

BIOGRAPHICAL INFORMATION

Martin Thorne
Solution Investment Manager
Advantica

Specific Responsibilities

Joined Advantica (then British Gas Research & Technology) in 1992. Responsible for the evaluation of a portfolio of investment ideas and their development, where appropriate, into commercial solutions. This includes “Uptime”, a brand encompassing pipeline integrity management offerings, comprising software products, engineering consultancy, and internal tools to support consulting engagements

Past Experience

Previously responsible for development of Transmission Network Analysis software and the porting of this software from a text-based to a graphical environment. Prior to this worked on real-time software systems for the defense sector.

Educational Information

B.Sc. Physics, Imperial College, University of London
M.Sc. Optics, Imperial College, University of London

Professional Memberships

GITA
Member, Institute of Physics
Chartered Engineer
Chartered Scientist

Quantitative Pipeline Risk Assessment

Martin Thorne
Advantica Ltd
Ashby Road
Loughborough, Leicestershire, England, LE11 3GR
Phone: +44 1509 282340 . E-mail: martin.thorne@advantica.biz

ABSTRACT

Recent US legislation is requiring pipeline operators to demonstrate that the risks associated with operating their gas transmission pipelines have been assessed and are being managed.

To meet this requirement, operators need to have their pipeline records (construction, operation, maintenance and inspection) under proper control, and they need a means of assessing the risks, particularly to those sections that lie within High Consequence areas.

A GIS-based system is described which builds upon the widely accepted APDM database model, extended to accommodate inspection data, risk data and data on the consequences of pipeline failure. Adhering to the requirements of ASME B31.8S, a methodology using quantitative, reliability-based models to quantify the various threats to integrity is presented. This approach incorporates validated models that draw upon data acquired during many years of pipeline operation and enables pipeline operators to assess the risks more accurately and efficiently than any other technique. The paper also describes the process flow for risk assessment, including - threat screening, dynamic segmentation, likelihood of failure calculations, predicted consequence of failure, and the assignment of a risk value for each segment.

INTRODUCTION AND BACKGROUND

Gas and petrochemicals can be seen as the lifeblood of the economies of the developed world, particularly in North America, and there is a need to transport these materials across countries and continents from the production field to the user. Over 700,000 miles of pipeline are installed on the North American continent alone, and over half the energy consumed is transported by pipeline. Pipelines are very cost effective - \$1 will move petrochemicals over 10 times as far by pipeline as by truck; and pipelines are relatively very safe – statistically the number of fatalities in road accidents outstrips by several orders of magnitude the fatalities from the small number of pipeline incidents that have occurred.

Note - This paper concentrates on Pipeline Risk assessment, which is just one aspect of the comprehensive Integrity Management Program that pipeline-operating companies need to establish

and maintain. Additionally, the paper principally discusses gas pipelines, but the arguments relating to risk are generally applicable for pipelines transporting liquids.

BUSINESS DRIVERS FOR RISK ASSESSMENT

Despite their relative safety, the integrity and risks associated with pipeline operation must be managed. Risk is defined as the product of the likelihood of a failure of pipeline integrity and the consequence of such a failure; the overall business goals are to prevent the failure from occurring and to minimize the consequences if failure does occur. These business goals have been established for several reasons:

1. To comply with legislation.

Recent pipeline incidents in the USA and elsewhere have driven the introduction of legislation requiring pipeline operators to produce an integrity management plan and carry out a risk assessment of certain pipelines. The requirements for gas pipelines are laid down in US federal code 49CFR192, which incorporates engineering code ASME B31.8S [1] by reference. The equivalent codes for hazardous liquids are US federal code 49CFR195, and the corresponding engineering guidance in API 1160.

2. To avoid financial loss

If a pipeline experiences a leak or a rupture, the financial loss suffered by a company can be considerable. The potential cost elements include:

- Cost of compensation for death or injury
- Cost of compensation for damage to property
- Loss of product
- Cost of repair and recommissioning
- Loss of capacity during repair
- Cost of environmental cleanup
- Fines by regulatory bodies
- Effect on investor confidence and stock price

3. To achieve financial efficiencies

Pipelines are expensive to install and operate, with average construction costs exceeding US\$1.2m per mile [2]. To provide the maximum return on investment, pipelines must be operated in an optimum manner. A good understanding of a pipeline's integrity will allow operators to run pipelines with safety margins that are appropriate without being unnecessarily high, and will enable cost-effective scheduling of integrity assurance activities. Subject of course to regulatory compliance permission requirements, this could involve deferring activities until a period of low capacity demand, deferring maintenance or inspection for some years to defer investment, or scheduling several activities together to achieve economies of scale.

