ABSTRACT

The proper use of risk assessment / risk management principles and tools can help the pipeline operator maintain the flow of pipeline integrity data and the analysis of this data by responsible parties. By the use of an algorithm (series of relationships) the rules for performing a mathematical expression of risk can be established and the attributes identified. These measures may aid in the rational, prioritization of resources and identification of improvement opportunities. Operating companies do a good job of maintaining their pipelines, but the decision as to where to allot resources in some cases may be generally a reactive measure. Advances in Pipeline Risk Management Software and Pipeline Inspection tools now allow a proactive approach to Pipeline Integrity Maintenance. This paper explains some of the risk management tools available to pipeline companies.

INTRODUCTION

In the last decade, the reported number of incidents, and their impact on the environment have been steadily decreasing in the United States1. However, increased public and regulatory attention to the pipeline industry has prompted operators to look beyond pipeline compliance maintenance programs into enhanced risk integrity management programs.

Recent high profile failures in the gas transmission industry, such as the June 11, 1999 Olympic Pipeline 16" products line failure2, has refocused attention at the risk mitigation measures that companies take above and beyond standard code compliance. Each year, gas distribution pipeline operators are plagued with releases. As shown in Figure 2, more than half of the gas distribution industry failures have historically been related to Third Party damage, another 25% are related to "Other" forces. Some of these may be avoidable through an integrated risk integrity program.
Several countries have acknowledged the technical benefits of pipeline risk assessment methodologies as an integral part of an operators overall risk management program. Countries such as Canada and Australia have existing standards in which the benefits of risk management are presented as part of potentially viable engineering alternatives to the more traditional options for conditions such as population encroachment. The Accountable Pipeline Safety and Partnership Act of 1996 in the US allowed the Department of Transportation (DOT) Office of Pipeline Safety (OPS) to create a new partnership with the pipeline industry to test whether structured and formalized risk management programs can be used as an alternative approach to pipeline regulation by:

- identifying pipeline-specific risks
- allocating resources to the most effective risk control activities
- monitoring safety and environmental performance leading to superior safety and environmental protection
- improving efficiency and reliability of pipeline operations

The pipeline distribution industry is faced with similar changing regulations. One of the most significant is the new proposed changes to 49CFR192 sections 451 through 491 in which operators of bare (uncoated) pipelines, will need to establish corrosion control programs – even though a line may have no history of corrosion problems. It is in applications such as these that risk management and risk assessment techniques may offer an operator alternate tools for strict code compliance. The fundamental components of a good risk assessment analysis are discussed in the next section.

**RISK MANAGEMENT AND RISK ASSESSMENT**

Risk management is the overall process by which management decides what actions to take, if any, to control or reduce existing or anticipated risks. Risk management involves the systematic application of management policies, procedures, resources, and practices to the task of assessing, analyzing, and controlling risk. The goal of a good risk management system is to protect the general public, the environment, company employees and assets. Risk assessment is only one component within the overall process of risk management.

Traditional pipeline risk management has been based on regulatory code compliance issues as it relates to replacing or repairing corrosion damaged pipe, maintaining cathodic protection potentials, third party protective measures (i.e., ground cover depth, signage), or population encroachment issues. Many times, the decision to perform maintenance on a section of pipe was left up to the opinion of a limited number of people, relying on either their own experience or an even more limited amount of information before them.

An effective risk management program utilizes the components outlined in Figure 3.
The assessment revolves around a thorough and comprehensive knowledge of an individual pipeline segment and how it correlates with the company's overall pipeline system. A proper assessment starts with an evaluation of the currently available system data (i.e., pipe design, product characteristics, right of way conditions) and integrating it with corrosion monitoring data collected through compliance monitoring and other inspection programs (i.e., cathodic protection surveys and in-line inspection results). With knowledge of the higher-risk areas, the risk reduction impact of several options can be evaluated—with the ultimate goal to increase safety, system reliability, and future designs.

DETERMINING RISK MANAGEMENT OBJECTIVES

Risk assessments can be designed to answer many questions. Assessments can be performed to quickly screen for a limited number of significant events (<20 variables) that have the potential to identify higher risk pipeline segments. More rigorous risk assessments can consider the impact of over 200 variables. The downside in using only a limited number of variables is that the analysis becomes much more qualitative than quantitative. Similarly, when considering a large number of variables, the potential exists for "diluting" the impact of rare occurrence events among the myriad of other potential pipeline problems. Therefore, developing and "fine-tuning" the risk algorithm to insure that potentially dangerous conditions are adequately highlighted is the most critical step in any risk analysis methodology.

