Pipeline Operations Training Using a Pipeline Simulator

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ABSTRACT

This paper details the authors' experiences in using a pipeline simulator in pipeline operations training programs.

Pipeline simulators allow trainees to practice basic and advanced operating techniques in a "safe" environment. In the early stages of applied operator training, the simulator usually represents a fairly simple, generic pipeline. This allows clear illustration of operational concepts with a focus on specific tasks. In more advanced stages of an operator's training cycle, the simulator can provide an exact simulation of the pipeline that the trainee will have to control in the future. Realistic scenarios can be presented and operator trainees are able to exercise almost all tasks and deal with any possible incident that may occur during the operation of a pipeline. Accurate records detailing trainees' operational decisions during a simulator exercise are maintained and help in determining the skill level of different trainees. This information allows pinpointing of specific areas where more training may be needed.

At the same time, pipeline operations training which uses a simulator can address certification requirements. A simulator allows a company to set standards, and then to test operational skills and knowledge against those standards in a quantifiable and controllable manner. Since the performance of a trainee during a simulator training session is fully recorded, companies can use this record as a measure when qualifying operators.

INTRODUCTION

The ultimate goal of each pipeline operations training endeavor will always be to achieve operational proficiency. In order to achieve operational proficiency, a pipeline operations training program will have to be able to compress a pipeline's operational experiences into a consolidated and focused professional development package. Furthermore, this vast amount of knowledge and experience will need to be delivered within a limited timeframe and a defined budget.

With the development of new operational systems and the retirement of a generation of operational experience, many organizations are faced with the not small task of replacing experienced staff and responding to new technical challenges when recruiting and training new staff.

Historically, operational strength and quality has come from operators that combine a strong technical background with practical experience, either through previous control assignments or through thorough on-the-job training. While there is no denying the benefits of on-the-job training (trainees gain an immediate appreciation of their responsibilities, training is completely job-related, etc.), its disadvantages in the initial stages of pipeline trainees' education are obvious. With on-the-job training, operations trainees will have to acquire their skills in a real operations environment where there is no room for error. If there is no room for error, there is also no room for experimentation, methodical learning and trial-and-error forms of learning. A solution to this dilemma of providing trainees with practical experience while also allowing the benefits of trial and error is the use of pipeline simulators.

IPL Technology and Consulting has developed a pipeline operations training program that attempts to integrate theoretical instruction about pipeline hydraulics, fluid behaviour and best pipeline control practices with hands-on simulation sessions. The simulator is used to illustrate the presented theoretical material in the first part of the training program and to provide operational scenarios in the second part of the program. As a simulator can be programmed to accurately represent an existing pipeline, trainees can practice operational tasks from routine operations to emergency scenarios on a simulated version of their future work environment, without compromising the integrity of the actual operations. A further advantage of a pipeline simulator lies in its ability to compress time frames and to run simulations in faster than real-time steps. Thus, the time spent waiting for the pipeline to respond to operational commands can be drastically reduced and a training course itself can be more efficient. In addition to the training and development of new operators, a simulator can be
This paper will start with a brief overview of a pipeline operations training simulator and its function. We will then provide a very brief outline of the basic structure of a typical pipeline operations training program. This will help put the following discussion of the advantages we have experienced in using a simulator in training programs into perspective.

**BRIEF DESCRIPTION OF THE SIMULATOR**

In recent years we have seen an explosion of simulation programs on the market. Simulation programs that allow users to do just about anything from running a large city, fighting monsters in a maze to flying an aircraft or the space shuttle. With all this simulation surrounding us, a pipeline simulator seems like a very logical and straightforward conclusion. But what constitutes a good simulation for pipeline operation purposes?

**Pipeline Simulation Requirements**

A pipeline simulator needs to be flexible to allow for changes as the pipeline system it represents evolves. All the equipment detailed in the model, such as pumps, valves, etc., needs to provide for a level of interactivity which will allow system administrators to modify size and performance characteristics over time. These flexibility requirements also directly lead to another important consideration: a simulator has to be relatively simple to use and to understand. Simplicity in this case not only from a user's point of view, but also from a programming perspective. If only highly trained and specialized system experts can modify the system or provide trouble shooting support, it cannot be functional in a training environment that requires spur-of-the-moment modifications to a simulated scenario or equipment. Finally and most obviously, a pipeline simulator needs to have the ability to program interactive situations that can cover anything from very simple operational tasks to the worst imaginable system incidents, all provided in hydraulically accurate and operationally valid scenarios.

