THE CHANGING FOCUS OF PIPELINE SIMULATION

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ABSTRACT

Use of simulation in the control rooms of natural gas pipeline operators has changed over the last two decades. The early attempts in Europe met with mixed success. However, as simulation technology matured (and pipeline operators gained confidence in that technology) on-line system installation successes have been registered. The operational challenges that originally pointed European gas companies towards on-line simulation were simply not present in the U.S.A., where in excess of 50 pipeline companies control networks of 1,500km or more. However, market forces and new regulations have created new challenges for U.S. operating companies. In other countries where traditionally state-dominated monopolies have operated without competition, privatization is demanding operating efficiency.

In the U.S.A., the business of contracting, ordering, delivering, and accounting for natural gas deliveries has changed dramatically over the past decade, fueled by the regulation that created "open-access" pipelines. Originally being gas merchants and transporters, the new regulations have stripped the pipeline companies of the merchant role. They're now exclusively transporters of gas, and the transportation market has become more dynamic, and intensely competitive. The more aggressive operating companies are rising to the challenge of changing their business practices. Simulation technologies are among the vehicles that will allow these companies to take maximum advantage of fleeting market opportunities, so increasing profitability.

The Houston, Texas, based Texas Eastern Transmission Corporation (TETCO) division of Duke Energy is deploying an advanced automation system that combines many applications to assist in operational decision support. Central to that system is the Simulation Control Center (SCC). The whole project bears the title "FOCUS".

Within the commercial context of daily gas pipeline operations, this paper describes the various simulation technologies deployed in the FOCUS project, how they will be used, and their association and interaction with the SCC. Through the example of FOCUS, the focus of pipeline simulation technology will be shown clearly to have changed.

THE USE OF SIMULATION

Computer-based simulation of natural gas pipeline networks began more than 30 years ago. The first packages solved the "steady-state" design problem where nothing ever changed, all flows, pressures, and so forth remained constant in the simulation. During the next decade of development, transient algorithms were developed that would let the design engineer begin to understand the effects of inventory change over time on natural gas systems.

During this time, however, computing as we know it today was in its relative infancy. Even acknowledging the existence of effective transient algorithms, most were impractical because the computing resources necessary to run detailed analyses of any substantial magnitude were just not available on a cost-effective basis. Some software was made available by commercial algorithm developers on a time-share basis. As the 1970s turned into the 1980s, the newly available "32-bit" computing platforms offered the resources to turn these design tools into tools useful for control room operations.

The First Attempts at Real-Time Modeling

In gas control, computer systems scan field measurement devices and acquire pipeline operating data such as pressure (P) and flow (Q) through a telemetry system. The industry terms these computer systems Supervisory Control And Data Acquisition (SCADA) systems. A real-time simulation is one that takes a continuous stream of data from the pipeline SCADA system, and imposes these real-time measurement data onto a mathematical simulation, so forcing it to run, for all intents and purposes, simultaneously with the actual pipeline (Figure 1).

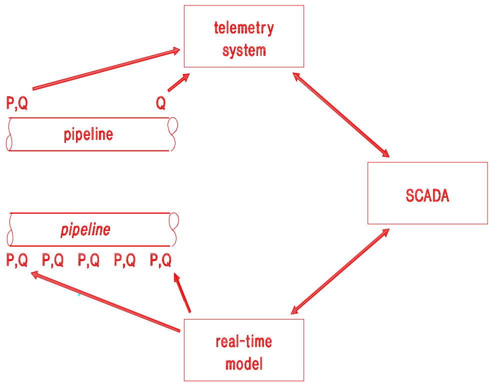

Figure 1: Real-Time Modeling

The early attempts (in the 1980's) at real-time modeling systems were predominantly undertaken in Western Europe. Having only a few, though large, localized gas sources (e.g. North Sea, the Groningen area of Holland) many nations were dependent on their neighbors for the pipeline access to these reserves, and indeed, onward transmission to other neighbors. The balancing of the supply and demand on these systems was a tricky exercise. For example, consider Distrigaz in Belgium at this time. With no domestic reserves, Distrigaz accepted North Sea gas by way of both Holland and Germany, and was responsible for domestic delivery in addition to onward transmission to France. Under-delivery by any one nation could be perilous to the entire gas transmission system in Western Europe. The dominoes were stacked in line, one mistake, and the whole row might collapse. To facilitate effective communication, an electronic nomination and messaging system was established between the control centers of five of the major Western European gas transmission companies [1].

In this tightly coupled environment, delivery contracts were written very stringently, with substantial penalties for under-delivery; the emphasis being on the predictability of the gas supply from one nation meeting the nominated demand by its neighbor at their international border. Of course, some countries had routing options: in the case above, Distrigaz could nominate North Sea gas from Holland (Gasunie) or Germany (Ruhrgas). But the problem then given to the Dutch or the Germans was how could they guarantee the nomination to Belgium so they were not penalized? How would they manage their inventory?

