An operator training simulator for a fuel products pipeline system was developed and delivered before the pipeline was completed to train personnel.

As part of a larger project to design and build a new multi-product fuels pipeline system for Trinidad and Tobago, an innovative operator training simulator (OTS) was developed that allows highly realistic training of the pipeline operators in all phases of operations prior to actual startup of the pipeline and for continuous training after startup. The pipeline, owned by a consortium of Trinidadian entities, including the Government of Trinidad and Tobago, the National Gas Company of Trinidad and Tobago (NGC), the Trinidad and Tobago National Petroleum Marketing Company (TTNPMC) and Petroleum Company of Trinidad and Tobago (Petrotrin), is designed to deliver up to 36,000 b/d of multiple fuel products (gasoline, diesel and aviation fuels) at peak by a state-of-the-art automated pipeline system roughly 47 km in length from the island’s Petrotrin West refinery to a new distribution terminal in Caroni County in the central part of Trinidad. Also included in the distribution system is a new 11 km pipeline to deliver aviation fuel from the Caroni terminal to Trinidad’s Piarco Airport (see Figure 1).

The pipeline system is being built to ensure secure and on-time delivery of fuel products to key points on the island, which otherwise relies on delivery by trucks. To ensure the quickest delivery times, the pipeline also employs a new “pigless” delivery system that loads one liquid product immediately behind another in a continuous, seamless fashion. The proper operation of the pipeline in this pigless mode is ensured by a leak detection system (LDS) and batch management system (BMS) from Krohne Oil and Gas, a company specialising in metering skid solutions and computational pipeline monitoring (CPM) pipeline leak detection. The LDS and BMS were integrated into the OTS, which would be used in tandem with the pipeline control system (PCS) and the terminal automation system (TAS) to plan, schedule and track product batches, keep track of the feed and product tanks, as well as provide alarms and/or advice to operators on abnormal conditions, and continuously detect for potential pipeline leaks.

Figure 1 Pipeline path on Trinidad and Tobago map
As some of these systems are new and to some extent custom built for this project, it was agreed and planned in advance to have an OTS to aid in the rapid familiarisation and training of operations personnel.

**Process overview**

The batch of refined products from Petrotrin West Refinery storage tanks consisting of unleaded RON92 gasoline, unleaded RON95 gasoline, diesel and Jet A-1 fuel will be metered and transferred by pipeline pump using individual booster pumps for each product.

The preliminary batch sequence would be as follows:

Jet A-1 → Diesel → RON 92 → RON 95 → RON 92 → Jet A-1

This batch sequence will be transferred to the Caroni facility, the distribution centre, using a pipeline pump via an 8in multi-fuels pipeline. Before transferring to the Caroni facility’s storage tanks, all the fuels will be metered at a metering skid entering the pipeline. The meter will be used to control the mainline pumps, while the tank gauging systems will be used for custody transfer. The general operation is designed to run with no pigs; however, an additional pig launcher was built to launch an intelligent/batch pig in cases when this operation was needed.

As soon as a batch arrives at the Caroni facility, it will be diverted to the appropriate destination tank by the operator based on the interface detection. For batch interface detection, density is the primary parameter used. Two densitometers are used to detect the interface of the multi-fuels. The first interface detector is installed 4.4 km from the Caroni facility to alert the operator about the product coming in the pipeline. The operator may use a second interface detector, located at the Caroni centre, to decide the correct time to switch valves to transfer the product into an appropriate tank.

The liquid fuels interface is one of the most important parameters to measure at the Caroni facility in order to transfer the product into an appropriate tank. When the multi-fuels are transferred using one pipeline, an interface mixture is generated. The interface mixture/off-spec product can be diverted to slop tanks or to the lower-quality product tank. Two slop tanks are provided to accommodate the interface/off-spec product from the slop tanks is trucked back to the Petrotrin West refinery for reprocessing.

Fuel from the individual storage tanks is
transferred to (truck) loading bays using individual transfer pumps for each product.

For the batch control of two grades of gasoline — RON 92 gasoline and RON 95 gasoline — their physical properties would be too close to reliably differentiate the products based on density alone. Optical interface detectors (OIDs) are also installed near to the densitometers. The two gasoline grades are dyed for taxation purposes, resulting in distinct optical signatures (primarily colour), which the OID can distinguish and signal to the operator. Additionally, the flow meter count could be utilised to guide the operator.

An additional dedicated pipeline 8in diameter and 11.2 km length is installed to transfer the Jet A-1 from Caroni to the Piarco facility. There are two isolation valves installed on the pipeline because of a river crossing, one valve at each side of the river. A 600-gallon-per-minute capacity pump can deliver jet fuel from the Caroni distribution centre to Piarco Airport.