To provide hydraulic accuracy, the simulator contains representations of, to name only a few, a system's valve curves, pump curves, hydraulic profiles and pipe length and diameter variables. This information is then connected to reflect the "as-built" status of a pipeline system. By programming the system information in this fashion, the designed model can be modified easily as the system changes or evolves.

**Simulated Scenarios**

Based on the above outlined design parameters, trainers or system administrators can program a library of simulated situations from which they draw according to specific training needs. If the programmed scenarios don't fit a particular training requirement, they can easily program a more relevant scenario, and add it to a thus ever growing pool of simulations. A library of situations can contain everything from simple cases such as a unit start or unit stop, to more advanced simulations such as running a line pipe diameter change, valve closures and, of course, ruptures. A very strong feature, from a training point-of-view, is the simulators reviewing capability, i.e. all trainee decisions during a simulation are recorded by the simulator and can later be reviewed and replayed. This allows training managers to assess practical skills and performance of a trainee in a completely objective and unbiased manner.

**Generic Simulations**

Training programs can use two types of simulations - generic simulations and accurate pipeline models. In the first part of a training program, which we believe should be dealing with fluid behaviour and hydraulics theory, a completely generic simulation model may be used. A generic model allows to simulate simple situations that isolate theoretical concepts and are not bogged down by system variables that introduce problems that are too advanced in an early stage of operations training. Once early hydraulics training has been completed, training progresses to higher level of generic simulation. This type of generic model should be largely developed from experiences in the training environment, but should also take into consideration real concerns found in the pipeline business. For instance, the generic model may have components of a system that has evolved over time and demonstrates the characteristics of a "retrofitted" pipeline. Retro-fitted in this context means pipeline modifications to improve throughput or adapt to service changes. These types of modifications will include parallel and diameter increase looping, as well as pumping station modifications. It also contains common modifications of pumping units like impeller changes and pump case modifications including station configuration changes to additional series units, conversion to parallel configuration and finally the less common additional parallel power to complement the existing series units. Other pipeline modifications can be in the form of additional terminalling stations to represent change in customer service and to be used to establish generic operational procedures for any variation of terminalling tasks.

Now this generic pipeline can be filled with any variation of crude, refined product or natural gas liquids. The impact of the changing densities and viscosities can be observed in this modeled environment through different pumping configurations and using different diameter pipe services. This will establish good understanding of pipeline fluid mechanics in both static and flowing states.

**Accurate Pipeline Models**

To address the more specific operational tasks of the Operating company's pipeline, an exact model of that pipeline can be programmed using as built information. In order to further increase the accuracy of such a model, the corporation's SCADA system can be linked to the model. The model will simulate, in real time, the hydraulic conditions of the corporation's operating system, providing much of the same information as generated by RTUs in the real world. Controlling the simulation and its specific problems or incidents can now be achieved through the familiar Graphical User Interface or Man Machine Interface that the corporation uses in its day to day business. Other than providing the most realistic training environment for the newest training operators, this will develop added credibility with veteran operators who can more closely relate to the simulator's professional development benefits if it demonstrates real practical applicability. Operations trainees and seasoned operators alike can easily see the value of being allowed a "crystal ball" view of what may perhaps become an actual situation in the future of the system's operation and the chance to prepare for such a situation in an environment as close as possible to their actual operating environment. It is our conviction that this will prepare operators for potential incidents both mentally (i.e. how to approach a situation calmly and with confidence) and in terms of operational skills (i.e. which commands to executed and in which order to diffuse the problem quickly and effectively).
**Hardware Requirements**

