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Volumetric Pipeline Environment Analysis: A Methodology for Creating 3D Data Suitable for Pipeline Environment Risk and Mitigation Products

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Abstract

Pipeline risk assessment GIS is constantly seeking to improve the tools and methodologies of data analysis to incorporate more world details. The need for complex 3D systems modeling is expanding as GIS takes a main stage in mapping the infrastructure and environment of medium scale, vertically complex, pipeline systems. Pipeline environments must be specially tailored to suit the data analysis capabilities of ERSI ArcGIS 10. Model based automation facilitates the conversion of data types and preparation of analysis results. The methodology presented is one avenue of possible development in generating a greater level of detail in intricate medium scale pipeline systems.

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Abstract

Pipeline risk assessment GIS is constantly seeking to improve the tools and methodologies of data analysis to incorporate more world details. The need for complex 3D systems modeling is expanding as GIS takes a main stage in mapping the infrastructure and environment of medium scale, vertically complex, pipeline systems. Pipeline environments must be specially tailored to suit the data analysis capabilities of ERSI ArcGIS 10. Model based automation facilitates the conversion of data types and preparation of analysis results. The methodology presented is one avenue of possible development in generating a greater level of detail in intricate medium scale pipeline systems.

Introduction

This capstone outlines the processes and methods of discovery in creating a toolset to enable the analysis of complex 3D spatial pipeline environments associated with the fuel pipeline industry. The ESRI ArcGIS 10 suite of tools provided the GIS platform for this methodology. The purpose of this paper is to provide a methodology and automated toolset for exploiting one of the byproducts of accurate facility models. The ability to assign pipe environment with respect to its 3D location is central to current mapping and analysis. Traditional methods of pipeline environment analysis fail to take into account the vertical component of feature locations and because of this a 2D cross sectional representation is generated. In the context of pipeline systems which reside on pumping stations, power plants or storage facilities, the 3D position of a pipeline has a pronounced effect on the environment that pipeline encounters. A pipe may begin in a building then move through soil before transferring to the open air and it may go over or under features which other pipelines go through such as casings or duct banks. The pipeline environment varies widely for any pipe in these complicated facilities. In order to process these pipelines efficiently for risk assessment and mitigation work it is important to accurately assign pipeline environments for any point along a length of pipeline. "As GIS becomes more prevalent among an increasingly diverse and rapidly growing set of users, there is an increasing demand for more sophisticated approaches to data management" (Curtin et al. 2007, 41).

GIS is a useful tool in the energy production and storage industry as a way to visualize and model complex world locations and data. A typical location comprises of a pipeline, tanks, buildings and any number of structural features which are involved in the movement of substances from one location to another. Pipeline condition and environment information derived from ultrasonic or visual inspection coupled with client records on size, type and thickness, provides layers of data regarding the overall state of a line. "As data is accessed and queried patterns begin to emerge. The more information you have, the better. It provides a more accurate picture for managers who are faced with prioritizing their replacement needs" (Anonymous 2008, 18). There is a growing drive to investigate aging piping systems in order to assess their condition and plan for remediation in order to ensure the continued safe production of these systems. This engineering push has fueled the assimilation of GIS as a means of organizing the many structural variables associated with the energy infrastructure into geospatial map products. Products which are made to emphasize variables of concern to energy infrastructure operators such as pipeline environment and condition. GIS is used to take inventory of and analyze pipeline infrastructure to provide a spatial context for the variety of data gathered and generated which are areas of interest for maintenance considerations. This data is easily displayed and queried in a GIS enabling quicker assessments to be made of large quantities of data. With the growing usefulness of 3D GIS and the ability to quickly model and/or import 3D models to represent features and problems along pipelines, often times GIS is done equally for the benefit of the pipeline operator as much as for the engineers. To the trained eye the tabular data regarding a pipeline is sufficient to see what the problems are and produce that information in a report. Conveying location in words is difficult because the spatial context of the information is relegated to an ID, pipeline name and distance. For a few locations this may be fine, but as a project grows the data can become difficult to manage. GIS produces a map which displays all that data in a manner which is easier to interpret. A client can navigate around the GIS to pinpoint different areas of concern. A GIS can quickly convey complex information to the user and enable them to rapidly glean relevant data from an elaborate set of variables.

A byproduct of creating a complex model of a pipeline system is the ability to run a variety of queries and analysis of the spatial relationships of the 3D features. The models produced by GIS technicians today are in many cases as close to a digital reproduction of a real world site as data can allow. In the case of gas, nuclear or oil facilities, pipeline and structural details are fairly critical components which are constructed to the best levels of accuracy provided by site drawings (yard, isometric, PID) and site data collection (GPS, photographs, surveys). This detail is critical to linear referencing operations which are used to locate various elements of a pipeline pathway in terms of distance from start of a pipeline. Direction of stationing is usually in the direction of product flow and pipelines are oriented in the direction they flow. Infrastructure and natural elements such as water, soil and air are constructed to support the underlying real world detail relevant to pipeline systems. These world details are often used simply to pretty up a map, but they can be used for more complex operations as elements which affect the condition of pipeine systems.

Some of the most exciting elements of GIS are the potential to develop methodologies for maximizing the effectiveness of modeling world systems as accurately as possible, and to make those processes simple and repeatable. "The goal of a true enterprise GIS is not simply to provide a common place to store data. A GIS also needs to provide front-end tools to assist its users in completing essential activities" (ESRI 2003, 14). As the map scale for pipelines transitions from regional scale to facility scale, a push for tools which can handle the increased complexity of 3D data arises. "Pipeline data is relatively simple (such as centerlines and values), but the surrounding data that determines its location can be more complex (such as digital elevation and proximity analysis criteria" (ESRI 2004, 6). A process to provide 3D context to piping systems routed through a facility would drastically reduce the need for a user to quality check automatic operations which are only 2D context aware in the ESRI ArcGIS 10 standard. Current processes fail with pipelines in a complex 3D environment. Multiple levels of pipeline traversing over, under and through various manmade structures are not processed in a way which observes the 3D characteristics and false overlaps occur, indicating pipelines in environments in which they are not involved and diminishing the direct usefulness of the process.

Tools exist to analyze 3D lines but the process to successfully use these tools in complex scenes is not defined and this functionality lacks direct software support in the current software standard. Though the 2D capabilities of ArcGIS 10 are quite complete there lacks a concise process and toolset to accurately analyze pipeline environments in a 3D world effectively. Useful information is ignored in the current 2D environment stationing tools, artificially crossing pipelines with features in a planar representation devoid of depth. Without this variable pipelines intersect features that they should be going over or under. Fixing this requires user time and skill to individually remove improperly located data. On a power plant site there are dozens of piping systems crossing dozens of environments totaling sometimes tens of miles in length. The task of identifying all the incorrect results can be extremely time consuming for even the most experienced data modelers. The construction of a process and toolset to tackle this problem enables a more accurate computer model to be used in place of tedious man hours and aids the industry in analyzing an aging energy infrastructure for defects or likely areas of concern. A process and toolset to accept polygon and vector input resulting in an accurate volumetric analysis platform is a logical next step in GIS modeling.

The methodology of the process evolved around the abilities of linear referencing to place data along a line feature (pipeline) based on an intersection. It was initially unknown whether or not data could be constructed in a way which would facilitate the tools available in ArcGIS 10 in accurately placing intersections of geographic features on a line. Primary testing yielded many interesting and frustrating results as the software did what could be expected but did not do what was required. Testing has been a process of creating a 3D dimensional world model which is functionally sound in terms of producing expected results when analyzed using the 3D linear referencing toolset. Automation of this process into a series of simple steps allows for multiple sites to be processed in an efficient manner with less concern for user error.

A difficulty in this project is that it is a very narrow push for specific functionality in a small portion of the pipeline maintenance industry. Research directly related to GIS volumetric pipeline analysis is sparse as the majority of work deals with lines on a regional scale. As the scale of pipeline projects grows the need for more specialized handling of complex geometry becomes evident. Rethinking the way data is constructed to represent the increasingly detailed scope of pipeline maintenance is central in pushing the capabilities of the technology. With new methodologies data modeling can take on new roles which have not been cost effective or practical in the past.

