
AN ESRI
WHITE PAPER

APRIL 2019

# Essential Gas Pipe Network Data Management in ArcGIS®

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# Essential Gas Pipe Network Data Management in ArcGIS

## Executive Summary

A gas utility today needs to answer more questions than ever from stakeholders about its pipe network and how it operates. Recent industry-specific capabilities developed in the ArcGIS® platform enable a gas utility to better answer these questions and further unlock the platform's full power to help achieve better business outcomes. These industry-specific capabilities include the following:

- Improved essential network management tools provided in the ArcGIS Utility Network Management and the ArcGIS Pipeline Referencing extensions
- An ability to define—in detail—network components and their behavior provided through the utility network's container capability
- Data Model (UPDM), a unified data model that explicitly represents each physical component—from the wellhead to the customer meter—of a gas pipe network

Esri's vision for vertically integrated gas companies is to create a single representation of the entire pipe network that mirrors the real network. This removes the traditional barriers between industry subsystems—for example, between transmission and distribution subsystems—that result in data silos

A single representation also enables users to work with that digital network just as they do with the real network. Linear referencing and connectivity modeling now can be performed on the same single network representation.

The purpose of this white paper is to provide an overview of the industry-specific capabilities of ArcGIS that enable gas utilities to achieve the Esri vision for vertically integrated gas companies.

## Questions Faced by Gas Utilities

A gas utility today needs to answer more questions than ever from stakeholders about its pipe network and how it operates. ArcGIS provides industry-specific capabilities that facilitate a gas utility's creating and maintaining the data needed to answer these questions. These capabilities are enabled through the Utility and Pipeline Data Model (UPDM), in which data related to everything from the wellhead to the customer meter can be stored, and two extensions—ArcGIS Utility Network Management and ArcGIS Pipeline Referencing—that allow users to build network models and assign attributes to them. Both of these extensions are intended to be further extended by Esri partners and customers to provide even more advanced functionality.

In answering questions, a gas utility faces a range of external, internal, and geographic information system-related challenges and requirements.

## External Challenges and Requirements

Some external challenges and requirements are due to the changing world in which gas utilities exist. Here are some examples:

- *Government* regulations are expanding and tightening.
- *Market opportunities* arise quickly and need to be seized immediately.
- *Operations* must be continually adjusted as regulatory and business conditions change.
- *Mergers and acquisitions* are consolidating the gas utility industry, resulting in fewer gas utilities operating large, complex, integrated pipe networks.
- *Customer expectations* are rising, with a desire for always-available information and different ways of engagement.
- *Stakeholder expectations* of performance and transparency are rising.
- *Biomethane* injections are changing operational plans.
- *The Internet of Things (IoT)* is introducing an age of real-time, high-velocity, and voluminous data from sensor networks.


Figure 1—External Challenges and Requirements

*Biomethane*, a purified form of biogas, is an appealing substitute for natural gas at a time when governments and scientists are focused on decarbonizing the energy supply. Biomethane can be injected directly into a pipe network in the same way that natural gas can. However, production of biomethane likely will be distributed throughout the network at biomethane plant locations. Biomethane producers will likely want to connect to the networks where natural gas is not injected. Gas utilities need to know more about their network and how it operates so they can understand the implications of using biomethane as part of their overall supply.

*Sensor networks* provide increasing volumes of timely data about operating conditions. With sensor networks, remotely monitored data on relevant operating parameters is streamed to a control center 24 hours a day, 365 days a year.

Enter the IoT. The buzz about IoT seemingly is everywhere these days. IoT is based on the notion of an always-aware knowledge of the state of things—typically, identity, status, and other relevant information—made possible by a huge number of sensors in interconnected devices. This is interesting and valuable information. But what good is knowledge of a problem if the location of the problem is not known? And if a sensor indicates that a colleague is in trouble, wouldn't it be equally important to know where help is needed? The IoT only realizes its full potential when it also includes location.

## Internal Challenges and Requirements

Other challenges and requirements are internal. One internal challenge is that staff in all functional areas and roles, as shown in figure 2, expect ready access—wherever they are—to the data they need to answer questions about their area of responsibility and do their job.


Figure 2—Typical Gas Utility Functional Areas

In many cases, data historically was treated as a departmental asset, not an enterprise asset. Even now, in some cases, data remains siloed in disparate systems, typically not accessible by all who need it. In yet other cases, the data is still on paper records that are filed away in cabinets, making it even less accessible than data that's in digital silos.

