence in using the APC application and to enable monitoring of the main effects of the APC. Also the DCS interface to the APC modules has been replicated so that the operator functionality (i.e. switching on and off the APC modules) is exactly reproduced.

In summary, the quality and accuracy of the process model depended primarily on the experience of the simulation engineers implementing the dynamic model as well as the involvement of the process licensor during testing of the OTS.

**Case study - Urea start-up**

Start-up is one of the most difficult and critical operations of the plant, and training in the field could not allow new operators to witness or practice these operations. The only feasible way to build the operator's confidence is by intensive and repetitive "hands-on" training that could be performed on an OTS with realistic, high-fidelity models.

Particular attention was paid in the development and testing of the models in these areas of operation. Close cooperation between Snamprogetti's process engineers with deep experience of the plant start-up and the Trident/ApcTech simulation engineers was the key point for obtaining of a high-fidelity model which would respond faithfully over a wide range of conditions. All the steps of a cold start-up are reproduced, with the only assumption that all the pre-start operations have been completed, such as testing, washing and purging of lines and equipment.

To perform start-up from empty and ambient conditions, first the medium pressure section, isolated from the rest of the plant, is pressurized. This is done charging ammonia and then heating and evaporating it. The same operation has to be done in the low-pressure section. The reaction zone is then heated with steam to 160°C before introducing process fluid and then pressurized with ammonia. During the ammoniation period, the CO2 compressor, driven by a steam turbine had to be put in service. Once all these conditions are reached it is possible to feed NH3 and CO2 to the reactor. From the moment the overflow of the reactor occurs the operator has to be skillful to quickly stabilize the plant condition and reach the design operating setpoints.

All these operations should be done within the ESD/logic sequence and bypassing some interlocks, so it is very important that the model exactly reproduces also the logic and that the hardwired panel functions are available. Figure 8 shows a screen display with some operations of the start-up in high-pressure section of the urea plant are shown.

This section is heated and pressurized acting on the steam and condensate local valves (from the FOS) and then drained. The DCS operator should follow and guide the field operator through the measurement on DCS of the reactor temperature.

**Case study – Disturbance from normal operating condition**

Operators needed to be trained to react quickly and properly on possible malfunctions or equipment failures. It was important to define all the possible scenarios to be taken into account and simulated in the model. This was done during the development of the Functional Design Specification between Snamprogetti's process engineers and Trident / APC Tech simulation engineers.

An example of a possible disturbance that occurs in a urea plant is condenser fouling. The presence of CO2 in the upper section of the M.P. absorber is very dangerous because it reacts with ammonia to form ammonium carbamate and as a result the downstream ammonia condenser will be plugged.

The instructor can monitor the CO2 content since he has the full visibility of all the model variables, while the operator does not have any indication of the overhead composition. When the CO2 content reaches the high critical value the instructor can decide to plug the ammonia condenser. This effect was not automatically included in the model since the instructor has more flexibility to enable this malfunction.

In order to avoid plugging it is very important to control the temperature at the top of the absorber to inhibit the reaction; this variable is the only key variable that the operator can see as an index of CO2 content.

A possible exercise to test the operator's ability to react fast to possible disturbance is to increase the fouling of the M.P. condenser upstream the absorber or to increase the cooling water supply temperature. The temperature at the top of the absorber increases and the operator should increase the reflux of fresh ammonia from the ammonia receiver to maintain the desired value. The DCS display with the absorber top temperature trend is shown in figure 9 for this kind of test where the operator increases the reflux flow rate to control the temperature.

**Cost Benefits & Discussion of Emulated Operator Stations**

Profertil had a choice of operator stations for the OTS: using emulated Foxboro I/A operator stations or having the OTS interfaced to real Foxboro I/A DCS equipment. Emulated Operator Stations were chosen for a number of reasons, including:

- Very realistic representation of the Foxboro MMI and controls,
- Lower initial investment cost and reduced longer-term maintenance costs,
- More functionality (multi-user capability, engineering applications)

The only way to truly evaluate if the emulated approach has sufficient realism for the OTS is to actually see the product. The keyboard and pointing device usage, screen displays, etc. should be nearly identical to the actual DCS. The emulation should preferably be configurable with utilities for both translating the graphics from the real DCS configurations as well as entering and modifying the basic DCS database. Of equal importance and often overlooked, the control algorithms should be included in as much detail as possible.

While realism and robustness of the operator station is important, the amount of training on the DCS usage represents only 20-30% of the total training on the OTS, with a far greater amount of training focused on the process model (ie startup, shutdown, emergency scenarios, etc.). From a cost / benefit basis, it makes sense to use emulated operator stations and invest the cost savings into the dynamic model.

The cost savings from use of emulated operator stations is significant, depending on which DCS and the availability of interface products. For example, a typical set of Foxboro I/A DCS hardware costs about $100,000.USD plus (depending on the specific interface approach used) an additional $100,000 to $200,000 for communication software and software CP's. The total cost for two (2) Emulated Operator Stations is about $30,000 to $40,000. so the cost comparison is easy for Foxboro I/A as well as for most other major DCS's.

Occasionally buyers will have concerns regarding future updates of the DCS and incorporating the same into the OTS. Ironically, the emulation has far less to be updated primarily because so few of the DCS releases actually impact the operator interface. On the other hand, an update to the DCS version / software could require extensive software updates to the interface software.

**Conclusions**

Many benefits were achieved with this OTS project which included both operator training and engineering.

The operator training simulator was successfully utilized to teach operators how to operate in critical conditions and to run the plant in a safe manner. It was also used to continuously test the operator performances in critical plant conditions, such as plant start-up, normal and unscheduled shut-down that otherwise with traditional on the field training are seldom tested. The results achieved were significant and could only be obtained through the intensive use of the OTS. As part of the training program, operators were trained in 8-hour shifts over a 24-hour period to simulate actual plant operations and shift changes.

Plant engineers practiced and witnessed many different plant scenarios, conducting what if analysis and monitoring the dynamic process behavior.

While it is difficult to quantify the exact savings, typically one unscheduled shutdown, trip, or plant upset can be avoided each year. On this basis, the OTS essentially pays for itself each year. If a serious event or equipment-damaging accident can be avoided, the simulator pays for itself many, many times over.

Results from several OTS users show that simulator training greatly accelerates the "real-plant" experience levels of new operators. Several studies show that new operators gain the equivalent of six (6) or more years of process experience from OTS combined with O-T-J. Snamprogetti also achieved benefits from their involvement in the OTS development. Changes were made to the DCS configuration before the DCS commissioning thanks to the use of the OTS. Engineers discovered, through the DCS emulation, minor deficiencies or inefficiencies in the DCS that were not identified during extensive testing carried out at the DCS Factory Acceptance Test. This experience was also important for Snamprogetti Licensor know-how and familiarization with dynamic simulation tools.

**Future Developments**

As the cost / benefit ratio for OTS continues to improve, there will be additional emphasis on OTS, both from cost-justification to safety to government regulation. Instructors will have more tools to conduct training and objectively measure operator performance. Models developed for "training" will be used for multiple applications including expanded engineering applications, control studies, and plant design. In addition, actual plant data can now be used to initialize the OTS to previous plant conditions for training.

Additional data on training benefits, resultant cost savings and improved plant performance criteria from all OTS users would greatly help others to evaluate and quantify the specific benefits which can be obtained from an OTS.

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