The equipment required to run models is as varied as the pipelines they simulate. Less than ten years ago process power requirements were foreboding. The only machines that could support the models were large mainframes and UNIX workstations. As few as four years ago, simple models were supported on eight megabytes of RAM and an SX50 processor. The models were slow in the transient state but had simple operational capabilities. Now large complex models can be supported very effectively on the "off the shelf" Pentium with thirty-two megabytes of RAM, running in a windows environment. The models also continue to be supported on UNIX systems as they have been in the past, as well as on other operating systems mimicking DOS. This platform flexibility has created a major breakthrough for training programs. A training program can now be put on in almost any venue, as long as the instructor brings along a laptop and, ideally, there are enough PCs for at least one or two trainees to work on one machine. Training no longer has to compete for UNIX workstation space or spend inordinate amounts of money to set up a strong simulation-training environment.

**Summary of Requirements**

Let me briefly summarize the requirements of a good simulated real time pipeline model for maximum effectiveness:

**Hydraulic Accuracy.** To be a relevant representation of a pipeline's operations system, hydraulic accuracy is a must.

**Flexibility of Customization.** Customization of modeled equipment is a priority. Furthermore, simplicity of change and maintenance is important to allow non-system experts (e.g. training administrators) to make changes to the system if so required by a specific training need.

**Data Archival.** Starting with established "Archived" states of the pipeline presents the user with many variations in the start up state. Variation in pressure, batching, flow rate or other conditions improves the efficient use of time while using the model. Accessing several different states will allow the user to arrive at the required test state quickly and efficiently.

**Historical Trending.** Reviewing the information to compare cause and effect situations is important for operational comprehension. To take the historical reference away from the actual operation environment can be compared to the removal of an athlete's leg. Any efficient problem solving technique involves the use of historical reference to confirm where the problem began or if the change will likely lead to an acceptable solution.

**Case Replays.** How many times have we said "I wish I could have another attempt at this task?" The simulator records every single trainee input and allows to replay a specific scenario and a trainee's responses step by step. Reviewing a simulation that caused problems or did not lead to the desired result coupled with the opportunity to interrupt the replay and to now complete it with the command (or commands) that will correct the problem provides for a tremendous learning tool. It also, as mentioned earlier, provides for an opportunity to review the performance of trainees or operations staff individually and to identify and correct deficiencies more pointedly. In a controlled environment the tool can be used for pre-qualification and performance skill checks without the danger or inconvenience of waiting to evaluate a trainee's performance in the live system.

### A BRIEF OUTLINE OF A PIPELINE OPERATIONS TRAINING PROGRAM

Any course curriculum for a pipeline operations training program will need to attempt to cover most of the relevant theoretical material and its practical applications. Due to most organization's financial and training time constraints, training programs often need to be compressed into relatively short time frames. For the purpose of illustrating the use of the simulator in different stages of a training program, we will focus our discussion on a five-week course. Following is a short outline of how such a five-week course may be organised.

**Week One - Hydraulic Theory**

The first week of the session confirms the hydraulic knowledge of the student operators and begins analyzing the shutdown state of pipelines. The concepts of head and pressure are discussed in the shutdown state and the influences of density and elevation are analyzed.

Before the course moves to the analysis of pipelines in a flowing state, a fundamental understanding of pipelines as a system becomes the topic of discussion. This concept is referred to as the Whole Pipeline Perspective and the remainder of the course is build on the premise that trainees buy into this concept. It can be demonstrated via the simulator that anything that happens anywhere within the system affects the entire system. This provides the background required to convince even a seasoned station operator that there is more to the pipeline system than the suction header into a station and the discharge header out. From this point, the focus moves to the running pipeline and the best state for a running pipeline. This segment is called "Balance" and describes the conditions which define the state of pipeline balance. Some definition of the state and some proactive operating to achieve the state fill most of the time assigned to this subject.

Now that most of the theoretical and "pipeline operations philosophical" groundwork has been laid, training can move on to more important corporate considerations. The next training segment is called "Pump Unit Selection". This is a complex section dealing with selecting pumping units for an effective pipeline operation. Time constraints usually prevent a detailed review of total pipeline efficiency, station efficiency with various pump configurations and complex energy contract considerations, but these topics should receive some time.