Literature/Industry review

GIS has been a growing presence in the mapping and maintenance of pipeline systems for the past two decades. Enabling companies to store, display, dispatch, query and maintain their inventories with greater speed and accuracy than was available with the older techniques (ie. paper records) (Sanders 2007). The falling costs of the hardware and software required to do GIS have enabled the industry to truly embrace the technology where in times past potential GIS users would have held off due to cost. (Romps 2006, 16)

As early as the 1990s GIS was recognized for its potential in pipeline mapping and government guidelines were drafted to cope with the eventual conversion of paper archives to digital databases. In the 1997 Government Guidelines Brief it was estimated that the cost for converting 302,000 miles of paper pipeline in current usage to digital archives would run at least 60 million dollars if not more, and that operators would one day pay the piper in terms of having to relent to the digital conversion trend and pay for old archives to be handled and converted to fit into the digital storage methods under development and in use (Barlass 1997, 8). By the early 2000s GIS was developing in the public sector to aid in efficient resource management of the infrastructure serving society. "The Boulder, Colorado public works department is using GPS and GIS to locate and map water and sanitary sewer lines throughout the city. The $470,000 project will allow the department to provide excavators with the exact location of existing utility lines in the public right of way" (Anonymous 2002). Incorporating the digital map into operations saves money by expediting the decision making process. Utilizing GIS, pipeline data can be managed in a highly accurate spatial database which is quickly queried and easily changed to represent current data. "The GIS format provides managers with a platform by which they can more easily evaluate pipeline assets" and "The ability to visualize pipeline features has proven to be a powerful tool for decision-makers—saving valuable time and resources" (Clemonds 2007, 8). GIS has grown in acceptance as the technologies to implement large scale have matured to fill the role of detailed data storage, analysis and display.

The energy industry and related engineering companies are willing to embrace GIS technology as a reliable and affordable way to handle the large quantities of complex data which describe the pipeline systems found in energy distribution facilities quickly and effectively (Anonymous 2000, 56). "Over the past couple of decades, GIS technology has grown in acceptance and has become a highly desirable tool in the operation of pipeline systems and networks across the U.S. and most of parts of the world"(Sanders 2007, 1). Part of the impetus for change is that the aging infrastructure is hastening the demand for digital conversion to promote current and future repairs. As data pours in on pipeline systems which may be in excess of 100 years old no better tool exists than GIS for keeping it organized and ready to be analyzed.

Most pipeline systems are handled with a linear referencing system, which assign pipeline features to that line based on a distance along the pipeline. Linear referencing refers to relying on the digital representation of a line, be it a road, delivery route or pipe for the location information on the whereabouts of any particular feature or features along that line. By aligning features to a distance along a line, data can avoid the problem of being independently referenced using a spatial referencing system such as WGS84. This avoids confusion by simply stating that X feature is at Y distance along Z line. One of the most commonly known and used linear referencing systems is the mile marker system on highways which clearly defines locations as distances from known starting points (Curtin 2007). Increasingly GPS is the standard method for bringing location information to digital lines as it is quick and accurate.

The principles of linear referencing are rooted in the larger field of network analysis which is tied to the mathematical disciplines of graph theory and topology. "Graph theoretic description of networks can range from simple statements of the number of features in the network to more complex descriptions based on structural characteristics of networks" (Curtin 2007, 103). GIS based networks can be used to represent any sort of real world network, from the internet to the electrical and fluid systems running beneath a power plant. Facility pipeline GIS centers around complex pipeline networks with multiple connections and spatial relationship occurring along each length of pipe. Maintaining spatial accuracy of line features in these locations is extremely difficult with geographic referencing systems. To deal with this, pipeline features are referenced linearly based on line name and line length, "Network GIS is the only sub-discipline within GIScience (outside of pure geodesy) that has developed a method for redefining the spatial reference system on which locations are specified" (Curtin 2007, 103).

Linear referencing has been a defined aspect of GIS since its refinement as a digital spatial computation in the mid to late 1990s when multiple efforts were made to ensure that the techniques would adhere to the most stringent of quality standards set forth by the industry. "One of the key aspects of any location referencing system is its ability to support the accuracy requirements of users" (Vonderhoe 1998, 48). The development of computational models for GIS allowed for comprehensive analysis which was not possible before such as assigning environmental considerations to transcontinental pipeline map products. Current linear referencing systems are highly accurate and built into most GIS platforms as standard equipment. Thanks to the mathematical expressions for linear referencing in GIS, academic and industrial uses began showing the fruits of the newly available tool in mapping long stretches of pipeline into modern digital inventories. Pipeline analysis typically has involved 2D environment analysis as it suits most purposes and is generally accurate enough for large scale planning as, "Gas companies are obliged to keep their pipelines and facilities in correct and sound condition according to governmental safety regulations" (Pache 2009, 35).

Higher resolution and detail oriented modeling seems to be somewhat outside the realm of what pipeline industry has done with GIS to date. Focus on transmission lines and long distance risk assessment dominates the research. Pipelines all over the world are digitized and analyzed for their spatial properties in order to assess the risk, integrity and cost of ensuring the continued operation and maintenance of energy conduits (Anonymous 2011). A similar battle is waged at the smaller scale ensuring the continued operation of the facilities involved in energy transport and storage. But the use of GIS is just beginning to be merged with the engineering and field work which goes into a comprehensive modern risk assessment of pipeline facilities. It is a continuing battle to maintain the viability of the energy infrastructure in the face of an aging and diverse inventory and GIS will have a front row seat to ensure those needs are met (Anonymous 1998).

Pipeline environmental risk analysis is perfectly suited to the technology of linear referencing. Pipelines encounter a variety of environments at all scales and accurately locating these risks or changes in environment is key to maintaining that pipeline efficiently as it provides the decision makers a more detailed model to work with. "Due to the widespread and dangerous impacts of the possible occurrence of any pipeline accident, it is essential to identify all the risks and potential hazards" (Jafari 2011, 947). GIS is becoming the backbone of pipeline environment analysis and risk management, and is often standard practice in industry planning, ensuring proper care is taken to mitigate any potential hazards to the integrity of the line. "Recently, risk analysis has already been extensively applied in safety science, environmental science, economics, sociology, etc. It aims at finding out the potential accidents, analysis on the causes as well as the improvements to reduce the risk" (Jafari 2011, 947). It is the continued goal and drive of risk analysis to be equipped with better models and tools from which to base those assessments.

"GIS allows energy companies to view information in advanced geographical maps, providing a more holistic and graphical view of infrastructure and assets" (Petrecca 2010, 8). Communicating the results of otherwise difficult to understand data becomes an intuitive representation that non-GIS users can grasp. "Humans are masters of abstraction. Data modelers extend the process of abstraction, reducing complex real world entities to rows of data in a database. GIS data modelers take abstraction even further, reducing complex real world features to attributed points, lines and polygons on a digital map. For GIS data modelers, the famous Korzibski quote ("the map is not the territory.") rings especially true." (Thorliefson 2011, 51) The ability to create abstractions of the world is constantly pushing the edges of what is possible as we seek to model with ever finer resolve, the systems we mean to understand. Pipeline GIS is a modeled system based on a tangible piece of hardware out in the field. For the purposes of analysis these models are laden with as many variables as can be collected. "We expect this data model to be around for a while. And we expect vendors to continue to enhance the solutions they provide" (West 2005, 32). These highly accurate spatial databases should be analyzed in new and interesting ways as the computer hardware and software make geospatial analysis faster, more accurate and accessible to anyone.

Typical GIS applications in the industry exist at the regional scale, demonstrating the use of sectioned pipeline running some hundreds or thousands of miles over changing local conditions. An equally important yet little talked about aspect of the major pipeline system is the complex network of pumping stations, tank farms, compressors and tangled web of pipelines which make up the core of the energy storage and distribution system. These smaller scale yet structurally more complex systems often have highly diverse local piping conditions and are in similar need of adequate analysis models at an appropriate scale and accuracy level. Many operators are taking inventory of their aging infrastructure and engineering firms are involved in the data acquisition and analysis process. The data derived from the field coupled with GIS users bring site models into the software for analysis and display so that the safety and functionality of this infrastructure can be more intelligently managed (Anonymous 2008).

Design

The process of finding a method to analyze 3D piping began with exploratory prodding into the way ArcGIS 10 worked in order to judge if it had the necessary capabilities. Research in the 3D Analyst extension revealed a reasonable set of 3D linear referencing tools and it was determined that those toolsets seemed to allow for 3D analysis. Using the tools and achieving a meaningful result, however, are two separate things. The problem was that those tools really did not work with standard data such as extruded polygons and instead used a datatype called multipatch. Multipatch data is nothing more complicated than a 3D polygon which natively handles its own volumetric characteristics. Unlike a polygon which has been extruded to fill space using the properties of a feature class, multipatch is stored as the complete volumetric structure it is meant to represent and is ready-made to have its characteristics analyzed as a 3D model of a real world element. An individual volume, such as a building, soil or airspace can be identified using the Intersect 3D line with Multipatch (see Figure 1.1) function which is a kind of linear referencing for Multipatch features. The output from running this tool on pipelines is a point Z feature class which has data at the entrance and exit points from pipelines which transect the space as well as lines which represent the lengths of involved in any given change of pipeline context. Generating accurate volumetric results required developing a specific process in order to achieve acceptable data which could be used as a possible replacement in future pipeline environment analysis.

