



PIPELINE OPERATORS TRAINING AND CERTIFICATION
USING THERMOHYDRAULIC SIMULATORS
Claudio V. Barreto¹, José Plasencia C.², Filipe Montalvão³, Luciano
Costa⁴

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This Technical Paper was prepared for presentation at the *Rio Pipeline Conference and Exposition 2009*, held between September, 22-24, 2009, in Rio de Janeiro. This Technical Paper was selected for presentation by the Technical Committee of the event according to the information contained in the abstract submitted by the author(s). The contents of the Technical Paper, as presented, were not reviewed by IBP. The organizers are not supposed to translate or correct the submitted papers. The material as it is presented, does not necessarily represent Brazilian Petroleum, Gas and Biofuels Institute' opinion, or that of its Members or Representatives. Authors consent to the publication of this Technical Paper in the *Rio Pipeline Conference Proceedings*.

Abstract

The continuous pipeline operators training and certification of the Transpetro's Pipeline National Operations Control Center (CNCO) is an essential task aiming the efficiency and safety of the oil and derivatives transport operations through the Brazilian pipeline network. For this objective, a hydraulic simulator is considered an excellent tool that allows the creation of different operational scenarios for training the pipeline hydraulic behavior as well as for testing the operator's responses to normal and abnormal real time operational conditions.

The hydraulic simulator is developed based on a pipeline simulation software that supplies the hydraulic responses normally acquired from the pipeline remote units in the field. The pipeline simulation software has a communication interface system that sends and receives data to the SCADA supervisory system database. Using the SCADA graphical interface to create and to customize human machine interfaces (HMI) from which the operator/instructor has total control of the pipeline/system and instrumentation by sending commands. Therefore, it is possible to have realistic training outside of the real production systems, while acquiring experience during training hours with the operation of a real pipeline.

A pilot Project was initiated at Transpetro – CNCO targeting to evaluate the hydraulic simulators advantages in pipeline operators training and certification programs. The first part of the project was the development of three simulators for different pipelines. The excellent results permitted the project expansion for a total of twenty different pipelines, being implemented in training programs for pipelines presently operated by CNCO as well as for the new ones that are being migrated.

The main objective of this paper is to present an overview of the implementation process and the development of a training environment through a pipe simulation environment using commercial software. This paper also presents their potential as a pipeline operators training and certification tool. Additionally, it mentions important points gained during our experience in this project.

1. Introduction to Pipeline Trainer Simulation

A pipeline trainer simulator is a numerical tool that mimics the hydraulic behavior of a real process state of a pipeline system including the response of automation devices like pumps and valves. In a real-time pipeline trainer simulator the time flows like in the "real world". The events are scheduled and passed to the SCADA database in the frequency of the real automation system. For example, the start-up and packing operation of a entire crude oil pipeline will take several minutes to finally stabilize the flow along the pipeline, typical of the steady state condition. This real hydraulic behavior will be the same in the trainer simulator, so it means it is a real-time pipeline simulator. Some additional parameters must be included in the trainer model to simulate this transient behavior. These parameters usually are not considered in the standard off-line models, but are crucial for a trainer model. The trainer model is by definition an off-line model because the simulator doesn't connects with the real field sensors and devices.

¹ Mechanical Engineer - SIMDUT PUC-Rio

² Master, Mechanical Engineer – SIMDUT PUC-Rio

³ D.Sc., Mechanical Engineer – Petrobras Transportes S.A

⁴ Master, Pipeline Automation Engineer – Transpetro S.A

Nevertheless, a pipeline model and operational interface are developed and featured as an exact replica of on-line SCADA operation console, offering a real environment training session like a “Flight Simulation Style Trainer”. This realistic experience is an important advantage considering the training purposes.