Prior to implementing any risk management program, the user must consider the company's objectives. The following are an example of some questions to consider when determining objectives and designing the assessment process:

- What defines a successful risk management project or process?
- What specific results are required from the risk model to support this process?
- What level of commitment and resources are required for successful implementation—both internal and external to the company?
- How quickly do results need to be available?

Implementing a risk assessment strategy as part of your company's overall Risk Management program generally produces three significant benefits:

- enhanced detection of potential problem areas
- education and increased awareness
- improved maintenance projects selections based on maximizing the risk reduction potential of the system given limited financial and manpower resources.

It should be noted that risk management is not perceived as a means to lower the amount of money spent on system maintenance, but is a process for enhancing and leveraging the available maintenance dollars. The ultimate goal is to reduce the potential for an incident thereby, increasing public safety, environmental protection and pipeline reliability.

DEVELOPING A RISK ASSESSMENT MODEL

An effective risk model must consider all aspects related to pipeline degradation and failure. A comprehensive Pipeline Integrity / Risk Assessment process includes, as a minimum, the following components:

- Identification of hazards—those essential risk-increasing conditions that could result in an incident. These hazards are based on experience and industry knowledge.
- An understanding of the consequences in the event of a pipeline release
- Regulatory compliance issues
- Development of an algorithm by which to assess or rank the risk significance of each hazard. The algorithm needs to be tempered with the beliefs, system failure statistics, operational, and maintenance practices of the pipeline operator.
- Establishing risk reduction objectives and goals.
- Development and implementation of investigative programs which gather data about each hazard
- Calculating the relative risks along each pipeline, and prepare a risk matrix—this may ultimately be used to confirm if the risk is manageable or unmanageable.
- Evaluating risk minimization projects that offer the desired level of risk while maximizing the benefit/cost ratios of potential projects.
- Modify pipeline operating practices to ensure that risk factors are reduced or eliminated in the future.
• Monitor systems, which have been introduced to ensure that the new operating practices are functional.

Data Collection

One of the most critical parts of any pipeline integrity program or risk management is the collection of accurate information on the present condition of the pipeline. Information on the condition of the pipeline's internal and external surfaces can be collected by excavation or various inspection techniques. One method to collect accurate data has been to inspect the pipeline via a "smart pig" or In-line Inspection Tool (ILI).

These Inspection Tools were developed for the purpose of locating and monitoring corrosion on both internal and external surfaces of the pipeline. There are several types of internal inspection tools available: the Magnetic Flux Leakage Tool (MFL) and an Ultrasonic Tool (UT). The most common type is the Magnetic Flux Leakage Tool (MFL). The advantage of these inline tools are that they offer the operator "direct integrity information" previously only available through hydrostatic proof testing or excavations. Typical in-line inspection output data includes anomaly location – both linearly along the pipe axis and as a function of internal or external position, and percentage wall loss.

The Risk Management process is also continuous. As a user becomes more experienced at risk reduction project selection, they will find that the data requirements become more involved. As with any analysis, the more complete and accurate the data, the more accurate the final results become. The risk analysis process must be flexible enough to allow the user to refine the selection and significance of risk variables as enhanced information about the system becomes available.

Risk Evaluation:

One of the most popular risk analysis approaches is based on relative risk analysis. In this approach the critical characteristics (referred to as variables) that either increase or decrease system risk are identified. Once identified, a mathematical relationship between the variables and their attributes is established. This mathematical relationship, referred to as an Algorithm, becomes the set of rules by which all pipelines in the system are evaluated. A typical Algorithm configuration is shown below where Total Risk (R) = Likelihood of Failure (LOF) * Consequence of Failure (COF).

\[
\text{Total Risk} = \text{LOF} \times \text{COF}
\]

Figure 4: Typical Relative Risk Hierarchy

Relative risk assessments enable the user to capture company expertise and industry knowledge into a mathematical model (algorithm) that uniformly and systematically assigns risk, much in the same way an experienced corrosion engineer would as they review design data, inspection reports, and the consequences of a potential incident. It is also very important that the calculations be able to evaluate the impact of each variable as it truly exists along the pipeline. The process by which this is accomplished is referred to as "Dynamic Segmentation". The ability to calculate the changing risk along a pipeline as a function of: position (i.e., foot by foot); design changes (i.e., grade, coating, etc.); or leak consequence factors (i.e., environmental or population sensitive area changes) greatly enhances the sensitivity of the model. Models built on large global assumptions always limit the resolution of the risk results to the assumption range (per line segment, per mile, etc.).