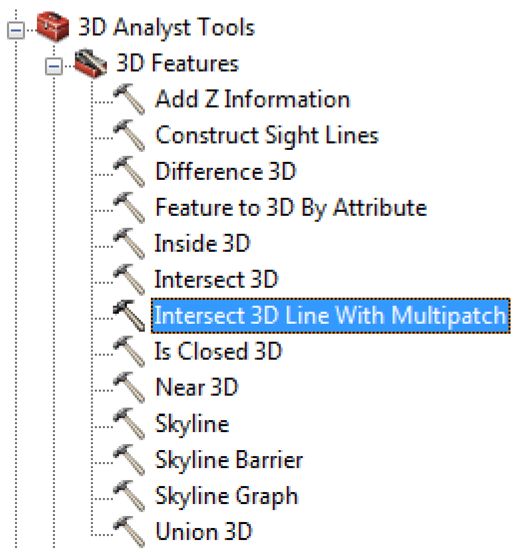


Figure 1.1: 3D Linear referencing tool

Once the correct datatype was determined it was found that the data did not work properly in analysis unless it was processed in a way which allowed the tools to work effectively. Several times in development the processes yielded unexpected results. These puzzling results were the impetus which led to modifications of the methods involved in producing a viable dataset which could be used for more detailed analysis. Viability was determined through linear referencing and user verification, checking that the model produced an appropriate pipe environment layer consistent with the path of the pipeline through space.

Several approaches were attempted before settling on and refining the process described in this paper. The initial testing involved a sample pipeline system in a simple single volume space. (see Figure 1.2) It was expected that the tool would produce a point feature at the interface between null space and the feature class. Points were produced at every interface. Line features were created but some lines were ignored altogether by this process, leaving behind lines which did not have a depth to the features they crossed. If a line went across a boundary between null space and a known space is simply switched on indicating that the environment changed.

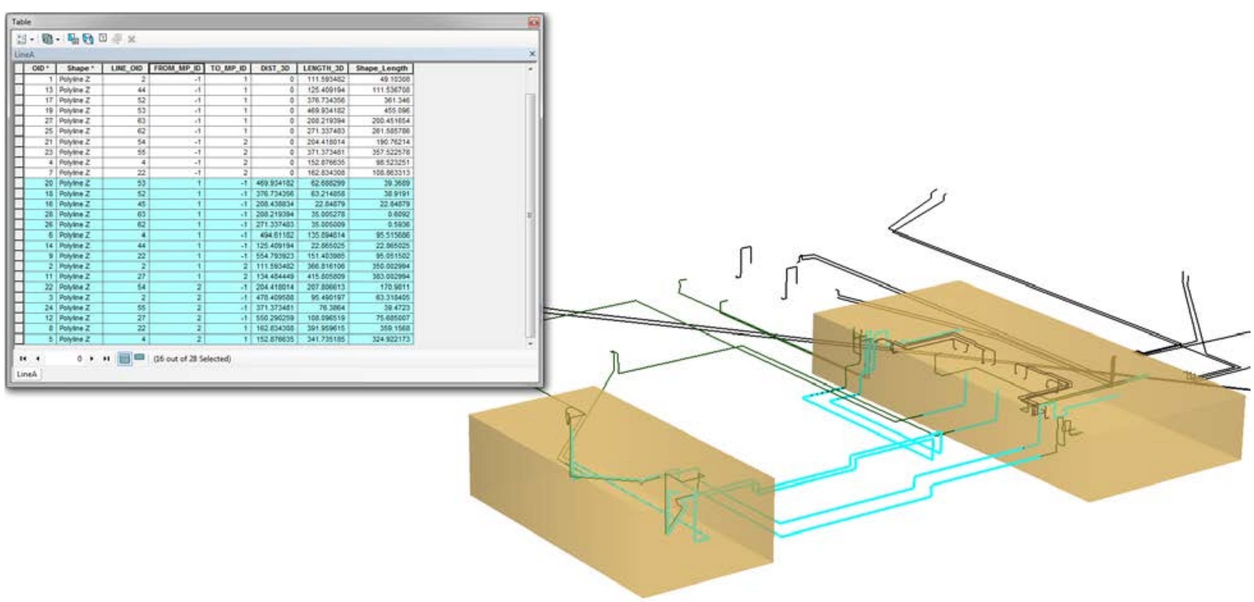


Figure 1.2: Intersect data unclear and missing information, to/from information is difficult to distinguish

Pipeline direction also plays a role in determining which portion of a pipe registers as being in a structure when a pipe goes from one building to another across empty space. This result suggests that ArcGIS works very well at defining a relationship between volumes based on line features, but fails to register a shape beyond its edge, leaving lines in null space with no useable environment information. The, from/to, linear referencing result is interesting because it provides a frame for more data. If the from/to parameters are defined with enough detail meaningful information can be generated about exactly where a pipe enters and exits a volume which is the core of 3D pipe environment data.

The next idea was to layer the results from all the data run in sequence, and then remove redundant or null data. It was thought that a result could be derived for each volume then merged together in an amalgamation of all the referenced volumes performed one at a time. Once the data is merged, any data returning a null value for the volume type is deleted from the result, creating a new line feature which covered all aspects of the pipe environment. However this process still fails to produce a record for a pipeline not crossing a polygon boundary, leaving some pipelines which begin and end within a structure or soil type out of the linear referencing results. It was found that the linear referencing tool only recognizes changes in volume type. Running each volume separately produces a fragmented result where the pipeline environment is incomplete and often incorrectly defined. It appears through multiple trials of various features that the inaccuracy is due to a lack of reference points for the referencing tool to assign to the lines as they run through space. With no real useable data layers derived from this method, new data setup options required experimentation. A more complicated model became the next logical choice as it seemed that the lack of sufficient environment information was the biggest roadblock. The linear referencing tool needed some basic level of real world continuity in order to apply enough data points to a line to create a map of the space with any accuracy.

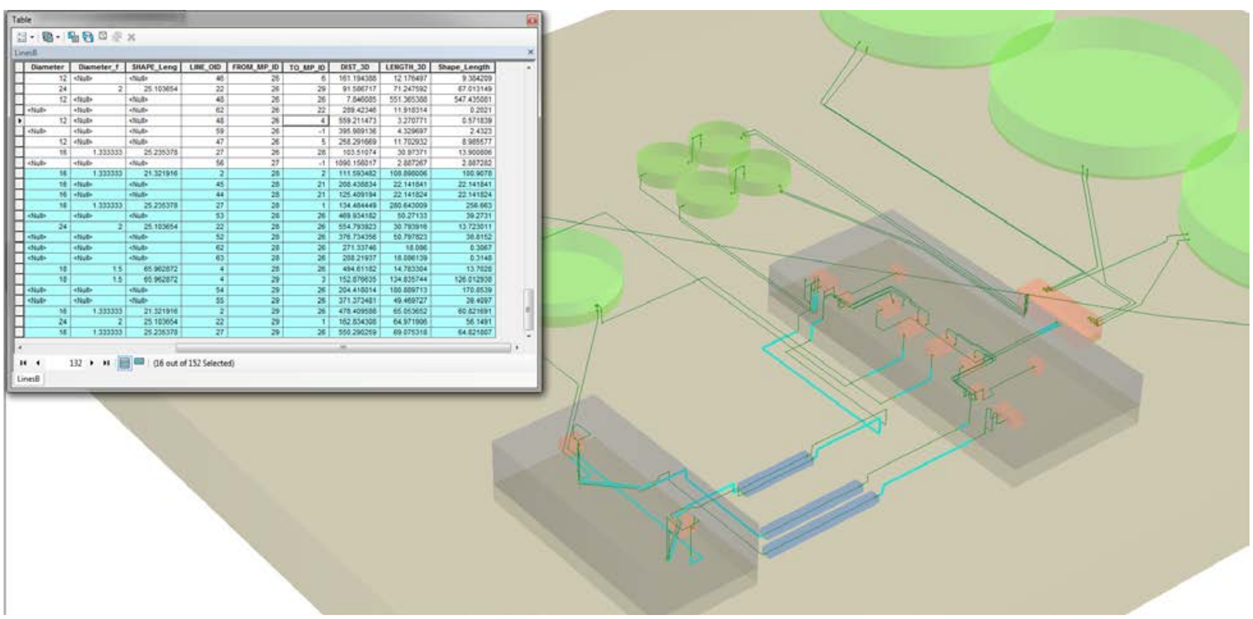


Figure 1.3: Here selecting the features which should be in a building yields incorrect segments as "in building"

Merging the multipatch feature classes (see Figure 1.3) into a single feature class was the next objective and the resulting feature class formed a composite of all feature classes. Using the linear referencing tool again resulted in much better definition in the data but the overlapping volumes produced some erratic results. Point features were now incomplete. There should have been two points for each point location, one for the volume exited and one for the volume entering, instead one or the other was generated. Line features were chaotic having from/to attributes which caused the lines to protrude beyond the environment represented, the either/or selection going on with the point features was having a bad effect on the, to/from, information of the line features. It appeared that the overlapping volumes were causing confusion as to which feature was related to what space. Removing the conflict by subtracting the smaller volumes from the large volumes added to the spatial accuracy of the process, by ensuring one feature to a given space. The difference 3D tool was used to clip the volumes from the background, leaving space behind for the features to occupy, without having the volumes actually overlap in at all. (See Figure 1.4 and 1.5)