In summary a pipeline trainer model is a more detailed version of the standard transient model with some new features:

- Real-time pipeline transient
- Open and closure valve time intervals
- Moment of inertia of the pumps
- Control system devices with all time dependent parameters configured
- Programmable Logic Controller (PLC) logics and routines
- Alarm Management (Hi/Lo Limits Alarms)
- Scheduled events like leaks, pumping station shutdowns and valve failure
- Communication interface command table
- Start/Stop sequences for all pumps
- History Data Manipulation

The main applications of the pipeline trainer simulator are:

- Offer to pipeline operators a realistic safe environment, that doesn't send any command to the real process pipeline system.
- Evaluate uncommon and exceptional pipeline operations and conditions.
- Perform new operational procedures
- Configure changes in the SCADA interface before the real implementation
- Tune the automation devices like PID controllers to the best transient response
- Evaluate the operator performance to ensure that it matches with the qualification criteria

2. Details of the Pipeline Trainer Environment

The pipeline trainer environment is composed of two main applications:

- **Transient Pipeline Simulation Software:** Client/Server application that solves the complete dynamic equations with the governing laws being the conservation of mass, energy and momentum and equation of state that defines fluids behavior. The pipeline simulator running a real-time transient and connected with SCADA database replaces the PLC - Programmable Logic Computer Controller (PLC) for on-line systems;
- **User Interface (UI) or Operational Interface Software:** Client/Server software that manages the trainee graphical environment and give the operator permission to log on, view and/or control the pipeline system using a graphical interface composed of screens and menus. In addition to enhance the realistic experience the real production SCADA software is used as trainer user interface

The Pipeline Trainer Environment classroom at CNCO-Transpetro supports four training sessions simultaneously, one trainee per pipeline training terminal. A pipeline training terminal is a client station connected with SCADA Trainer Server and two LCD monitors: one monitor displaying the SCADA Schematic View or Pipeline Monitor and other with Real Time Pipeline Simulator. Two extra terminals are reserved for instructors to load the training scenarios and give commands to pipeline simulator during the session. Actually, there are two implementation projects being developed for CNCO-Transpetro to create a pipeline trainer environment: Trainer Simulator with SCADA and Trainer Simulator Stand-Alone.

2.1. Trainer Simulator with SCADA

The trainer with SCADA project is based in a communication platform where the Pipeline Simulation Server communicates directly with the SCADA Database Server using modbus-rtu remote protocol. Using the native SCADA Interface Software the user has the same experience and commands of the real control screens used in the real operation environment.

Figure 1 shows a diagram with field and simulation communication structures, where both can share the same SCADA database and interface software. In the trainer simulation the analogic data (flow, pressure) and digital data (devices status) can be sent or received from the simulation server (virtual PLC) to the SCADA Database. Then, the data is transferred to SCADA Interface that manages all the screens designed by the SCADA development team to monitor and control the pipeline.

The trainer with SCADA environment project takes advantage of the shared SCADA interface and avoids further translations to a different UI. The Trainer with SCADA project developed for TRANSPETRO - CNCO by SIMDUT/PUC-Rio has four implementation phases described as follows:

- **Phase 1 – Pipeline Model Building:** Creates a simulation model based in the pipeline geometry, fluid properties, pumps and valves datasheets.
- **Phase 2 – Operational Screens Edition:** Edit and converts the SCADA interface field names for all screens that compose the user interface screens.
- **Phase 3 – Communication Configuration:** Edit communication files in the SCADA server database and Simulation Server. The communication configuration procedure is:
 - Create the new remote in the SCADA database.
 - Edit SCADA database tables (analog, status, etc).
 - Link the database tables with the new remote created.
 - Create the communication interface protocol file in the Simulation Server.
 - Trace and debug communication errors if occurs
- **Phase 4 – Macro Automation Implementation and User Interface Testing:** Program the simulator script file with the macro routines that handles the PLC Logic and events manipulation;

