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Original Research Article

STANDARD GEOSPATIAL DATA MODEL FOR WATER AND WASTEWATER INFRASTRUCTURE RISK ASSESSMENT

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Abstract:

Geospatial pipeline attribute data is required for the enhanced risk assessment of buried water pipeline infrastructure. Toward this end, a GIS can provide water utilities a means for viewing, understanding, interpreting, and visualizing complex geographically referenced pipeline information to reveal data relationships, patterns, and trends. Yet, no standard data model exists for utilities to follow in order to enable advanced risk assessment modeling. The primary objectives of this research were to develop a standard GIS data model to conflate disparate datasets from differing utilities, and further demonstrate its usefulness through developing risk assessment applications using the standardized data from participating utilities and publicly available data, such as that from the USGS. Field mapping files were generated from the standard data model and demonstrated in a Google Earth application using a risk score for the pipeline, and further a web-based mapping application using ArcGIS Server Manager for publishing, querying and the visualization of aggregated data in a map-based browser application. The aggregation of standardized data and further use in mapping applications will help in providing timely access to asset management information and resources that will lead to enhanced risk modeling for drinking water and wastewater utilities.

Keywords: Risk Management, Water Pipeline, Wastewater Pipeline, Web-based, Geospatial

Introduction

The condition of buried drinking water and wastewater pipeline infrastructure in the U.S. continues to worsen, with the potential to have increasingly harmful societal and environmental consequences. The American Society of Civil Engineers (ASCE) gave the nation’s water infrastructure a “D” rating in its most recent report card, citing such ailments as 240,000 water main breaks occurring yearly, and over 700 cities and towns being adversely affected by combined sewer systems prone to overflow events (ASCE 2013)[1]. This equates to billions of

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dollars needed to rehabilitate or replace ailing pipelines to maintain current levels of service (USEPA, 2008[2]; USEPA, 2010[3]). The United States Environmental Protection Agency (USEPA) has sought to remedy these problems by directing utilities to implement advanced methods for the operations and management of public drinking water and wastewater systems. As a result, water utilities must improve the efficiency with which their systems are operated and maintained, and particularly seek to understand the risk of failure of their buried pipelines. Utility managers are actively working to develop Geospatial Information Systems (GIS)to digitally map and efficiently store pipeline attribute data in a singular, centralized database, that they may have rich, valid data to support enhanced pipeline asset management and risk modeling. GIS have proven very useful in the storage and refinement of vital utility asset data (Halfawy and Figueroa, 2006)[4]. Further, asset management supported by a GIS helps to standardize data and allows for interoperability amongst departments, and enables utility personnel to track and share asset information operations in an effective manner. Incorporating GIS into the condition assessment and renewal (defined as the rehabilitation, repair, or replacement by the USEPA) decision making process for utilities provides previously unseen insights that affect which approach is chosen and the outcome obtained (Baird, 2011)[5]. Data exploration through visualization is an effective means to perceive and obtain insights from large collections of data (Koop, et al. 2008)[6].

However, there is no common standard GIS data model for water or wastewater systems buried infrastructure being used nationwide, hence each utility has developed its own method for storing data. This has created complex problems associated with multi-jurisdictional planning activities, research, and oversight. The differing GIS data models hinder the ability to effectively share information and perform risk analyses on a large scale, much like a project team working to solve advanced problems whose members each speak a different language. The value of using a standard data model for problem solving increases with the scale and complexity of the problem as the choices made will have profound and long-term consequences financially, socially, and environmentally. This research includes developing a universal data model to serve as a common foundation for future analysis and research, building on a model previously developed by researchers at Virginia Tech in collaboration with BAMI, the Buried Asset management Institute and the USEPA. The data model development was a very extensive process considering many different sources, formats, modeling, and results (Sinha et al. 2008)[7]. The preliminary standard data model was developed with support from the Center for Geospatial Information Technology (CGIT), a part of Virginia Tech's geospatial information sciences, while the project was funded by BAMI/USEPA. An updated version of the standard data model was developed as part of this research after contacting utilities to improve the applicability of this model. The comments and suggestions from the utilities were incorporated into the updated data model version by adding new attributes and tables. The additional attributes were related to condition assessment from publicly-promoted data models, hence allowing municipal utilities better tools to manage their infrastructure internally, and share their utility data with neighbors, researchers, and regulators. In addition, risk assessment applications and tools utilizing the data model were developed to showcase the importance of such a data model and to provide utility decision makers with information necessary to understand the risk of their pipeline system and allocate the limited resources efficiently; Visualization and Query tools enable a fuller understanding of the data.

