Title of Paper:

Integrating GIS with Pipeline Simulation Software

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Abstract:

Over the last ten years, energy companies, including gas gatherers, transmission and distribution companies, have begun using Geographic Information Systems (GIS) to make maps, meet regulatory requirements, and as a business development and planning tool. Because GIS and pipeline simulation software have similar characteristics and use the same data these companies have begun integrating the two. However, they are finding this easier said than done. This paper discusses the issues and experiences of creating pipeline simulation models from GIS and displaying the results in GIS.

Paper Body:

Introduction

Targa Resources is one of the largest independent midstream natural gas and Natural Gas Liquids (“NGL”) companies in the United States. Targa owns or operates over 11,300 miles of natural gas gathering and NGL pipelines and 22 natural gas processing plants with over 10 billion cubic feet of capacity in the United States. As a prudent and profitable operator, we have invested significant time and resources to develop and use information and engineering systems such as Geographic Information System (”GIS”) and pipeline simulation to help us operate our pipeline systems safely and efficiently. In order to reduce costs and maximize benefits we integrated GIS and pipeline simulation. This paper discusses the issues and experiences of creating pipeline simulation models from GIS and displaying the results in GIS.

Background

In 1996 Warren Petroleum, then part of Natural Gas Clearinghouse (NGC), later part of Dynegy, and now part of Targa Resources, purchased a pipeline simulation program to help design and operate their gas gathering pipeline systems. To get started we hired a consultant familiar with the pipeline simulator to build a model of a small part of one the gathering systems. The consultant obtained copies of the gathering system paper maps and began building the models by sketching the system free hand using the pipeline simulator’s graphical interface and entering information about the system such as pipe length and diameter by hand into the model. The consultant soon found that the maps were not up to date and in some cases were in error. After spending many months in the field updating and correcting the information in the model, the consultant developed a model that correctly represented the gathering system. When the consultant presented the information to the drafting department to update the paper maps the head of the drafting department said that the information was of no use because it had not been developed according to drafting standards. Unfortunately, the model was also not very useful as a map.

GIS Study

As a result of our frustrations with building pipeline simulation models from our maps and keeping our maps up to date, we undertook a study of our business processes and determined that we needed integrated tools to work with geographic information. We were already using GIS for locating and analyzing oil and gas drilling and production in our business development group. We decided to implement a GIS and integrate it with pipeline simulation and material balances for the purpose of improving our gathering system efficiencies and reduce losses. The primary concept was that we would update and correct the GIS data so that we could build pipeline simulation models directly from the GIS. This would make the process more efficient by avoiding duplication of efforts and cost effective by utilizing GIS technicians instead of engineers to build models. As a side benefit, the GIS could also be used for other things such as analyzing material balances, maintaining gas purchase and Right of Way ("ROW") agreements, and quickly evaluating gas supply and business development opportunities.

GIS Pilot

In 1998, we started a GIS pilot to create an enterprise GIS strategy and execute a proof of concept. The goals of the proof of concept were to create an accurate map of a gathering system, correct the topology, create pipeline simulation models from the GIS, develop systems and processes to create and maintain accurate maps, and analyze the cost and benefits of a corporate GIS. The proof of concept evaluated several data gathering and GIS correction processes including interviews, georectified aerial photography, and survey grade Global Positioning System ("GPS"). We tried a variety of processes to determine their feasibility and cost effectiveness. Along the way we made numerous decisions that we continue to believe were correct such as switching from AutoCAD to GIS, eliminating cartographic displacement, using a georeferenced aerial background as frame of reference, not using measures, and not using standard data models.

AutoCAD or GIS

One of the first decisions was to decide how the data would be put to bed each night. When the pilot was started the head of the drafting department in charge of maps insisted that the even if we used GIS to view and work with the maps during the day, they should be converted back to AutoCAD each evening for storage and safekeeping. We began developing procedures to translate the maps and information from AutoCAD to GIS and back again each day. It soon became apparent that this development work would exhaust the budget of the pilot and and after much heated discussion we were able to convince the drafting department that it would be safe to use and store the maps in GIS.

