Less is More

Accuracy versus Precision in Modeling

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As computers have increased in speed and capacity, pipeline modeling software has kept pace. Modelers can simulate larger networks, and work on local personal computers (PCs) instead of timeshare systems. Now, modelers can construct larger, more complex, more detailed, and precise models. Many modelers assume that building with more precision yields a more accurate model. Is this really true? Are these models any more accurate than the less-detailed models of previous decades? Does the added precision (detail) improve hydraulic calculations? Could additional precision make the modeling process more difficult? What is the necessary level of detail?

Inexperienced modelers may find such questions difficult to answer. If the device is in the field or on the drawing, they reason, it must be in the model. In many cases, though, including detail on a device requires assumptions about hydraulic parameters that affect the modeling accuracy. They need to consider the purpose of the model, the computational significance of the device to the model, and how their hydraulic assumptions affect model accuracy and performance.

Also, hydraulic models are being used in many different areas of pipeline companies. No longer just planning tools, these models serve as tools to operations and even marketing staff. How does the use of the model influence the level of precision needed? Can the same model apply to more than one application? These questions should be asked whether you are running steady state or transient models, simulating transmission or distribution, or gathering and analyzing gas or liquid fluids.

Remember learning to solve story problems? The most difficult lesson to learn was how to ascertain what information was actually needed for the solution! The same applies here. Pipeline simulation models are extremely large math problems. As with any math problem, it is essential to consider the solution one seeks. To converge on the solution, use only the information required to arrive at the solution.

None of the questions posed here have absolute answers. This paper provides insight and guidelines to aid in exploring the answers and to make model building an easier process. The real examples provided draw on the combined modeling experience of the authors.

Introduction

Simulation History

Simulation has made some major advances in the pipeline industry. Prior to the 1960’s, most pipeline simulation was done with hand calculations (using slide rules and log tables) and nomigraphs or lookup tables. Most of this work used empirical correlations such as Panhandle A, Panhandle B, or Weymouth, since there was no friction factor to calculate and no iterations to find the answers. In the 1960s, people began to recognize the capabilities of computers (which were in their infancy), and developed computer programs to run pipeline simulations. Because of the restrictions of the hardware available, the original programs were fairly simple and could handle a very limited problem size (normally with a maximum of 100 devices). Engineers would submit jobs and wait hours or, sometimes, days to receive results. It was very important to configure systems correctly and keep them simple so that few runs were necessary.

During the 1970's, computers became more reliable, faster, and interactive, and timeshare companies came into existence. Engineers could run software on the timeshare companies and pay a per-run fee. The software programs were improved to handle more devices and more complexity. Engineers still kept the detail to a minimum, since the fee structures were based on connect time, access, and number of devices. Computer-aided design (CAD) systems were also introduced.

During the 1980's, new types of computers were introduced: PCs, mini-computers, workstations, and super computers. Memory and disk space expanded considerably, making it possible to create larger models. Computers became significantly cheaper and companies purchased computers and the software programs. Geographic information systems (GIS) became available, and companies started to extract data from the GIS systems to build their piping models. The software was more robust and could process significantly larger models. Modelers were able to make multiple runs in a day. Models could be configured more easily through the use of graphical user interfaces (GUIs). Models were larger, but the size was still limited by the memory and hard drives of the machines. More detailed equipment modeling was common; but a modeler was able to make multiple runs to get a system working correctly.

During the 1990's, PCs became more powerful than some mainframes previously used. Software vendors continued to improve their products to model larger networks with more detail. The new computers solved problems so quickly that the new level of detail was not apparent in run times. The basic concept prevailed that "if the piece of equipment is in the field, it must be included in the model". Equipment, which is hydraulically insignificant, is often included in models. Heat transfer and composition tracking are standard. Many pipeline companies have GIS systems and are extracting data from them for modeling purposes. Application service providers (ASP) were established and could warehouse data and modeling products (return to timeshare).