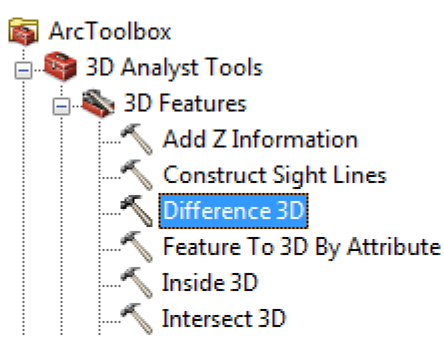


Figure 1.4: Difference 3D tool (volume subtraction)

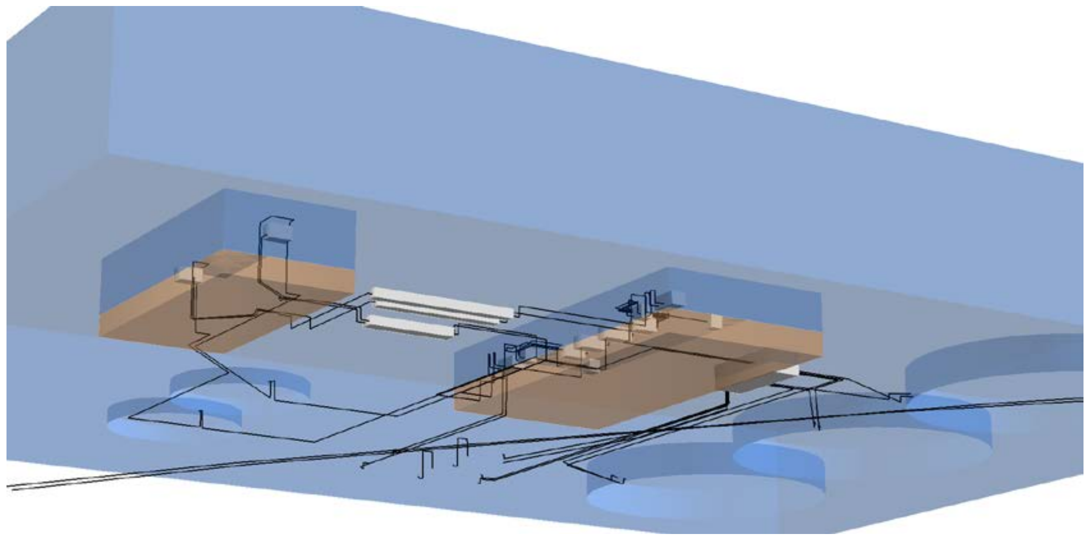


Figure 1.5: Example of the clipped air space multipatch with Features nesting in gaps, tanks are off in this image

Multiple levels of foreground-background relationships exist in complex scenes and features best can be thought of as nesting in one another. A tank can be abstracted as a complete volume which is unique from the geospatial context around it. All buildings and manmade features are thought of as foreground features in the world canvas. In order to make room, foreground layers were subtracted from the background layers they occupied to remove overlapping space. Proper ordering involves clipping the structures, tanks, etc. from the soil and air layers first, then running a pass on the second set of foreground layers, such as subtracting out any small features which overlap spaces like buildings. When completed, every multipatch feature has a space left over within the larger structure where it fits in. These layers were merged into one feature class as before and the line analysis was run again. This process generated clearer delineation than the previous attempts created, though still not always correct. Features often were in the right place but point and line data seemed to be missing or off in placement in some locations. Points were missing from the interfaces between volumes. As a line went from soil to building for instance, it would have a point for either soil or building but not typically both. The output line features began looking much more complete; all pipelines were transferring to the output but the environment information was not always correct. (see Figure 1.6) The line features going into a feature were correctly assigned an environment, while those leaving a feature were assigned the environment they were going into, not the one they just left.

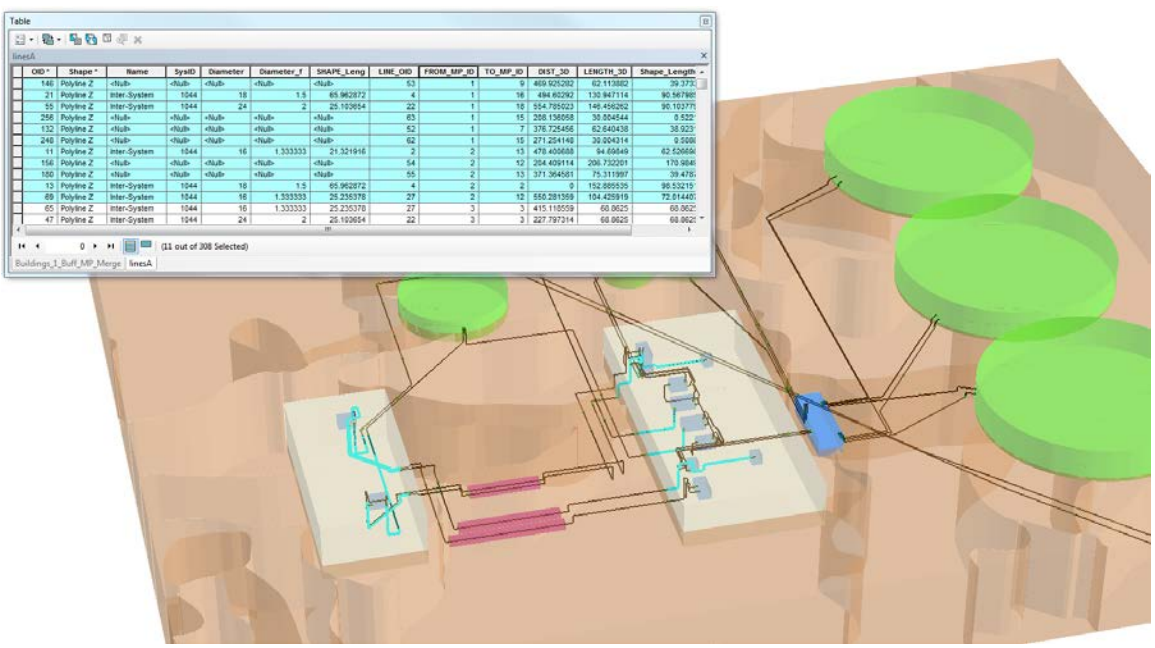


Figure 1.6: Selecting the pipelines in a building with this data set yields some correct data but it is incomplete

This causes some lines to not register in the environment they are in but rather the one they go to next. This sort of either/or reporting by the software led to the hypothesis that placing two points at the exact x,y,z coordinate was enough to confuse the computer, yielding a result which identified one environment based on the direction the line is going. To eliminate the overlapping edges of volumes buffered features were utilized to clip out a space slightly larger than the space occupied by the unbuffered features. This buffered approach created the desired effect and was incorporated into the final methodology.

Methods

Complicated multipatch scenes are the core of pipeline modeling. They are not ready to be used for data analysis without first cleaning up the space, clipping unwanted intersections and overlaps in the data. This makes way for only a single feature to occupy any one space. The early testing revealed that intersecting volumes are inappropriate for analysis as they do not work properly with the linear referencing operations. Volumes can only occupy their own space, which may not infringe upon the neighboring volume's extents. To this end, buffered volumes which are typically less than 1cm larger on all sides are subtracted from the relative background layer, creating spaces which fully envelop a volume in its own region of space. When recombined into one feature class each volume is spatially isolated from its neighbor, eliminating the possibility that any one point contains more than one possible data value for environment type.

This process of leaving spaces slightly larger than the object occupying it provided the required accuracy in accounting for all the transitions between environments. The gaps between data report a null value which provides a line with the necessary context to define which volume it occupies at any given location. Since the null space is not considered by the linear referencing operation null values act as a signpost to indicate that a pipeline has exited one volume type and entered a new one. A line crossing from one volume to null space into another volume registers this interface as two points, a from point and a to point. The associated line feature between those volumes is identified with null space and the volume it goes into.

