Training tools to evaluate pipeline operator performance and to validate pipeline operational procedures

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ABSTRACT

The current regulation environment for pipeline companies has created or reinforced the requirements for operational training programs and quality assurance procedures. Pipeline operators in the USA are regulated by the standards defined by DOT and companies overseas are establishing their own standards, following and sometimes exceeding the regulations of USA.

At installations like the OCP (Oleoducto de Crudos Pesados – Heavy Crude Oil Pipeline) in Ecuador, where the pipeline crosses high sensitivity areas, including the Amazon Jungle and the Andean mountains, the pipeline operators are subject to extreme pressure by environmental and government agencies to guarantee safe operation of the line.

The particular situation of the OCP, being a brand new pipeline, made the implementation of a training program a very special and highly demanding project. The first steps were to define the professional profile of the operators, select the tools to train them and then evaluate their performance on a line that was just being built.

The main objective of this paper is to present the process that was stablished at the OCP to implement the training application, to train and evaluate operator performance on a completely new installation and how they gained confidence in this application to become their daily assistance tool to double check operational procedures and new strategies to run their pipeline.

The paper also describes the requirements of the system defined by OCP, the functionality available in the application, the implementation process, the training program and the current procedures related to the usage of this application.

ABOUT OCP

Oleoducto de Crudos Pesados (OCP) Ecuador S.A., a partnership between EnCana, Repsol-YPF, Occidental, Petrobras, Agip Oil and Perenco, constitutes a strategic asset for the present and future of the Ecuadorian oil export and the country itself.

The OCP Pipeline transports heavy crude oil approximately 500 km from the Eastern Ecuador to the Pacific Coast of Ecuador near Esmeraldas (See Figure 1) exhibiting an extreme elevation variance, approximately 14,000 feet total variance (4,064 meters). The pipeline consists of 4 different diameters NPS 24, 32, 34, and 36 and 31 associated diameter wall thicknesses and it is designed to transport a blended heavy crude oil. The pipeline is designed to be capable of delivering 450,000 bpd of heated crude oil, at a minimum pipeline blend of 18 degrees API Gravity, on a sustained basis to Esmeraldas. The corresponding peak delivery capability is approximately 518,000 bpd. See Figure 2 for a pipeline schematic.

PROJECT REQUIREMENTS AND BACKGROUND

Background

Before the start of operations and for approximately one year during construction, an extensive recruitment and training plan was conducted at the OCP. Priority on Ecuadorian labor was a requirement and the lack of Ecuadorian pipeline background (only SOTE pipeline, the national 30 year-old pipeline without a SCADA system) was an important limitation. Extensive training programs were stablished to cover the lack of experience of most of the recruited people.

A group of eight pipeline operators was recruited, with them having limited experience in pipeline operations, although all

of them are graduated engineers and with experience in SCADA systems, control and instrumentation.

The objective of their training program was for them to be able to fully operate the pipeline at the moment it was handed over from the EPC Contractor. A short period of about four months was allowed for the EPC Contractor to operate the system after it was completely built. This was a very good chance for the OCP operators to gain operations experience after their training was completed.

Project Requirements

Vendor was required to supply fully configured software solutions and training services to be used for the OCP Pipeline. The project requirements and deliverables can be summarized as follows:

- **Engineering Transient Pipeline Simulator Software:** software package for off-line transient and steady state pipeline hydraulics and thermal simulations to be used for engineering purposes.

- **Pipeline Model Programming:** configuration of the OCP Pipeline Hydraulics Model for the above.

- **Engineering Transient Pipeline Simulator Training**: engineering personnel training on the use of the Engineering Simulator.

- **Pipeline Simulator Trainer:** package for pipeline operations training. This package shall produce the same situations that occur in real pipeline operations.

- **Pipeline Simulator Trainer programming:** configuration of the Pipeline Simulator Trainer and screens similar/equal to OCP Pipeline SCADA System.

- **Operators Training & Qualification Management Module:** training management and control module. Qualifications and records of each operator shall be controlled and stored in this module.

