Modeling Cross Bore Risk

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Abstract

Existing cross bores represent a serious integrity challenge for many gas distribution utilities. Best practice recommendations suggest a risk-based approach for effectively identifying and addressing the areas of highest cross bore risk within the distribution system. As with any integrity effort, the accuracy of the risk model plays a critical role in the effectiveness of the risk management program. In this paper the structure for a probabilistic risk model based on the underlying mechanistic factors impacting the potential for the existence of cross bores is presented (a mechanistic-probability model). The incorporation of data uncertainty, a common challenge in cross bore risk assessments, directly within the model is discussed along with use of the model in directing integrity management programs.

The Risk of Legacy Cross Bores

Legacy cross bores–where natural gas lines intersect with a gravity drain system (storm or sanitary), sewer or septic system as a result of the use of trenchless installation technologies–represent a serious risk to many pipeline operators. Due to their nature, cross bores represent a high risk because of the potential consequences that can occur as a result of an incident. When the cross bore results in a blockage of the drain system, standard cleaning operations can result in compromise of the natural gas line and a rapid release of natural gas. This natural gas can travel back through the drain system into the structure creating a hazardous condition.

The first such recorded incident occurred on August 29, 1976 in Kenosha, Wisconsin. The home in which the incident occurred did not have natural gas service. A drain cleaner punctured a 2" plastic main that had penetrated a 6" sewer lateral; the resulting explosion killed two people and injured four. The subsequence National Transportation Safety Board (NTSB) investigation prompted a number of recommendations for addressing the risk posed by cross bores[1].

Best practice guidelines for addressing legacy cross bores, along with guidelines for avoiding cross bores in new installations, have since been developed[2]. These guidelines recommend a risk-based approach to assessing the potential for cross bores and directing remediation and mitigation efforts. As with any pipeline integrity initiative, the risk models upon which the risk assessment is based play a critical role in the effectiveness of the risk reduction actions taken. The more accurate the underlying risk model, the better informed are the decision makers and the better the resulting decisions.

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[1] NTSB Safety Recommendations P-76-83 through P-76-86, November 12, 1976

[2] OTD 12/0003, Cross Bore Best Practices – Best Practices Guide, November 2012

Cross Bore Risk Model

There are many different risk modeling approaches employed in the gas distribution industry, ranging from index models to full mechanistic-probability models. In index models, a list of attributes related to the probability of an event are weighted to provide a relative risk ranking. With mechanistic-probability models, models are developed based on the underlying mechanisms of pipeline failure and tied to specific data to provide a probabilistic ranking of risk.

In this paper, the framework for a probabilistic risk model is presented based on the underlying mechanisms related to cross bore incidents. Specifically, a model is presented for assessing the probability of a cross bore existing in a given installation. For details of the full risk model, including consequence of failure estimates, contact the authors.

Probabilistic Risk Models

Risk in pipelines is typically represented as the probability of failure (PofF) times the consequences of failure (CofF). Risk reduction efforts are then directed at reducing the PofF, the CofF or both.

In probabilistic modeling, PofF can be represented as[3]:

$$\text{PofF} = \text{exposure} \times (1 - \text{mitigation}) \times (1 - \text{resistance}) \qquad (1)$$

where:

- Exposure is an event which, in the absence of any mitigation, can result in failure if insufficient resistance exists
- Mitigation is the effectiveness of all activities designed to stop the exposure (a number between 0 and 1 representing the probability of the mitigation stopping the exposure, 1 representing 100% effectiveness)
- Resistance is a measure or estimate of the ability of the component to absorb the exposure force without failure once the exposure reaches the component (a number between 0 and 1 representing the probability of the component to resist failure)

The PofF is typically calculated for each specific threat or exposure type. The overall PofF for a pipeline segment is the sum of the PofFs for all possible threat types. PofF is typically described in terms of events/mile/year or events/component/year, providing an absolute (as opposed to relative) estimate of the probability of failure.

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[3] K. Muhlbauer, Pipeline Risk Assessment: The Definitive Approach and Its Role in Risk Management, Clarion, 2015

CofF can be represented as:

$$\text{CofF} = (\text{Hazard Zone Size}) \times (\text{Receptor Density}) \qquad (2)$$

CofF is calculated for each specific threat or exposure type. CofF is typically described in terms of $/incident. Again, an absolute–as opposed to relative–estimate is provided.

The resulting PofF and CofF values for each threat or exposure type are multiplied to provide the risk for a given pipeline section or component. The results are typically expressed in $/mile/year or $/component/year.

The benefits of this type of modeling approach:

- Provides a true measure of risk when properly constructed and applied
    - Quantitative: numerically quantifies risk
    - Mechanistic (or deterministic): mathematically represents the underlying physical processes
    - Probabilistic: inputs are represented by probabilities
    - Explicitly able to address data uncertainty in probabilistic terms
- Enables comparisons across different assets, as it expresses results in absolute as opposed to relative terms

Modeling the Probability of a Cross Bore in Existing Installations

There are two key factors tied to the probability that a cross bore incident will occur: (1) the probability that a cross bore exists and (2) the probability that an incident will occur given the existence of a cross bore. This paper is focused on assessing the probability of the existence of a cross bore in existing installations.

Starting with the base PofF model (*equation 1*) and the factors impacting the probability of a cross bore incident occurring, the structure of an overall cross bore PofF model was developed that provides a probabilistic estimate of a cross bore being present for each segment in the gas distribution network.