A nested design was found to be the most effective method of data compilation as it made for simple analysis to be run on complex piping systems rather straight forward. The clipped layers are combined into a single multipatch feature class. The single attributed environment layer can then be used to analyze various piping systems together or separately depending on the needs of the project or analysis at hand. (see Figure 2.1)

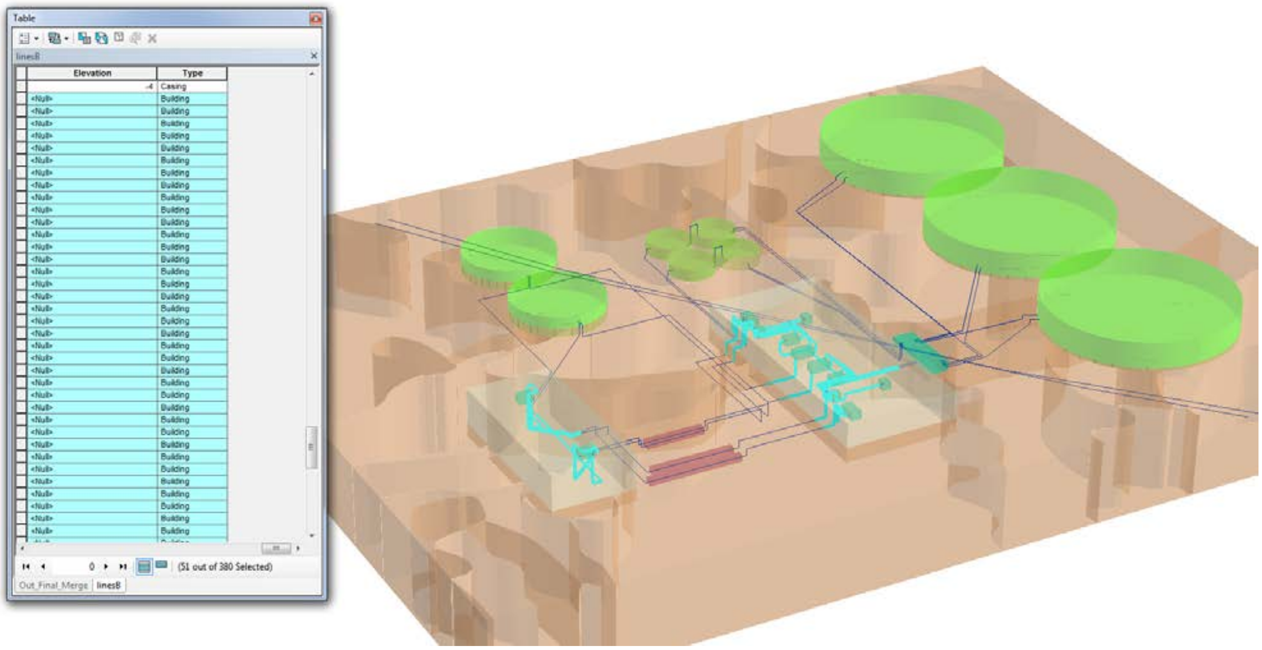


Figure 2.1: Finished model, showing selection of pipelines indicated as being within a building, correct result

Implementation

The steps to creating a viable volumetric analysis model are conceptually important to understand in order to ensure that automation is carried out appropriately. Without a firm grasp of the manual processes it is nearly impossible to automate and automation is a central goal of this process. The layers required to create a 3D volume are going to vary from site to site depending on the information available but the major types are ground type, buildings, structures, pipelines, tanks, casings, water, and air. Each layer presents unique variables which must be taken into account. All layers need to be constructed in a way which represents their 3D characteristics accurately. All buildings, tanks, casings, should contain base elevation and height data. The soil layer should have a depth which covers all underground piping systems. The air layer should have a base elevation ~1 cm above the ground elevation and should extend high enough to cover all structures.

The goal of creating suitable layers for volumetric analysis begins with buffers. ArcGIS has a problem with understanding complicated three dimensional space in that if faces of two different multipatch volumes are coincident, the software randomly picks one of those volumes to be the new pipe environment. This is not correct as there should be an accounting of each change from one volume type to another. For instance when a pipeline transfers from a soil environment to an air environment there should be an indication where the soil stops and the air begins. In order to solve this problem buffering is used to create ~1cm gapping in 3D between each volume in the model.

All layers are now ready to be rendered in 3D using the elevation and height values stored in the feature tables. These models are just temporary and get converted to multipatch features. Once in multipatch format the data is ready to be edited into the correct layout. At this point we have a set of overlapping multipatch features; this is not desired as multiple volumes do not generally intersect one another. The process of deleting space from the volumes in order to neatly nest the site in the soil and air it occupies is crucial to accurate analysis. The operation is a Boolean difference tool which looks at two volumes and subtracts the space of one from another, allowing one model to fit neatly inside another without having the problem of dual identity space. This is where the buffer process comes into play, using the buffered structure polygons a space is created slightly larger than is needed for the actual structural polygon. This approach conformed to the requirement that there must be gapping between multipatch elements for the software to properly register environment changes.

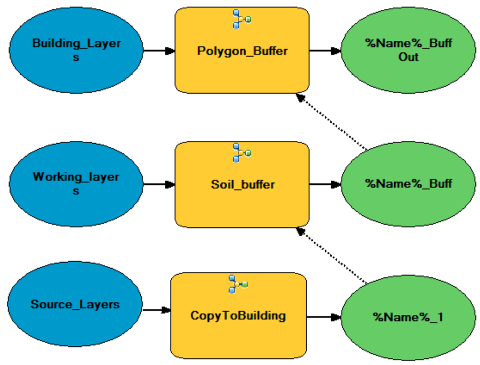
The order of operation for this process seems to work best acting from the largest geographic feature to smallest, subtracting the next smaller feature from the bigger as needed. Soil and air are the largest polygons buildings, tanks, casings, and any other major exterior structure should be clipped using the buffered layer of that feature. The original extent multipatch features are then merged with the clipped and buffered air and soil polygons into one feature class with represents all of the volumes which occupy the facility area. This model is suitable for the intersect line 3D with multipatch tool.

The data created with the intersect line 3D with multipatch tool, is nearly complete on creation. Point interfaces can be seen and queried to find all instances where a line enters or exits a volume. There is never a case where a line would have two null values for [from]/[to] data. A line always goes from null to known to known to null. The left over dangling null ~1cm lines are well within accuracy considerations and can be converted on and either/or basis as they make little difference in real world applications. To clean up the results the line features have all of the null values found in the [from] and [to] fields converted to equal the values found in the corresponding column. This means all null features in the [from] column receive their value from the [to] column and vice versa. This result is in the direction of greater accuracy in pipeline environment analysis but the process is cumbersome and slow to process by hand.

Automation Design

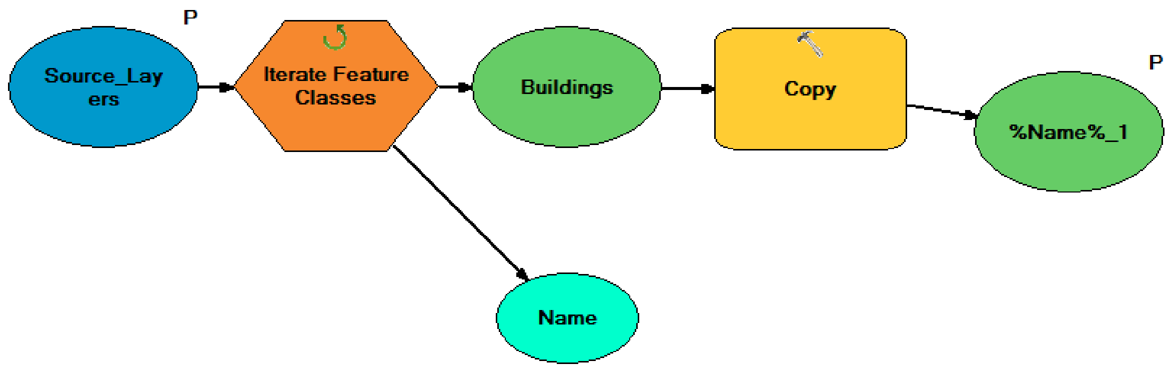
Assuming data is set up correctly the following is a series of tools which a run to produce features class representing all attributable volumes within a pipeline domain. The tools rely heavily on the multivalue iterative processing of the Modelbuilder toolset and the entire process has been grouped into two major tools that are run with one break between for user data processing. The major tools are each comprised of several lesser tools which preform sub operations unique to each stage and operation.

The first tool run by the user contains three separate automated functions. (see Model 1.1) This type of tool acts as a director, running specialized models in the appropriate sequence with the appropriate variables to produce a final output. This saves the user running three separate models with individual options and settings and can be configured to operate with new perameters as needed.