**Simulator development**

The OTS was designed and delivered by KBR’s Advanced Chemical Engineering group with support from the Pipeline and Operations groups. Overall, the OTS consists of four components:

- A custom dynamic model of the pipeline system (resembling actual pipeline operation) and an “instructor station” to train the operator, with various features such as operating training on field devices. The safety instrumented system (SIS) logic was also implemented in the model. The SIS hardware/software was not replicated because it was possible to model its functionality with the pipeline software. A portion of the pipeline system, the TAS, handling loading on logistics operations, was not included in the OTS system. Only some of the main operations screens were simulated
  - A BMS and LDS identical to the real pipeline’s BMS and LDS systems
  - A dedicated Emerson DeltaV distributed control system (DCS) identical to the real pipeline’s DCS
  - DeltaV Operator consoles identical to the actual pipeline's consoles.

These OTS components are interfaced through a standalone local area Ethernet network using industry-standard OLE for Process Control.
(OPC) protocol for communications. Figure 2 shows the architecture of the OTS.

The OTS also includes auxiliary equipment to ensure the proper working of the integrated system as a standalone OTS. As such, the OTS had no physical connections to actual pipeline’s PCS or other pipeline systems.

**Software**

On reviewing the details of the process and requirements for the modelling of various process upsets, it was decided to use the Stoner Pipeline Simulator from GL Noble Denton to provide the required rigour and accuracy for the pipeline model.

The Instructor graphics were developed using Iconics Genesis32 that comes with the Stoner software.

The BMS, was developed by Krohne Oil and Gas, and it is used to manage and track the batching operations. It was fully integrated with Krohne’s LDS, PipePatrol, used for the detection of leaks along the length of the pipeline.

A dedicated Emerson DeltaV DCS identical to the actual pipeline Delta V hardware with the complete PCS and TAS database provides a highly realistic training environment.

**Actual pipeline and associated equipment modelling**

The model included all physical equipment (pipes, valves, pumps, and so on) in the pipeline from the feed tanks to final destination tanks and includes complexities such as truck loading racks and loaders. In addition to the physical equipment available in the software library, programming was done to define operation of special equipment like Yarway valves, truck loading, pig status, and so on. The model also included the complete safety instrument system logic resembling the actual SIS system. Figure 3 shows a screen capture of a Stoner Pipeline Software (SPS) scheme.

**Instructor station**

Overall control of the OTS is through a special graphical display system called the instructor interface, which provides such functionality as the run/pause of the simulation, load/save of initial conditions, touch points for failing critical equipment, and standardised scenarios for operator training. Figure 4 shows a screen capture of the Instructor interface.

**Leak detection and batch tracking management system**

The Krohne leak detection and batch tracking/management system functionalities are intended to manage the batching process, to track the current position of a batch in the pipeline and to schedule the next batch. Also, operators can be informed of the likely location of a leak in the pipeline if it occurs.

Krohne was required to create and test two new functionalities for the BMS — pause/start and speed-up/slow-down — in order to complete the communication and integration of the OTS system. Many rounds of further testing had to be
done to ensure proper two-way communication between the BMS and the DCS. Figure 5 shows a screen capture of the batch management system. Figure 6 shows a screen detail of the status of pipeline batches and alarms.

The LDS is a real-time transient model (RTTM) type. It has special parameters that determine its sensitivity during pumping and standstill conditions. Also, the parameters that detect a creeping leak can be set in the system. A creeping leak is a leak that does not cause significant pressure drops or pressure waves. For false alarm-free operation, these parameters have been fine-tuned based on recorded data to find the best compromise between minimum detectable leak rate and detection time.

Next to the leak detection, which determines the volume of a leak, this system has two different algorithms based on pipeline pressure and flow to determine the leak’s location.

**Modelling and integration**

The overall modelling effort for the OTS was rigorous and detailed to include the complexity of the modelling of some equipment, such as the Yarway valves downstream of the pumps and, in particular, the prover circuits, the implementation of the logics, the interlock system and the communications among the OTS components.

Some new functionality and custom features had to be incorporated into the SPS software in order to properly implement OTS functionality, such as pause/resume and save/restore, which had to be transferred to the DCS and the instructor interface systems. In order to save a run or a file for the initial condition of a scenario, the OTS system saves a file in the DeltaV system and a file in the simulation system simultaneously, and both files are loaded at the same time when the instructor restores a saved run. The BMS is a real-time system that was originally not intended to perform as an OTS, but the feature of pausing and restoring the simulation was added successfully; pausing of the signal to the BMS is available via OPC command but not necessary because the flow totaliser automatically stops.