Where will the future take us?

Precision versus Accuracy

Many people confuse precision and accuracy. Precision is exactness or detail, the degree of refinement with which an operation is performed or a measurement taken. Accuracy is correctness, the degree of conformity of a measure to a true value or standard. Modelers strive to be accurate in their modeling. A very precise model is not necessarily an accurate model. The accuracy depends on the accuracy of the details. Very simple models can be very accurate. When adding detail, it is important to ensure that the detail is accurate.

Pipeline software applications are, by their nature extremely precise. The accuracy of a model is determined by the accuracy of the input data more than the numerical precision of the software application.

Modeling Process

The modeling process has remained consistent over the years. The basic process for planning studies is:

1. Determine the type of model needed and the data required
2. Gather model data
3. Build a base model in steps
4. Tune the model to match known conditions
5. Determine what cases need to be run
6. Modify base case as necessary to run cases

In building the base case, the main problem may be determining the amount of detail that is necessary for the cases to be modeled. The amount of detail that is necessary depends on the type of system being modeled (gas or liquid, transmission, distribution or gathering); the type of model (steady-state, transient, real-time, or trainer); and the solution being sought.

After the descriptions are available for pipeline systems, equipment, environment, and fluid composition to input into a pipeline simulation, the key questions to ask are: "Is all this information necessary to reach a solution? How does this data affect the accuracy of the solution? Is it worth the input precision to obtain an accurate solution? How accurate is the solution?"

Experienced modelers have an advantage—the detail in their models was slowly added as new features were added to the software applications. Less experienced modelers or modelers building new systems often make the mistake of initially building a very detailed model, and then trying to get it running. This approach can lead to considerable heartache and long hours. Often the true problem is masked by numerical problems that the software application is having. An error may indicate a problem at a station when the problem is, actually, in the pipe description.

In general, the more detail input into a model, the greater the input time and the greater the chance for error. Therefore, when constructing a new model, it is best to initially limit the number of pipes and fluid detail input for the model. When troubleshooting a model, this can prove to be a very time consuming process in determining what factor is influencing the problem.

Examples

Elevations

The following example shows a single-pipe segment with a supply and delivery. The pipe is 50 miles of 12-inch pipe with set pressures for the input and output. The flow is calculated.

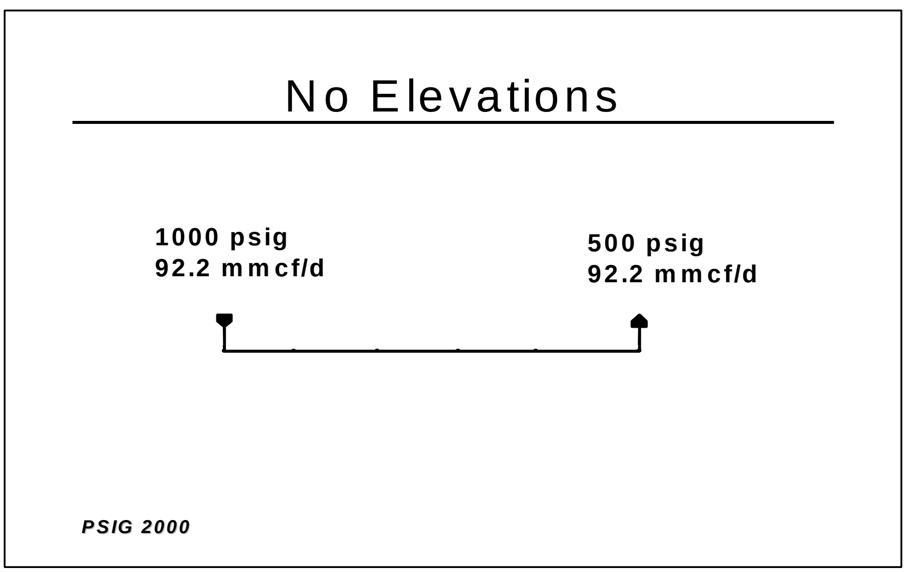

Figure 1

Assume the supply point is at an elevation of 500 feet and the delivery is at an elevation of 1000 feet. With these elevation points added to the simulation, the following flow is calculated for the same pressures.