Cartographic displacement

Another major decision was whether to abandon cartographic displacement of closely located features. For example in order to clearly show two parallel pipelines on a paper map with a scale of 1 inch = ½ mile, they would be drawn 1/8th of an inch apart. This means that the real world representation is 330 feet even if they were only actually 20 feet apart. This displacement is very noticeable and misleading when zooming in using a GIS. It is also misleading if you are trying to use a GPS to locate features. We evaluated several alternatives such as maintaining the fixed scale cartographic displacement to make the printed maps look the same as they had in the past, eliminating the displacement and using a geographic representation so that the GIS would be accurate, or keeping two sets of data in the GIS, one for printing paper maps and one for GIS spatial analysis. At the time there was not a good algorithm to add cartographic displacement on the fly when printing maps from GIS. We decided that it would be cheaper and more useful to drop the cartographic representation in favor of the geographic representation. There were numerous complaints because this made it difficult to separate features on printed maps when they were close together. This decision has be discussed and cursed by all paper map supporters ever since but the arguments have diminished as more and more people have switched from paper maps to GIS and as people have become dependent on GIS.

Dynamic Segmentation

The next major decision was whether or not to use dynamic segmentation a.k.a. measures. About the time that we were developing our GIS, dynamic segmentation was all the rage. This concept originated from the use of stationing on alignment sheets. Several problems with measures soon became apparent. First, in 1998, the technology was difficult to use. Second, for gathering systems, measures caused more work than they saved. In a gathering system, measures are subject to constant revision due to changes in operation and ongoing correction of errors. Each time the system was revised, the measures had to be recalculated. We found that it was much simpler to just give each pipe segment a unique identifier that did not change. If the pipe segment was split the longer segment retained the identifier and the smaller segment was assigned a new identifier. Instead of locating appurtances such as meters, valves, relief valves, drips, cathodic protection devices using measures, we simply snapped the pipeline appurtances to pipeline vertices. If the appurtance affected the flow such as a valve, regulator, or compressor, then we split the pipe at that location and snapped the appurtance to the endpoints. If the appurtance did not affect the flow, then we simply created vertices on the pipe segment and snapped the appurtance to the vertices. If we moved the appurtance or the pipe, then we manually moved both and snapped them back together

Pipeline Data Models

The next major decision was whether or not to use a standard pipeline data model. About the time that we were developing our GIS, the Pipeline Open Data Model (“PODS”) was being developed. PODS is a derivative of the Integrated Spatial Analysis Techniques (“ISAT”). Since PODS and ISAT relied on dynamic segmentation, which we were unable to use with our gathering systems, we were also unable to use PODS or ISAT.

Topology

Real pipeline systems often consist of many pipe segments of different sizes and materials connected in a network. The topological model we developed was simple and relied on a few rules. Networks consist of points or nodes and interconnecting segments or legs. In order to simplify the modeling we decided to rely on endpoint snapping to carry topology. This made it simple to understand and develop topology checking tools. We used polylines to represent pipe segments and points to represent flow into and out of a system. We broke our gathering system down into smaller material balance systems in which we had measured all the flows into and out of the material balance system using meters. Flow into or out of a network or system could only occur at a meter which was represented as a point that was snapped to the endpoint of a leg. Therefore, if we had several meters close together we drew pipe to each meter just like in the real world. This made the ends of lines with multiple meters look like pitchforks.

Pipeline Simulation

Pipeline simulation is the process of using a computer model to simulate the behavior of fluids in an actual pipeline system. It can be used to design pipeline systems, to check how it will work if conditions change, or to see how well the actual pipeline system is working. There are three basic types of pipeline simulations: (1) Compressible or incompressible, (2) Single phase or multiphase, (3) Steady state or transient. Currently, most gas gathering systems are modeled as a steady state single phase compressible system.

