STANDARDIZED PIPELINE RISK COMPARISON AND PREDICTION

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INTRODUCTION
Pipeline transmission is the preferred choice in terms of safety, reliability, and cost effectiveness for transporting large volumes of fluid intra-continentally. Still, infrequent and occasionally traumatic pipeline failures can cause public concern and spur regulatory responses, typically scaled according to the impact of the event (e.g. Accountable Pipeline Safety and Partnership Act of 1996, PIPES Act of 2006). To address this, modern pipeline systems are designed and operated with the intent of being intrinsically safe and indefinitely maintainable. This is a demanding objective with many challenges, including 3rd party and environmental threats, Operations & Maintenance (O&M) incidents, design flaws, manufacturing and installation flaws, product contamination, etc.

Tools and technology to encompass and manage this objective continue to be developed and successfully applied in the industry. Today, they are being applied not only to new pipeline systems, but to systems that were designed and installed in the early 1900s. Proper application of these technologies and research-based tools enable the quantification and minimization of operating risks associated with pipeline facilities. Geospatial Information System (GIS) platforms have been employed by the transmission pipeline industry as a means to both (1) collect, contain, and locate permanent pipeline records, and (2) serve as a basis for development and deployment of Integrity Management Programs (IMPs).

The objective of this article is to demonstrate the inherent value of an interactive and detailed GIS landscape, emphasize the importance of industry standardization, and encourage regulatory agencies and operators to systematize and incorporate these technologies to produce a standardized basis of observation for these independently operated systems. The illustrations discussed herein are provided using a Standardized Pipeline Observation Tool (SPOT) to display and compare the basic elements of pipeline risk management, which are:

§1. Fundamental pipeline information and location with identified boundaries,

§2. Standardized risk parameters recognized throughout the industry, and

§3. Potential threats to and from the pipeline systems that are in place.

There are existing GIS tools and IMPs which have provided these risk management benefits to owner/operators since their implementation. However, it will be demonstrated that the utilization
Figure 2. Pipeline Failure Impact (Pulled from PHMSA records [2]).

[NOTE: Additional mapping and system information has been intentionally excluded for privacy protection]

Figure 3. Texas Railroad Commission, Southwest Houston Area [3]

Figure 4. River, Bridge, and Power Generation Station along Gas Transmission Pipeline [3]

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of a standardized comparative-type tool can be extended to the governance of (product, process, utility, and chemical) transmission pipelines in order to provide an unbiased comparison (or even ranking) of similar pipelines.

**Figure 1** illustrates natural gas and hazardous liquid mainlines in the United States. This information is made available to government, operators, and the public by the National Pipeline Mapping System (NPMS)[1].

Federally mandated Pipeline Integrity Management Systems [PIMS] are also integral to the natural gas transportation industry. These PIMS are often individually customized to meet the needs, concerns, and facilities of each specific operator so that the operators can uniquely specialize their IMP. However, this specialization also makes comparison to other pipeline systems more challenging because of the disparate nature of the analyses and reporting. SPOT compiles this various data into one, overall, standardized package for use by pipeline operators and Governance.

Application of this technology allows access to publicly available spatial data, common design data, operating history, identified correlations, and conservative estimates in order to generate comparable projections of multiple individual pipeline sets. These comparisons can be used to anticipate pipeline incidents and their potential interactions with the environment and society as well as with each other. Furthermore, historical GIS records are continuously available to illustrate pipeline interaction with historical dates and societal changes. A platform of this sort also permits a boundless set of predictive future scenarios for each pipeline where potential results can be grouped and compared to one another on both an absolute and a relative scale.

This article will draw on examples from high pressure natural gas transmission systems; however, readers should understand that this technology can be extended to gathering and distribution across any given set of product or process pipelines.

**STANDARDIZED BASE MODELS**

The first step in managing the risks (probabilities and consequences of failure) and threats (sources and methods of potential incidents) with a pipeline asset is to identify what is known about the asset and to identify and quantify what is unknown about that same asset. This means identifying parts, equipment, and location, as well as understanding the variabilities and uncertainties about the identified information. Information as fundamental as the diameter and wall thickness of the pipeline have intrinsic variability defined within the specifications and the manufacturing requisites of the equipment. Focusing on the largest sources of uncertainty allows the operator or user to quickly recognize where the most substantial deficiencies may exist. With transmission pipelines, the largest impact of uncertainty tends to be in the location accuracy of the assets. However, equipment misidentification and lack of certainty on some fundamental historical design data (e.g. specified minimum yield strength [SMYS], longitudinal wall seam information, wall thickness, depth of cover, coating integrity, etc.) can have a tremendous impact on the operational safety of the system as well.