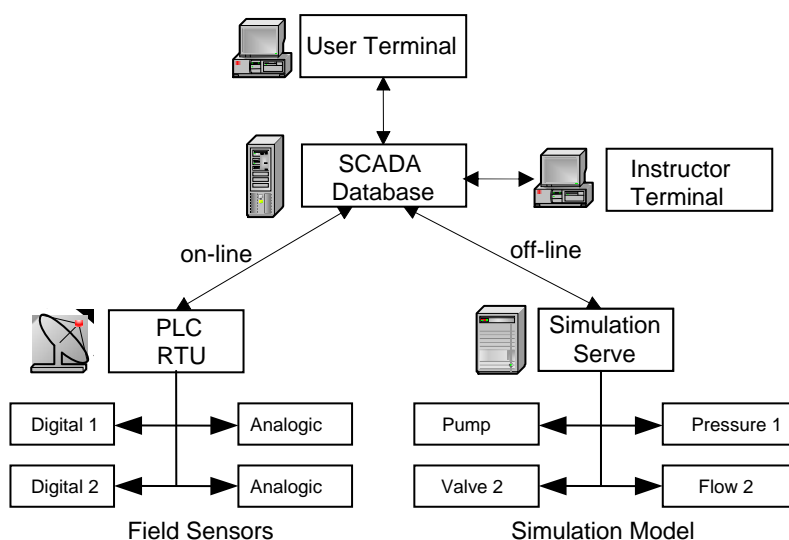


Figure 1. Field and Simulation Communication Structure

2.2. Trainer Stand-Alone

The Trainer Stand-Alone project was developed in parallel with the Trainer with SCADA project to increase the portability of the trainer environment, and now can be applied for simple pipeline system to exercise hydraulic knowledge and operations logic. In the Trainer Stand-Alone platform the operational interface and the pipeline simulator runs in a single computer without network connection (stand-alone mode). It is optional the use of a network server for both simulation and user interface, but it is still necessary a commercial license of the pipeline simulator installed in the client computer to start real-time trainer scenarios.

The Trainer User Interface developed by SIMDUT/PUC-Rio uses Excel with VBA as programmable language. The worksheet created is composed of VB components and routines that mimic the essential commands and functions of the SCADA operation human-machine interface (HMI) and was implemented in three programmable VBA modules:

- **Graphical Module:** Integrates the routines necessary to manipulate all graphical objects used in the operational interface windows. The graphical objects found in the user interface are:
 - Dynamic shape objects that changes color with the respective status (pump, valves)
 - Dynamic text boxes that changes data over time (sensor labels)
 - Push buttons that trigger actions (start/stop pumps, open/close valves, change the controller set-point, etc)
 - Dynamic charts to plot historical data of the sensors and pipeline profiles
- **Steady-State Module:** The steady-state module is a numerical routine that calculates the pipeline flow and the pressure/head profile given the pipeline geometry, pump and valves datasheets, fluid properties. The model input and output tables are saved within the worksheet, and the results are calculated by steady-state routine just in time the operator do any change in the pipeline system.
- **Communication Module:** This module covers the routines necessary to start the transient pipeline simulator, connect with pipeline model shared database, send interactive commands from Excel to pipeline simulator and read devices status and process values over time.

The first released version of the Trainer Stand Alone was built only with the Graphical and the Steady-State modules and was created to test the VB components and the graphical capabilities of Excel as a trainer environment. The limitation of this approach is the necessity of translation of all SCADA screens to VB components and for this reason at present it is restricted to simple pipeline systems.

The second version of the spreadsheet includes the communication module. The VBA was used to manipulate the data request functions that works with the local database service attached in the pipeline model. Figure 2 shows the data flow between the Trainer Stand Alone Version 2 modules and the pipeline trainer simulator. Nowadays it is available Trainer Version 2 for ORBIG and OSCAN 16.