Flow Equations

The motion of fluids can be predicted using the fundamental laws of physics together with equations of state that relate the physical properties of the fluid. The applicable laws of physics are: conservation of mass and conservation of energy. Conservation of mass is expressed as an energy balance equation in which every thing into a system is equal to every thing out of the system. Conservation of energy is concerned with the conservation of three types of energy; (1) Elevation potential energy, (2) Pressure potential energy, and (3) Velocity energy (momentum). These relationships are expressed by Bernoulli’s equation. If the fluid is compressible, the properties of the fluid generally behave according to the ideal gas law which is a combination of Boyle’s and Charles’ laws that relate pressure, volume, and temperature. A compressibility factor is added to account for the real world deviation from the ideal gas law. Fluid flow is always accompanied by friction which causes a loss in pressure. The general equation for pressure drop due to friction is the Darcy equation which relates pressure drop to distance, velocity, density, and pipe diameter by means of a friction factor that is primarily a function of whether the flow is laminar or turbulent. A general flow equation for isothermal, one dimensional, single phase, and compressible flow can be derived by solving the differential equations representing these relationships. The general flow equation relates the following variables:

Q = function of (P1,P2,D,L,T,e,SG, and E)

Q = Flow (Mcf/D)

P1 = Upstream Pressure (Psia)

P2 = Downstream Pressure (Psia)

D = Inside diameter (Inches)

L = Length (Feet)

T = Average temperature (F)

e = Pipe roughness

SG = Specific gravity of gas

E = Efficiency factor

Since each leg of a pipeline system has a material balance equation and a flow equation, pipeline simulations require solving a large set of simultaneous non linear equations that cannot be solved directly but must be solved iteratively. That is the beauty of the computer; it can easily solve this large mess of equations using advanced iterative techniques.

Knowns and unknowns

In order to solve an equation there can only be one unknown variable. The rest are known or assumed and treated as known. For flow equations, the unknown variable to be solved in pipeline simulations is either the flow Q, the upstream pressure P1, or the downstream pressure P2. The variables associated with the pipe such as diameter, length, and roughness, and efficiency are called pipe variables, do not change unless you change the pipe, and are usually assumed known. The other variables such as specific gravity or temperature associated with the fluid are called fluid variables, do not change unless you change the fluid, and are also usually considered known. The material balance equation adds another flow Q variable for which to solve. Therefore for each leg you have a flow in and a flow out and a pressure in and a pressure out.

As stated earlier, a pipeline simulation model is based on a network of nodes and interconnecting nodes. Pipeline simulations are actually made by solving the simultaneous equations so that all the flows into and out of a node balance and all the pressures at the ends of legs connected to a node are equal. Since flow only enters or leaves a system at the nodes and since the pressures are set or calculated for nodes, the user actually enters flows and pressures at nodes and not by legs. This works out that for every node there is a flow and a pressure variable.

When you have a network of pipelines with many inlets and outlets you must simplify setting the flow and pressure knowns and unknowns for nodes. A good rule is that you don’t use check meters in models. Break the network up into balance systems where all the the flows into and out of the system known. For gathering systems the best way to set knowns and unknowns is to pick the largest outflow downstream node as the node with the unknown flow and known pressure and make the flows known and the pressures unknown at all the other nodes. The simulation will calculated the unknown flow and it can be compared to the known flow to determine system losses or gains. If all the legs and nodes are properly connected and you have not entered ridiculous pipe geometry values such as zero diameter or length, the model should run.