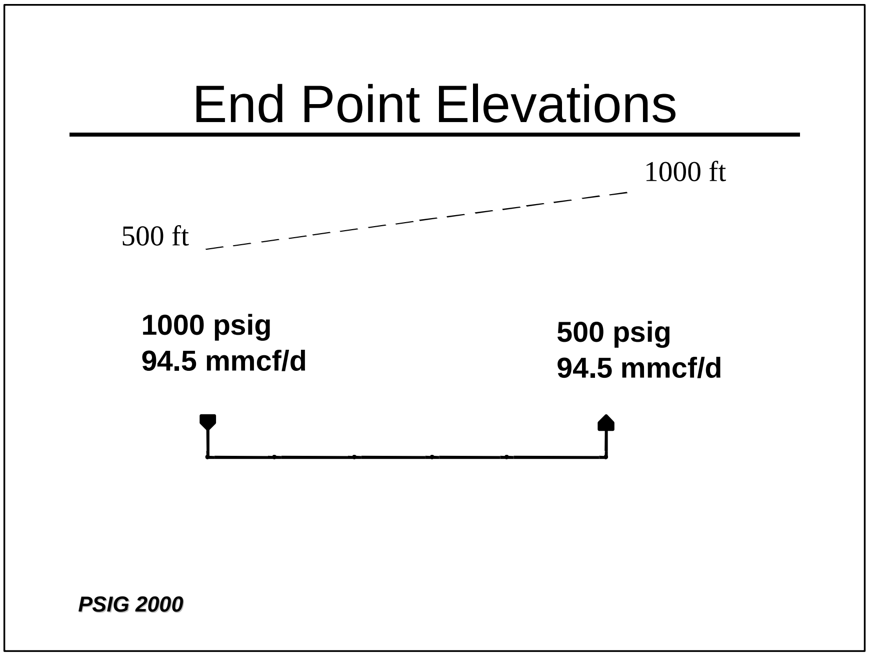

Figure 2

If the pipeline is broken into five 10-mile segments and add the following elevations: 500 feet, 800 feet, 200 feet, 900 feet, 300 feet, and 1000 feet

What would be the calculated flow if the pressures remained the same?