In terms of the base PofF model, the overall probability of a cross bore is represented by:

$$\text{PofCB} = \text{exposure}_{\text{CB}} \times (1 - \text{mitigation}_{\text{CB}}) \times (1 - \text{resistance}_{\text{CB}}) \qquad (3)$$

where:

- The ‘$\text{exposure}_{\text{CB}}$’ term in the PofF model represents the unmitigated probability that a cross bore could exist in a given installation

- The ‘$\text{mitigation}_{\text{CB}}$’ term refers to the effectiveness of all mitigations applied to prevent a cross bore at the time of the original installation (such as specific installation practices like locates and day lighting)
- The ‘$\text{resistance}_{\text{CB}}$’ term indicates the resistance of the drain[4] to penetration of the gas line and is typically assumed to be zero

The unmitigated probability of a cross bore existing ($\text{exposure}_{\text{CB}}$) mechanistically depends on the probability that trenchless installation was used for the gas line installation (P_T) times the probability that an intersection of the gas line and drain line could have occurred (P_{INT}). This can be represented as:

$$\text{exposure}_{\text{CB}} = P_T \text{ x } P_{INT} \qquad (4)$$

Obviously, the potential of a cross bore existing drops to zero as the probability of trenchless installation drops to zero and/or as the probability of an intersection drops to zero.

The model uses attribute tables to assign probability values based on the specific parameters that can impact each factor. These attribute tables are developed based on the operator’s specific practices and available records, along with probabilistic analysis of historical data. For example, the probability that trenchless installation was used is typically tied to the year of installation, the type of pipeline (main or service) and diameter (i.e. the utility may not have used trenchless installation above a certain pipe diameter), the location within the network (i.e. trenchless may not have been used in certain areas of the network or cross bores may have been identified in certain areas of the network (indicating potential for cross bores based on similar utility installation practices or field conditions)) and other utility-specific factors that would indicate whether trenchless installations may or may not have been used. Based on the attribute tables and the segment specific data, an overall probability that trenchless installation was used is calculated for each pipeline segment. As attribute tables are used that are tied to segment specific data, the analysis process can be automated and processed in batch, to facilitate assessment of the overall pipeline network. The handling of data uncertainties in the model is addressed in a subsequent section.

The probability of intersection (P_{INT}) of the gas line and the drain line depends on the relative vertical location (depth) of the two lines (probability of a vertical intersection (P_{VI})) and the horizontal location/service path (probability of a horizontal intersection (P_{HI})). This is represented as:

$$P_{INT} = P_{VI} \text{ x } P_{HI} \qquad (5)$$

Again, attribute tables are developed based on the operator’s specific practices and available data records, along with probabilistic analysis of historical data. The depth of the gas line is typically tied to installation records, locate data or area specific knowledge. The depth of the drain line is typically tied to the type of building construction (e.g. shallow basement, on slab construction, trailer park installations, etc.) and area specific knowledge. The horizontal location of the lines is tied to available mapping data, service type, meter set location and other area specific information. As this is typically an area of high data uncertainty (typically due to lack of installation specific data),

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[4] The term ‘sewer’ is used generically to represent all potential cross bores such as sanitary sewers, storm sewers, gutter drains, yard drains, cleanouts, off-set clean outs, branched laterals, etc. Each of these is typically analyzed separately.

addressing data uncertainties plays a key role. The handling of data uncertainties is addressed in a subsequent section.

The mitigation term (mitigation$_{CB}$), in terms of the probability of a cross bore existing, refers to the mitigation actions undertaken to stop cross bores during the installation phase (other mitigations carried out after the installation process, such as inspection of potential cross bores, customer and drain cleaner awareness programs, whether or not drain line operators participate in One Call notification systems, etc. are addressed in other areas of the overall risk model). Attribute tables are developed based on the operator's specific historical installation practices based, for example, on the use of locates, camera inspections as part of installation process, hand digging/potholing to verify location of utilities, etc.

The overall probability of a cross bore (PofCB) is then calculated for each pipeline segment based on the probabilities for exposure$_{CB}$ and mitigation$_{CB}$ (again, resistance$_{CB}$ is typically assumed to be zero).

Addressing Data Uncertainty

Utilities are commonly faced with data uncertainty issues. Despite the potential lack of data or questions around data accuracy, the integrity of the pipeline still needs to be managed. The risk model addresses this through assessing the impact of data uncertainties on the probabilities and risk scores for each segment.

Data uncertainty is explicitly captured in the attribute tables. In the absence of specific data, the worst case situation is assumed. Other data is assigned a reliability ranking based on SME (subject matter expert) assessment and a general set of guidelines. In addition to overall probability or risk scores for a given segment, the calculations separate risk into 'known' risk and risk due to data uncertainty. This provides decision makers with an assessment of the value of data collection efforts in risk reduction as well as identifying known higher risk segments of the pipeline. It also provides decision makers with an understanding of the uncertainty associated with the model outputs.

Application of the Cross Bore Risk Model

The outputs of the cross bore risk model are used to provide decisions makers with the information to make informed risk management decisions. This is typically in the form of prioritizing inspections of high probability cross bore sites, directing data collection efforts, targeting public awareness efforts, etc.

As additional data is obtained from the field the risk model is updated. When structured in a batch processing format (computer program), it is easy to apply new information across like assets; i.e. if a cross bore is discovered by inspection or reported, like installations (same area, type of installation, installation date range, etc..) can be flagged within the risk model for assessment.

Modeling Cross Bore Risk

Summary

An overall mechanistic-probabilistic risk model has been developed to assist gas utilities in addressing the risk of legacy cross bores. The structure of the model for assessing the probability of cross bores existing in the installed asset base has been detailed in this paper. The model provides utilities with the ability to obtain a true measure of risk in absolute terms with explicit capturing of data uncertainty.