**Week Two - Control**

Week Two focuses on the logic and techniques of control. Control at even the station level is often not completely understood, but should really form the first and basic level of comprehension. Next, the overall pipeline control logic is presented. Once a thorough understanding and appreciation of the logic of control has been established, it becomes possible to discuss best control techniques to achieve the states of Balance discussed in Week One. Trainees should also be able to control a pipeline to a state of stability (Balance) and make long lasting, efficient pump unit selections. Because the variations and complexity of whole pipeline control are difficult and diverse, a complete week of exercises and lecture around this subject will usually prove to be of great benefit.

**Week Three - Routine Operations**

Week Three should be focused on as many routine operational tasks as can be accomplished in the week. The method to be used is to
first define some technical peculiarities of each operation. Then the student operators are supported in discussion toward the best approach to the operation, then develop a procedure and finally test it in the simulated environment. Any mistakes in the operation are discussed during the debriefing session following the exercise. Beginning with week three, the last day of the week (usually the Friday) may be reserved as an evaluation day. The student operators are given a complete day's task to resolve on their own, reviewing all the situations studied and putting into action all the skills acquired to date.

Week Four - Transients
Week Four needs to begin with a look at the pipeline in a transient state. The content presented in this week covers unscheduled operational events like unit and station losses as well as indicated valve closures. The operational techniques used to diffuse these conditions are of a highly skilled nature. Therefore the entire week should be dedicated to various unstable states and the techniques required to return the pipelines back to stability. Ideally the operation is to be completed in the shortest time frame possible while initiating the smallest transients possible to diffuse the problem.

Week Five - Incident Analysis
The fifth week handles the most severe pipeline problems. From ruptures to sudden valve failures and other puzzling pipeline problems derived from historical pipeline events. Diagnostics and techniques of analysis and response are developed and proven on the simulator. To prove comprehension and sufficient skill acquisition, the last day of the course is a full day evaluation that attempts to simulate an actual control centre environment as accurately as possible. To make matters a little more interesting, this evaluation may also include a number of unexpected incidents. In our own training programs, we have come to term this final day lovingly as "The Gauntlet" or, in our Spanish markets "The Test of Fire". The Gauntlet is not meant to discourage as many people as possible from a career in pipeline control, but to encourage a respect for the multitude of situations and problems that can arise in a control centre.

USING A PIPELINE SIMULATOR TO ACHIEVE OPERATIONAL PROFICIENCY
Operational proficiency can be defined as the ability to optimize, detect, respond to, quantify, notify, manage, co-ordinate, and communicate all pipeline situations in a timely and efficient manner. In the following, we will attempt to outline what we consider to be the seven major requirements to achieve operational proficiency and how a pipeline simulator can be used in training programs to facilitate the development of operational proficiency.

Hydraulic Comprehension
Hydraulic theory is not an awe inspiring topic. But a complete understanding of hydraulics is paramount for the development of operational proficiency. A pipeline operations training program will definitely have to begin with the introduction of fluid mechanics and hydraulic theory. By integrating simulation programs even in these early stages of a pipeline training program, learning is greatly facilitated and enhanced. Based on the review of student evaluations, we conclude that learning is improved in mostly two ways:
1. theoretical concepts are linked to practical applications; students can instantly review cause and effect of changes in fluid properties or hydraulic variables;
2. the hands-on, practical nature of using a simulator introduces trainee participation and involvement right from the beginning of the course; this allows for a much smoother integration of theory into the practical framework.

The great advantage of the pipeline simulator from its first use in the classroom during this prerequisite hydraulic theory session is that it does more than merely present the material in two-dimensional simulations for graphic reference. The real strength lies in the simulator's capability to use an actual pipeline system as a reference point. At this early point in the training, the simulator need not be the specific system of the company employing the trainee. It is actually considered more effective at this point to simulate systems which exhibit variable operational considerations. The different hydraulic influences of elevation, product characteristics, pipeline diameter and flow rate become good case studies in a generic system which remains reasonably simple but offers variety in all these hydraulically dynamic areas. Keeping the simulation simple and generic allows trainers to isolate and focus on the theoretical concepts without having to consider other operational factors. For example, the ability to demonstrate the effects of increasing the viscosity of the crude type within a system or the cold weather effects on the system's performance are invaluable training tools.