THREATS TO PIPELINE INTEGRITY

Although pipelines are generally buried and incidents are relatively rare, they cannot be considered as “fit and forget”. Unless inspected and maintained, all pipelines may eventually suffer from leaks or ruptures. Engineering studies have identified 22 types of threat to the integrity of a pipeline, which are recognised in the American engineering code [1]. Grouped into nine threat classes, these are:

- External Corrosion
- Internal Corrosion
- Third Party Damage
- Stress Corrosion Cracking
- Manufacturing Defects
- Construction Defects
- Equipment Failure
- Incorrect Operation
- Weather Related / Ground Movement

Some of these threats are considered to be time dependent (for instance, corrosion; a small area of corrosion could grow over time to cause a failure) while some are time independent (for example, Third Party Damage; a pipeline being struck by equipment during building construction near an established pipeline would be characterised as a random event not dependent of the build-up of a condition over time).

Definition of Pipeline Risk

In general, risk is defined as the product of the likelihood of an event and the consequences of that event. In discussing pipeline risk we assess the likelihood of failure of the pipeline, and multiply that by the consequences to human life, to property or to the environment, should that event occur. As discussed below, some methods of determining risk give absolute measures of risk while others give relative measures. Risk can be considered for individual threats or for combinations of threats.

Methods of assessing Pipeline Risk

The ASME code B31.8 (S) [1] discusses several approaches to risk assessment, including Relative Assessment and Probabilistic Assessment.

Qualitative Methods (Relative Assessment)

Qualitative or relative risk ranking approaches are based on the concept of risk scoring against a number of relevant parameters, with weighting applied to each of the parameters to reflect their perceived contribution to the overall level of risk.

This qualitative approach to assessing the risk associated with pipelines (with potentially major hazards) has a number of shortcomings that include:

- Much of the engineering knowledge for each credible failure mode is ignored in order to promote a ‘simple’ approach. The functional dependencies between the relevant parameters at failure are replaced with weightings.

- While a statistical approach can be applicable in cases where significant failure data is available to develop the weightings based on trends, few pipeline systems have experienced a sufficient number of failures to warrant a purely statistical approach. The relative weightings tend therefore not to be well validated against operational experience and can be subjective.
- The output provides a measure of the risks along the pipeline in a relative manner.
- This approach is relevant for prioritizing resources to address the overall level of risk; however the output from these models is highly dependent on the opinion of the persons entering the data. The approach therefore has the potential to lead to inconsistencies.
- Significant emphasis is placed on collecting data. Due to the lack of clarity in which parameters are dominant in the analysis there is the opportunity for resources being inappropriately directed and the risk management process being inefficient.

Quantitative Methods

Quantitative methods of risk assessment are based on an understanding of the mechanisms causing pipeline failure, and consideration of the consequences of such an event. The quantitative method referred to in this paper is based on Structural Reliability Analysis (SRA). SRA is a rigorous and validated method for assessing the fitness-for-purpose of a pipeline based on a calculated probability of failure. The method incorporates information on:

- Loads applied
- likely damage mechanisms (random and time dependent),
- variations in geometry and material parameters, and
- the effects of risk mitigating activities (such as in-line inspection, surveillance, pressure testing, and maintenance).

SRA is a systematic means of calculating the probability of failure (utilizing probability theory to account for the uncertainties in the acquired data) based on an appropriate combination of structural mechanics, operational, design and construction data. The approach takes into account previous historical data and incorporates proposed future operating conditions such as inspection frequency and changes to operating pressure. SRA is used to quantify the reliability associated with pipeline design and operation. The basic philosophy of SRA is to specifically identify the potential causes of failure, establish the mechanism which leads to the failure (failure mode) and, with due consideration of consequences, evaluate the risks associated with these failures.

While qualitative methods can be useful for quick assessments of pipeline integrity, they depend too heavily on engineering judgement, and the number of pipeline failures has been too low to form by itself a reliable statistical platform on which to build predictive formulae. Quantitative techniques, based on structural mechanics and an engineering understanding of the mechanisms of failure, are a more robust and defensible basis for a risk assessment.

Probabilistic models have been developed for the threats where it is appropriate to do so, for instance for corrosion and third party damage. For Equipment Failure and Incorrect Operations, full probabilistic models are less relevant. In these cases, statistical information derived from analysis of actual failures is used – the information used has covered reportable pipeline failures over a fifteen-year period for North America. [6]

A full description of the SRA methodology is beyond the scope of this paper, but [7] – [11] give further details on the SRA method.