The Data Visualization included the development of a Google Earth simulation tool and a risk visualization model, with a time span command enabling the simulation of asset deterioration over time. Attributes such as performance, age, risk, likelihood of failure, and consequence factor of failure can be simulated to view the change with time. Such visualization can be tailored to serve the needs of the utility based on their priorities and relative agendas for asset management and risk mitigation. Over and above this, a querying tool complements a map-based dynamic web application and provides the utility personnel the ability to initiate a query over the internet. The use of the web application promotes collaboration among utilities, government authorities and agencies, and researchers seeking to develop enhanced methods for water pipeline asset management, and allows a far easier method for developers and other key players to take advantage of work that has been previously done.

Thus the objective was to lay the foundation for a common data management framework that can facilitate better overall utility asset risk management (operations, maintenance, rehabilitation and replacement) through access to good information. Although the data model and tools have been developed for water, wastewater and storm water utilities, the concepts could be applicable to other areas of municipal infrastructure asset management. The task of translating the utilities' data into the common data framework is not enough to understand the system; however it is the first step of the process. The results illustrate the challenges inherent in any effort to conflate disparate municipal utility datasets into a common data model, and demonstrated the scarcity of data relevant to water and wastewater infrastructure condition assessment.

Materials and Methods

The BAMI/USEPA project (Sinha et al. 2008)[7] provided the foundation for the work. That project included development of data model that began by contacting utilities for sharing their data for research purposes. The Virginia Tech research team signed a memorandum of understanding with all the utilities for the safety, security and sharing restrictions of their data. The meetings consisted of conference calls between the Virginia Tech research team and GIS managers of the utilities. The meeting process followed a standard protocol of:an introductory meeting, a data transfer meeting, and a follow up meeting to resolve questions regarding the data. In addition to these, meetings took place with the San Diego Supercomputer Center (SDSC); these were necessary to set up the database link between Virginia Tech and the SDSC. The methods for data transfer were mostly mailing DVDs or an FTP file transfer. Most of the utilities have data stored in shape files or Geo database tables which are compatible formats with Esri's ArcMap. Hence they can be imported by ArcMap directly without any need in change of the file extension. However, small utilities do not have access to ArcMap so they store data in traditional ways such as Excel spreadsheets or hand-written documentation.

Implementation of the data model began with the creation of a feature dataset for each city, with individual feature classes for manholes, pipelines, etc. in each dataset. The main advantage of the standard structure is that the data from each city is stored separately and can be retrieved also in a similar fashion. In addition to the individual databases, all the data was aggregated into one common database each for water and wastewater. A common data framework to support condition assessment has been defined and populated by conflating disparate datasets from several partner utilities as illustrated in Figure 1.

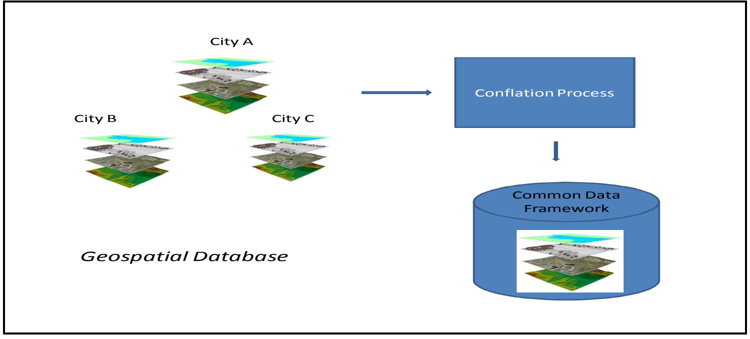


Figure 1: Conflation process of disparate Municipal Utility geospatial data

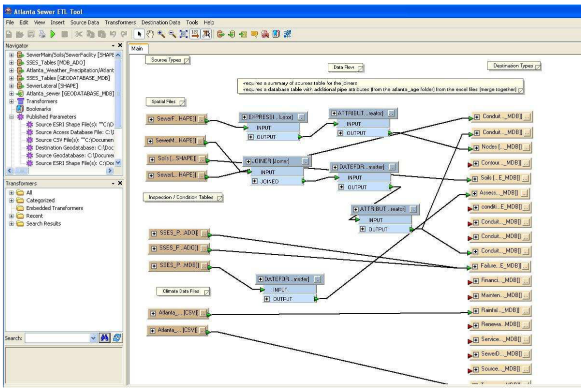
Guidance was also taken from another previous project at Virginia Tech, funded by the Water Environmental Research Foundation (WERF) under their Strategic Asset Management (SAM) Challenge, wherein researchers identified approximately 100 parameters thought to affect the pipeline infrastructure. The goal was of these previous projects was to eventually create a national standard data model for the pipe infrastructure (Sinha et al. 2008)7. This national standard data model was developed to aid the decision making process in asset management program. The data model was meant to support the development of condition index, prediction model, prioritizing repair and rehabilitation, prioritizing inspection, planning operation and maintenance, developing capital improvement program and making high level decisions.