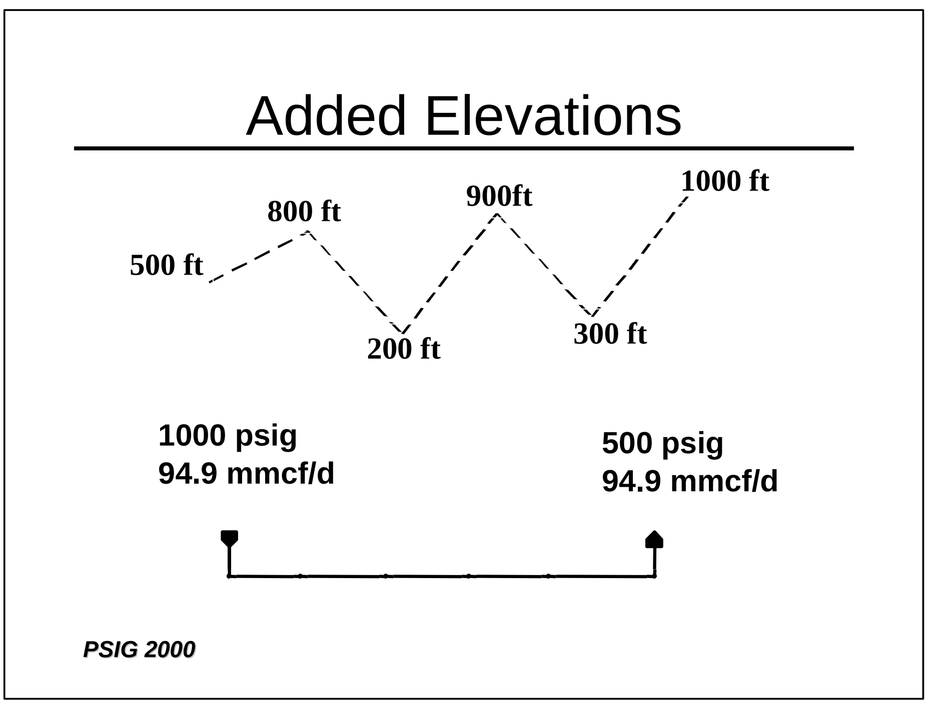

Figure 3

The last two examples calculate different flows for two cases. One case assumes only the elevations at each end of the pipeline, and the other assumes intermittent elevations throughout the pipeline. The flows calculated for each case were 94.5173 MMCFD and 94.918 MMCFD. For the added input there was less than a half percent difference in the calculation. This is only an example of gas flow and may not be indicative of specific cases. This represents an example of adding detail for precision and not gaining a representative level of accuracy to the solution.

If a gas pipeline extends over the Rocky Mountains, it is very important to include elevations. For liquid pipelines, elevations can be more important. A detailed elevation profile is needed for pipelines where slack line operation can occur.

Block Valves

Block valves can affect precision and accuracy in two ways: 1) actual inclusion of block valves in the model; and 2) the model detail included for a block valve.

The block valve is probably the most over-used equipment in models. Modelers have a tendency to place block valves at every supply and delivery point, pipe interconnect, compressor station, and crossover. Though the block valves are physically there, the block valves may not affect the operation of the pipeline. For example, many modelers will model a long transmission line and depict every mainline block valve on the system. These block valves are always opened and rarely used. For every block valve, this adds another equation step to the simulation calculations, actually slowing down the model calculations. A more prudent approach would be to show a node for the block valve locations on the pipeline and adjust tuning to adapt for pressure losses experienced across the block valve. In loop lines, using a connecting node and omitting the block valves can simulate normally opened crossovers.