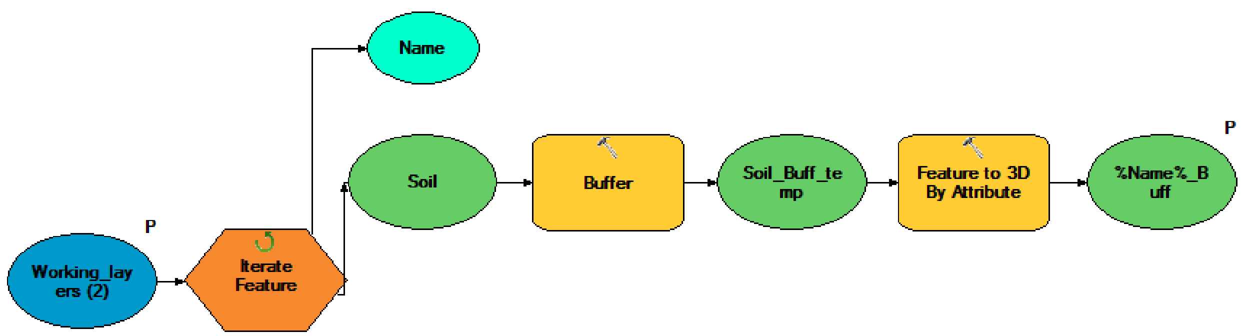


Model 1.1: Data Setup and Processing

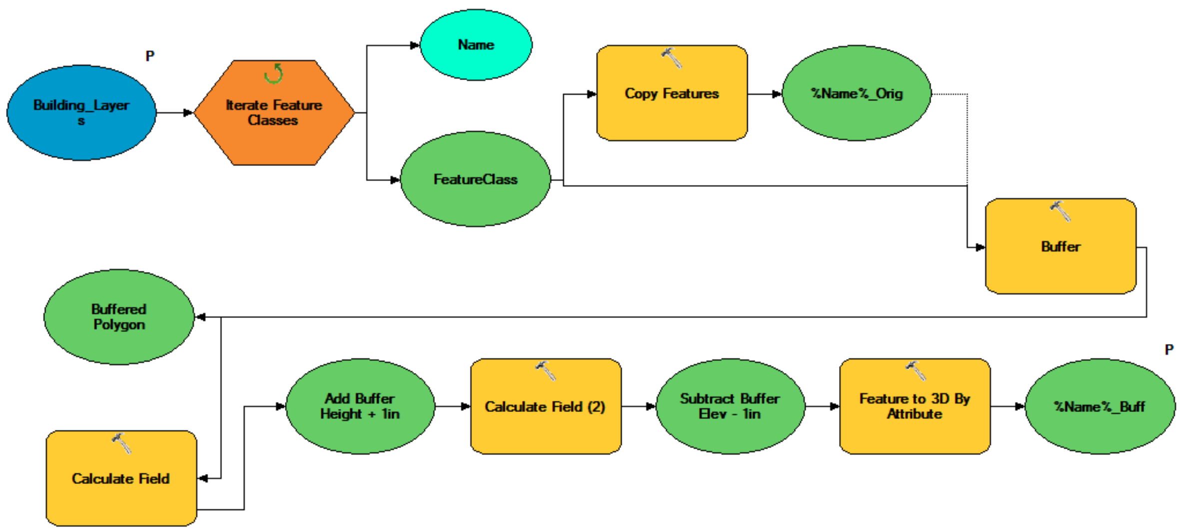
The first part of this tool (see Model 1.2) runs a data copy operation, moving each source feature class to a working folder and renaming for future processing. It does this using a dataset iterator which goes though all feature classes in a specified feature dataset, in this case source layers, and executes the same operation. Naming is handled using the wildcard output value which is updated for each iteration of the tool. The second and third parts buffer and prepare the soil and building layers for processing, generating new layers and placing them in a working folder. (see Model 1.3 and 1.4) The soil tool is setup to handle multiple soil layers though only one is used at this time. The building tool handles all man made polygon features and can accept any type of polygon data as long as it is constructed in accordance with the required elements of height and elevation.



Model 1.2: Copies features into working layers and renames as needed



Model 1.3: Buffers Soil, calculates fields moves to working layer



Model 1.4: Buffer and calculate new extents for all structure polygons move to working layer

In order for the multipatch conversion to to work, feature classes need to be displayed in 3D prior to running the second automated process. Adding all features from the Working folder in the project folder to the TOC (Table of Contents) and extruding based on the [Height] field is required of the user. This displays all features in 3D and sets the stage for the final sequence. (see Figure 3.1) Unfortunately there is no way to automate this step without higher level programing available in the ArcObjects API (appplication interface).

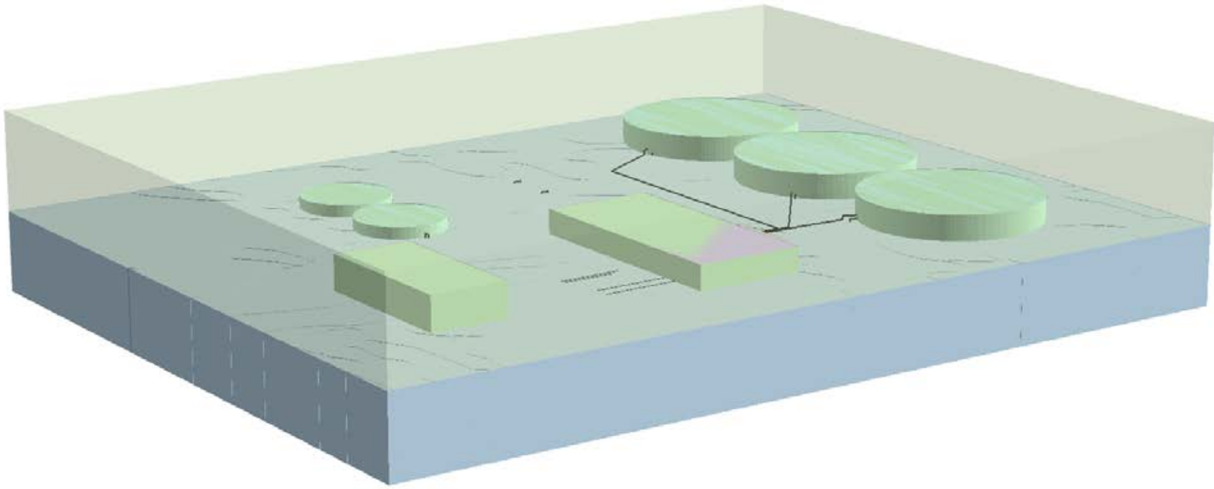
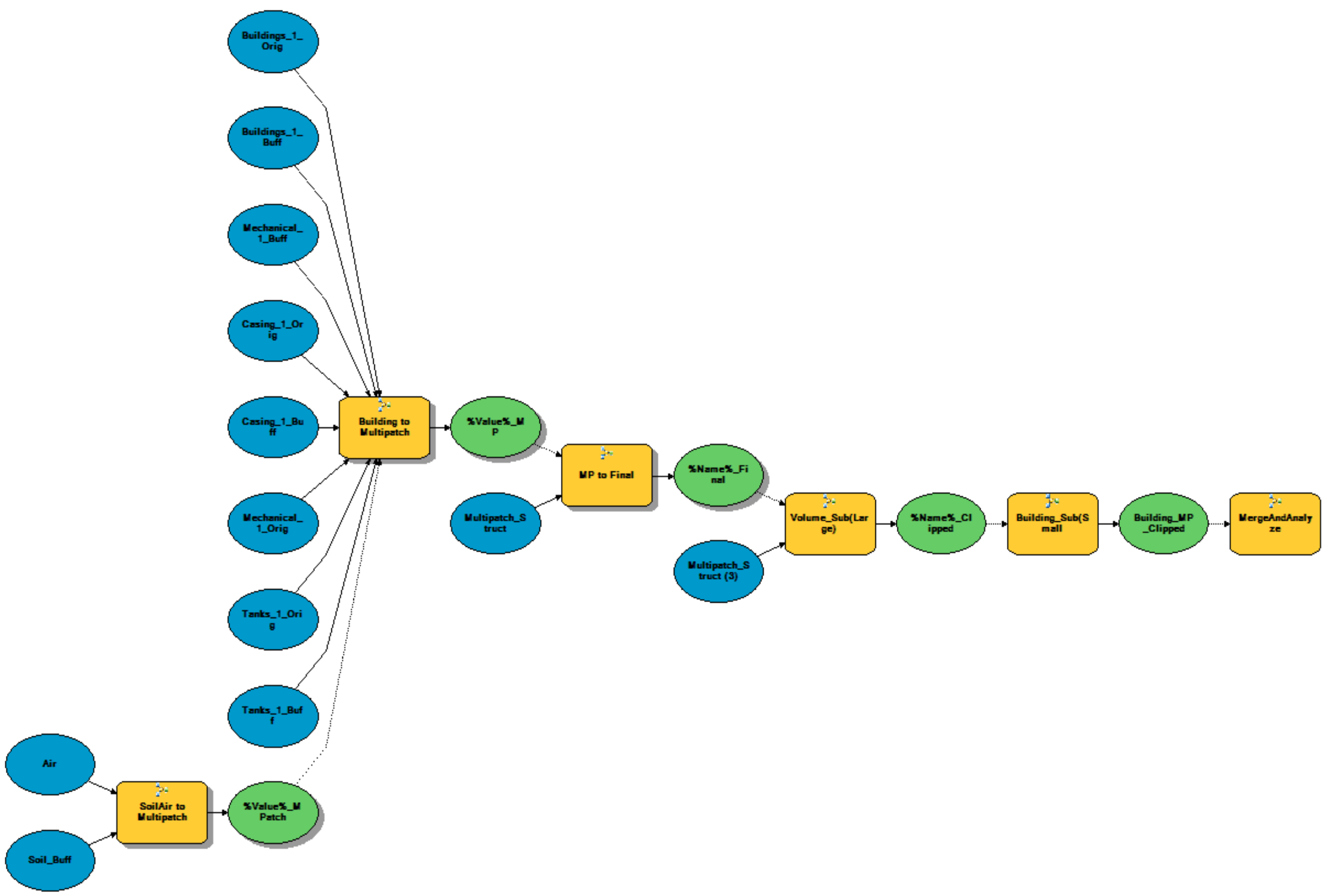