## GIS Challenges and Requirements

For some gas utilities, other challenges and requirements are the result of reaching the limits of legacy GIS solutions and the older technology within them.

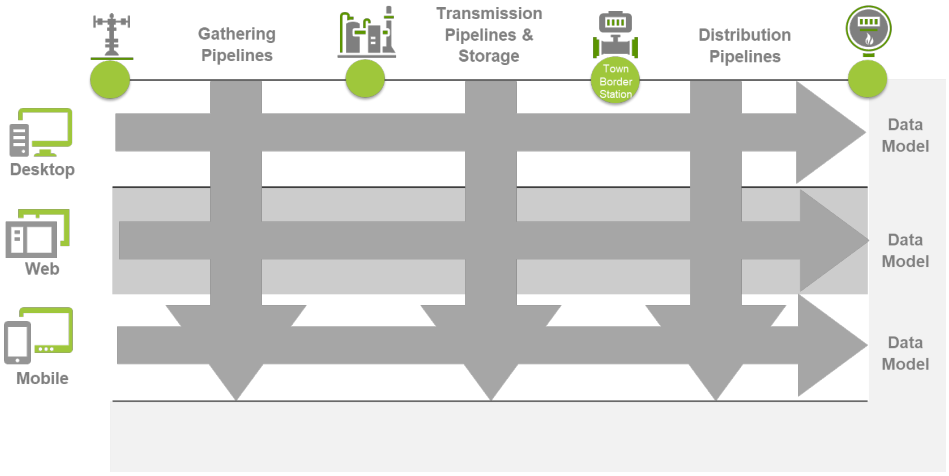


Figure 3—Legacy Gas Network Data Management

Figure 3 illustrates how gas utilities traditionally have multiple GIS instances, data models, and data repositories. This has complicated the efforts of a vertically integrated gas company to run a unified business. One reason for this complexity has been that each industry value chain link network often was managed independently—in a transmission GIS and a distribution GIS. Each of these had its own data model and data repository. In many cases, the boundaries between these were artificial. A question that presented a further challenge was this: how to manage high-pressure distribution mains that are operated as distribution mains? Also, users in the office, in the field, and on the web used disparate systems for accessing information. And each of these systems developed its own data management method for defining location. Some used connectivity modeling, while others used linear referencing.

In these traditional GIS implementations, industry segment-, task-, or department-specific point solutions—which had been implemented in older technologies—didn't lend themselves to easy or efficient integration with other point or enterprise solutions. Consequently, there were data silos and data accessibility limitations. Moreover, their stand-alone nature presented impediments to efficient processes and the ability of colleagues across the enterprise to work effectively together.

There also are other significant factors:

*Data volumes and velocity* are increasing, in some cases substantially. This is due to the rapidly growing number of sensors in the network. For instance, supervisory control and data acquisition (SCADA) systems utilize more advanced technology. Pressure and flow sensors are being placed throughout the network. Field crew locations are streamed as work progresses. Customer meters are capturing and sharing data frequently. In-line inspection runs are yielding extensive data about internal pipe conditions.

*Departmental solutions* are not geared for the enterprise. It is not uncommon for a GIS to be implemented to meet the requirements of a single department. These point

solutions often are not intended to evolve to serve the requirements of other departments or provide other capabilities.

*The large number of narrow-scope solutions* from many vendors being reduced to a smaller number of broader-scope solutions from fewer vendors—to improve efficiency and effectiveness and to reduce the total cost of ownership—is frequently a gas utility management financial priority.

## Defining the Gas Pipe Network

It is essential to gas pipe data management to be able to create and maintain a digital mirror representation of the in-ground real gas pipe network and its surroundings.

This is as critical a responsibility as any other for a gas utility. As a practical matter, once pipe and related components in the trench are covered, the digital mirror representation becomes the gas utility's primary authoritative record of assets in the ground.

Advanced software functionality accesses this single digital mirror representation to address the previously mentioned internal and external challenges. This advanced software functionality must provide

- *Data management* tools to assist editors in accurately and efficiently creating and maintaining the digital representation of the pipe system.
- *Linear referencing* models and tools.
- *Advanced network modeling* to store and maintain an accurate representation of how gas system components are connected.
- *Visualization and embedded analytics* for advanced derivative representations of the connected pipe system and its many subsystems.
- *Pervasive access* that enables all employees and contractors to get the information, regardless of their location.