As mentioned earlier, simulations can be run within or outside real time. Demonstrating hydraulic effects in real time will provide solid evidence of the instantaneous effects of, for example, conducting a changing density batch into pumping units. An example of the benefit of running outside of real time or at a time greater than real time is to demonstrate the effects of a low viscosity batch being replaced by a higher viscosity batch. In this specific example, the real time approach must be used to confirm the effect of viscosity increases over time but for an impacting demonstration, a simulation faster than real time will allow for a more efficient and effective demonstration of the hydraulic principles underlying the scenario.

As an example of the effectiveness of using a pipeline simulator in operations training, I would like to draw your attention to an instructional topic in the area of energy consumption. Consider, for instance, how varying the density and viscosity of the system's crude influences and monitoring the energy consumption changes clarifies the head loss due to friction in relation to system power requirements. Some of the most useful results in this training area can be obtained by simulating a system filled with single light density and low viscosity crude and comparing such a system to another one filled with heavy density and high viscosity crude. Finally, a system can be simulated that mixes the crude types. When comparing systems without any changes in pumping units, the difference in pressure loss due to friction and the changes in flow rate confirm the drastic impacts of changing viscosity and density, a very powerful discovery in understanding the importance of hydraulic theory.

Equipment Applications
Pipeline systems are by no means static systems but continuously experience change in their equipment and operational requirements. Outside its training function, the simulator can be used for operational studies during which it simulates the changes and anticipates potential effects on the system's performance parameters. Within a training context, such simulations can be used to allow operational staff to experience the planned changes before the system construction or expansion is actually completed. Thus, operators can prepare for the operational challenges such a new or expanded system will pose to their jobs. Take for example a change in established station spacing by half. The original station spacing caused a transient wave travel time...
of about one minute. The operational impacts of such a change would be great and offering operations staff an opportunity to test the new operation before it becomes active, complete with thirty second transient wave travel times, will reduce the time to achieve safe and effective operation under these new conditions.

**Static Pipelines**

Pipelines are not always in a running state. Pipeline segments and complete systems are periodically in a shutdown state. This shutdown condition is not experienced frequently enough and historically, few operators achieved the high level of competency required to complete all tasks in a shutdown state optimally on each occasion. A simulated training environment will allow the creation of shutdown scenarios which are used during operator training to ensure that all operators can respond to a shutdown situation in the safest and most effective manner. Different shutdown cases and emergency scenarios are presented during training in order to refine the operational approach to be taken in such situations and to ensure a best shutdown procedure is followed even in the worst of pipeline situations.

**Flowing Pipelines**

This is the state in which pipelines are designed to be operated and its variability is almost infinite. The varying characteristics of linefill and unpredictable changes in flow rates present operations trainees and experienced operators alike with ever-new challenges to improve safety and efficiency of the operation.

The best operating system is one which remains in a balanced predictable state for the longest period of time. This allows the corporation to prepare reliable forecasts and predictions. Returning pipelines to a stable condition quickly after upset conditions, closing the tolerance on pipeline capacity, and maintaining pipeline balance and system configurations for the long term are tasks easily refined in pipeline simulation environments. A good portion of any pipeline training effort should be spent on achieving and maintaining balance on a flowing pipeline. The concept is easily enough defined in words, but it has been our experience that it takes concentrated efforts and numerous different simulated scenarios to truly establish an appreciation for the benefits of maintaining a balanced pipeline. The simulator provides invaluable help in this area not only by showing the advantages of best practice, but sometimes more importantly, by clearly revealing the disadvantages of operating an unbalanced pipeline. In the classroom, the instructor presents an operational situation or task. After some initial discussion, the trainees together with the instructor develop the operational steps to complete the task and then implement their solutions on the simulator. After the allotted simulator time, the results of trainees are analyzed and compared to the best practice solution. It is in this trial-and-error procedure that we see the greatest benefit of the simulator. "Learning from one's mistakes" may be an often misused platitude, but we have found the discussion of simulation results with varying degrees of success to be immeasurably beneficial to the development of trainees. Many a breakthrough has been achieved by recognizing why a technique thought to be correct did not provide the expected results. We can think of no tool other than a simulator that can provide such a stimulating variety of feedback.