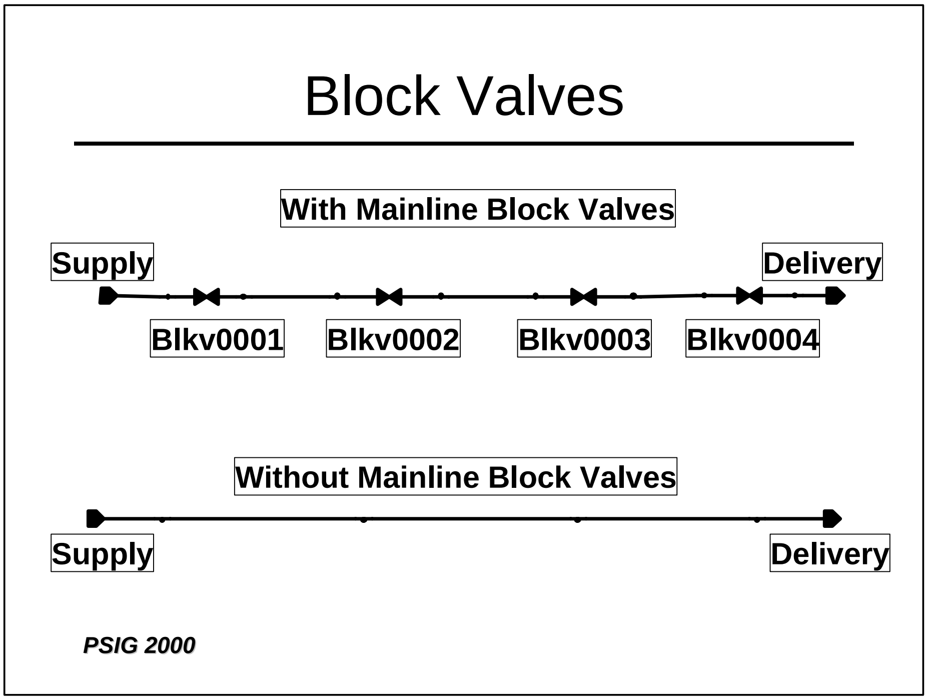

Figure 4

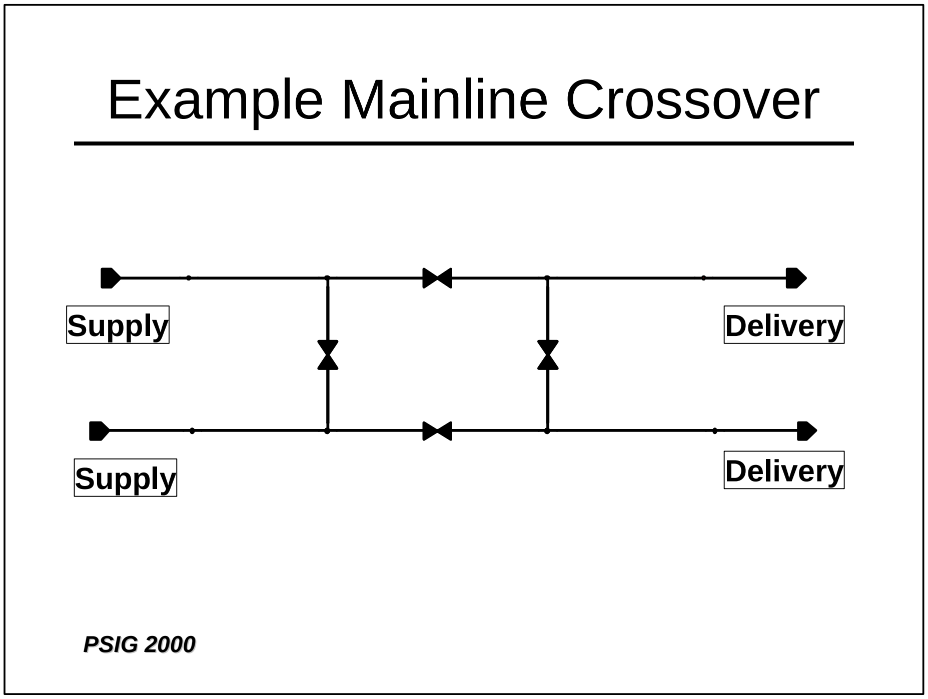

Figure 5

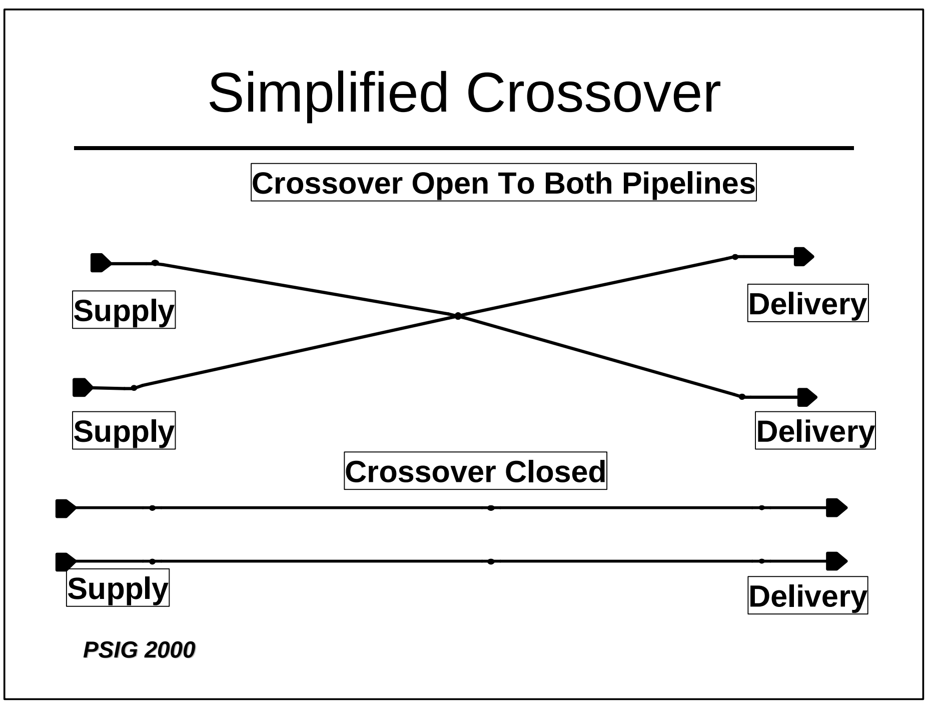

Figure 6

When a block valve is needed for a simulation, the modeler is often given the option of valve size and valve coefficient or detailed valve descriptions (down to the make and model of the valve). Many modelers estimate these values. The result is valves with no pressure drop or huge pressure drops, which adversely affect the numerical analysis. The modeler needs to review how the block valve affects the problem being solved. Does the interest involve the valve closure time and resulting hydraulics? Or does the model need a simple closure to review various operating scenarios over long periods of time?

Once again, the modeler must decide if the required precise input will add to the accuracy. A basic plan of action usually begins with a simple valve model. Additional details can be added later to the block valve and the results compared.

Based on these test cases the modeler will, eventually, understand when detail is required. Of course, the added benefit may still be less than the guaranteed accuracy of the instrumentation that generates the comparison data.

Pipe Diameters

In a perfect world, a pipe specified by a nominal pipe diameter would have one outside diameter, inside diameter, grade of pipe, etc. associated with that nominal diameter. Unfortunately, this is not a perfect world and, for any given pipe diameter, there are many wall thicknesses resulting in as many inside pipe diameters. For instance, the same 20" pipe can have numerous wall thicknesses or a segment of pipeline will have various pipe diameters. Along any given pipe section, pipe diameters will vary for many reasons: road crossings, river crossings, MAOP, class changes, later pipe additions, pipe repairs etc.