The ArcGIS platform provides gas utilities with all the above capabilities.

The ArcGIS Utility Network Management extension, the ArcGIS Pipeline Referencing extension, the ArcGIS Pro desktop application, and ArcGIS Enterprise are the core software products of the ArcGIS platform that enable this essential approach to gas pipe data management.

## Extensions Operating on One Geodatabase

Esri's development direction is for the ArcGIS Utility Network Management extension and the ArcGIS Pipeline Referencing extension to operate on the same geodatabase. This reinforces the ability of ArcGIS to work the way vertically integrated gas companies work. This development direction aligns with Esri's vision for vertically integrated GIS.

## Vertically Integrated GIS

Esri's vision for gas utilities—operating an integrated pipe network spanning multiple industry subsystems—includes removing the traditional silos. This creates a singular representation of the entire pipe network that mirrors the real network. It also enables users to work with that digital network just the way they do with the real network. Figure 4 illustrates this vision for vertically integrated GIS.

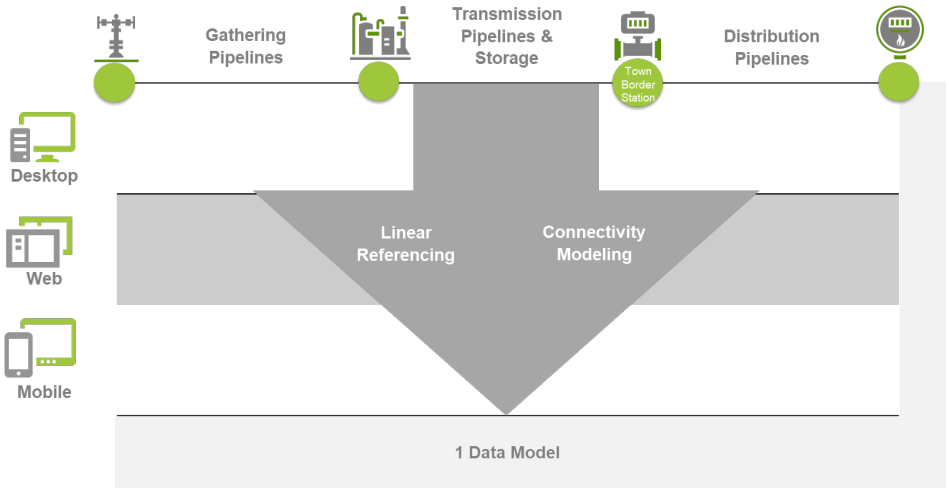


Figure 4—Esri's Vision for GIS in Vertically Integrated Gas Companies

The single representation of the pipe system requires a unique data organization approach to store the entire pipe system—from wellhead to meter—and support the information model requirements of ArcGIS Utility Network Management and Pipeline Referencing. UPDM is the data model template to provide this data organization.

## Utility and Pipeline Data Model

UPDM is Esri's data model for managing essential gas pipe system geospatial data. The goal of using UPDM is to provide a best-practice data model template that makes it easier, quicker, and more cost-effective for gas utilities to implement the ArcGIS platform. UPDM was created and tested with ArcGIS products to ensure that it works.

To ensure that UPDM is addressing the internal and external challenges of gas utilities, Esri collaborates with industry and academic leaders to continually evolve the enterprise geodatabase data model template. Much of the structure and content of this data model is based on Esri users' feedback and lessons learned from the many ArcGIS implementations in the pipeline and gas utility industries. To further simplify the adoption of this data model template, UPDM can be freely downloaded.

UPDM is a moderately normalized data model that explicitly represents each physical component of a gas pipe network, from the wellhead to the customer meter. This representation of the pipe system is detailed. In addition to modeling standard system components such as pipes and valves, UPDM supports representations of the individual components of gas facilities such as regulator and compressor stations, wellheads, and meter settings.

The detailed modeling of UPDM includes the information schemas for ArcGIS Pipeline Referencing and ArcGIS Utility Network Management. UPDM includes gas pipe system-specific modeling of the connectivity rules, subnetwork representations, and network properties.