The data model was broken into four separate models according to data quality, in order of increasing quality: Wood, Bronze, Silver, and Gold. The utility pipe data model was further broken into essential and preferable/desirable data due to the utilities lack of readily available data for a certain number of parameters. Once the data parameters were identified, each of the utility's data was analyzed to evaluate the challenges for translation of data.

The process of translating the utilities' data into the standard data model framework started with preparing mapping files. Data mapping is the method of creating data element mappings between the distinct data models. It was used as a first step for a wide variety of data integration tasks including data transformation between a data source and a destination. These mapping files were prepared manually for all the participating utilities in Excel to link the field of the standard data model to the corresponding field/attribute used by the utility.

Esri's Data Interoperability Extension provided the functionality for the data conflation. Conversion tools for specific municipal utility datasets were developed using this software, and can be shared with other Data Interoperability Extension users via an Arc Toolbox file (*.tbx) (Sinha et al. 2008)7.It is not a necessity to use this extension if the nature of translation is simple such as adding a constant attribute value, naming an attribute etc. The basic translations can be performed manually while custom-built software can also be used for the purpose.

The Data Interoperability Extension, as shown in Figure 2, provided a graphical interface to design the conversion tool. Each conversion tool was designed to transform the source data for a specific municipal wastewater or water utility and insert it into a geo database pre-formatted according to the data models developed for the BAMI/USEPA project. The Data Interoperability Extension was used to perform intermediate processing on the attribute values using a collection of transformers, which perform common operations like adding a new field, calculating a field value, joining a value from another table, and so on



-requires a summary of sources table for the joiners
-requires a database table with additional pipe attributes (from the atlanta_age folder) from the excel files (merge together)

Figure 2: Screenshot of Data Interoperability tool

As part of the present research, changes and updates have been made to the standard data model described in the previous section. The list of parameters was sent to various utilities in and outside the United States in order to get feedback to improve the data models. The eventual participants directly involved in the project included:

- City of Atlanta
- Seattle Public Utility
- Orange County Sanitation District
- Pittsburgh Water and Sewer Authority
- VPI Sanitation Authority

Also, the data models of some of the utilities were closely examined while incorporating the changes to the data model. Additional tables and attributes are added to the existing structure to improve the practicality and usability of the data model. In the future, improvements and changes to the data model are also expected.

The changes made to the water model include adding contour, failure record, renewal record data, and additions to the wastewater data model include conduits, laterals, contour, renewal record, failure record, and pipeline condition. The base XML document was updated with the changes and then exported to Microsoft Visio program to create a readable version of the data model. The tables of the Geo database were then related in the Visio program to design a visually enhanced version of the model. Once the data model was modified, simultaneous changes were made to the mapping files and the ETL tools which were used to translate the raw data into the modified data model structure. The whole process of translation of data into the data model was done as described in the background section. All the modified individual databases were combined into a single database each for water and wastewater. Once the databases were created, applications were developed to complement the data. The researchers chose to visualize pipeline failure risk and consequence as part of the study.

Results and Discussion

Risk is defined as:

"The chance of something happening that will impact upon objectives, and is measured in terms of a combination of the likelihood and consequences of events" (Standards Australia and Standards New Zealand 2004)[8].

The risk/performance of the system is determined by two basic measures:

- Event: The probability of failure or breaches
- Consequence: The impact of failures or breaches

The parameters used to calculate the risk rating were taken from the standard data model. Taking into consideration the risk rating as defined by Washington Suburban Sanitary Commission (WSSC) and the definition of risk, the empirical equation is formulated as below.

Risk rating = Likelihood of failure (LOF) * consequence factor

Equation 1 Risk Rating

LOF = average of (PD+MD)

Equation 2 Likelihood of Failure Calculation

Consequence Impact = average of (EI+TFI+SDI+FI+PHI+DI+FP+ON)

Equation 3 Consequence of Failure Calculation

$$\text{Risk} = (PD+MD)/2 * (EI+TFI+SDI+FI+PHI+DI+FP+ON)/8$$

Equation 4 Total Risk Score

Where,

PD - Pipe Defects
MD - Manufacturing Defects
EI - Environmental impact
TFI - Traffic flow impact
SDI - Service Disruption Impact
FI - Financial Impact

PHI - Public health impact
DI - Diameter
FP - Function of Pipe
ON - Operational

The risk rating is a relative risk system where the results of likelihood of failure (LOF) are calculated on a 0-1 scale, as are the score for the consequence impact factor. The total risk is the product of these two, which is also reported on a 0-1 scale. The pipes are color coded according to the rating for better visualization as illustrated in Figure 3.