- **Simulator Trainer training:** engineering personnel training on the use, administration and configuration of the Trainer.

- **Operators Training Services:** includes all the services that are required to train pipeline operators from hydraulics basics to complex pipeline operations simulated scenarios.

TRAINING APPLICATION DESCRIPTION

Introduction

The need for training solutions in the pipeline control room has never been greater. The realities of today's pipeline industry include increased scrutiny of pipeline safety; regulations requiring operator qualification; historically high levels of turnover in the control room; and ever increasing demands on pipeline operators. Simulation based training has emerged as a key component of an effective control room training solution.

While there is more than one way to apply simulation technology to pipeline operator training, a "Flight Simulator Style Trainer" was the one chosen for this project. Flight Simulator Style Trainers represent the very best method yet devised for employing simulation technology in the training of pipeline operators. Simply put the goal of a Flight Simulator Style Trainer is to recreate the reality of the pipeline operator's work environment with a high degree of fidelity. The reality comes from two sources: the model and the operator's interface.

The concept of a training environment with a highly realistic trainee interface is certainly not unique to the Flight Simulator Style Trainer. As the name suggests the Flight Simulator Style Trainer owes a conceptual debt to the flight simulators used to train airline pilots. These are complex electromechanical devices driven by sophisticated computer software. Achieving the flight simulator concept is somewhat easier for pipeline operations. While the aircraft-simulation level of realism is probably excessive for the pipeline operator application, the underlying principle is sound: effective training is realistic training.

The trainer is an extremely effective tool for the training of operators and for use by others to look at how the pipeline is affected by planned and unplanned changes in the pipeline environment.

System Overview
In order to fulfill the needs of the market, **Energy Solutions** developed an advanced training application tool. The concept of this tool is based on four main elements, including a fully hydraulic detailed transient model, an instructor interface, an operator interface and an automatic evaluation module (see Figure 3).

- The transient Model calculates all the hydraulics of the pipeline based on the input on the Trainee Interface. The model simulates all the measurements and indicators (analog and digital points) as if they were collected by the real SCADA system. The input data are processed in a similar way as in the SCADA system and the results are displayed in pictures equivalent to the SCADA screens.

With an accurate transient model environment known as *pipelinemanager*, the operator will observe very realistic behavior of the pipeline network. Trained using this technology the operator can be confident that the real world will behave in ways that are totally consistent with the environment in which he/she was trained.

The pipeline model is a fully transient hydraulic and thermodynamic model and includes solutions of the complete dynamic equations with the governing laws being the conservation of mass, energy and momentum.

The complete transient model has the prime advantage of being able to model the process very accurately and can therefore provide accurate real time information.

When the simulation engine is running, the model calculated outputs (virtual measurements) of flow, pressure etc. at all SCADA metering points are sent to the SCADA-like screens. Set points can be changed and OPEN/CLOSE valve commands can be issued by the Trainee from the trainee console.

Changes in pressure, flow or pump set points will result in a gradual change in the model calculated conditions, simulating the real interaction between the controllers and the pipeline. Any events included in the scenario will be carried out at the programmed point in time.

The Trainer model will simulate the development of pressure, flow and temperature transients throughout the pipeline in response to any set points specified by the Instructor or Trainee.

- The Instructor Interface allows the Training Instructor to set up operating scenarios resembling the real world by definition of inflows, products and operation of equipment in the pipeline. Through this interface, the Instructor is also able to define a range of upset conditions, which may occur in the real world such as a pump trip or improper operation of valves, as well as the criteria to evaluate the performance of the trainees.

In addition, the Instructor is able to set goals and limits within the evaluation module which are respectively related to rewarding certain variables reaching given values and maintaining certain variables, such as pressure or flow, within defined limits (see Figure 4). The Instructor can also describe the expected Trainee reactions to each incident.