The solution was sought in computer simulation of their networks. Real-time modeling was a necessary first step toward predictive analysis, which was expected to provide the additional insight into future operations. With a real-time model installed, the current transient state of the pipeline and its inventory would be constantly available to launch an off-line predictive simulation to assess network performance several hours into the future; of course, the predictive model also requires a forecast of demands off the system.

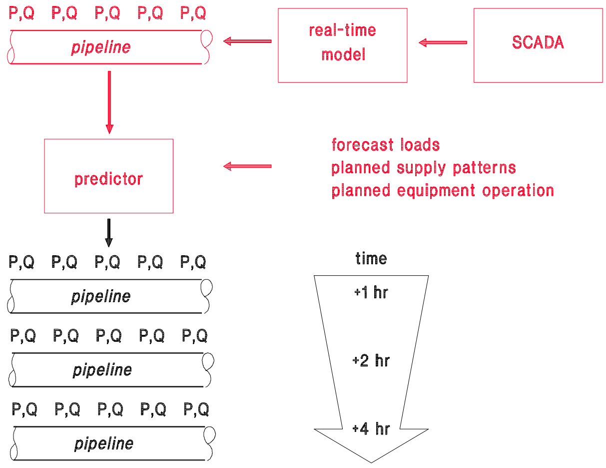

Figure 2: Predictive Modeling

Predictive simulations could produce alarms if future operating constraints were violated, to alert gas control staff that other equipment or load changes would be required in the near future. Some of the uses envisaged for these first on-line systems included:

Contingency Analysis

With the operational dominoes arranged with few options for contingency operations, future predictions could have pre-programmed contingencies built into the operating scenario (e.g. the loss of compression at a critical station). The prediction could then be used to judge the level of risk represented by the current operations, and to develop operating strategies to minimize that risk.

Gas Quality/Composition Tracking

Gas mixing was a key operational problem for Gasunie in the Netherlands, with North Sea gas and the domestic Groningen gas being of different qualities. Gasunie had actually built substantial pipeline networks for each gas quality, with only a few interconnects at purpose-built mixing stations.

Contract Monitoring

With the punitive penalties associated with under-delivery at national borders, an intense focus was placed on providing gas controllers with a tool to help them monitor delivery contracts. It was envisaged that a predictive model could be set up to monitor automatically the progression of delivery contracts (both by volume and by BTU) and to generate warnings if a contract violation was deemed likely. Warnings might be associated with the total daily delivery or with a temporary transgression outside agreed limits (e.g. pressure, or BTU content).

For example, output from a predictive model (Figure 3a) shows that the forecast daily delivery (DELIVERED) of around 1100mmscf ($31.1*10^6$m^3) will fall short of the daily contract quantity (DCQ) of 1400mmscf ($39.6*10^6$m^3) by more than the lower contract tolerance of 1300mmscf ($36.8*10^6$m^3). Following an adjustment of the planned operating strategy, the predictive simulation is re-run and verifies (Figure 3b) that the forecast delivery indeed falls within the contract tolerances.

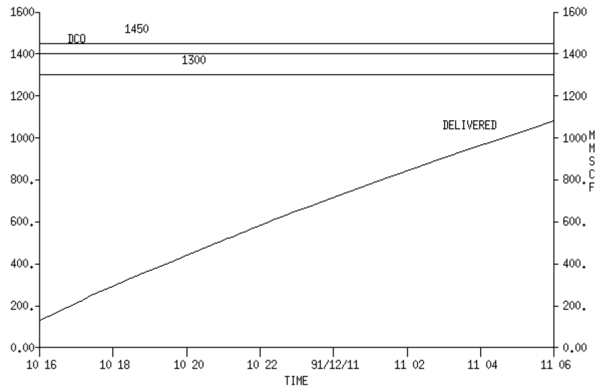

Figure 3a: Contract Violation

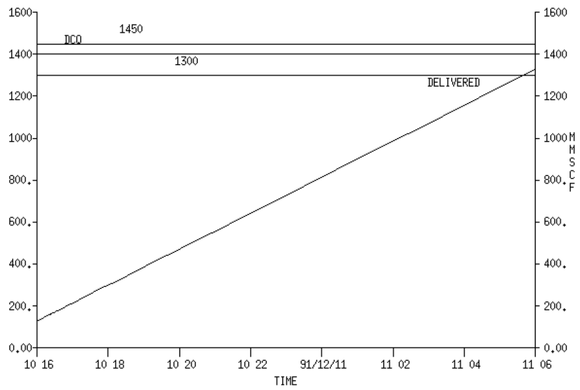

Figure 3b: Contract Verification

The Reality of Real-Time Modeling

So as can be seen from the above, it was really the predictive simulation applications that drove the need for real-time simulation in the European gas industry (there were other drivers in other industries, most notably detecting pipeline releases in the liquid hydrocarbon pipeline industry). Again, real-time simulation is the imposition of measured SCADA data onto a characterization, or model, of the pipeline and equipment to generate a simulation of actual pipeline operations.