## ArcGIS Utility Network Management Extension

The release of the ArcGIS Utility Network Management extension provides industry-specific capabilities to define networks by connectivity. These capabilities were designed to assist gas utilities in addressing the internal and external challenges they are facing today.

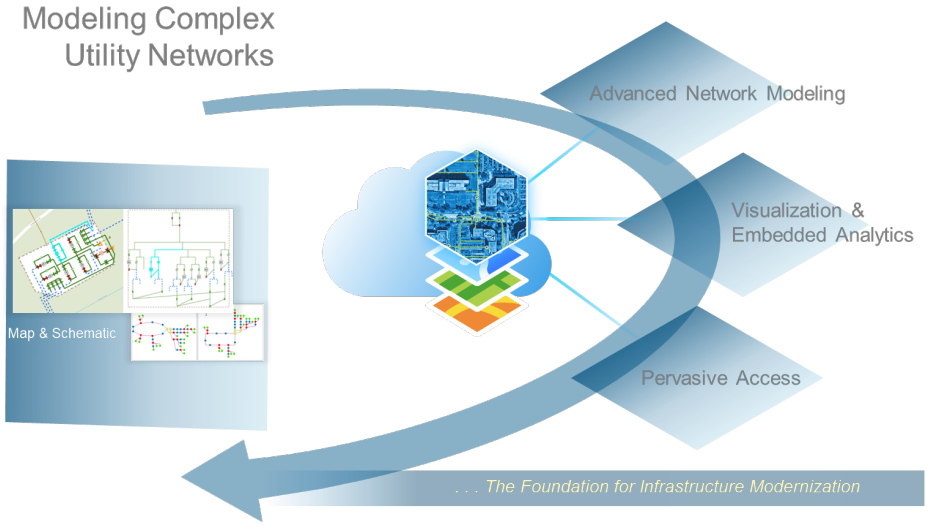


Figure 5—ArcGIS Utility Network Management Extension

As highlighted in figure 5, ArcGIS Utility Network Management provides advanced network modeling, visualization and embedded analytics, and pervasive access. This allows users to share information across the organization—in the office and in the field.

### Advanced Network Modeling

The utility network helps ArcGIS platform users understand how the components of the gas pipe system connect. It is not enough to simply draw a digital representation of an asset on a map, as is commonly done with CAD software—it also needs to be understood that the two polyethylene pipe segments that have been butt fused together are connected.

Previous generations of network modeling applications typically supported one method of determination of a connection. This method was based on the spatial coincidence of a vertex between two assets. This method was very simple for editors of the pipe network to understand, as all they had to do to establish a connection between two assets was to snap the vertex of one feature to a vertex of the other feature. The editor first placed the polyethylene pipe segment. Next, the editor placed the plastic fusion weld feature by snapping it to the end vertex of the pipe segment. Finally, the editor placed the second polyethylene pipe segment and snapped it to the plastic fusion feature.

The real gas pipe system has fittings that are bolted or welded to other fittings. Accurately modeling this point-to-point connection in the digital mirror representation of the gas pipe system requires an enhancement to the traditional methods of defining connectivity. This additional capability is called a connectivity association. The connectivity association allows the two bolted-together fittings to be connected without requiring an intermediate line feature.

## Network Analytics for the Pipe Network

The advanced network modeling provided by the utility network allows network analytics to be performed on the gas pipe system. Network analytics, such as tracing, is used to examine operational events, customer impacts, and forecasts and to assist with engineering and asset management decision support. A gas industry-specific example would be to use the enhanced utility network tracing capabilities to dynamically sum the volume of the pipe system for an isolated section during a gas outage emergency response.

## Tracing

The most frequently used network analytics tool for understanding a gas pipe system is the Trace tool. The utility network Trace tool now can dynamically leverage your digital gas pipe system asset attributes in addition to their location within the connectivity model. This allows an isolation trace to stop at a device whose device status attribute has been set to Closed. Tracing now allows the pipe volume attribute on the pipe segments to be dynamically summed to provide the total pipe volume for all pipe segments selected as part of the trace result. The Trace tool also allows the gas meter consumption data to be summed for all trace-selected meters.

## Visualization

Leveraging the advanced network analytics, the utility network enables new methods of visualizing the gas pipe system. This new visualization helps users understand the gas pipe subsystems such as the system, pressure, and isolation zones and cathodic protection areas. These representations of gas subsystems are called subnetworks.