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**Figure 5** Batch management system typical display
counting in the pause mode of the Stoner simulator.

The DCS database is complex. Many extra logic points were required to be developed in the simulation and connected to model variables to allow a complete range of operator actions from the DCS. The DeltaV system is capable of working in simulation mode when it is not connected to the real and physical system.

Figure 7 shows a distance plot of both of the pipelines, from Petrotrin Refinery to Caroni Distribution Centre, and from Caroni to Piarco Airport.

Reverse flow operation had to be defined and configured within the operator training system. This operation occurs when a substantial amount of

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<th>Overview screen of pipeline, batches and alarm status</th>
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<td>Pipeline distance plot, from the simulation program and displayed on the Instructor station</td>
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off-spec product is not accepted at the distribution centre and has to be sent back to the refinery via the pipeline. This procedure is a manual operation and consists of opening a set of valves, in the right sequence and at the right time, from the tank with the off-spec fuel to the reverse flow pipeline at the Caroni Centre. Then, operators have to start the dedicated reverse pump and continue with the opening of the downstream valves to direct the flow to the main pipeline and let the rejected product travel in reverse motion to the refinery. Training for this operation procedure is important because it will be done very seldom at the actual pipeline facilities; therefore, the only means by which the operators can be trained for this eventuality is the OTS system. By doing this, the operator will be ready when a reverse operation is needed in the real pipeline.

A particular limitation of the model was the OID, which was modelled as though it is driven by density due to the absence of an optical characteristic model in the software.

Communication using OPC connectivity

OPC Mirror, a server-to-server/client communication software utility from the DCS vendor, was used to connect OPC servers (pipeline model to DCS and BMS/LDS) on the OTS system and to enable two-way data communication from one system to another. In the OTS, the linkage was between the DCS, OPC server and the Instructor server, StOPC. Additionally, the Instructor server and the Iconics graphics interface communicate with the simulation model variables. The OPC communication was server-server between the DCS and the Iconics graphical interface, as a client-server between Iconics graphics and the simulation model, and as a client-server between the OPC mirror and BMS system. The development team had to go through additional technical development on the DCS, the graphical interface and the BMS to be able to engineer a fully working system.

Figure 8 shows the general OPC connectivity architecture within the OPC system components.

Operations support

Additional support was required from the Commissioning and Startup Services group of KBR and the client operations personnel to help define and test the training scenarios and to define the details of the standard operation procedures. In order to have detailed procedures on the standard operations of the pipeline, batch startup, batch changing, batch receiving, interface disposal and so on, client personnel and KBR Commissioning and Startup Services personnel had several meetings defining and simulating the procedures and the exercises to prepare the training program for the operators. Some of those procedures were also taken as exercises for the final site acceptance test of the system.

Training

Table 1 shows a set of the different scenarios that were prepared for training the trainer initially and for further training of operators. Some of them are related to the OTS as an integrated system tool and others are related to operations procedures.
While the primary purpose of the OTS is operator training, several benefits accrued to the project as a result of the early development of the simulator. It was also beneficial to project staff who came to the project late as a conceptual tool in understanding the scope and objectives of the pipeline system.

One of the key benefits was that it was possible to completely check the designs of both the DCS and BMS systems prior to actual implementation. Several missing details and incomplete functions were found and corrected, particularly those relating to the travelling and volume of the interface along the length of the pipeline and its properties shown on the systems in real time; for instance, the distance from the pumps and length of the interface between two consecutive batches.

Further, it provided an invaluable platform for completely testing and validating the operating procedures for the pipeline. It was possible for KBR operations and training experts to run through each procedure many times to ensure that all aspects were thoroughly tested. As part of the testing process, NGC has also already reaped significant benefits through early familiarisation and training of their operations supervisors.

By using the OTS in a repeated fashion, it is envisaged that operators will quickly become familiar with and learn how to control daily activities in the pipeline, such as starting a batch of a specified product, modifying batches, receiving a batch at the distribution centre, performing operations such as starting and shutting down the pipeline system, and responding to upsets. The company plans to complete this OTS-based training before the actual startup of the pipeline so that operators are completely familiarised with actual operations well in advance.
Conclusion
This was the first integrated OTS system for pipeline operations developed by KBR. Close working relationships between various groups and support from the client were critical to the successful completion of the OTS. Acceptance by the client has been high based on early assessment. Experience showed that such pipeline systems can derive significant benefit from a BMS and LDS as standard equipment.

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