- The Trainee Interface - The window through which pipeline operators view their world is the SCADA system HMI (human-machine interface). The operator uses the SCADA HMI to monitor the state of the pipeline and to enter commands that will cause something to happen on the pipeline. The Flight Simulator Style Trainer uses a set of the SCADA-like screens as the interface between the simulated pipeline and the operator (trainee). The Trainee Interface emulates the SCADA environment, allowing the operator to interactively, enter the same type of

commands as in the SCADA system, e.g., change of set-points, start/stop of pumps, close/open valves. Such entries from the Trainee will have a direct impact on the Model in a similar manner as control output from the real SCADA system. Thus, the trainee can observe the reactions of the pipeline as he/she was operating the real pipeline. This gives the operator the possibility to perform operations within a safe simulated environment. The result is the highest possible degree of fidelity between the operator's working environment and the training environment.

The concept is that the trainee operates the trainer through SCADA-like screens where data is displayed at the same locations where real SCADA instruments is available, but such data is actually calculated by the trainer model. Thus, from the operator's perspective, the trainer model reacts as the real pipeline.

At the beginning of each session, the trainee logs into the system and selects the scenario that he/she wants to run. The training system tracks each session conducted by each trainee, including the time and score of each session. Once the training session is initiated the trainee will interact with the application as if he/she were working on the real pipeline, opening and closing valves, operating pump stations, modifying set points, etc. All trainee actions are done using the SCADA-like screens. During the training session, the operator also has the possibility to insert comments for the Instructor. Those comments are included in the evaluation report.

The trainee also has the option to control the speed of the simulation, in that way it will be possible to run long operational scenarios in a matter of minutes. When the trainee detects that the pipeline gets in a stable condition and wants to move ahead with the session, the trainee can increase the speed of the simulation until a new state or operational condition has been reached. At that time the operator can go back to normal speed and continue normal operator duties.

- The automatic evaluation module keeps track of the performance of the Trainee throughout the training session. The evaluation criteria is dynamically defined by the instructor, who sets the tasks to be accomplished during the session, as well as the bonuses and penalties that will apply depending on the actions taken by the Trainee.

This module automatically generates a score, based on the predefined bonus and penalty structure, which qualifies the performance of the operator under the conditions specified in the scenario.

In order to evaluate the results of a training session a number of criteria for success and/or failure can be defined by the Instructor. Evidently, there are many ways to reach a given state of the pipeline, so the criteria should not be given as a set of specific actions that the Trainee

must perform. They should rather be defined as a set of pipeline variables being within certain limits combined with two sets of events: desired and undesired events.

The structure of this application allows the Trainee to do self-training using a predefined scenario, or to be interactively taught by an Instructor. The Instructor defines scenarios and scoring metrics for both types of sessions. For an interactive session, the Instructor can monitor the Trainee, control the performance of the trainer, and introduce unexpected pipeline changes and upsets that require Trainee response.

System Architecture

The Trainer is a client /server application, which can be configured in several different ways, to accommodate customer requirements:

- The model and the instructor interface could be running on a server, with the trainee console connected through a network.

- The model could be running on a server, connected through a network to the instructor console and the trainee consoles.

- It can even be configured as a fully stand-alone application, with the model and both the trainee and the instructor interfaces running on the same computer; however, in this case the interactive scenarios are limited.

Training Session Description

A training session is managed from a Control Screen accessed only by the Instructor. Only in a self-taught session the Trainee would be allowed to use the control screen. In an interactive session the Instructor is the one operating that screen. From the Control Screen the instructor can control the entire training session, including the following actions:

- Register instructor, trainee and training session
- Initialize the training session – Select the scenario to be simulated.
- Start, Stop, and Pause the simulation
- Control the simulation speed.
- Rewind and Fast forward simulation.
- Archive specific state of the simulation.
- Restart a session

The initial state of a training session consists of building the training scenario, which comes from the same trainer model (possibly executed in fast mode for a certain number of cycles until it reaches the desired hydraulic state), from an archived state from a previous run or, when it is available, from a saved hydraulic state of the online Real Time Model. The training scenario consists of the changes in boundary conditions that will take place during the simulation. For example, an analysis is required to determine the effect of closing a valve in the

system. The training scenario then establishes that at a given time the valve state is changed from open to close. These training scenarios can be configured in different ways, including:

- The instructor can manually input all boundary conditions (e.g. valve states, set points, etc.) using the instructor interface. Essentially the instructor operates the simulated pipeline until the desired starting point of the training scenario is achieved. Once this is done, the starting state can be archived for future use.