Calculation of Consequence

In calculating risk, likelihood of failure is calculated as discussed above. The other element is the calculation of the consequence of failure. Many consequence models are available with different degrees of sophistication. A liquid consequence model will consider soil properties, liquid toxicity, terrain, flow, water courses and environmental factors. A gas consequence model will consider the impact area from a pipeline rupture that ignites. In the system under consideration, the consequence model considers the number of lives at risk from a rupture, based on the proximity of buildings and populated areas within a distance from a pipeline. The distance used is a function of the pipeline design pressure and diameter.

RISK ASSESSMENT IN PRACTICE

The system built by Advantica embodies the concept of Quantitative Risk Assessment into a GIS framework. The system arose from a diverse collection of structural reliability and consequence analysis models. While excellent in engineering terms, these programs lacked common interfaces, a common data model and could not easily interoperate. In designing an integrated system the following decisions were made:

- The ESRI GIS system was chosen as the framework within which the system would operate. The interfaces to existing risk models were reengineered to work as extension applications in the ESRI environment and to interact with the common database. This means that the operator is provided with a common look and feel when interacting with different applications.
- Existing Pipeline data models were considered including PODS [3], ISAT [4] and APDM. (ESRI ArcGIS Pipeline Data Model) [4]. APDM was selected since it already contained many classes required for the system being designed, is easily extended to hold data relating to risk analysis, and is designed to work in the ESRI environment. To use within the GIS system for Quantitative Risk assessment, tables had to be added to accommodate data on calculated frequency of failure per mile / year of each segment, by leak and by rupture, for each of the failure modes. Tables to accommodate Consequence of Failure calculations were also required.

The system thus brings together diverse risk assessment applications into a common framework, and allows the use of common, up to date data.

Core User Activities

To use the system for Risk assessment, a company must go through the following steps. Some steps will be required only on system commissioning, or on an infrequent basis.

- *Establish Geodatabase*

The user's data requirements must be examined to establish whether any additional data, for which provision has not already been made in the extended APDM is required, and database extensions implemented accordingly. An example of this would be accommodating outputs from any pipe inspection device not already accounted for in the core model.

- *Populate*

The empty database must be populated with the user's pipeline data. This may be a one-off process if the APDM is to become the prime data repository; alternatively an initial data transfer with periodic updates may be appropriate if other databases are to continue as the prime data repository. The time this exercise will take depends on amount of data, and more importantly on the current level of organization and consistency of the data. Constructing a database from another database is clearly much easier than constructing a database from a mixture of reports, tables, spreadsheets and paper records.

- *Pipeline Data Navigation tools*

In addition to the standard ESRI GIS tools, further tools have been developed as extension applications in the GIS. These tools are tailored to the needs of the integrity engineer and allow the user to navigate around the system effectively – for example by identifying pipeline faults that exceed a specified size threshold, found through the use of an inspection device.

- *Segmentation*

Pipeline Risk Assessment is carried out on the segments that make up a pipeline. A pipeline will not have uniform characteristics along its length; some parts may be made of steel of a different specified strength; there may be variations in wall thickness, or design pressure, and so on. In the segmentation process, the software works down a pipeline and “breaks” the one pipeline into a series of segments, with a new segment starting whenever the value of one of the specified parameters changes.

- *Assess credible threats*

This optional process allows the user to determine which threats are credible and which can be ruled out at an early stage. The process operates by presenting a questionnaire to the user. For each of the nine threats covered, a series of questions are asked relating to that threat. For instance, for the Internal Corrosion threat, the questions would include:

- Has the pipeline ever carried anything other than dry gas?
- Is H₂S known to be present?
- Has any internal corrosion ever been identified in this pipeline?

The user completes the questionnaire, together with any accompanying comments recorded for audit purposes, and the software applies simple logic algorithms to the responses. A report is generated showing which threats are credible and which are deemed non-credible. The report can be saved to the database and printed for audit purposes. The report also includes mitigation advice for credible threats drawn from the applicable engineering codes.

- *Identify High Consequence Areas and Consequence of Failure*

The system allows the user to identify High Consequence Areas and the consequence of failure, from information held in the database regarding building type location in relation to the pipe centerline.

- *Calculate Risk*

For each threat deemed credible, the user may now calculate the risk to each segment. This can be achieved with little user input since the probabilistic models being used have modest data requirements. However they can be configured to suit the specific requirements of the pipeline if there are sufficient integrity data to justify changes to the models. The software will cycle through a calculation of Likelihood of Failure by Leak and by Rupture for each selected threat and each selected segment.

A Risk value is calculated as the output of the above process, as the product of the likelihood of rupture and the consequence of failure, for each threat.