Properly imposed, the simulation will track actual real-time pipeline operations very closely. From the perspective of natural gas on-line simulation systems, "real-time" can mean anywhere from tens of seconds to some small number of minutes between consecutive SCADA scans. The reality of SCADA system operation is that within each scan there are frequent temporary data or communications outages. Even when data are available and sufficient for operators, those data contain significant uncertainties when trying to resolve the mathematical equations governing the system's operation. Equally, friction effects within the pipeline are unknown, but are still required by the mathematical simulations.

In some systems, the number of deliveries off the system that are not measured in real-time can be quite large. Therefore the on-line simulation is faced with a task of using incomplete and mathematically imprecise SCADA measurement data to try to reconstruct, or estimate, what is happening in the actual system. It would be no understatement to suggest that this is the single largest challenge to on-line simulation systems.

Some of the early, elementary methods ignored this problem. They simply required that the pipeline operator install better, and more measurement data in order to sustain basic operation; a costly exercise. Even then, such systems operated only under "perfect" data availability, which rarely occurred.

With the reality that measurement systems could not reliably deliver the quality of data for then-current real-time simulation technology, the earlier on-line system installation attempts failed to deliver on their promise of an effective tool to help gas controllers manage their pipelines.

Real-Time Modeling Technology Advances

Keeping with the situation in Europe for a little longer, note that it was perhaps Gasunie in the Netherlands and Ruhrgas in Germany that were faced with some of the greatest operational challenges. These two companies were at the front line, being the recipients for the whole of Europe of North Sea gas from Norway. The technical groups in both these companies recognized the tantalizing benefits that a real-time/predictive simulation system could offer, and also the limitations of the current on-line simulation algorithms. The major limitation was that then-current real-time model algorithms needed consistently available data of good quality, which clearly their SCADA systems could not deliver.

The development emphasis of these companies turned to algorithms that could excuse erroneous data and derive a legitimate hydraulic state of the pipeline network from these sparse, and often unreliable measurement data. The key technique in this approach is termed "state estimation", or "state reconstruction". In the Netherlands, it was an internal R&D project that developed an innovative mechanism of mathematical "springs and resistances" [2] that really laid the foundation for the subsequent success of that installation [3, 4]. At Germany's Ruhrgas, their approach was to fund a commercial development by a third-party that included the concept of "fictitious flows" [5].

With the development of more reliable state estimation techniques, predictive simulation became a reality, but only to the extent that another technology, that of load forecasting, could provide useable and useful estimates of future system loading. Some in the industry even at this time offered the conjecture that the emerging technology of rule-based expert systems might be successfully applied in the evaluation of predictive simulation results, and subsequent development of network operating scenarios for predictive analysis [6]. However it would take another decade before this was really achieved.

Today's state estimators recognize that there are fundamental uncertainties in SCADA measurement data. Rather than "calculate" a current state, they "estimate" it based on what is known about the uncertainties associated with the SCADA data [7]. State estimators apply sophisticated filtering and dynamic adjustment algorithms to the incoming measurement data. Using these algorithms, state estimators can generally obtain an hydraulically legitimate current pipeline state estimate that is close to, or even better than, the state being reported by the SCADA system. The state-of-the-art has advanced to the point where some operators place more confidence in the results from their state estimator than their SCADA data! [8]

THE GAS BUSINESS IN THE UNITED STATES

The limited success in the application of on-line simulation in Europe was greeted with some healthy skepticism, and even some fear in the United States. The skepticism was founded in several areas:

- The natural gas industry was substantially older in the U.S.A than in Europe. In the U.S.A. it dates back to the 1820's when hollowed-out logs were first used (cast iron mains were first laid in the 1870's), whereas the European industry started in the 1950's. The experience levels in the control rooms were such that many U.S. gas dispatchers had more experience than the age of the entire industry in Europe.
- The need for these advanced tools just was not perceived. Why become more efficient when inefficiencies were simply passed on as government-approved rate increases to customers, who were generally held captive by long-term gas delivery contracts.
- Many fundamentally just did not believe that digital computers could calculate what was going on in the pipeline; remember that some SCADA systems in place at this time were still analog! This should be compared to the European industry that grew up along side the digital computer industry. The disbelief also had an element of (presently unfounded) fear that a computer might some day replace the gas dispatcher.
- Those U.S. companies that had dabbled with on-line simulation had been less than delighted with their systems. As the Europeans had learned earlier, these systems were just too sensitive to measurement system perturbations. Being commercial enterprises, U.S. pipeline companies did not have the resources available to fund independent developments, as did their European counterparts. Some systems never really worked, and worse, the simulation industry as a whole was painted with the broad brush of those failures.