- If a given state is not exactly as desired, the Instructor has the ability to change one or more set points and run the Trainer in fast mode if necessary. When the desired state of the Trainer model has been reached, the state can be saved in an archive. At any later point in time, the model can be initialized using the archived state.

- When an online Real Time Model is available, it is possible to save a snapshot of its current hydraulic state and the instructor could upload such hydraulic state and use it as the initial state for training scenarios or as a starting point to operate the model until it reaches the desired state.

Whenever a stable hydraulic state is achieved, the instructor can save this state in an archive. The instructor may use this archived state to initialize the model for future runs. The instructor can also define as part of a scenario or in an interactive mode, several conditions that affect the operational stage of field devices.

Once the training scenario is defined, the trainee can then access that scenario and initiate his/her training session. The trainee will interact with the system as if he/she was operating the real SCADA system. As it was mentioned above, the trainee can manipulate the simulation speed, fast-forwarding or pausing. Once the training session is completed the application automatically generates the evaluation report with all the details related to the performance of the operator based on the predefined evaluation criteria. These details include all goals reached as well as all limits violated during the entire simulation.

PROJECT IMPLEMENTATION

The project was executed over a period of 7 months starting with a kick off meeting and ending with successful completion of the operator training courses and operator performance evaluation. The following main activities were part of the project:

Kick-off meeting: the project started with a kick off meeting in Ecuador where the detailed project schedule was presented

and agreed upon. Also the operator control room was inspected with focus on the SCADA system, which would be modeled in the simulator.

Data gathering: during the first month of the project all necessary data for creating the training courses and configuring the training simulator were gathered. This resulted in a large amount of data ranging from technical and physical specifications of all relevant equipment to descriptions of all pipeline operational procedures. This also included screen shots of all relevant operator screens being used in the control room in order to make the look and feel of the training simulator as realistic as possible.

Data review and simulator configuration: all data was reviewed to ensure that all details necessary to configure an accurate training simulator were present. Then the configuration process was initiated - the single most time consuming phase of the entire project. A lot of data had to be transformed from spreadsheets, pdf-files and other documents into configuration readable by the simulator. Most of the configuration was done using a graphical configuration tool, which made it easy to ensure that all devices and equipment were connected according to the P&IDs that were received as part of the data-gathering phase. Additionally some very project specific configuration was carried out manually (e.g. emergency shut down procedures/sequences). Finally a complete set of operator screens were configured using the supplied screen shots as foundation. All relevant dynamic data fields (basically the output from the trainer model) were added at appropriate locations.

Verification procedures: In parallel with the simulator configuration, verification procedures were created including detailed procedures for testing of all features and simulator components as defined in the contract. The main purpose of the verification procedures was to ensure that all parts of the training simulator would perform properly. Efforts were made to test each component in an isolated mode in order to be able to more easily identify potential problems or misbehavior.

Internal unit test: upon completion of the simulator configuration, all features were tested internally by following the approved verification procedures. All non-conformances were identified and corrected.

Factory acceptance test: all tests were performed similarly to the internal unit test, however this time witnessed by the end user. The end user team consisted of both operators and SCADA engineers to ensure the proper performance of the simulator. All non-conformances were identified as well as some minor adjustments necessary to ensure realistic behavior (e.g. timing of valves).

Training Material: during a two day meeting, the contents of the training material was discussed and agreed upon, including the theoretical material as well as simulator scenarios to support the operator training courses. Each scenario was assigned a set of goals and limits necessary for the automatic performance evaluation application. Approximately 25 different scenarios were identified where hands-on training exercises would benefit and support the theoretical contents.