Algorithm development will dictate the data collection requirements. Collecting and entering unnecessary data or incomplete data will increase data acquisition costs and possibly dilute risk results. A primary objective in any risk model should be to locate the most current and accurate information. Many times, this can be accomplished by accessing existing company databases (e.g., GIS or maintenance management systems), in-house spreadsheets, or vendor supplied electronic sources (e.g., inline data or cathodic protection data). In some case, data will need to be transcribed from historical paper records (e.g., alignment sheets, design records). To simplify the maintenance of the data, the model should also automatically recognize newer information (i.e., localized pipe replacement data, newer CP values, etc.) without the user having to update or delete non-active data. Early in the design, the risk model must be able to effectively integrate data from these various sources or
the continued maintenance and effectiveness of the system will be limited.

RISK EVALUATION EXAMPLE

The key to any successful risk management program is the pro-active selection of pipeline maintenance activities based on either the likelihood of a failure or the consequences of a failure. Therefore, an effective Risk assessment process needs to identifying, quantifying and analyze these areas.

The IAP™ – Integrity Assessment Program is a comprehensive tool that performs pipeline risk assessment calculations and analyses. The following example is based on the risk analysis module outputs from the IAP software. Another unique module within IAP models various risk-reduction scenarios. It provides a means for the user to not only qualify the value of a maintenance project based on a benefit-cost analysis, but to also evaluates the project's risk reduction impact versus established benchmarks or comparison criteria.

The following example demonstrates how an operator could locate high-risk sections in a pipeline system using IAP. It also evaluates the specific causes contributing to the increased risk, the impact of a possible risk reduction project, and quantitatively measures the beneficial impact of that risk reduction activity.

**STEP 1 – Locate Highest Risk Pipeline in the System**

Evaluate the overall risk of all pipelines in the system in a logical, reproducible manner, and visually display the results for analysis (see Figure 5). This phase of the risk analysis calculations are initially performed on the entire database.

**STEP 2 – Locate Highest Risk Portion of the Line**

The next step is to rigorously analyze the highest risk sections as a function of position along the pipeline length. This means of analysis will help identify whether the increased risk is associated with localized or widespread issues. In this example, the preliminary Ranking Matrix analysis (shown below) reveals the highest risk section of the line (calculated on 2000-ft. intervals) lies between stations 446,000 ft. and 448,000 ft.
In reference to the company’s tolerable risk criteria (vertical & horizontal lines in figure), the higher-risk sections exhibit likelihood of failure characteristics above the company desired levels (i.e., to the right and above the lines). Risk scores resulting in values either below or to the left of company criteria lines are then managed at a different priority based on where the results fall on the matrix.

**STEP 3 - Determine Risk Increasing Variables**

Using the calculated risk results shown in Figure 7, identify the specific characteristics contributing to the increased risk. In this example, several isolated higher risk locations are present along the pipeline, with many concentrated at the end of the line. High risk is defined as those regions that exceed the comparison criteria (solid horizontal line).

The highlighted high risk section is due to the interaction of the variables shown in the table (starting with Cathodic Protection Criteria and decreasing order of contribution).

**Step 4 - Design Risk Reduction Projects**

Risk reduction projects can now be specifically designed to mitigate the influence of these high risk contributors.