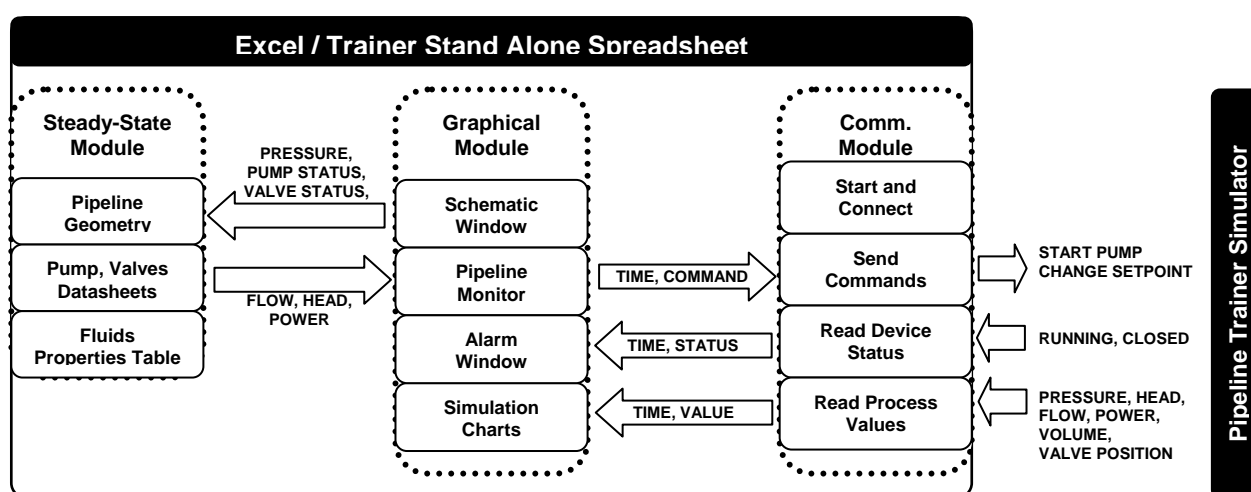


Figure 2. Trainer Stand-Alone Version 2 Data Flow

3. Trainer Operational Interface Overview

In this section it will be presented and overview of the Trainer Stand Alone Version 2 that was developed for TRANSPETRO using Excel with VBA as programming language. This simplified trainer interface allows the operator to view the state process indicators (flow, pressure, temperature), product and transport indicators (density, accumulative volume, tank level), the current status of the automated pump and valves, the target and position of the control valves (setpoint and fraction open). In general the basic operational spreadsheet has four interactive screens:

3.1. Pipeline Schematic

The pipeline schematic window displays the state process variables and the status of the devices in a schematic view. Figure 3 illustrates the schematic window of the operational interface. The schematic window has a color pattern

associated with the devices, the red color indicates a running or opened status, otherwise the green color indicates a stop or closed status. The main state process indicators for liquid pipelines are FI (flow indicator), PI (pressure indicator) and its colors indicates the priority of the alarm like the Alarm Management Window.