## Subnetworks

Subnetworks enable gas utilities to visualize their subsystems and maintain summary information about them.

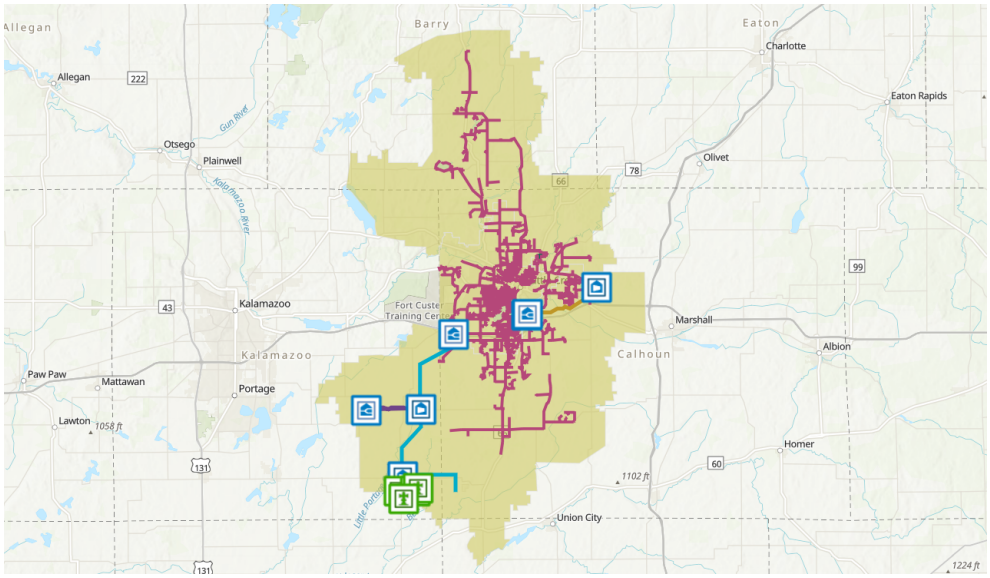


Figure 6—Visualization of System Zones

Figure 6 shows the visualization of system zones in a vertically integrated gas pipe system. The utility network provides the tools that let editors easily create and maintain these subnetwork features. These subnetworks do more than provide the means to visualize gas pipe systems' subsystems. They also include embedded analytics to help users better understand the key characteristics of the gas pipe subsystems.

These embedded analytics provide automated summarization of gas system information. This means that information such as a cathodic protection (CP) area's total metallic pipe surface area can be automatically tabulated whenever the subnetwork feature is updated. The CP department staff can now view a CP area's total metallic pipe surface area to aid in determining the correct amperage to set a rectifier to.

Other embedded analytics—preconfigured into UPDM to let users take advantage of this utility network capability—include the following:

- Total pipe volume for pressure zones
- Total pipe length for system and pressure zones
- Number of valves for an isolation zone
- Number of meters for an isolation zone
- Maximum Allowable Operating Pressure for pressure zones

## Pervasive Access

The underlying architecture of the ArcGIS Utility Network Management extension is web services. This technology allows a singular representation of the gas pipe system to be edited, queried, and analyzed across desktop, mobile, and web applications.