Often, these pipe diameter changes may be numerous in a long segment of pipeline; but, as a whole, are minor representations of the pipe diameter along the entire length of pipe. A transmission pipeline will be interrupted with crossings of different pipe diameters that only cover a distance of feet (as compared to miles) of same-diameter pipe along the total segment of pipeline. Is it necessary to input all these diameter changes into a model? Generally, for long distances, the prevailing pipe diameter can be used. Some benefits to simplifying the pipe diameter entry are:

- Quicker, simpler input
    - Less chance for input errors
    - Quicker solution time
- Improved transient solutions
    - Helps avoid short pipe segments

When modeling small sections of pipeline segments, it may be necessary to include all the pipe diameters. As mentioned earlier in this paper, it is recommended to err on the simplicity side and gradually add detail. Some instances that may require a more exact diameter model are:

- Simulating small sections
- Heat transfer models
- Experience tuning problems

If problems arise when tuning a pipeline system using a single-diameter pipe, it may be indicative of an efficiency problem. If a simulation will not tune without input of a smaller diameter, it may indicate that this short section of pipe is adversely affecting your entire pipeline. It may be cost-effective to replace this section of pipe. In general, simplified diameters should be easily tunable.

It is important to remember that this process is about using the most prevalent pipe diameter and wall thickness over a specific pipe section. This is not averaging of pipe diameters and lengths!

It is recommended to start with as few pipe diameters as reasonably possible. If you suspect that a crossing with a pipe change may affect your simulations, put a node at the start of the section and continue using the single pipe diameter. Then if you need to adjust your model with this specific pipe diameter change, you can easily implement the change later. In general, start with a basic overall pipe diameter and add to it later as the simulation of the pipeline system progresses.