A Changing Regulatory Environment

Before the re-regulation of the gas marketplace, there was little incentive for U.S. gas pipeline companies actively to seek operating efficiencies. The landmark Notice Of Proposed Rulemaking (NOPR) number 436 (also known as the mega-NOPR for its huge impact on the gas business) from the Federal Energy Regulatory Commission (FERC) changed everything. It would no longer be legal for pipeline companies to buy and sell natural gas, they were simply to be allowed to transport gas. NOPR 436 evolved into FERC Order 636, which eventually became law in 1993.

Clearly this fundamental realignment of the mission of pipeline companies could not be an overnight change. Business practices had to be overhauled. Enabling technologies had to be developed and deployed. The entire business of running a transmission pipeline was forced to change. The stage was set for the industry to become intensely competitive.

Before 636 became law, interstate pipeline companies were also natural gas merchants, buying and selling gas as well as providing transportation (delivery) services. Local distribution companies (LDCs) that supply gas to U.S. cities contracted for their gas supplies with the interstate pipelines. These gas supply contracts were typically for many years at maximum tariff prices. The contacts allowed great flexibility in the amount and rate at which the LDCs took gas from the interstate pipelines. The accounting for the gas supplied to the LDCs lagged the physical delivery by months.

Today, in the post-636 era, the interstate pipelines can no longer merchant gas; they are limited to transportation services. The business cycle of contracting, ordering, delivering and accounting for the transportation services offered by interstate pipelines has shortened from many months to daily and even hourly cycles. The competition brought about by these new laws affords the LDCs, and other gas users, many choices as they now have the ability to contract their business among multiple pipelines, with or without the assistance of independent gas marketers. In response to these competitive forces, the more aggressive pipelines have enhanced the operational control of their pipelines to save costs and to capture market opportunities.

The competition came on two fronts. As independent marketers and end-users were freed to contract with any gas supplier, the transportation of the gas from point of purchase (pipeline receipt) to the point of sale (pipeline delivery) became very competitive among pipelines. The "all-in" delivery cost of the gas at the point of sale was minimized via the lowest cost transportation option. The short-term, interruptible transportation rates (plus fuel retainage) of one pipeline were compared to other pipelines. Often, the discounting practices of a pipeline’s interruptible transportation rates were in direct response to competitors’ rates.

Even more competition was brought to bear on the pipelines by their own customers (shippers) in the "capacity release" market. The capacity release market is essentially a secondary market for firm capacity that a shipper had purchased from the pipeline, but did not need every day. An example would be a shipper who contracted for 300 MMBtu/day of capacity on a pipeline to ensure transportation of his gas to his customers during winter (high demand) periods. The shipper may only need 50 MMBtu/day of pipeline capacity during periods of low demand. This excess capacity can be re-sold to replacement shippers based on terms agreeable between the original shipper and the new, replacement shipper. In this market, the original shipper can recover some of the cost of capacity it did not need from time-to-time. This secondary, capacity release market directly competes with offerings of interruptible transportation by the pipeline.

Another result of the gas market deregulation is that business cycles have shortened. Customers who had contracted for long term gas supplies bundled with transportation now became short-term shippers constantly searching for lower rates. Years-long contracts were terminated, renegotiated or not replaced as their terms expired. In their place are market sensitive contracts with flexible terms and pricing. Yearly and monthly agreements were replaced with short-term daily and even hourly deals.

A New Business Philosophy

To use the phrase popularized by Star Trek's Dr. Spock, in order to "live long and prosper" in this newly competitive and fast-paced environment, pipelines sought efficiencies everywhere. But it was not just a matter of longevity, it became a matter of survival. Business and operational practices alike were overhauled. Up-to-the-minute marketing and operational information has become the currency of the new marketplace. The acceleration of information flow is pervasive throughout the business, from contracting, nominations, confirmations, physical delivery of service through imbalance management and accounting. Shippers and transporters alike must now keep close vigil over their operations to avoid non-performance penalties, save costs and capture fleeting opportunities.

To satisfy this new requirement for up-to-the-minute information, pipelines have invested heavily in facilities, communications, software, and technical expertise. Electronic Bulletin Boards and internet web sites have replaced faxed paper nominations and confirmation. Electronic flow measurement communicated via SCADA has replaced paper charts for many supply and delivery meters. Satellite communications have replaced periodic dial-up telephone communications at the most critical locations. Hourly nominations are replacing monthly nominations. This is an exciting and dynamic market..