Let it also be said again that it is our experience and belief that not only operation trainees benefit from honing their skills on a simulator. Pipelines are constantly evolving and requirements are changing. Using pipeline simulations to allow all operators to test new linefill, new pumping configurations and forecasted changes well before they are implemented has proven to offer efficiency benefits that could not be realized otherwise.

**Pipeline Control**

One of the most difficult to understand concepts has proven to be station control logic. We are not only talking about station control functions of suction, discharge, flow, speed and amperage as such, but more importantly about the effects of those control types on the overall pipeline.

Consider, for instance, a training situation in which the trainees come mostly from a Refinery control background. Refinery operators' experience is mostly based on controlling a system using discharge control. If such a group is placed in a situation where they become responsible for a cross-country pipeline system containing several significant elevation changes, a change in control techniques from controlling on discharge to controlling on suction will have to be enforced. On the downstream side of an elevation change, the benefit of a suction control logic to maintain the upstream positive column pressure can be demonstrated through the pipeline simulation model. The benefits of using such an operational logic will be seen in pipeline stability and more importantly the improved analysis of potential leak conditions. Again, changing control philosophies that have been correct for the trainees' refinery control tasks but are no longer applicable in a pipeline situation is greatly enhanced by demonstrating the results of different control options in a simulated exercise. Carefully programmed scenarios show clearly that slack line flow or negative column pressure remove accuracy and make leak detection more difficult.

**Pipeline Routine Tasks**

The simulator can be heavily used to develop best practice operational procedures for safe and efficient execution of routine tasks such as deliveries, injections, pipeline starts and stops, and maintenance tasks such as flowing, shutdown and bypasses. The simulator should, in our opinion, also be used in control centres on an ongoing basis to improve and maintain the safety, efficiency and effectiveness of the operation. Operators, whether they are seasoned operators or rookies, are exposed to simulated routine task scenarios with hydraulic and control accuracy. Veteran operational staff takes advantage of confirming or improving existing operational routine task procedures while new staff is exposed to a best process. Repetitive operational skill checks can be performed on the simulator until all operators have achieved a predetermined level of proficiency.

**Pipeline Problem Solving and Incident Analysis**

An important part of any pipeline training program is to establish techniques of control and response to problems, incidents or emergency situations. The worst time to test proficiency of operations staff in dealing with emergencies is during a real operational emergency when delayed or incorrect reactions can have fatal results to the safety of staff and the public, to the environment and finally to the corporation. Training programs dedicate time to presenting worst case scenarios that are either developed from historical cases or try to simulate those types of accidents that every operator and every corporation fears. Having been consistently exposed to simulated disasters in "safe" training environments should help operators to develop confidence in recognizing triggers and signals that announce an incident or emergency situation and what steps to take to correct a situation before it can escalate. Although we can at this point in time not present any empirical evidence for this assumption, we do

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speculate that exposure to such simulated emergency scenarios will create calm, conviction and confidence in real world decision making.

CONCLUSION

The long-term benefits of using a simulator as a training tool in pipeline applications is just being explored. Student operators that have completed simulator training programs have gone back to their established operational environments and implemented the techniques tested in a simulator training environment to the betterment of the system’s efficiency. In other cases, we have seen student operators that joined training programs almost directly from post secondary schools without much practical work experience in the field, move straight into operations positions as pipeline commissioning coordinators.

Many developing pipeline systems and SCADA integration projects have used the advantages of the simulation tool to pre-qualify personnel and prepare them for their future tasks. Classroom and blackboard discussion alone cannot prepare individuals for such dynamic future assignments. And in our opinion, this does not exclude senior operations personnel who can maintain skill levels on infrequently executed tasks and test pipeline changes before engineering can install them. Overall, we are convinced that by using a pipeline simulator in initial as well as continuing training for operational staff, a pipeline company will benefit not only from future operational efficiencies but also from the all-important goal of increased safety.