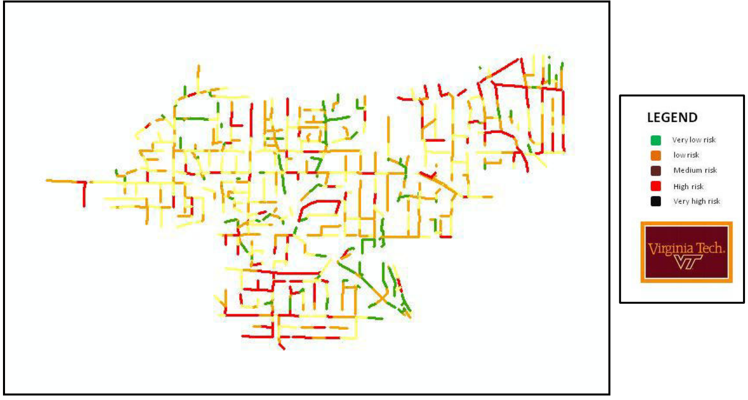


Figure 3: **Total risk of pipes**

Each utility can change the parameters according to their needs and importance. For example, length of a pipe can also be added as an attribute to calculate likelihood of failure; considering all other parameters equal, a long segment has a greater likelihood of failing than a shorter one by virtue of the additional exposure to conditions that could cause a failure. The risk methodology can incorporate diverse data sources to provide a quantitative analysis of the probability and consequences of failure.

The risk methodology may be used to provide a quantitative guide for investment in future inspections, pipe replacement, or repair, changes in security measures and other mitigation activities to reduce the risks of pipe failures to the utility and community. The methodology can also incorporate the impact of failures on the surrounding community, whether that is due to overland flow resulting in damages, loss of service, or other consequences (Magelky 2009)[9].

The spatial risk analysis can be a powerful tool when imported into Google Earth as shown in Figure **4.** This tool provides decision makers with additional information to optimize the investment of limited funding to avert risk.

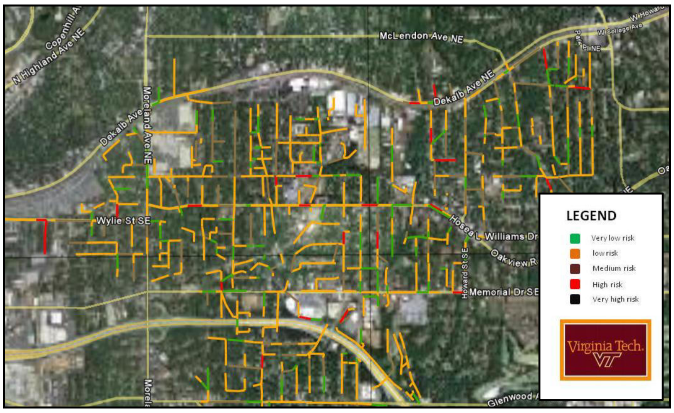


Figure 4: Overlay of risk rated pipes on Google Earth

This enhanced visualization tool assists utilities to evaluate a quantitative analysis of the likelihood of failure and consequence impact factor. It can also assist when it is necessary to allocate limited funds in the most effective manner. The risk algorithm is a relative risk system. A utility can use this output and determine a threshold score at which a remedial activity is warranted for use in planning future expenditures.

GIS can play a vital role in the process of knowing and evaluating all the threats of the system. The following steps need to be considered while developing the risk visualization model for the utility pipeline network:

1. Know the system and evaluate each facet of risk to the pipeline system.
2. Identify all the attributes to be considered for determining likelihood of failure and consequence impact factor.
3. Calculate the weights of each attribute according to what the utility thinks is the relative importance of a particular attribute when compared to others. In the model shown here, all attributes are considered to be of equal weight.
4. Develop the risk rating matrix for each attribute considered to affect the risk rating. The classification levels can differ for each utility.
5. Calculate the final risk rating using the empirical formula
6. Decide on the threshold levels and color code the pipes according to the risk rating.
7. Convert the layer into a KML file which is compatible with Google Earth for a better visualization.

Each utility can develop an individual risk rating system facilitating their needs and limitations. Also, the utility can visualize the likelihood of failure factor and the consequence impact factor individually on Google Earth for a better idea of the whole pipe system. However, the challenge for any utility would be to identify and use all the data needed to evaluate risk. The utility has to incorporate all the available data into one process for quantitatively evaluating the risk of the pipe system.