Clearly, the better a pipeline transmission company understands what is happening inside its pipeline, the better positioned it will be to capitalize on that knowledge. The successful application of Information Technology (IT) in and around gas control and the deployment of advanced applications using that technology is the key to spreading pipeline knowledge to the departments that can use it [9]. This is why on-line simulation technologies that can provide a clear picture of current pipeline operations, are now being evaluated and deployed in the U.S.A. with more urgency than in the past. On-line simulation forms the starting point for a wide range of potential applications, such as predictive simulation (coupled with load forecasting), optimization, and the introduction of rule-based systems for supporting business decision-making.

But not all companies can take advantage of all technologies. Realizing that loads on its system were less than predictable (hence not susceptible to accurate forecasting) one pipeline operator postponed the installation of a predictive simulation capability to concentrate on the tangible benefits being obtained from just the real-time state estimation. These benefits are stated [10] as:

- Pinpoint false telemetry information and allow Gas Controllers to act upon model generated corrected data.
- Find anomalies in the pipeline and within stations (e.g. leaking check valves and flow restrictions).
- Identify inefficient compressor operations.
- Identify poor field operating practices (e.g. pinched valves).
- Locate faulty regulators that do not properly control the flow of gas.
- Provide Gas Control with a tool to determine when to run scrapers.
- Accurately determine ownership of gas within a pipeline owned by more than one company.
- Display the quality of gas within the pipeline to aid Gas Control with their decisions on operating the system.
- Minimize the bypassing of rich [high quality] gas around gas plants.
- Provide accurate flow calculations and therefore eliminate the need for in-line flow meters.
- Provide Gas Control (using a Graphical Interface) with assistance in configuring stations.

- Compute operating costs.
- Compute any pipeline's gas capacity and determine its current usage of that capacity.
- Assist in operating the pipeline safely during field work.

Clearly, these benefits of on-line simulation are predominantly targeted on field staff and the control room. What U.S. pipeline companies are looking for is a business decision support system that integrates many technologies, not just on-line simulation, to help them run their business more profitably. This is where the FOCUS project of Duke Energy's Texas Eastern Transmission Corporation leads the way.

In response to the changed regulatory mandate, Texas Eastern Transmission Corporation (TETCO) has undertaken a major effort to upgrade its business processes. This effort is called FOCUS, for Future Operational Capacity Utilization Strategy. Its stated objectives are doing within-day business, decreasing costs and supplying more information to customers related directly to Gas Control operations. In relation to Gas Control, many of these objectives were met through the development of new systems. The new systems include Load Forecasting, a Real Time Model to help in online verification of current operations, a Predictive Model to help in planning of pipeline operations and Decision Support tools that account for storage availability and that compare customer obligations with actual deliveries.

DUKE ENERGY'S TEXAS EASTERN TRANSMISSION CORPORATION

Duke Energy Corporation is an integrated energy and energy services company providing the ability to offer physical delivery and management of both electricity and natural gas throughout the United States and abroad. Duke Energy provides these and other services through seven business segments:

- Electric Operations
- Natural Gas Transmission
- Field Services
- Trading and Marketing
- Global Asset Development
- Other Energy Services
- Real Estate Operations

Today Duke Energy owns and operates three interstate gas pipeline companies (Texas Eastern Transmission Company, Algonquin Gas Transmission Company and Maritimes & Northeast Pipeline). The corporation's headquarters are in Charlotte, North Carolina. Natural Gas Transmission is managed from Gas Control Centers located in Houston, Texas.

During World War II, the 24" Big Inch and 20" Little Big Inch War Emergency Pipelines were built to carry crude oil to the Northeast from Texas. Texas Eastern Transmission incorporated and purchased the pipelines in 1947. Both pipelines were converted to gas transmission. In 1949, Algonquin Gas Transmission Company was formed to extend service into New England. In 1951, construction of the 30" system began. This system had a capacity far larger than the original Big Inch and Little Big Inch lines combined. In 1958 the Little Big Inch was converted back to a liquids carrier and now serves the Texas Eastern Products Pipeline Company.

Today, TETCO's system consists of approximately 9,700 miles (15,600km) of pipeline, including 74 compressor stations. The TETCO pipeline system extends from the U.S.-Mexican border near Brownsville, Texas to Staten Island, NY. TETCO's pipeline takes two separate routes. The 30" system parallel's the Texas and Louisiana Gulf Coast before turning northeast across Mississippi, Tennessee, and Kentucky into southeastern Ohio at Berne Station. The 24" (Big Inch) system extends from south central Texas across Arkansas, Missouri, Illinois and Indiana into southeastern Ohio at Berne Station. The Berne compressor station is the start of the system that continues through Pennsylvania and on into New Jersey. This so-called "Penn-Jersey" system is designed primarily to be a peaking system. In the Penn-Jersey system compressor stations are close together. TETCO’s Market Area storage fields reside in this area.