A standardized set of design data, operational parameters, historical information, and location accuracy can be applied to establish an unbiased representation of the physical properties of the assets. Default data values and unverified assumptions can be clearly identified and assigned conservative factors to precisely illustrate where informational improvement can provide positive returns.

Once this data is collected and assembled, it is projected across the Earth’s surface to illustrate how the system potentially impacts the environment and populace. **Figure 2** illustrates a documented pipe failure with a pre-existing aerial projection in the background set to show the condition of the surrounding area a short time after the incident. The green line represents the pipeline that failed and the light pink area represents the Potential Impact Radius (PIR), plus the spatial uncertainty of the pipeline accuracy. Within the boundaries of this highlighted area the potential damage associated with a past pipeline failure is evident. Note that additional information, such as assessed property values, can be included in the aerial projections.

**Figure 2** also illustrates how certain information can be hidden when appropriate. Users can manage what information is made available, and to whom.

The NPMS[1] has collected and maintained geospatial data sets for industry and government use and all state gas transmission regulatory agencies have access to this data. Some states (e.g. Texas and Arkansas) have used this and other information to create their own individual GIS platforms. **Figure 3** illustrates a web-based platform maintained by the Texas Railroad Commission[3]. This system is designed to provide critical information on Interstate Pipelines, Intrastate Pipelines, Well Logs, and other levels of pertinent map based data to the public and first responders.

These base models can also be used to demonstrate and compare relative design and uncertainty risk profiles, which can be enhanced by using specific shapefiles from pipeline operators. These shapefiles should contain a predesignated listing of pertinent design and operational data which are fundamental to managing the integrity of the pipeline (Nominal Diameter, product, Maximum Allowable Operating Pressure [MAOP], Wall Thickness, Pipe Grade, Depth of Cover, Pipeline Classification, Line or System Names, Pipeline Manufacturing Information, Date of Construction, Assessment Date, Assessment Method, Line Strikes, Number of Callouts, etc.), as well as any identified data variability Additional information (Station Locations, Valve and Regulator Locations, etc.) can also be incorporated into these initial models.

Once the shapefiles (containing the pipeline centerlines and tabularized pipeline data) are populated, the pipeline data and variability is validated. The verified pipeline data is then used to generate pipeline representations based on specified standards. **Figure 4** shows a combination of two standardized centerline model representations that illustrate the design risk of a pipeline. The Affected Area Model is the wide colored band around the centerline of the pipeline that is intended to demonstrate the
surface area that could interact with the pipeline. It has been colored according to a standard scale that is intended to show higher design risk areas with hotter colors (e.g. red, yellow) and lower design risk areas with cooler colors (e.g. green, blue). Another Pipeline Centerline Model is included along the diameter of the pipeline and the elevation of this model is equivalent to the PIR minus the Depth of Cover. The intent of this Pipeline Centerline Model is to demonstrate the safety benefits that are provided as the result of validated increases in Depth of Cover. The Pipeline Centerline Model could also be colored based on a pre-set ranking scale.

Figure 4 provides a perspective projection of an Affected Area Model and Pipeline Centerline Model identifying a pipeline as it parallels a bridge and freeway across a river, next to a power generation station. The height of the centerline represents the PIR value (in feet) minus Depth of Cover and the PIR area is highlighted in yellow to characterize an area of some concern around this pipeline due to the fact that it is within a High...
Consequence Area (HCA) and the MAOP is slightly higher than the claimed 50% threshold.

This Affected Area Model clearly indicates civilian and geographical areas that are potentially impacted by this pipeline. Each of these models can contain tabularized data (accessible through GIS, database, or spreadsheet tools) clearly indicating the pertinent data that is included in the indicated shapefile. Furthermore, these models can be both annotated and colorized according to standard specifications. Color schemes and annotations are used to immediately convey pertinent information to the user.

Affected Area Models can have various color schemes to highlight pipelines that are operating with specified design risk characteristics (%SMYS, # of line strikes, time since last pipeline assessment, etc.). The line annotation can also be used to convey pertinent system information (Operator name, contact information, etc.).