Scenario generation: non-conformance issues from FAT were corrected along with adjustments of certain simulator parameters. All the simulator scenarios were then created in preparation for the training courses – including setting up the parameters for automatic operator performance evaluation.

Site installation: the simulator was installed on site and a quick site acceptance test was performed. Since this simulator is an offline tool there was no need to repeat the entire FAT – only non-conformances from FAT were tested to ensure that all identified issues had been properly addressed. Furthermore the simulator was installed on 6 machines that were to be used during the operator training courses (one machine for each operator).

Training courses: the end user decided to split the training course into two courses in order to have a smaller class with better support and attention from the instructors. The duration of each course was three weeks and consisted of both theoretical and practical exercises. General pipeline hydraulics as well as specific operator procedures were explained and practiced using the training simulator. At the end of each day a written test was conducted to ensure that each student had understood the relevant concepts. The results of all practical exercises using the simulator were automatically saved for each student. At the conclusion of the course all theoretical and practical test scores were gathered and a final performance review was done for each operator.

CHALLENGES FACED DURING IMPLEMENTATION

Configuration of Application

Several challenges were faced during the project implementation - mostly due to the main difference between training simulators and transient models used for applications like leak detection: the level of details required. The main objective in a training simulator is to achieve a realistic environment very similar to the real operating environment. The following is a list of challenges that are specific to training simulators:

- **Amount of data**: to ensure a realistic simulator a very high level of detail is required. For this reason many devices had to be included in the simulator, which meant that a large amount of data was requested during the data gathering phase. The main challenge was to sort through the data and identify the necessary data and filter out data not required by the simulator, keeping the main goal in

mind: to provide a training simulator with as realistic a behavior as possible.

- **Scenario generation**: in order to setup the practical training scenarios the simulator had to be treated like the real pipeline. Due to the size and reaction time of the pipeline, it was not possible to change the hydraulic state in a matter of minutes, and a realistic training simulator behaves the same way. Although a simulator can be run faster than real time, finding the balance between high execution speed and not missing significant events was a challenge during the creation of the training scenarios. Following the detailed operational procedures provided by the customer proved helpful during this phase.

- **Device interaction**: due to the need for a very detailed and realistic simulator a significant amount of devices had to be included in the model. Ensuring that all devices worked together properly without problems was a small challenge. The following is a list of the major devices that were included in the simulator:
    - Shipper inlets to tanks with proper blending of crude properties
    - Metering skids
    - Tank farms with automatic and manual tank switching
    - Booster pumps (positive displacement)
    - Heaters (incl. fuel consumption calculations)
    - Main pumps (centrifugal)
    - Pig launch and receipt (by command or valve manipulation)
    - Pressure relief valves
    - Pressure control valves (and pressure reduction stations)
    - Line block valves with automatic closing features (based on absolute pressure or range of change)
    - Detailed shutdown sequences (including emergency shutdown)

Operators

Several challeges were faced with training operators. As usual, each person or group of persons comes to a program with their very personnal and unique knowledge and expectations. The most important decision in order to minimize conflicts was to involve one selected trainee operator in the implementation team. Although an effort was done to try to satisfy those expectations and level their theoretical knowledge, several challenges were faced:

- Training program schedule: training schedule was extremely compressed for the amount of information and practice needed. Aproximatelly one month (8 hors a day) was scheduled. This was somehow compensated with the possibility for the operators to continue their practice after the course.

- Previous knowledge: there was a need to identify previous theoretical basic training needs and provide those not to delay the program.

- Knowledge leveling: there was a need to level operators' basic knowledge prior to the program.

- Model: operators' belief that the simulator model should be perfect and exactly the same compared to the pipeline was a source of discussions. Timeframe and complexity of the pipeline system didn't allow for a 100% fully detailed model and it was difficult for operators to understand this balance between complexity and usability.

- Scenarios scoring: to the operators' view the scoring system defined for the training scenarios was not correct. Weight given to each task of each scenario was not always comfortable for them and the source of many discussions.