Google Earth is a cost-effective means to explore rich geographical content that is ideal as a collaboration tool for location-specific information. It helps organizations with imagery and other geospatial data make that information accessible and useful to all who need access via an intuitive, fast application. This tool is used to visualize, explore and understand information on a fully interactive 3D globe or 2D browser based maps. It also enables collaboration, improved decision-making, and faster and more informed action based on geospatial information.

Google Earth also allows users to explore the world in more than just three dimensions. It uses Keyhole Markup Language (KML), which is XML based language schema for expressing geographic visualization on three dimensional earth browsers. The KML file specifies a set of features (placemarks, images, polygons, 3D models, textual descriptions, etc.) for display in Google Earth.

A Placemark is one of the most commonly used features in Google Earth. It marks a position on the Earth's surface. By adding a TimeSpan to the placemarks, it is possible to explore and animate the content through time. To display polygons and image overlays that transition instantly from one to the next, the beginning and ending of a time period is specified using the Timespan object. This technique is typically used to show the changes in polygons and images such as ground overlays—for example, to show the retreating path of glaciers, the spread of volcanic ash, and the extent of logging efforts over the years (Wernecke 2008)[10].

Timespans are used in cases where only one feature is in view at a given time, and an instant transition from one image to the next is desired. The Timespans must be contiguous and cannot overlap. A time slider appears in the upper-right corner of the 3D display in Google Earth for all of the time-enabled placemarks. The time slider allows the user to control the visibility of placemarks by adjusting the active time range and play through the timeline as an animation.

For data sets with Timespan, the Google Earth user interface time slider includes a pointer that moves smoothly along the time slider from the beginning to the end of the time period. The transition from one feature to the next is an instant change (Wernecke 2008)[10].

The syntax for the time span command is given below. It represents an extent in time bounded by begin and end *dateTimes*.

```
<TimeSpan id="ID">

<begin>...</begin><!-- kml:dateTime -->

<end>...</end><!-- kml:dateTime -->

</TimeSpan>
```

If <begin> or <end> is missing, then that end of the period is unbounded. The *dateTime* is defined according to XML Schema time. The value can be expressed as *yyyy-mm-dd*T*hh:mm:ss*zzzzzz, where T is the separator between the date and the time, and the time zone is either Z (for UTC) or *zzzzzz*, which represents ±*hh:mm* in relation to UTC. Additionally, the value can be expressed as a date only. The elements specific to time span are <begin> and <end>where <begin>describes the beginning instant of a time period and <end>describes the ending instant of a time period. If these commands are absent, their respective places are unbounded. For the purposes of this research, pipe deterioration curve is assumed to be a simple straight line with no repairs or rehabilitation conducted over the lifecycle of the pipe. In the future, sophisticated pipe deterioration models might be developed which can be incorporated into the simulation. The simulation at various future time periods is shown in Figure 5through Figure 8