There are many telemetered measurement stations coming from the field to SCADA that have scan rates from 15 seconds to 6 hours. There are several other low technology units that are scanned daily that do not come into the SCADA system, but come directly into the measurement system. TETCO uses a variety of leased line, dialup, cellular dialup, multiple access radio and satellite to communicate with these units.

The Focus of FOCUS

The laws resulting from FERC Orders 436 and 636 have changed TETCO from being a merchant to a transporter. Gas Control’s role has changed from controlling the pipeline system and supplies to one of reacting to the demands put upon it by its customers.

TETCO has formed an initiative called FOCUS, its Future Operational Capacity Utilization Strategy. Through the FOCUS effort, TETCO is taking the initiative in providing the best possible services to customers. This effort is an attempt to implement a proactive strategy for dealing with these implications while supplying customers with the best available low cost services. The FOCUS effort has more fully integrated and shortened all business cycles in the company. Gas Control is at the center for these issues, since this is where the physical and business realities come together. Specific objectives in the initiative include:

- Shortening business cycles to operate "Within Day"
- Decrease Energy Costs
- Identify unused capacity available to customers
- Provide more information to customers

Within-Day Business

During extreme weather conditions, Gas Control needs to have a good awareness of customer takes relative to their obligations. Tools comparing nominations with physical flows can generally provide this information. In some cases, meters may be shared through operating agreements, etc. It becomes necessary to allocate flows before comparing them with nominations. Shortening of the allocation process also requires shortening the measurement process. TETCO’s goal is to have a within-day "operational" allocations process to aid in these extreme conditions.

Before FERC Order 636, the measurement cycle was a monthly one. Many charts existed on the system providing weekly information. Now, with Order 636 in law, this cycle has shortened to the point where close-outs of measurement information occur shortly after the end of the business day. It is desirable to make the RTU calculated volumes as close to billable as possible, allowing more rapid within-day closeouts and more accurate information for customer use.

Decrease Energy Costs

The compression on TETCO's pipeline is driven, variously, by reciprocating engines, gas turbines, and electric motors. Electric motors make up a large amount of this compression, due to the inexpensive cost of electricity at the time the lines were built and the conversion of electric driven pump stations on the Emergency War Pipelines. Electric units are typically used as the base load. Electric contracts and their demand charges have a high impact on the choices of compression used to operate the pipeline.

TETCO wants to optimize the use of power on the system to provide the lowest rates it can to its customers. Studies are currently performed using an in-house developed program that is designed to optimize the cost of running the system. TETCO wants to look at tools available externally which can do the job closer to "real time".

Identify Unused Capacity

The pipeline is generally close to fully utilized during winter operations. Within the day, marketing may receive requests for increased nominations. To increase the certainty of being able to meet nominations, an accurate forecast is required. Due to the significant amount of No-Notice Service on the east end of the pipeline, the nomination based pipeline schedule is not very accurate (No-Notice Service is where, for example, an LDC may take more gas than nominated, but at premium rates above normal delivery charges).

Storage is also used to meet incremental demand not met through transportation. It is desirable to use the minimum amount of storage required to meet the demand. If too much storage is withdrawn to pack up the line, it can back up into transportation capacity constraint points and trap saleable capacity upstream of these bottlenecks. Meeting as much demand as possible through transportation allows greater storage inventory later in the year when it is most needed.

Provide More Information to Customers

Customers want to see more information about their current flow and pressure conditions. One objective is to give customers quicker access to within-day information. As stated earlier, it is desirable to make RTU volumes as close to billable as possible, giving customers more timely and accurate information.

This effort also deals with making information available to internal customers. Integration of the business processes between departments is required to make the objectives come about. For example, the marketing department needs to be able to see if excess capacity exists on the pipeline before it can be sold.

The FOCUS Project

The above requirements are met through the use of new applications. The FOCUS project supplied the applications that take care of these needs. Several applications were identified to meet the needs associated with Gas Control. A Load Forecaster forecasts hourly system supply and demand. Storage Analysis determines the ability of storage to meet the forecasted demand. A Real Time Model creates online inventory and state information about the system. A Look Ahead Model verifies current system operation based on the load forecast and a Predictive Model verifies the operation plan produced in conjunction with the load forecast and Storage Analysis. Energy Management is performed by an off-line optimization model, which provides the lowest cost of operation. The allocation process was shortened along with the measurement process to provide within-day information about the current operating conditions. These efforts are more fully described below.

Load Forecasting

A more accurate forecast can be obtained by using historical weather and economic information along with the forecasted weather. With a better forecast, it is possible to determine receipts and deliveries more accurately, resulting in better operation of the pipeline.