APPLICATION USAGE

After the initial training program, the main purpose of the application has been to provide permanent training to already qualified operators, train new operators and certify both new and current operators in monitoring, control and recognition of operation variables that are presented during the operation.

The application has been defined as the main tool of the OCP training and certification program according to DOT CFR 49 PART 195, API 1119 and API 1161.

For training of new operators, the application allows the operator to familiarize with the SCADA system navigating through the main screen of the pipeline control system (pumping stations, pressure reduction stations, terminals and valve stations that are configured in the model). The operator in the training stage learns how to interact with the main and auxiliary processes through the simulated SCADA system for the execution of safe and efficient operations. Operator also has the possibility to learn how to identify and recognize alarms that appear usually during normal and abnormal situations.

For the qualification and certification of operators, five selected scenarios are executed by the operators, which cover the different situations with which the operators could be exposed during real operation, for example: increase and reduce flow, in-line pump changes, slack flow, normal or emergency shut down, etc.

Additionally, the training system has the possibility to work as a high-end engineering simulator for the evaluation of new and existing operative conditions.

CONCLUSIONS

The implementation of a complete operator training program for operators represents a very intensive Project where users and vendors need to be committed to fulfill very well defined expetations.

For this type of project it is important to define a clear balance between model complexity and simulator usability; due to the nature of this applications it is easy to engage in a situation where the application is perceived as an engineering tool to evaluate hydraulic behavior of new operations, loosing focus on the main objective, which is a tool to be used by operators to maintain and evaluate their skills as well as to warrant the quality of the operation,

During the implementation of this type of application it is important to maintain a constant communication with the users not only to gather the required information to configure the system, but more importantly, to define realistic operational scenarios and evaluation criteria.

The success of such projects can be summarized in three main elements: solid and reliable applications, interactive implementation process where the user and the supplier define very well operational scenarios and evaluation criteria, and probably the most important one, a well defined training program and qualification procedures for operators with scheduled sessions on a regular basis.

REFERENCES

1. The Trainer – PipelineManager® - Product Description document by Energy Solutions International Inc.

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BIOGRAPHY

Morten Kristiansen has a Bachelor of Science degree in Electrical Engineering from the Danish Engineering Acedamy in Copenhaven, Denmark. He has 11 years experience in pipeline simulation software including implementation and development. He is currently Product Manager with Energy Solutions International in Houston, Texas.