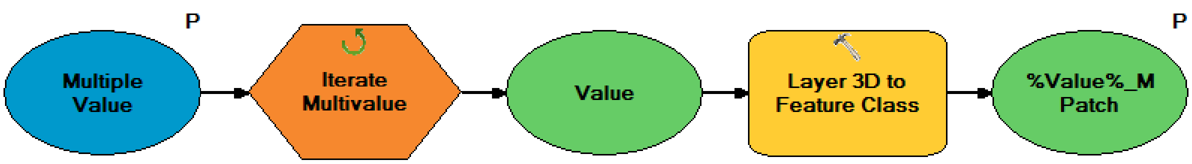
Figure 3.1: All features from working folder added and extruded to [Height] values



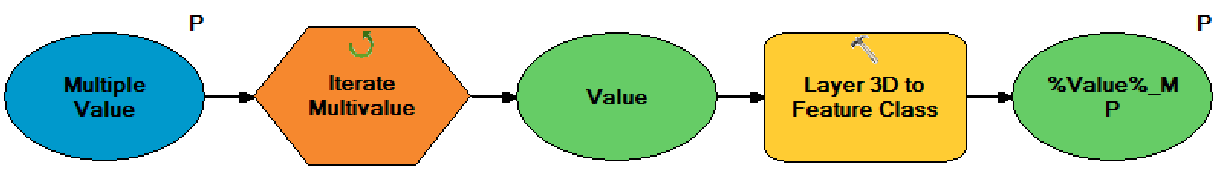
Model 2.1: Runs the following series of models to generate and run analysis on multipatch scenes

The second automated process is similar to the first in that it runs multiple smaller tools to generate the required results in the appropriate sequence so that subsequent tools have the data they need to function. This process is comprised of 6 tools. (see Model 2.1)

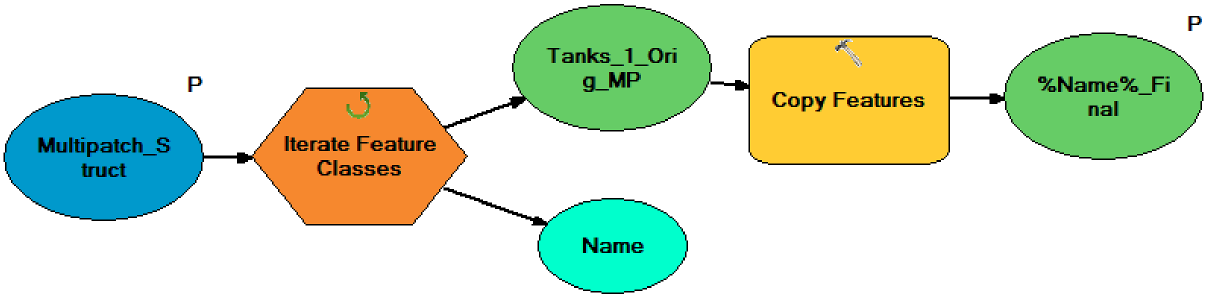
The first two iterators convert extruded polygons to multipatch features and place the data in the multipatch folder. Soil and air layers get a different suffix than the structural layers which is used later in the recombination process. (see Models 2.2 and 2.3) The third step copies the unbuffered multipatch structural features to the multipatch folder where they await final processing. (see Model 2.4)