On the market end of the pipeline (the Penn-Jersey system) there is a significant amount of No-Notice Service. Due to the nature of No-Notice Service it is difficult to schedule the pipeline with nominations. This part of the pipeline is very much driven by weather conditions. Classical load forecasting using the weather (temperature, wind, precipitation, and so forth), and base load components (day of week, holidays and season) may work well here.

On the 30” system, transportation contracts dominate the system. The pipeline typically operates at capacity. Scheduling on this system tends to be fairly accurate. Load forecasting here is dominated by the scheduling information in the short term.

On the 24” system, there are a significant amount of deliveries along with transportation. A combination of nominations and weather driven forecasting is useful here.

In the gathering areas, the amount of gas available is determined by offshore production and competition with local markets. Freeze-offs of production can occur during cold conditions that deplete the supply of available gas. In addition, the local market uses gas for heating in the winter and for power generation to drive air conditioning in the summer.

Traditionally, load forecasting has involved the use of historical weather information for several locations on the pipeline kept in files or some kind of database. Regression analysis or pattern matching of like-day were used to determine the forecast. Newer tools are also available for the analysis portion of the load forecaster. The use of neural network technology may be implemented here. Neural network technology works to “learn” inherent patterns that are in the information supplied to it. After learning these patterns the neural network can predict future trends based on these patterns.

The load forecaster creates forecast reports for review and supplies forecasts to the Look Ahead and Predictive models. The models use this information to determine if the pipeline setup needs to be adjusted. Forecast demand is also be compared with storage information to determine how readily the storage withdrawal capability can meet demand.

Storage Analysis

TETCO has significant amounts of market area storage. Storage and pack are used to meet demand swings in the market area of the pipeline. Demand swings are due to direct customer obligations to storage, the use of No-Notice service, and the within-day swings in demand by customers. Analyzing storage consists of being able to see and compare customer and system projected demands with physical deliverability. Direct customer obligation to storage is projected through the use of the load forecaster and nominations made by the customer. A comparison is made between the projected and nominated values. No-Notice customers swing rapidly without corresponding changes in supplies. Demand by No-Notice customers is forecast through the use of the load forecaster.

After projecting the use of storage by customers, it is compared with the physical deliverability of the storage required. Some amount of line packing helps in meeting this storage deliverability. Physical deliverability is tracked.

Real-Time Model

A Real Time Model was implemented to obtain real time pack and pack rate of change for various sections of the pipeline. The model also supplies pressures, temperatures and flows at points where they are not measured. The model has the ability to notify Gas Control of any upsets on the pipeline. Upsets may be due to faulty readings or pipeline upsets which cause the real world to deviate from the model pipeline. The model is also able to tune the pipeline system thereby calculating roughnesses and efficiencies that can be monitored over time. A mass balance is performed on the system that detects discrepancies between measured flows into and out of the pipeline network.

Gas Control views the pipeline model though the Simulation Control Center (SCC). The SCC utilizes a graphical map of the pipeline which allows accessing information through a simple point and click approach. It is described more fully below. Acceptance by Gas Control is a crucial part of the modeling effort.

Look-Ahead Model

A Look Ahead Model was implemented which runs from the current state of the Real Time Model. It is started at a predetermined time interval to run and verify the current operating plan based on up to date pipeline readings and current forecasts. The Look Ahead Model can also be run on demand by the Gas Controller. The model generates alarms if the current operating plan is not physically feasible for the current conditions. If the plan is infeasible, the Gas Controller is able to make changes on the pipeline and adjust the plan so that it is feasible. Feasibility of the new plan can be verified with a new Look Ahead Model run.

Gas Control is able to view Look Ahead Model information from the Simulation Control Center (SCC). Again, it is important for the acceptance of the Gas Controller to have an easy to use tool for accessing model results.

Predictive Model

The Predictive Model is the primary tool used to develop the operating plan. The predictive model is run by Planning Engineers to develop the operating plan for each day. It may also be used to develop longer range plans. The Predictive Model looks very much like the Look Ahead Model except that it is not kicked off automatically and runs over a longer time frame.

Energy Management

One of the main goals of the FOCUS effort is to reduce operating costs. This effort depends on reducing the cost of operating electric and gas driven compression. The TETCO system has substantial amounts of electric power driven units throughout the system. Contracts for these systems make it difficult to optimize the demand charges written into them that may kick in peak load situations. A demand charge resulting from a short duration usage may alter the rate structure of electricity for the entire month.

TETCO currently uses in-house designed tools to optimize on a pipeline section level. These tools run off-line based on input from the online models. Operating plans are developed from them that can be put back into the Predictive Model for verification.