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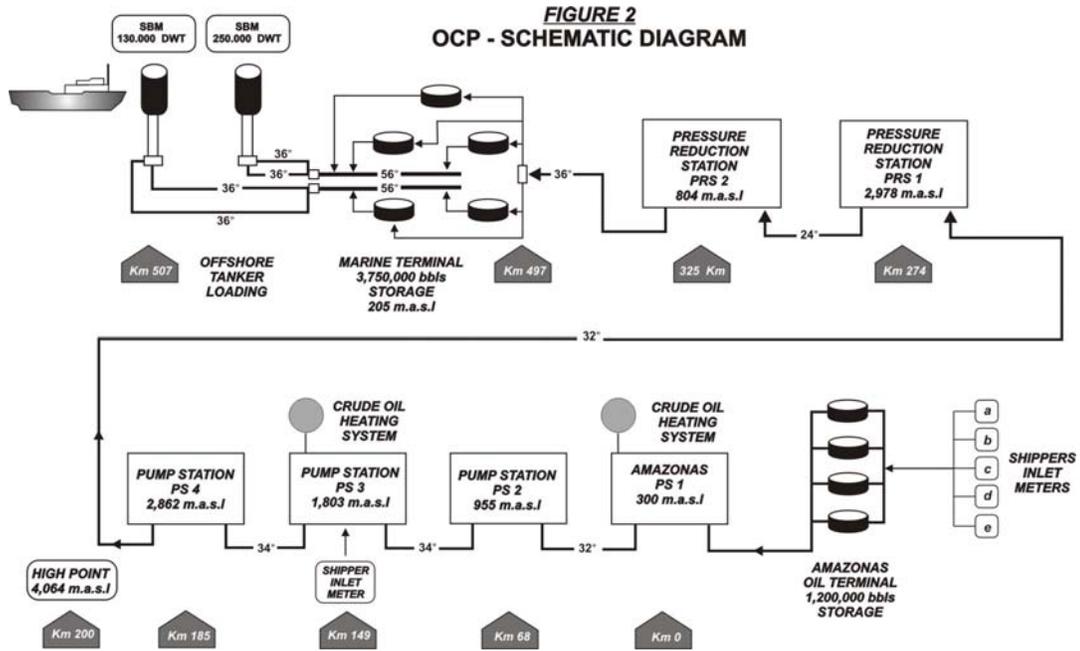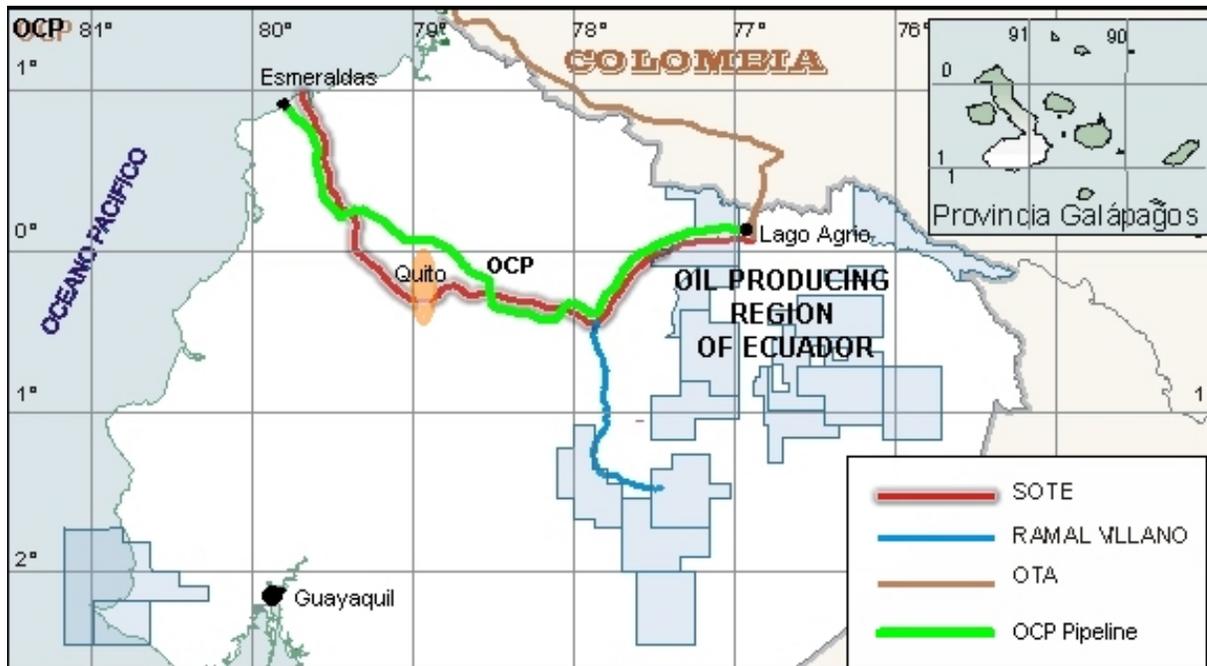
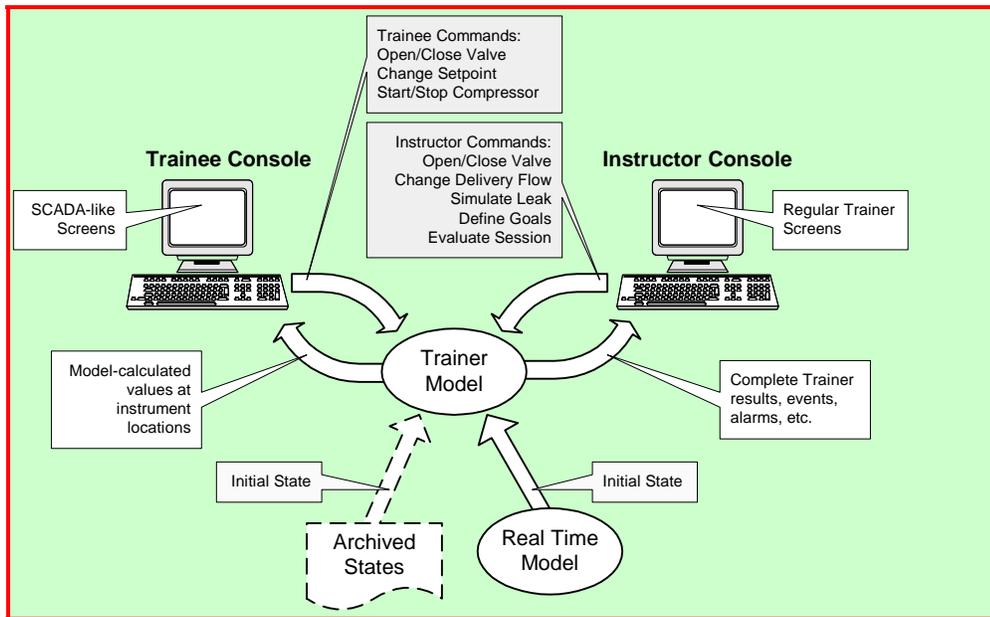**Figure 