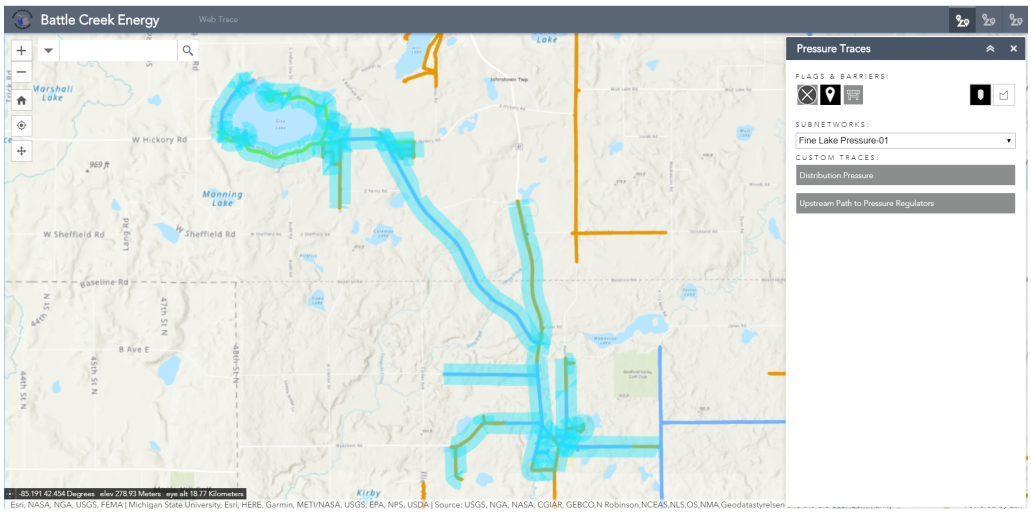


Figure 7—Utility Network Services Powering a Web Application

Figure 7 provides an example of a web application calling the utility network services to perform a pressure trace. This enablement of pervasive access to the single representation of the gas pipe system will help gas utility IT departments address the internal challenge of legacy siloed GIS deployments.

## Detailed Digital Representation

Internal and external challenges are requiring gas utilities to manage a more detailed digital representation of the gas pipe system. These challenges include

- Reducing excavation damage by providing locators with a more detailed representation of the gas pipe system.
- Knowing where those assets were installed, in the event that a supplier of gas system components issues a recall.
- Reducing operational errors by providing staff and contractors with a complete representation of gas facilities.

The ArcGIS Utility Network Management extension provides two core capabilities to assist gas utilities with addressing these challenges:

- Three-dimensional network connectivity
- The use of containers

The first capability is to fully model the connectivity between assets in three-dimensional space. A 3D network connectivity model allows editors to place a meter set atop a vertical riser pipe. A wellhead—with its vertically stacked valves, flanges, tees, and couplings—can be correctly drawn.

The second capability is the use of containers. Containers allow complex gas facilities, such as a meter bank for an apartment building or a compressor station with multiple runs, to be fully modeled in the GIS digital representation of the gas pipe system. Containers let users manage the visualization of a dense amount of information in a very small space.

The addition of these two capabilities reduces the total cost of GIS ownership by consolidating into one system of record what previously was in multiple systems. In a sense, this advance brings GIS closer to being a true digital representation of the real pipe system.

## Rule Base

When constructing the real pipe system, there are many standards and specifications that dictate how construction crews can assemble it. Construction crews are not allowed to place a steel cap on the end of a polyethylene pipe segment. Maintaining a true digital representation of the real pipe system likewise requires the ability to define rules to ensure that it is assembled like the real system was constructed. In this respect, the editor should not be able to snap the steel pipe point feature to the end of the polyethylene distribution pipe segment.

The ArcGIS Utility Network Management extension lets users define the rules that dictate how the pipe system can be assembled. There are five types of rules:

- Junction-Junction Connectivity
- Junction-Edge Connectivity
- Edge-Junction-Edge Connectivity
- Containment
- Structural Attachments

An example of a gas Junction-Edge Connectivity rule would be to allow only metal couplings to connect to metal pipes. A steel coupling would not be allowed to connect to a polyethylene pipe.

Defining all the possible valid connections for a system as diverse and complex as a vertically integrated pipe system is a daunting task. To simplify assembling the rule base specifically for a gas pipe system, Esri has undertaken the effort to define a starting base configuration. This configuration is included in UPDM.

To further simplify the implementation and modification of these rules, the ArcGIS Utility Network Management extension also includes new tools to help administrators.

These tools are written as geoprocessing tools in ArcGIS Pro and can also be referenced in Python scripts. The Python scripting capability simplifies defining these rules in a development environment and reapplying them to the test and production environments.

## Attribute Rules

The application of attribute rules is a geodatabase capability of ArcGIS. These rules provide the ability to enhance the behavior of a feature class attribute within an enterprise geodatabase.

One example of an attribute rule is for the GPSX, GPSY, and GPSZ attributes of a gas fitting to be automatically populated with the geometry's x-, y-, and z-values when a fitting is initially inserted into the enterprise geodatabase. Another example is to constrain the operating pressure of a pipe segment to a specific range based on its engineering system type and material values—for example, AssetGroup = Distribution Pipe, and Material = PE2708; such a pipe segment cannot have an operating pressure greater than 200 psi. If an editor attempts to submit a pipe segment with an operating pressure greater than 200 psi to the geodatabase, the geodatabase will reject the edit.