**STANDARDIZED COMPARATIVE RISK MODELS**

Standardized comparative risk models can then be generated using additional pipeline information (and variances) commonly available to the operators. Standardized risk quantifications, such as those recommended by W. Kent Muhl Bauer[4], or In-Line Inspection (ILI) results (and resulting Probability of Failure [POF] evaluations), or Internal Corrosion Direct Assessment evaluations can also be presented using standardized representations.

**Figure 5** provides an example of prioritized POF evaluations that have been produced based on recent ILI information.

**Figure 6** provides an example of evaluations that were performed in order to support Internal Corrosion Direct Assessment mitigations. The results of these calculations were then imported into a GIS platform to simplify the data interpretation and provide immediate access to supplemental information. In this specific example, each line is colored according to how slowly water is being transported through the line (water transit rates exceeding 1,000 hours/mile are indicated in red). The values shown as line labels indicate the number of gallons of water contained within each line segment.

The example shown in **Figure 6** illustrates how quickly areas of interest can be identified and illustrated on a standardized scale once all the information has been independently validated. Once identified, specific areas of interest can be inspected more closely through the use of a GIS application which is independently maintained and updated with both present and historical data. **Figure 7** demonstrates how the item of interest denoted in **Figure 6** can be investigated in further detail.

**STANDARDIZED PREDICTIVE THREAT MODELS**

Predictive models can present sets of potential outcomes for comparison. There are multiple techniques which can be applied for predicting concerns and testing predictive accuracy. As with the base models and the comparative risk models, a pre-determined set of predictive mechanisms can be evaluated using the standardized pipeline representations that have been developed. Applying predictive models to the developed standardized models
will again produce unbiased estimates and weightings that can provide insight on potential risk mitigation. Some of the predictive techniques include, but are not limited to the following:

- Monte Carlo Analyses
- Barrier Based Approaches
- Bayesian Inferences
- Black Swan
- Risk Matrix
- Index Model
- Fault Tree/HAZOP
- Scenario Based

Recommendation and exploration of predictive models are beyond the scope of this article; however, the demonstrations provided in previous sections should illustrate the capability of advanced modeling systems to present and explore these predictive threats.

**SUMMARY**

This article has discussed and illustrated the value of applying Standardized Pipeline Observation Tools to pipeline assets and facilities, and projecting them across a detailed GIS platform in order to quickly identify and compare design information, asset risks, and asset threats. The authors hope that owners, operators, and regulators of these pipeline systems will consider the examples provided herein and consider incorporating this technology as a part of their ongoing PIM systems.

In this article we have tried to demonstrate the capabilities and value of available GIS tools and show that these high pressure pipeline systems share common designs, risks, and threats. We seek to emphasize and encourage the need for governance and industry standardization when it comes to reporting these designs, risks, and threats if the industry is to become more effective at managing pipeline risks and mitigating their probabilities of failure. A commonly accepted reporting standard provides the foundation for comparative assessment and identification of improvement opportunities. Standardization will also improve industry performance and increase public safety. There is growing public concern regarding both new pipeline facilities and the aging infrastructure of existing high pressure pipeline facilities. Industry standardization addressing the application of GIS tools to quantify and report certain design, risk, and threat parameters provides regulators and industry with an unbiased measuring system by which to compare all pipelines of similar service.

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

**REFERENCES**

1. NPMS - www.npms.phmsa.dot.gov
3. TRRC - http://wwwgisr.rrc.state.tx.us/GISViewer2/
CRAIG SWIFT
Craig Swift is a Professional Engineer experienced in Gas, Product, & Oil Transportation, Gas & Product Storage Management, Flow Optimization, Pipeline Integrity & Risk Management, Design & Project Management of Pipeline & Facilities, and Geospatial Technology Integration. His experience ranges from ICDA, multi-phase transient flow analyses, pipeline and compression and pump design and installation, planning and execution of in-line inspection and other rehab projects, gas processing, hydraulic modeling, facility design and planning, as well as capacity and fuel management. A strong understanding of industry economics has been developed through direct interaction with Operations, Marketing, Risk Management, and Financial Groups. Mr. Swift is presently a Project Manager with Bureau Veritas working for a natural gas regulatory group reporting regulatory compliance and process conformance with a focus on pipeline safety, pipeline integrity, and pipeline risk management.