1 – Pipeline Schematic**
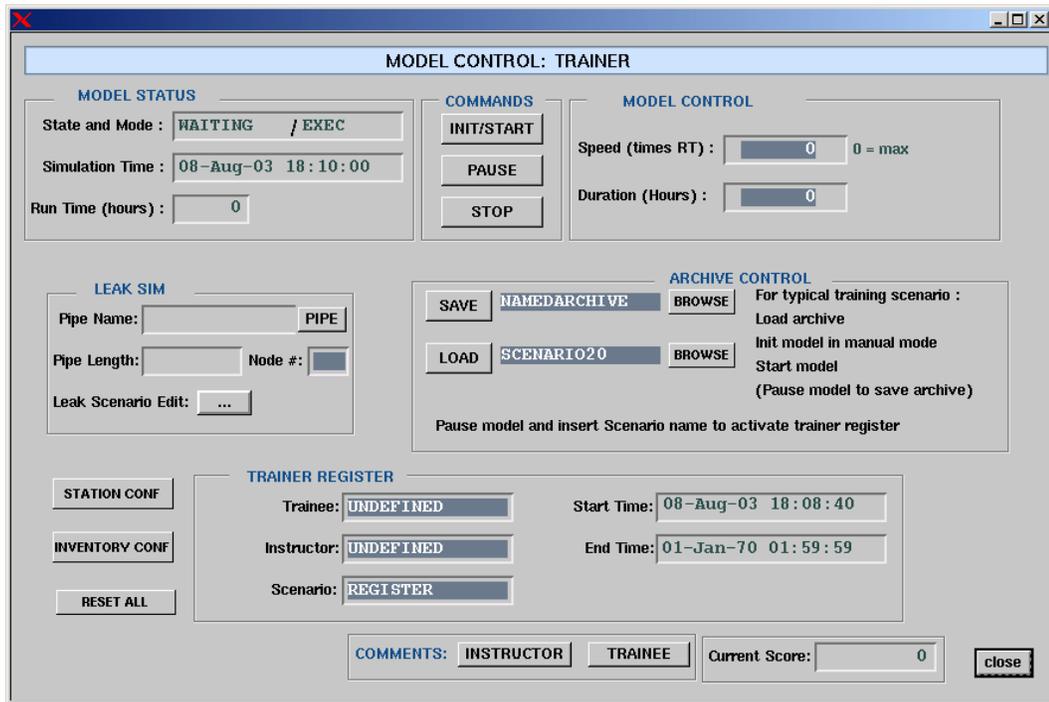

Figure 2 – Pipeline Route

Figure 3 – System Architecture

Figure 4 – Instructor Control Screen