Attribute rules are unique in that they are not a property of the client application but instead are a property of the enterprise geodatabase. This ensures that any editor, working from any type of application (desktop, web, or mobile), will experience the same automation benefit. The population of attributes reduces the time required for the editor to enter information. A gas industry-specific example is the use of attribute rules to decode the ASTM F2897 bar code data. A field or office user can enter the bar code for a plastic pipe segment, device, or fitting. The attribute rules will automatically be initiated to decode the bar code and autopopulate the manufacturer, date of manufacture, lot number, model, material, diameter, and wall thickness attributes.

Attribute rules improve not only editor productivity but also the data quality by reducing human error, ensuring the consistency of the input information.

## Stamp Templates

Using stamp templates is an ArcGIS Pro capability.

Attribute rules improve editor productivity and quality when attribute information about an asset is entered. What about improving the productivity of defining and placing the geometry portion of the asset? As previously mentioned, a modern gas utility GIS needs to store and manage more assets. In this context, a variety of regulatory and business drivers have pushed the need for a higher-fidelity representation of their assets in the GIS. How can this be done without significantly decreasing the productivity of the users maintaining the GIS representation of the pipe system?

ArcGIS Pro provides capabilities to create multiple feature edit templates to help editors place more features with fewer clicks.

For instance, a basic regulator station with a single bypass can easily be composed of over 20 individual components. With the utility network, this facility can have additional configuration requirements to define subnetwork controllers, terminals, and containers. If each component or utility network configuration were done individually, this would be a daunting task. The edit templates of ArcGIS Pro allow the entire regulator station and its many components to be placed with just one click.

Using these edit templates can be as simple as prepopulating the attributes for a single asset such as a 4-inch steel coupling. They can be composed of multiple features such as a 1-inch plastic service line with an excess flow valve and a meter set. Or the templates can be very complex, such as for a regulator station or a compressor station.

The ArcGIS Pro edit templates provide the editor with the productivity enhancements needed to keep up with the demands for managing the pipe system with increasing detail.

## ArcGIS Pipeline Referencing Extension

Pipeline Referencing is an extension of ArcGIS Pro and ArcGIS Enterprise This extension enables industry-specific functionality to manage and locate specific points and parts on or around pipe networks.

The extension uses linear referencing to define a location along the pipe system. Linear referencing is a method of associating attribute and event locations to existing linear features, such as a pipeline, from a defined starting point.

The location model in the Pipeline Referencing extension is established by the sequence of measures along a section of the pipe network, defined as a route. These measurements can be a continuous network, which is a sequence of strictly increasing or decreasing measures along an unbroken, nonbranching run of physical pipe. Or the measurements can be a more complex engineering network. An engineering network can be composed of multiple routes logically grouped in lines that can increase or decrease in measure as they are traversed. Equation points are used at locations where one route ends and another route starts.

Both types of location-referenced networks establish the foundation for building a network model that provides data—known as events—for integrity management applications, regulatory reporting, and other business needs.

Management of the routes is performed through an ArcGIS Pro ribbon, shown in figure 8. This enables the creation, realignment, reassignment, retirement, and extension of routes using a context-based toolbar. It also enables the editing of calibration points and centerlines.


Figure 8—The Pipeline Referencing Toolbar

Point and linear event data editing is performed in an HTML5-enabled web browser. This allows owners of specific event layers of data to manage their own content, without inadvertently also being able to edit the event layers managed by others.

Pipeline Referencing allows users to automate route geometry and event alignment through rule-based location management. You can define how event measures and route associations should react to changes or edits. You can arrange to preserve event position (x,y coordinates) and allow m-values to change, preserve event location (measure values) and allow x,y values to change, or preserve both historical position and location prior to the effective date of the route edit.

Often, the vast amounts of information that a pipeline operator deals with are diverse and distributed throughout the organization in multiple, disparate systems, each with its own linear referencing system (LRS). Pipeline Referencing makes it possible for pipeline operators to integrate data that's from multiple LRS networks and maintained with multiple measurement systems, to get a single, comprehensive view of their pipeline.