Outage Management

To address the need for automatic entry of outage information, TETCO extended the existing outage database system that was used to schedule and track outages to include an automatic interface to the modeling systems. The new outage system was developed using the Lotus Notes™ application. Outages can now be entered by planning engineers or field personnel, and updated by gas control through the Notes system. Communication and coordination of outages improves, and the modeling system is kept aware of significant pipeline capacity changes without adding to the burden of the users. The detail of how outage information is brought into the simulators is presented below in the discussions of the Operating Plan.

Simulation Control Center

The Simulation Control Center (SCC) was developed to provide and easy to use interface which allows pipeline operators the ability to enter non-telemetered information required by the models (such as valve states, compressor station modes, setpoints, etc) and the presentation of model and load forecaster results.

Most modeling implementations do not provide a method for entering the non-telemetered valve states which is familiar to the user. The operator is required to keep them up-to-date using whatever data entry procedure is inherent to the model. This responsibility is considered burdensome to the operator, whose primary function is to keep the pipeline running smoothly, not baby sit a simulation model.

The SCC was developed with an easy to use map-based interface which allows pipeline operators the ability to easily find what they want to enter and change. A change in the simulations is made by clicking on a map of the pipeline to drill down to the facilities they want to change and to click directly on the facilities to make changes.

Load Forecast and model results are also presented in this same easy to use interface.

Allocations

During extreme weather conditions, Gas Control needs to have a good awareness of customer receipts and deliveries relative to obligations. Tools that compare nominations with physical flows can generally provide this information. In some cases, meters may be shared through operating agreements, etc. It becomes necessary to allocate flows before comparing them with physical nominations. Shortening of the measurement process will aid in this allocation ability. TETCO's goal is to have a within-day "operational" allocation process to aid in these extreme conditions.

The measurement process is being shortened to occur "within-day". Quality information will now be downloaded to the RTUs within the day so that the information in the RTUs is as close to billable as possible. Customers will now be able to see information within-day, that is almost final. The ultimate goal of shortening the measurement process is to perform this operation as close to hourly as possible. TETCO has many different customers and ways of communicating with the RTUs. Because some of these units measure small volumes and are on cellular dialup lines, it is unlikely that the entire system will close out hourly. Larger volumes on the microwave system will close out rapidly.

Decision Support Tools

Ultimate success of the project is dependent on being able to widely publish the results of the applications and integrate them into the business environment in a meaningful way. An application was developed which allows the publishing of results in a high level map based approach. The application is readily accessible on the corporate network. High level users can see summary information available on the map. Users wishing to see and work with more detailed information can drill down from the map to increasing levels of detail. Very detailed information is presented in tabular report form.

The tool publishes information for a variety of time frames and purposes. Information is provided for the long-term future. This shows the level of contracted services and the capacity of the pipe along segments of the pipeline. This long-term view allows the identification of available capacity for sale along various segments of the pipeline and what it should be worth from point to point. In the future, the application will be more tightly integrated with the business systems and will allow the creation of contracts that will subscribe for the service.

In the short-term future, it provides comparison of capacity (from model runs with outages taken into account) with levels of requested and forecasted services (from the load forecaster and predictor models) along the pipeline. The color of flowing gas (firmness of service) is identified in segments along the pipeline. This view allows the identification of unutilized short-term capacity. The tool will be extended in the future to compare the cost of moving gas from one point to another (produced from model runs) with unutilized capacity relative to the demand for transportation (as indicated by differing spot prices between locations).

In the present, it provides comparison of capacity with levels of requested and utilized services along the pipeline. The color of flowing gas (firmness of service) is identified in segments along the pipeline. This view will show deviations between customer requests and actual customer utilization.

Information is also shown for the short-term past. This information is primarily available to compare to the present and future, to show how forecasted results in the past have translated into actual behavior on the pipeline.

THE FUTURE

The FOCUS project at TETCO clearly shows the dramatic transition in the deployment of simulation applications that has occurred in the last decade of the 20th century. Previously, pipeline simulation had been deployed, primarily in Europe, to assist in the complex fundamentals of gas pipeline operations. The new laws in the U.S. that govern the gas business have motivated pipeline companies to look to for any technology to help run their business, and pipeline simulation is a key enabling technology. While SCADA brings operational measurement data into the control room, real-time pipeline simulation can amplify dispatcher's awareness, and predictive simulation provides a first look through the looking-glass into future operational viability.

But further, pipeline simulation, specifically predictive simulation based on the foundation of a stable real-time model, can provide the competitive edge in a competitive market. By providing advance knowledge of future pipeline operations to the marketers of pipeline capacity, the very business of a transmission company is dramatically enhanced by the deployment of simulation technology.

Among the technologies that need to be deployed in this environment, clearly SCADA, simulation, and forecasting are paramount. The key to a successful deployment, however, is in the tying of these technologies together in a user-seamless environment. The technologies deployed and the manner in which they are accessed and published through TETCO is where the SCC, and its further developments have really made the FOCUS project, and TETCO as a company, an industry leader.

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