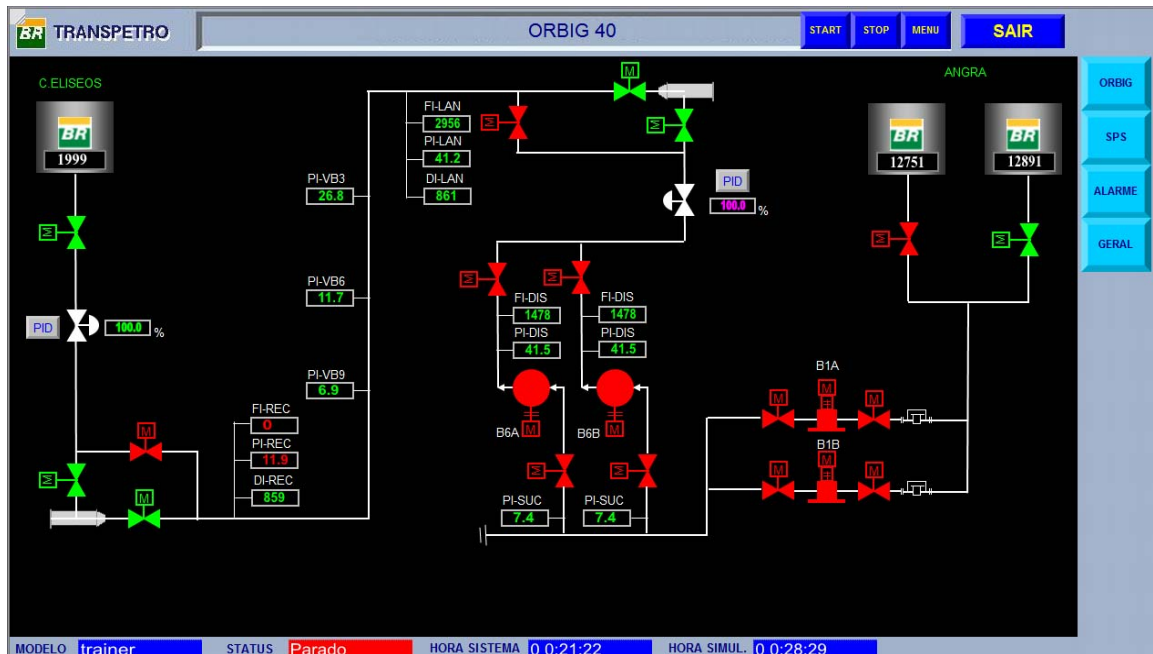


Figure 3. Pipeline Schematic Window

3.2. Alarm Management

The Alarm Management window (Figure 4) lists all the alarm messages with the respective timestamp of the event, the description of the alarm, and the tag of the indicator that generates the alarm. These alarms are classified with color codes that indicate the priority of the alarm. All analog indicators have HIHI/HI/LO/LOLO limits to trigger the alarms messages. The values above HIHI or below LOLO threshold limits are shown in pink, values between HIHI/LOLO limits are shown in red. The operator can configure the alarm limits during the training session to aid him identify abnormal pipeline conditions. In general, the alarm limits are set when the pipeline approaches to a near stabilized condition and reset when a change occurs in the operation.

Tela de Alarmes		
0 0:0:33	VAZÃO NA BOMBA B6B	PI-004
0 0:5:40	PRESSÃO NA VÁLVULA V-3	PI-013
0 0:9:49	PRESSÃO NA VÁLVULA V-9	PI-015

Figure 4. Alarm Management Window

3.3. Pipeline Simulation

The Pipeline Simulation Window displays the distance plots for the entire pipeline. Figure 5 illustrates the head/elevation and maximum allowable operational head (MAOH) curves in the left axis and the volumetric flow curve in the right. It is possible to change the right axis to plot pressure instead of head/elevation.

This window is only available during exercise sessions to increase the operator confidence in the pipeline transport scenarios. After the scenarios, the trainer supervisor will block the access to the simulation window.