- *Report*

The consequence of failure, likelihood of leak and likelihood of rupture information thus calculated, is presented in spreadsheet form for information, decision support or further analysis, and for audit purposes.

- *Visualize*

In addition to reporting on the values produced, Risk information can be symbolized within the GIS environment as a colored line offset from the pipe centerline. This can be done for a single threat or for all threats combined, and can show likelihood of failure or risk.

While lacking the engineering rigor of the numerical output, this is a useful display tool for quickly evaluating the areas of highest risk and understanding such areas in their geographical context, showing their proximity to other physical attributes or features of the built environment such as road or river crossings.

- *Save for Audit*

All threat assessments and risk-ranking calculations can be saved to the database as named runs, which is useful for audit purposes. The runs include data such as date, time, operator, pipeline extent, plus any user-definable parameters that were entered by the user at run time, together with

free-form comments the operator may enter, for example to explain any assumptions that may have been made.

- *Business processes*

If a risk ranking system embodied within a GIS is to be used to good effect in an auditable manner, the supporting business process must be thought through, agreed and implemented. This will include decisions such as:

- Is the GIS regarded as the master repository of all integrity data? If not, how are updates to the risk ranking GIS from other systems to be managed?
- Who has authority and responsibility for maintaining the data?
- Is there a robust system in place for managing database backups?

The implementation of a risk ranking system based on a GIS platform presents a good opportunity for such questions to be addressed to demonstrate that robust data management procedures have been designed and implemented.

BENEFITS OF GIS FOR PIPELINE RISK ASSESSMENT

Given the need to manage pipeline data and assess risk in a controlled and auditable manner, a GIS offers many benefits as a way of achieving this goal, including:

- *Existing Data models*

However data is stored, it needs to be done in a controlled and consistent manner. Pipeline Database models, designed for use with GIS systems, are readily available which facilitate storage of the majority of the information any company may require. These models can also be extended to store additional, specialist information should the need arise. Availability of such models reduces system design time.

- *Future-proofing*

Using a GIS with one consolidated database, into which risk calculation engines are embedded, provides a framework into which further engineering models can be added later should the need arise.

- *Integrated view of data*

The availability of all pipeline and integrity data together in the same place, along with raster map information for geographic context, allows the user to gain insight into the results of integrity calculations. For instance, a pipe segment giving a high risk value may readily be seen to be in proximity to relevant physical features such as particular soil types or other environmental factors. Essentially, the real value of having Quantitative Risk Assessment and GIS on the same platform is in providing the integrity engineer with a clearer view on where his real problems are now and where they are likely to be in the future. The engineer benefits from

having models that accurately predict pipeline condition/integrity information (Probability of Failure for each threat and Consequence of Failure) and the combined risk, and being able to show these values and how they change over time, in relation both to where the pipeline is and in relation to other parameters. The system helps the integrity engineer with what he needs to do and where to monitor and really focus on the key issues for each section of his system. Should he be closely monitoring the Cathodic Protection levels since the corrosivity is high in that location and the Consequence of Failure is severe? Should he be ensuring more frequent aerial and patrol activities to reduce the number of encroachments and therefore reduce the incident frequency because the External Interference risk value is excessive? Further examples of the benefits of an integrated view would include:

- gas release areas,
- liquid spills and impact on water courses for hazardous liquid lines
- relating condition and locations of defect to populous areas
- locating soil environments that might increase susceptibility to corrosion and Stress Corrosion Cracking
- fault zones
- land slips

IMPLEMENTATION CHALLENGES

Implementing a risk analysis system based on a GIS is not a trivial task, and requires proper planning. The core issue is the establishment of a robust database containing verified data, and implementation of policies for its future maintenance. The way in which this is achieved will depend largely on the starting point, and whether the company concerned already has validated, consistent data, or whether it is starting from a position of heterogeneous data sources perhaps including paper records.

Software licenses, roll out and training also need to be planned. It is important that the users of the system sign on to the concept of a GIS-based risk ranking system, and are involved in the system from an early stage. Failure to do this risks alienating the user base and will make it difficult to realize the benefits the system is intended to provide.

CONCLUSIONS

Driven by legislation in some regions as well as by the need for good governance of engineering practices, there is a need for the risk to the integrity of pipelines to be properly understood and actively managed. This can be achieved through qualitative assessments, which require a degree of engineering judgment, or by quantitative assessments, which are based more on investigation and understanding of the structural reasons for failure. In practical terms, delivery of quantified pipeline risk assessment can best be achieved by integrating the risk calculation facilities into a GIS, allowing integrated management of pipeline integrity and risk data.

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