Model 2.2 Converts Soil and Air polygons to multipatch

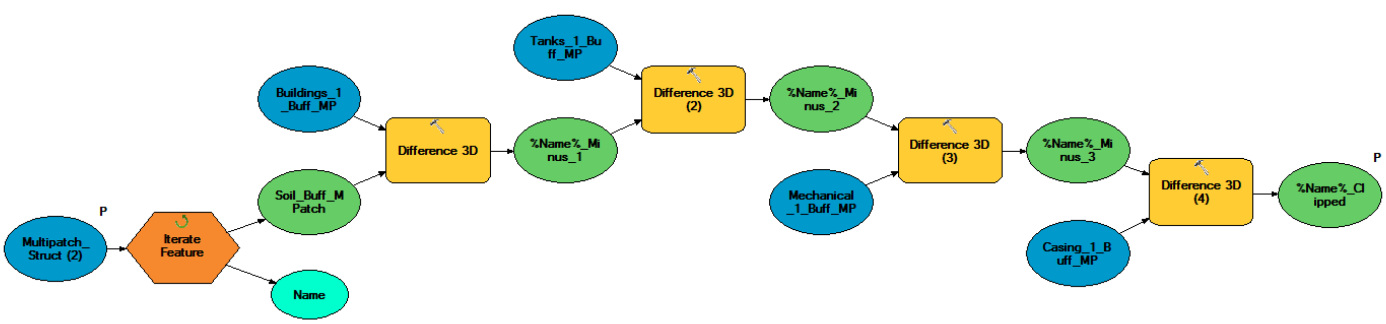


Model 2.3: Converts structures to multipatch

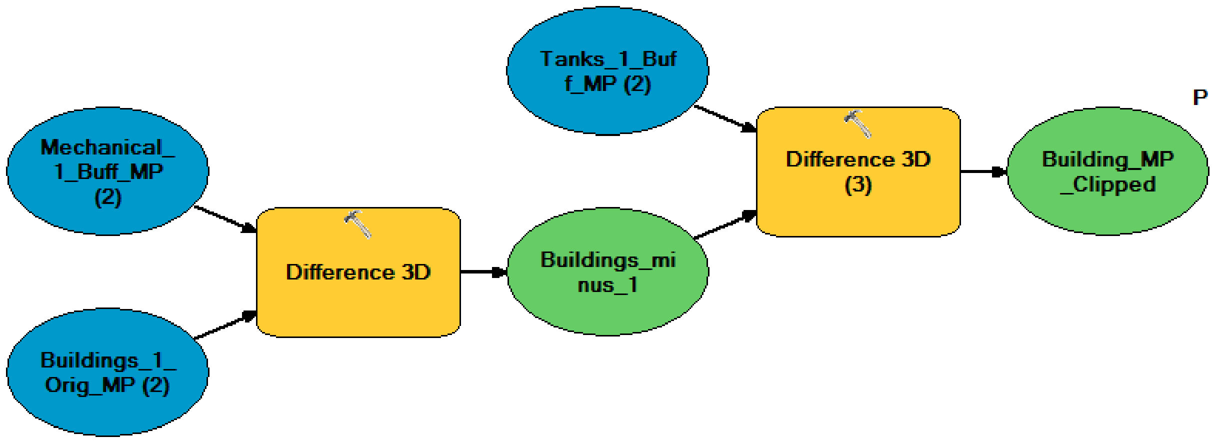


Model 2.4: Moves unbuffered multipatch layers to final working directory

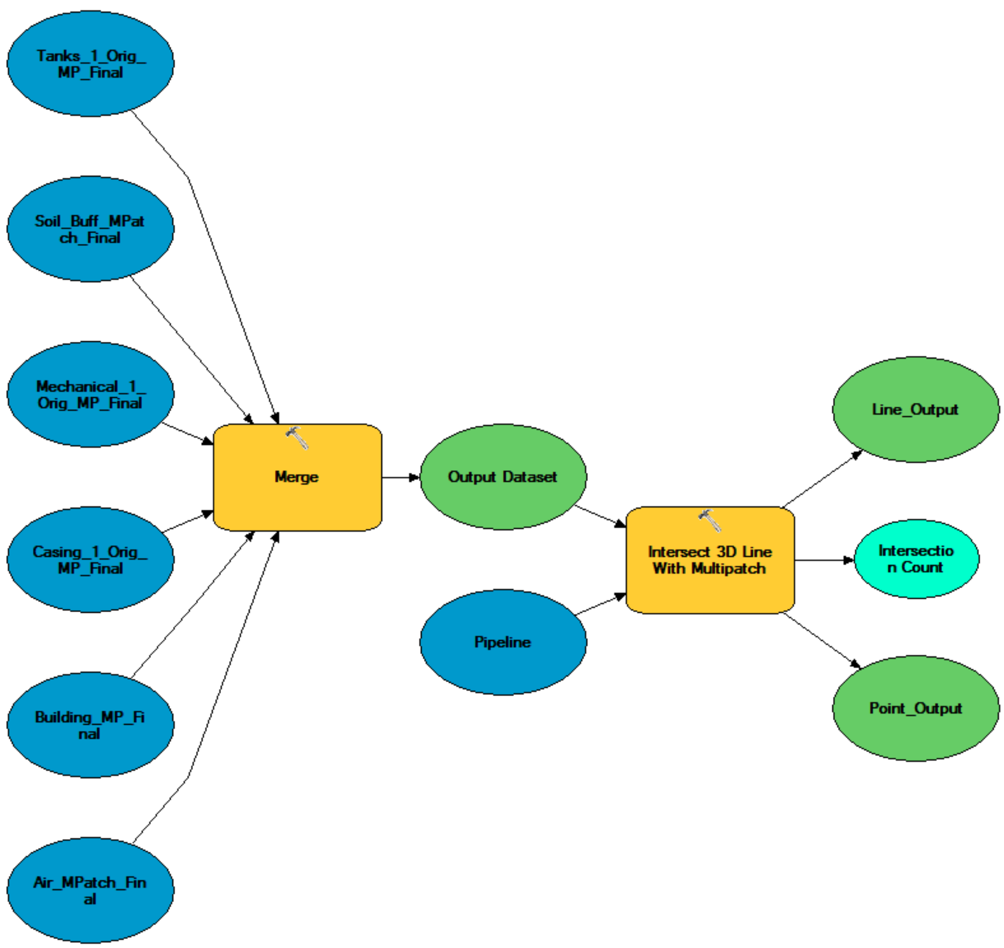
The next two models handle the subtraction of the buffered features from the background layers. These tools are easily chained together to allow any number of features to be subtracted in whatever order they need to be. The first of these iteratively processes the soil and air layers, clipping out every feature from those spaces. The next processes the buildings layer in a similar way. (see Model 2.5 and 2.6) The last model in the sequence recombines the multipatch features into a single multipatch feature class. Then runs the intersect 3D line with multipatch tool generating the point and line pipeline environment data. (see Model 2.7)



Model 2.5: Subtracts buffered structures from the background soil and air layers



M odel 2.6: Subtracts overlapping layers from buildings



M odel 2.7: Com bining m ultipatch features together and generating pipeline environm ent results.

Results

Through various process revisions it became possible to produce a useful pipeline environment dataset by utilizing a nested feature approach. The technique of creating gaps around all features provided the necessary marker points to effectively locate and place point and line data in reference to changes in pipeline environment. With a more detailed representation of changes in volume type, environment delineation became rather straight forward and a simple manner of running a tool and calculating some fields. Analysis produces clean line and point data which define volumes clearly though little manipulation to the final output data.

The results obtained from this method are viable at accurately measuring the distances to, and placing markers on, changes in pipe environment with respect to 3D space. The output layers describe the volume that particular length of pipeline belongs to, identifying the location of environmental variations. The point and line features generated are useful in data modeling as they provide accurate distance values for the environments the pipeline encounters. These lengths and distances provide the context for a pipeline location which can be used to assist in planning measures which take into consideration a pipeline location. When assessing the likelihood of failure or areas of concern for any given segment of pipeline, the type of environment it resides in often drastically alters the risk factors assigned to that section.

Further research

This is a proof of concept methodology, using a simulated site as the basis for testing. While the site model was created with features common to a typical site, nothing can replace the variability of an actual facility. Future research in this area will focus on testing multiple real world sites with this process, refining the tools and methods for everyday use and sharpening the detail of relevant features. Incorporating real world locations into the data setup and automation processes should refine the data assimilation and conversion process considerably as new possibilities for spatial interactions are considered. It is believed that the level of detail for environment analysis is just beginning to be explored and that this project is just beginning to dive into the 3D model detail which may be possible. Complex multilayered models incorporating multiple levels of soil information including such things as cathodic protection data, chemistry and soil type could be incorporated to deepen the perspective captured by the GIS. Also more realistically defined structures to include features such as interior airspace, interior concrete, walls and floors could be constructed. With a greater complexity in model design come more demanding procedures for clipping and combining the data in order to cope with the growing depth of information and the current practical limit for model detail is unknown.

Automation is an area which succeeded in many ways by eliminating tedium which a user would encounter running this iterative process by hand.

There are still gaps in the cycle and contingencies the automated models are not equipped to deal with. Modelbuilder has some capacity for increased automation though selection statements such as For/While operations of traditional programming languages. These might be of use in handling a variety of data more effectively. Reworking the current automation tools with new considerations is possible, to a point, but then Modelbuilder lacks the software hooks to affect more complex processes. A step up in capability would be python integration which could more easily handle the variety of real world data through defining operations based on meeting various checks custom designed to fit the process. It would be possible to create a piece of software designed to look through an appropriately formatted database to pick out which features are present and handle them accordingly with little to no user interaction beyond setting up the data and running the python program. The highest potential for application development lies with the ArcObjects library of classes and methods. Using something like C# (C Sharp), a programming language which is supported by ArcObjects, a tool could be made to perform all of the functions required to import, process and export the complete dataset.

It would be ideal to incorporate the processes into a tool which could process larger more complex datasets through a checklist menu system which verifies with the trained user that the appropriate data is in place.

“Customizing the project menus will allow non-GIS specialists to utilize the basic tools of the risk management system” (Filho et al. 2010, 640). The user could then initiate the process, do QC, and generate final results without being bothered to reconfigure the automation or change source data. A fully programmed application that handles the entire operation on its own may be a bit down the road, but the potential exists to allow it to happen.

Conclusion

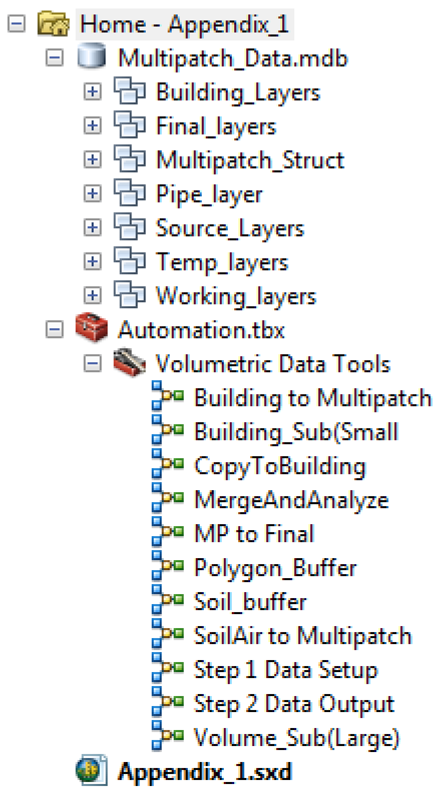
GIS involvement in pipeline maintenance and mitigation continues to develop new methods and technologies to include ever increasing levels of detail in digital models. The increasing detail allows for a greater depth of analysis to occur and provides clearer context from which corrective actions can be planned. Increasing the efficiency of data extraction through novel processes and automation is a core element of why GIS involvement in the energy infrastructure maintenance industry continues to grow. This paper demonstrated one avenue of utilizing geospatial data to derive practical application.

The growing need for GIS in handling pipeline environment on the smaller scale has facilitated the development of a tool which allows for precise environment results to be derived. Overall this capstone project was successful at generating a methodology and toolset capable of converting standard data types into meaningful 3D context aware data. Appropriate environment data was derived and a measure of automation was achieved for a reasonable portion of the work. User involvement in data preparation and analysis has been simplified to a large extent, allowing the user to focus time and energy in other areas beyond the tedious repetitive processes associated with multiple files and processes.

The core of the functionality comes down to the final model of the pipeline facility which contains sufficient detail and spatial separation to allow the available linear referencing tools to operate unimpeded. Through proper initial data setup, this model is constructed by automated tools which take the input pipeline environment data, rework it to handle 3D complexity and export results. Development of this process is in the early stages-testing on idealized models and limited project scope. The results, however, are promising, indicating that more complex models can be generated to accommodate the geospatial variety found in practice. The methodology of creating a complete scene with discrete multipatch features for each environment variable proves a viable technique for extracting a greater level of detail from geospatial data. As the masters of abstraction delve deeper into the realm of digital modeling, our understanding and communication of the variables affecting our livelihood become clearer.

Appendix

Included with this paper is a Zip file titled Appendix which contains the following geodata and tools.



- The **Multipatch_Data.mdb** contains all intermediate data layers generated in the process.
- The **Automation.tbx** contains all of the tools which were created to support the processing of the data.
- The **Appendix.sxd** contains a scene ready to be explored which contains the data in several stages from input through final pipe environment products. Symbology is set to emphasize the changes in pipeline environment.

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