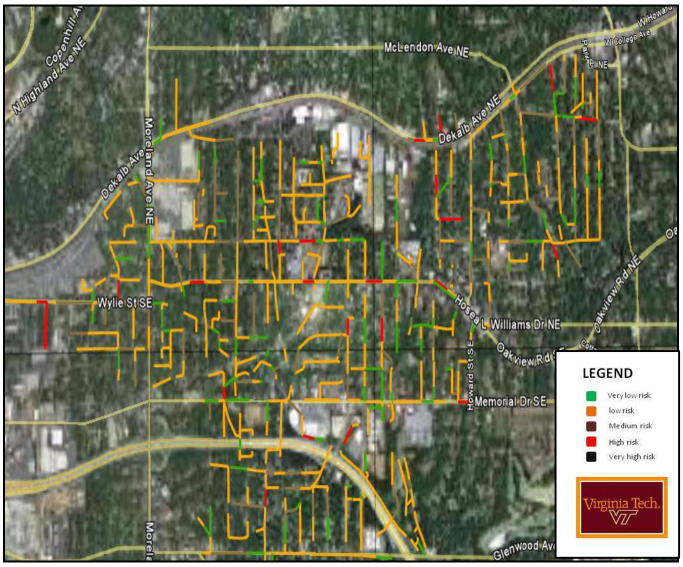


Figure 5: Risk assessment in year 2012

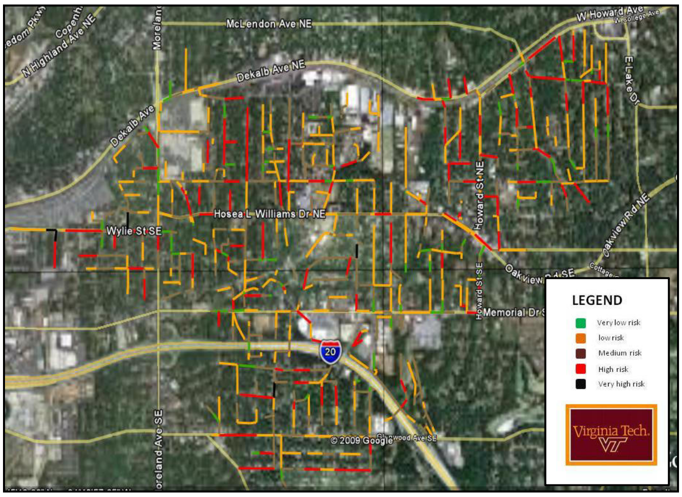


Figure 6: Risk assessment in year 2035

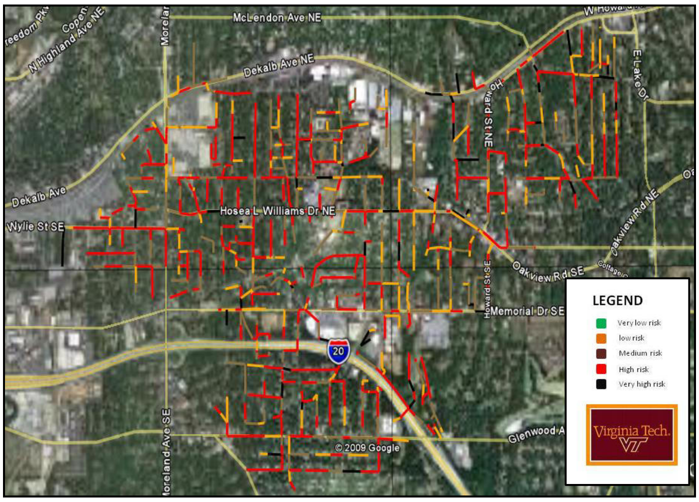


Figure 7: Risk assessment in year 2060

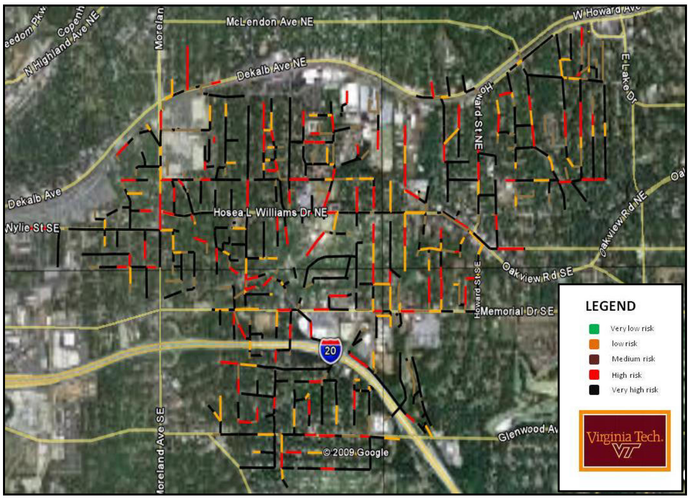


Figure 8: Risk assessment in year 2080

The present simulation animates a series of pipelines based on projected data derived according to the straight line deterioration. The illustration above shows four of the different stages of pipe condition at various time intervals in the future. A separate <Folder> contains the name and data for each stage. Each <Folder> contains a <Placemark> with a <name> that is used as the label for the pipe. The <Timespan> is defined with each such <Placemark>. Also, each <Folder> has a <Linestyle> element that specifies a background color for its entry in the list view. The number of pipes considered in the simulation is huge while the timespan command being described is to be added to each of the placemarks of the KML file. The process of adding the timespan command to each of the placemarks manually is nearly impossible and time consuming. As an alternative, a Pearl code is developed to automate the process of adding <timespan> to all the placemarks of the KML file.

Each stage of pipe condition is stored in different folders. The Pearl code is run for each data set and the final KML is prepared by integrating all stages of pipe condition into one folder. The final KML is then imported onto Google Earth and the play button on the time slider is clicked to start the simulation. In the settings tab on the time slider, the speed of the simulation can be changed according to the requirements.

The following steps need to be considered while developing the Google Earth Simulation model for the utility pipeline network:

Evaluate the system and decide on the attributes that change with time and need to be simulated to understand the system better.

Collect all the available historical data for the attributes and project data if needed using forecasting methods.

Color the pipes of the various data files according to the threshold value decided by the utility decision makers.

For each of the data file, run the pearl code to add the <Timespan> command to all the placemarks in the data file.