Data Cleanup

You cannot run a model from a GIS unless the topology and pipe variables are correct.. This means you must clean up the GIS data. GIS cleanup is hard work. As we stated earlier our topology is stored by snapping the ends of the pipe segments together and snapping the pipe segments to meter points where flows into or out of the system occur. GIS created from old AutoCAD maps often are full of cartographic symbols and annotations that must be removed and the network repaired. There are two basic ways to clean up GIS data. One way is to trace over the old maps and redraw everything. The other is to look for errors in the old data an fix them one by one. We have tried both ways and find both take a lot of work. In order to speed up the cleanup process we developed some ArcView extension tools. The first set of tools allowed us to cut, copy and paste from like layers. The second tool allowed us to snap polyline ends to points and points to polyline ends. The third tool checked for connectivity. When executed, the tool would check all the pipes and highlight any pipe that was not connected to the other pipe. We had another set of tools that check for multipart lines, zero length lines, and duplicate lines. Finally, we had another tool that checked to make sure each meter was snapped to the end of a pipe segment.

GIS to Pipeline Simulator

In order to build pipeline simulation models from GIS data we developed a multi step process that took advantage of the pipeline simulator's scripting and template program. The pipeline simulator already had a script and template to read American Standard Code for Information Interchange ("ASCII") Comma Separated Value ("CSV") files to create models from scratch and update flow equation variables. Therefore the first step was to export the following three files from the GIS; (1) a node file, (2) a leg file, and (3) a flow file. We created a GIS application that exported the three CSV files directly from the GIS. The node file export part of the tool created a CSV file with an x and y coordinates record for each pipe endpoint, eliminated the duplicate records, and gave each endpoint an unique identifier. We found that by working in a State Plane US Foot Coordinate System it was easy to create models in feet. The leg file export tool created a CSV file with a record for each leg, gave each leg a unique identifier, listed the from and to nodes, and extracted information such as length, diameter, and roughness for each record. The flow file export tool created a CSV file with a record for each meter that gave the meter identification, the node identification corresponding to the meter, and the flow, pressure, temperature, specific gravity, and flow and pressure known or unknown flags associated with that meter. The second step was to create a model from the three CSV files. First we used the pipeline simulation script to automatically combine the data from the nodes and legs CSV files together to create a model. Then we added the flow, pressures, temperature, specific gravity and known or unknown flags to the appropriate nodes. Once the model was created, we were able to run it and compare the results to actual operations. Once we had the model running, we tuned it by adjusting leg efficiencies to cause the calculated pressures to mach actual pressures to account for flow blockages caused by sediment or liquid buildup.

The pipeline simulator now has a very powerful shapefile import / export tool that allows the user to simply import the model from meter and pipe shapefiles. We can now create pipeline simulation models directly from shapefiles with just a few clicks of the mouse. This makes it very easy to run both the GIS and the pipeline simulator simultaneously and switch back and forth. The pipeline simulator can also import shapefiles and images as backgrounds. This provides a frame of reference for the models. Once the model is corrected, we can even export the model back out as shapefiles to update our GIS or display the results in our GIS.

Conclusion

Based on our experience we have found that it is practical and cost effective to create pipeline simulation models directly from our GIS. Our GIS and pipeline simulations have been invaluable in helping us operate, optimize and expand our gathering systems. We have also found that the simulations help us correct and update our GIS data. Simulations are very good at highlighting incorrect pipe data and network geometry. We have found that data clean up is very tedious and that there is no magic bullet. We have developed processes and tools set that speed up the process. With the ability to import and export pipeline simulation models as shapefiles the process has been speeded up even more. This has allowed us to closely integrate pipeline simulation and GIS.

Future plans

Based on the successes so far, we are continuing to enhance and expand our GIS and pipeline simulation integration. We are developing automated processes to use flows and pressures from our Electronic Flow Recorder (“EFR”) Supervisory Control And Data Acquisition (“SCADA”) radio network to update and run our pipeline simulation models daily and display the variances between calculated and measured pressures on our corporate internet GIS maps. We are developing an online and offline redline process that allows field persons and engineers to markup the GIS for the GIS technicians to correct. The redline markups will be displayed on the corporate internet GIS as layers so that all coworkers are aware of the proposed changes and corrections immediately. We are now working integrating our GIS with Digital Elevation Models (“DEM”) so that we can easily develop two phase three dimensional pipeline simulation models.

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