Pipeline Referencing also provides dynamic segmentation functionality. Dynamic segmentation is the process of computing the map locations of linearly referenced data (for example, event attributes stored in a table) on demand so they can be displayed on a map, queried, and analyzed using a GIS. The dynamic segmentation process enables multiple sets of attributes to be associated with any portion of a line feature without segmenting the underlying feature. A dynamic segmentation example is shown in figure 9.

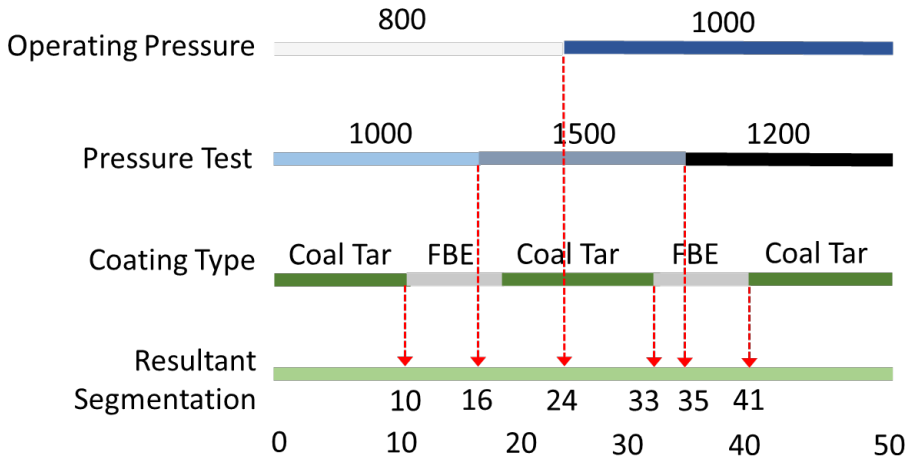


Figure 9—Dynamic Segmentation

## Conclusion

Many gas utilities are searching for a better way to achieve their business objectives as they chart a path forward in a time of increasing regulatory and market change. This is driving them to reimagine how they conduct their business and to modernize the key enabling technology systems needed for them to do so.

Among the key enablers of change is GIS. Esri is the global market leader in GIS. Since 1969, Esri has helped customers unlock the full potential of data to improve operational and business results. Esri engineers the most advanced solutions for digital transformation, the Internet of Things, and location analytics to create the data and maps that run the world—including gas utilities.

Esri continues to improve its technology and develop solutions that are specifically designed for gas utilities. ArcGIS offers the most powerful mapping and spatial analytics technology available. Today, network management in ArcGIS continues those efforts by offering strategic capabilities to facilitate network modernization. ArcGIS does this while helping to contain data-related costs and add customer value. Esri provides a standard gas utility model that can be extended to meet a utility's unique needs.

Esri® ArcGIS provides essential data management for gas utilities through ArcGIS Utility Network Management and Pipeline Referencing. These extensions are part of the ArcGIS platform and leverage its fundamental capabilities to assemble and store data with location intelligence, allowing users to analyze and share information conveniently with all stakeholders. Esri offers many training and professional development opportunities to help users learn how to apply this technology.

Esri gives customers several options to receive assistance in implementing utility networks. Esri's Jumpstart packages assist with data preparation, software installation, and configuration to launch utility networks in support of daily tasks and workflows. For a more comprehensive approach, the Esri Enterprise Advantage Program provides a flexible framework of services, training, and premium support to help any organization reach its full GIS vision. Finally, the Esri Partner Network is a

rich ecosystem of organizations that work together to build on, extend, and help implement the ArcGIS platform including the ArcGIS Utility Network Management extension and the ArcGIS Pipeline Referencing extension.

ArcGIS Utility Network Management and Pipeline Referencing model gas pipe networks in greater detail with higher performance and improved scalability, and these extensions underpin network modernization activities. Esri's network management capabilities in ArcGIS help utilities tackle many of the business challenges they face as they reimagine themselves.

*This document is an overview of the capabilities of the ArcGIS Utility Network Management extension and the ArcGIS Pipeline Referencing extension, their impact to network management within ArcGIS, and their value for gas utilities. It is not intended to be a complete or technical description of the extensions' functionality.*

## About the Authors

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**Tom DeWitte** is technical lead—natural gas industry, on Esri's utilities and telecommunications team. DeWitte joined Esri in 1998, having worked for seven years at the US Army Corps of Engineers. He earned his BS in aerospace engineering from Iowa State University.

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