Also for each data file, change the time period according to the needs of the utility.

Integrate all data files into one master KML file after adding the <Timespan> command to all the individual data files.

Import the master KML file onto Google Earth and run the simulation.

Each utility can develop an individual Google Earth Simulation model facilitating to their needs and limitations. Also, the utility can visualize any time variant attributes like risk rating, age, condition of pipe on Google Earth for a better idea of the whole pipe system. This provides the decision makers with additional information to allocate the limited resources of the utility. In addition, this helps the utility to prioritize repair and rehabilitation and other mitigation activities to reduce the unpredictability of the system. However, the challenge for any utility would be to identify and use all the data needed to develop such a model. The utility has to incorporate all the available data into one process for quantitatively simulating the attributes of the pipe system. Such a simulation tool assists the utility personnel to foresee pipe failures or any undesirable service interruptions. To further demonstrate the uses of the data model, a web application was created using ArcGIS Server Manager.

ArcGIS Server Manager was used to create a geospatial enterprise application to showcase the utilities' geospatial pipeline data after fitting it to the standard data model. ArcGIS Sever Manager was further used to create and deploy standard Enterprise Java Beans (EJBs) to provide geospatial services such as mapping, querying, routing, and geocoding. The ArcGIS Server for Java Eclipse plug-in has a template for building and deploying the samples. For creating the web-based map application, Java was chosen as the programming language. Developing the source code in Java, the Geo database and the ArcGIS sever were connected to create a map based web application to answer specific questions.

To implement a query attribute task, it was added as a managed bean to the faces-config.xml file

```
<managed-bean><managed-bean-name> queryTask</managed-bean-name>

<managed-bean-class>com.esri.adf.web.tasks.QueryAttributesTask</managed-bean-class>

….

<property-name>webcontext</property-name>

<value>#{mapcontext}</value>

….

<property-name>taskConfig</property-name>

<value>#{queryTaskConfig}</value>

<managed-bean><managed-bean-name> queryTaskConfig</managed-bean-name>

<managed-bean-class>com.esri.adf.web.tasks.QueryAttributesTaskConfig</managed-bean-class>

….

</managed-bean>
```

Prompts such as “Task Info” provide metadata about the task such as parameter, action and tool descriptors while “Task Config” gives access to properties of the task such as labels, messages and functionality. The final web application is illustrated in Figure 9where a sample query is demonstrated. It is connected to the data services managed by the ArcGIS server manager. All the services must be up and running with all the maps to be queried in the web application. The web application has various tools to query for any attributes of the pipe. It also has tools such as pan tool, zoom tool, measure tool for a better interaction with the map data for the utilities. The data to be queried by the web application can be changed by changing the maps in the Arc Server Manager Service. When a query is submitted, the queried pipes are highlighted in the map and the list of pipes is identified in the results panel located on the left side of the web application. The queried pipes are also zoomed to the layer for a better distinction from the rest of the pipes.

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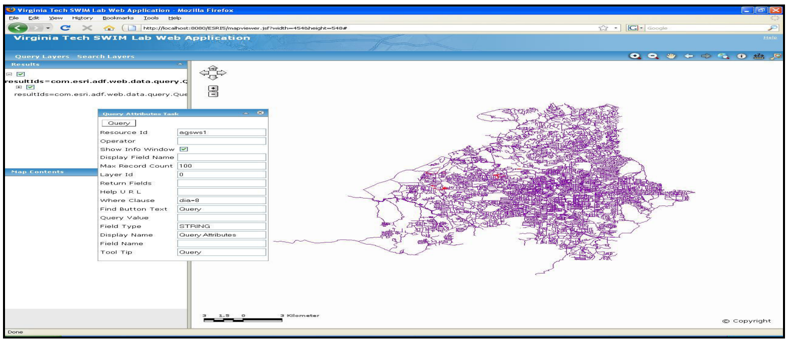
Virginia Tech SWIM Lab Web Application - Mozilla Firefox

http://localhost:8080/ESRI5/mapviewer.jsf?width=454&height=548#

Virginia Tech SWIM Lab Web Application

resultIds=com.esri.adf.web.data.query.Q

resultIds=com.esri.adf.web.data.query.Que

Query Attributes Task

Resource Id	agsws1
Operator	
Show Info Window	☑
Display Field Name	
Max Record Count	100
Layer Id	0
Return Fields	
Help U R L	
Where Clause	dia=8
Find Button Text	Query
Query Value	
Field Type	STRING
Display Name	Query Attributes
Field Name	
Tool Tip	Query

Figure 9: Sample Web Query. The pipes in red are the pipes which satisfy the specified criteria in the Where clause.