The user should identify the level of risk desired and then review the potential risk reduction benefit from each activity to design projects that result in risk reduction. The above tornado diagram indicates the risk reduction potential (to the left of center at 0.0) for a given attribute. If the activity deteriorates, the risk level could increase (to the right of center at 0.0).
Step 5 – Evaluate Risk Reduction Projects

A useful risk assessment software model should allow the user to not only develop but also model the impact of potential risk reduction projects.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Scenario Type</th>
<th>Station Start (ft)</th>
<th>Station End (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Derate 10%</td>
<td>Reduced MAOP or MOP</td>
<td>0</td>
<td>200,000</td>
</tr>
<tr>
<td>Pressure Test</td>
<td>Pressure Test</td>
<td>0</td>
<td>200,000</td>
</tr>
<tr>
<td>High Pass ILI</td>
<td>ILI Inspection</td>
<td>0</td>
<td>200,000</td>
</tr>
<tr>
<td>Pipe Replacement (5 mile)</td>
<td>Pipe Replacement</td>
<td>174,540</td>
<td>200,000</td>
</tr>
<tr>
<td>Line Lowering</td>
<td>User</td>
<td>179,850</td>
<td>200,000</td>
</tr>
</tbody>
</table>

Figure 9: Project scenarios

Risk projects should be evaluated based on their ability to reduce the highest risk areas below the required criteria level (horizontal line shown in Figure 10). The following charts show the original risk calculations (background) and the new risk condition after the proposed risk reduction activity (foreground).

The above results indicate that a line replacement project (figure No 10) does reduce the risk, but only within the replacement area. The lower chart (figure No 11) indicates that an ILI inspection would offer more risk reduction over the entire line length. This activity also achieves satisfactory reduction within the highest risk region indicated by the horizontal criteria line.

However, pure risk reduction should not be the only consideration. Projects should also meet a company’s minimum Benefit/Cost project acceptance requirements.

In this example, of the five proposed projects, not only does the inline inspection (ILI) project achieve the desired risk results, it also offers the optimal benefit/cost ratio (10.25) in contrast to the 0.85 ratio for the pipe replacement option.
Step 6 - Confirm Results

When properly designed, the risk reduction benefits of a project can be clearly demonstrated. This is illustrated in the risk matrix below where the sections of segment E previously shown in Figure 6, have shifted down and to the left after risk reduction activities.

![Risk Matrix for 'Main Line E'](image)

Figure 13: Risk matrix after risk reduction activity

Over time, a company’s system-wide risk condition can be monitored and trended to assure that the higher risk pipeline segments are being identified. Figure 14 shows a normal distribution of result, the higher risk segments could be identified by applying a criteria such as the mean plus one standard deviation.

![System wide risk distribution](image)

Figure 14: System wide risk distribution

Step 7: Export Risk Results

Risk results may have applications beyond the corrosion engineer. Environmental and Safety departments, pipeline designers, First responders, and others can benefit from the risk analysis generated by the program. As such, the interchange of data – both import and exporting ability to share data between other existing company electronic databases is essential. The most common initial uses have been the transference of risk results on to alignment sheets generated by GIS companies or within the IAP.

FUTURE OF RISK ASSESSMENT

The pipeline regulatory environment is quickly changing from one of strict code compliance based on minimum integrity requirements, to one that is supplemented with good, sound engineering judgment. Pipeline engineers will be called on to add greater value to their designs – whether they are on a new construction project or a smaller maintenance activity. Designers and engineers that can recognize project enhancements that will reduce the long-term risk potential of a pipeline system will greatly impact the overall reliability and safety of the system.

Key aspects to remember in future pipeline designs:

- Remain cognizant of the likely causes of pipeline failure in the environment it will be installed. One design does not fit all environments. Assume more responsibility for the design as if you were the one that had to operate it.
- Design risk reduction philosophies into the project (examples: use the most appropriate coatings given the CP requirements and soil movement conditions, specify higher toughness materials to reduce the likelihood of a rupture.
- Consider construction and installation techniques that minimize risk-increasing conditions (i.e., use-engineered backfill, factory-applied coating, automated welding, etc.)
- Ensure that the pipeline system includes the ability to directly inspect the condition of the line without excavation (i.e., pipeline can be inspected using inline technology, corrosion coupons and probes are installed in appropriate locations, etc.)
Risk assessment has the potential to save operators a significant amount of money – money that can be better spent on system enhancements. In order for risk assessment techniques to be as successful as possible, the pipeline designers and the maintenance engineers need to communicate. As with any organization, effective communication will better match the performance of the pipeline design with the expectations of the operators. Improved pipeline designs will not only benefit the operator's profits, but more importantly will increase the safety to the public and the environment. In the long run, the incremental cost in designing a pipeline system with enhanced risk assessment requirements is ultimately more cost effective than repairing or replacing a pipeline segment after an incident.

REFERENCES