Tuning

Tuning a simulation model can be a paper unto itself. However, a paper discussing precision and accuracy should touch on tuning and the effects on simulation.

During the course of running models many modelers will realize the need for tuning. In the authors' experiences, there are two types of tuning—steady state and transient. Most models are run as steady state and are tuned based on this data. The modeler must be cautious when using the same model tuning for a transient simulation, especially on a transient pipeline system. It is always wise to collect approximately six hours of data and compare actual versus modeled. Do not be surprised to see the comparison resemble the figure below:

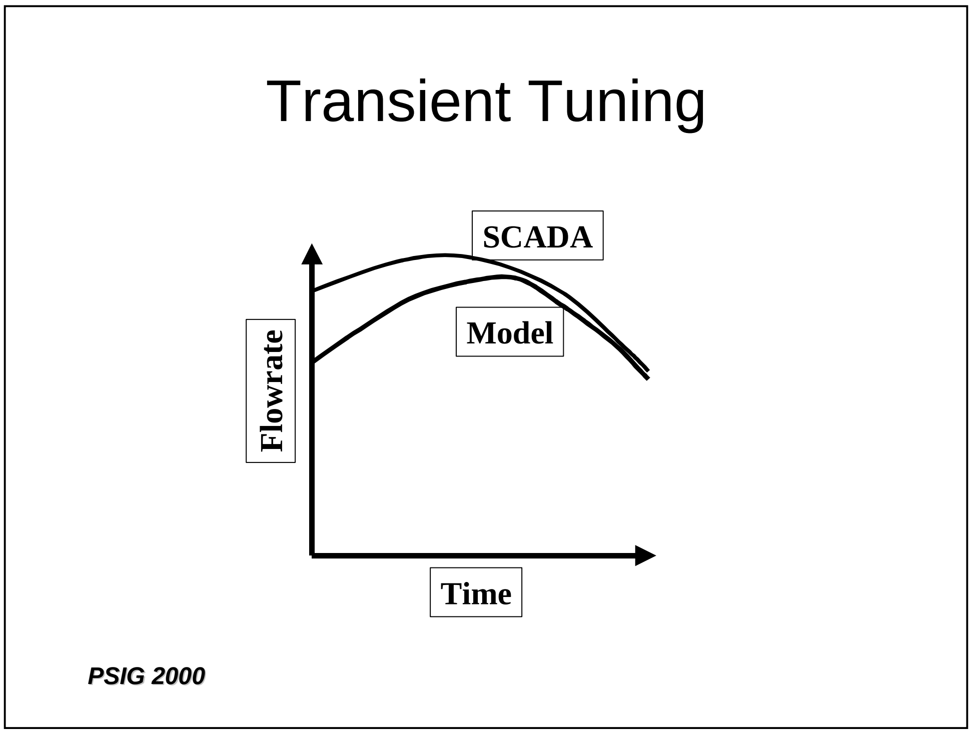

Figure 7

The first few hours of the transient are absorbing the line pack differences in starting from a steady-state and running a transient. The last hours are used for tuning comparisons. The modeled data should quickly start to track actuals after two or three hours. If it does not track, the mode requires more tuning.

Another rule of thumb is to type downstream first and work upstream along the pipeline. If the modeler starts upstream and moves down to tune, any changes made downstream will invalidate any upstream tuning that was completed.

One of the biggest mistakes made in tuning is to ignore the accuracy of the data used for tuning. Every instrument in the field has an accuracy associated with the measurement. Instruments tend to "drift" between calibrations. Modelers often take snapshots of SCADA data to tune to. It is important when using a SCADA snapshot to know whether it is an appropriate snapshot. Has there been a recent operational change: a pump or compressor start or stop, change in set point, sudden change in flow conditions, etc.? If any of these have occurred, this is not a valid snapshot to tune against.