The Query layers tab helps users select or view certain data on the map based on that data's attributes. For example, to select pipes by entering a city name and a diameter, the expression in the WHERE Clause for this selection might look something like this: “dia = 8 AND city = ‘Atlanta’”. The users of the Web application might have to know the field names of the data (Table 1). However a higher level web application can be developed by using the Query Attributes task to create an easy-to-read form with text like the following: "I want to select pipes in the state of: (user picks a state from a drop-down list) whose average pipe diameter size is greater than or equal to: (user types a number in a text box)."

By default, ArcGIS Server map services limit the number of records returned by a query to 500 records. Queries that return more than 2000 records can cause performance to degrade. The combination of any of the attributes listed in Table 1 can be queried from the existing data. Querying other attributes returns a null value as the data for all the attributes does not exist. In the future, as the fields in the database are populated, additional attributes can be added to the list.

Table 1: List of attributes which can be queried

Attributes (Field names)	*Type*
Content	text
Material	text
FromNode	text
ToNode	text
XSshape	text
Dia	number
FromInv	number
ToInv	number
DateInst	Date/Time
Status	text
street_no	text
city	text
state	text
zip	text
pipe_len	number
pipe_loc	text
condition	text
Boolean operators	AND, OR, NOT, etc.

A Search layers tab was created to search pipes which satisfy the search criteria. The drop down menu in the layer list provides all available layers of interest and search string is entered to search pipes. Clicking the search tab returns the pipes of certain search criteria. This kind of search is similar to the simple Web search. After searching for something, the user can then select, zoom to, or pan to any features in the list of results.

The following steps need to be followed while developing the web application for the utility pipeline network:

1. Know the system and collect the data for the attributes of the pipe.
2. Store all the data in a geodatabase format and map all the conduits, nodes of the utility pipe network.
3. Create an .mxd file with all the layers of the pipe data in the map.
4. Log into Arc Server Manager and start a service with the .mxd file created in the previous step
5. Add the maps into an Eclipse project by adding the ArcGIS server.
6. Customize the application by adding a custom task into the faces-config.xml file.
7. Run the application to perform the dynamic queries on the map data.

Utilities can develop their own web applications**.** However these applications are limited to the utility needs while the web application developed as part of research considers the integration of data of all the utilities across the country. The web application is created as an interface for all the utilities to come together and share information, strategies and asset management techniques.

This online platform can promote effective collaboration with others who have a common interest. The web application is a powerful sharing tool that allows users to find layers, and query information about the pipe network. The utilities can also choose with whom to share their maps and data by allowing or restricting access at the individual or group level or choose to share with anyone.

Utilities can identify urgent repair needs via database queries to locate pipes that possess a specific attribute or combination of attributes. It can also view attributes for a single pipe on a map as well as any other data set. The web application tool is particularly very useful for small utilities which do not have the manpower and resources to maintain the whole GIS enterprise system.

The main contributions of this research are the following:

- A standard geospatial data model for buried water pipeline infrastructure to improve the transfer, storage, and understanding of pipeline system data and to greatly enhance the effectiveness and reach of existing risk models
- A Google Earth visualization tool to simulate time variant failure risk of pipelines
- A Web application which can perform dynamic queries and allow for enhanced collaboration efforts

The objective was to lay the foundation for a common data management framework that can facilitate better overall utility asset management (operations, maintenance, rehabilitation and replacement) through access to good information. Although the data model and tools have been developed for water, wastewater, and storm water utilities, the concepts could be applicable to other areas of municipal infrastructure asset management. The task of translating the utilities' data into the common data framework is not enough to understand the system; however it is the first step in the process of building robust models for enhanced pipeline system risk modeling.

In the future, the standard data model can lead to the development of condition and preventability indices which help in understanding pipeline networks. Spatial data of pipes, quantitative and qualitative risk models and expert knowledge can be combined to develop a spatial decision support system. Graphic user interfaces can be created using Eclipse software that allows decision makers to choose input variables.

Interactive maps are becoming more and more popular in web applications. It is very useful to implement dynamic interactive maps on the Java web application, using the Google Maps Application Programming Interface (API) for the web interface. Also, once the fields are populated in the database, the web application can be modified to perform multi-layer dynamic queries. Example queries might include pipes within 50ft of water bodies or the total length of concrete pipes in US.

Enhanced asset management requires knowledge about pipe assets: where they are, how they are performing, what the likelihood and consequences of failure are, and most importantly, the costs associated with those failures. Database auditing and monitoring can be performed by the utilities to mitigate data risk by discovering critical data in the database. Furthermore, the viability of the risk visualization model can be improved with the development of sophisticated deterioration models.

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