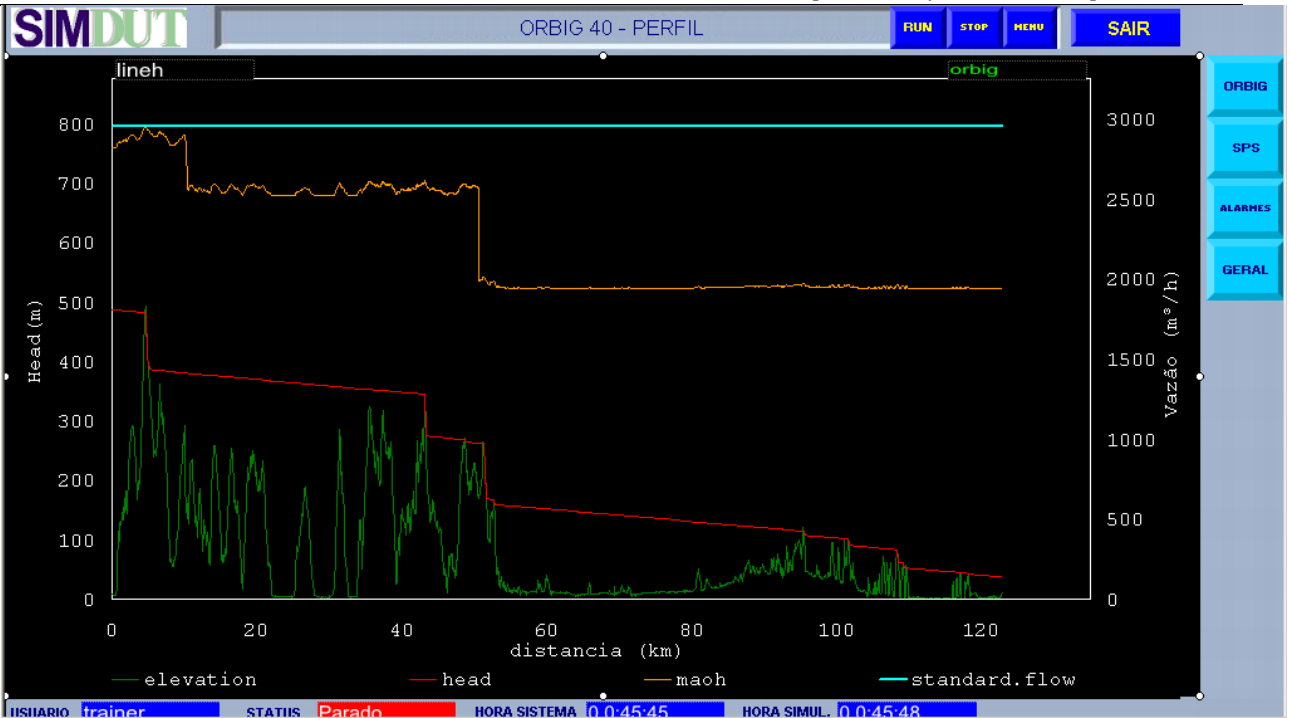


Figure 5. Pipeline Simulation Window – Head/Elevation and Flow Profile

3.4. Pipeline Monitor Window

This window is the main control panel of the pipeline system with the instrumentation data available to monitor and operate the entire pipeline. Figure 6 displays in a tabular format the values of pipeline pressure (PT), flow (FT) and density (DT) at each station. For the pump stations displays the suction pressure and discharge pressure, and the status for the booster and main pumps. The PID controller window can be viewed when the user clicks the PID button in the PCV column (pressure controllable valve). Inside the PID controller window the operator can control the discharge and the suction pressure of the main pumps in ANGRA and the upstream pressure at PCV of C.ELISEOS. In the bottom position is displayed the tanks data: tank name (TQ), level (LT) and product (PR).



Figure 6. Pipeline Monitor Window

4. Operational Interface for Performance Evaluation

One of the main applications of the pipeline trainer environment is to evaluate the performance of the operator during a training session. The trainer environment can be used since to check operator hydraulic knowledge to automation concepts about the pipeline operation. Another important usage is to evaluate operator response when submitted to abnormal operational conditions that seldom occurs in the field. To simulate the pipeline automation behavior and transport scenarios some macros must be included in the trainer model to perform these HMI commands and automation:

- Start and stop sequences for booster and main pumps
- Tank alignment checking
- Emergency buttons routines
- Valve opening and closing validation
- PCV automation routines that allow switch from automatic mode to manual mode
- HI Pressure limit alarms to guarantee the pipeline safety
- LO Pressure limit alarms to avoid pump cavitations and slack line

The Transpetro's Pipeline National Operations Control Center (CNCO) started a pilot project to develop trainer models and operational interfaces for liquid pipelines using Trainer Simulation with SCADA platform. As part of the Pipeline Operator Certification Program of the CNCO a pilot project started in 2008, to develop three separated trainer environments based in the production pipelines with different transport scenarios and abnormal conditions. The complexity of the transport scenarios increases from model to model as follows:

4.1. ORBIG

The first trainer model named ORBIG represents a crude oil pipeline with 40 inches of nominal diameter and a total length of 123 km. This pipeline connects the marine terminal ANGRA with the delivery terminal C.ELISEOS. The pumping station at ANGRA has two booster pumps and two main pumps, with all pumps turned on it can transport up to 5500 m³/h of light crude oil. The trainer model differs from the real production console because it was included a PCV valve in C.ELISEOS to control the pressure of the pipeline.

The ORBIG40 model works well to consolidate the operator's knowledge about hydraulics, flow assurance and safe-operation. Consider a trainer session that starts with all pumps turned off and valves at close position, and the pipeline in the slack line condition. The operator will perform these tasks:

- Valve alignments from the supply tank to the delivery tank
- Start and stop pumps following the transport schedule and procedures
- Control the pressure in the discharge PCV avoiding surge pressures
- Control the pressure in the delivery PCV reducing the time necessary to get flow stabilization.
- Change the pumping product
- Stop the pipeline avoiding slack line condition and the HI alarms (maximum pressure).