Heat Transfer

Many people are modeling heat transfer in their systems. Ample data—information on the soil (surroundings) heat conductivity, depth, and the ambient (ground) temperature—are required to do proper heat transfer calculations. Some of this information may vary by season or even month. There are definitely systems that must use heat transfer such as:

- Viscous crude systems
- Systems with wax deposition
- Gas systems where the suction temperature of a station depends on the discharge temperature of the previous station (can happen with internally coated pipe).
- Any system where there is a need to keep fluid temperatures between specific bounds

Usually, the assumption is made that modeling heat transfer makes a model more accurate and the line pack and pressure drop calculations are more correct. Without accurate data, adding heat transfer calculations adds additional precision to the model with little change in accuracy. The model can be tuned using the ability to add temperature to pipes and closely match the answers with heat transfer.

Station Details

The details needed for station modeling definitely depend on the fluid, the purpose of the model, and the type of model. Also, the availability of up-to-date performance data is an issue. For liquid surge analysis or training models, detailed stations need to be modeled. This includes details of the pump performance and detailed valve information. For initial design studies, generic stations are typically used.

For gas systems, it is recommended to use block horsepower when:

- Performing planning studies to determine power requirements for a new system
- Doing studies on an existing system that has sufficient horsepower, but has pipe bottlenecks
- The performance information that is available for a compressor is over ten years old and the compressor has had major overhauls

If a system is compressor-limited, detailed compressor performance needs to be modeled. Detailed valving in the station only needs to be modeled when stations have separate suction or discharge headers that the compressors can be switched among.

Secondary piping systems such as relief systems, sump systems, blow downs, etc. do not need to be in general models. They may need to be included if a detailed study of a single station is being done.

Boundary Conditions

Boundary conditions confuse many modelers. Modelers tend to under-specify parts of the system and over-specify other sections. Typically, modelers try to control too many model details and do not let the software application find the result. In general, this is a result of expecting the software application to perform functions that cannot be done in the field. At a supply point, pressure or flow can be controlled, but not both. In general, all models should have at least one fixed pressure point where the flow is calculated. As a simple rule of thumb, for either steady-state or transient analysis, make supplies (flow into the system) pressure-controlled; deliveries (flow out of the system) flow-controlled; and stations discharge-controlled. If a modeler is confused on how to set up a model, they should ask the people who control the pipeline how they manage the system.

GIS Extractions

GIS systems are becoming standard tools. Companies do not want to maintain multiple definitions of the pipes and equipment that they have. They are becoming leaner and no longer have large staffs to maintain models. Companies are extracting data from their GIS systems to build models. This can be very effective if there is some filtering during the extraction.

Remember, GIS systems have every small piece of pipe in the system included in the database. There may be problems with fittings such as tees and elbows, where systems become disconnected. When building the GIS system, it is important to ensure that pipes are truly connected. I just worked on an extracted system where many of the laterals were not physically connected to the mainline. The person doing the GIS system did not break the main line at the point where laterals connected to the line. Working from a GIS system takes teamwork between the GIS people and the modeler to make corrections or additions so that subsequent extractions go smoother.

Conclusion

The best rule is to keep models as simple as possible. Simple models are easier to work with and to understand. Layer on detail as needed in keeping with the model requirements. Run the model as you add detail to determine if the detail is accurate. It is much simpler to add detail to a model than to determine what detail is causing the model to not run.

General Rules of Modeling

1. Define the problem
    - What is the purpose of the model.
    - Realize what are the causes and effects of this operation.
    - What are the control points needed to incorporate the model?
2. Build the model in layers
    - Start simple.
    - Try to construct or outline the system in a simple manner. Run this simple layer.
    - Draw the problem showing operational constants and necessary equipment.
3. Review the solution
    - Review the input and output
    - Review assumptions.
    - Is more detail needed?
    - Add and re-run.
4. Tune

Run cases

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