4.2. ORBEL I

The trainer model named ORBEL I represents a refined products pipeline with 18 inches of nominal diameter and a total length of 362 km. This pipeline carries refined products from the refinery REGAP to C.ELISEOS terminal and has two intermediary stations called ESMAN and ESTAP. The both stations have pressure and flow sensors for upstream and downstream station. The pipeline system counts with two pumps at REGAP, and three control valves placed in REGAP (pumps discharge), ESTAP and C.ELISEOS.

The ORBEL I trainer model works with multiple refined products and batch tracking composition. The operator has to follow the transport schedule and will be in contact with abnormal conditions. Considering a trainer session that has stabilized flow and the pipeline is filled with diesel and gasoline batches. The supervisor will evaluate the operator's time-response to identify and treat the following abnormal conditions:

- Pipe leaks in different points along the pipeline
- Unexpected valve closure
- Batch cut – control and optimization

4.3. ORBEL II

The trainer model named ORBEL II represents a crude oil pipeline with 24 inches of nominal diameter and a total length of 362 km. This pipeline transports crude oil in the reversed direction of ORBEL I, from C.ELISEOS to REGAP using the two pumping stations ESTAP and ESMAN. For ORBEL II trainer model the PCV station valves now can operate in automatic or manual mode. In the automatic mode the valve logic controls suction pressure, discharge pressure and pump current simultaneously. In the manual mode the valve is only controlled by valve open percentage.

Emergency and Start/Stop sequence buttons were included in the user interface to give operators the same skillful commands available in production HMI. Very similar to the last trainer, the supervisor will evaluate the performance when submitted to abnormal conditions but now simultaneous events would take place, besides the operator must be able to manage two more pump stations during training session.

5. Pipeline Operator Certification Program

The Pipelines Operator Certification of CNCO is composed by several stages. At first the candidate is submitted to the interview and a Personal Profile test that will verify if he or she has personal characteristics demanded by the section. Then, the chosen trainees will participate in an apprenticeship of 30 days with practical work in Transpetro Units to familiarize the trainees with the pipeline system in which will work out, providing them information about the field instrumentation, and integration with professionals that will support them during everyday situations. At third stage the trainee begins theoretical trainings, equally for a period of 30 days, where specific information will be acquired as: General Vision of the Pipelines System and Section Philosophy; Procedures; Fluids Mechanics; Product Characteristics; SCADA System, Real-time Simulator, where he acquires knowledge of operation of pipelines with reactions tested in abnormal conditions; among others.

After these first three stages, all preliminary rounds, he or she will begin his probation period in the pipeline console, also eliminatory, with a Certificate Operator Instructor, for a maximum period of 8 months and with evaluations ever two months. It is possible to be certified in a smaller period, depending on his acting, but with a interval at least of four months.

6. Conclusions

The process of developing and testing the training operational interface: creating the pipeline model, editing the operational screens, testing communication, and developing the automation macros that performs abnormal conditions and other training scenarios is relatively time-consuming, compared with training itself. The training console has to fulfill not only the Pipeline Operator Certification Program, but the trainer and trainee expectations.

During six months the Trainer with SCADA pilot project developed three fully functional pipeline training models described in the section 4. At the beginning the project consumed 45 days to get through the four phases of developing the simplest pipeline model ORBIG. At that occasion the work involved the research and developing of pipeline trainer commands, communication file structure, network configuration, SCADA System, and an extensive study for surpass hardware and software limitations. Even with progressive difficulty level of the pipeline models, due the apprenticeship curve and better implementation techniques the most complicated pipeline console ORBEL II with three intermediary pump stations has taken about 45 days been developed.

In the end of 2008 was scheduled the developing of 16 new pipeline trainer models. The list includes refined products pipelines (OSBRA, OPASC, ORSUB, OSPLAN18, OSPLAN 24, OSRIO), crude oils pipelines (OPMAC, OSDUC I, OCAB, OSVAT, OSBAT, ORSOL) and heavy combustible oil pipelines (OBES, OPASA16), a small but representative sample of liquid pipelines actually been controlled by CNCO-Transpetro and others that will be migrated (ORSOL II, OSCAN 22). In a near future all CNCO operators, newbie and experienced ones, will have their performance evaluated using pipeline trainer simulation.

7. References

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