Pipeline Integrity Management System

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Abstract

Good industry standards are nowadays available to support logical and consistent approaches to many of the key processes of pipeline integrity management (PIM). This paper presents a case study within Europe where a PIM system was customized to the individual needs of a pipeline operator. It reviews the underlying principles of customization and examines how codified processes, rules and standards can be used during customization to ensure conformity with industry best practices. Moreover, the paper examines the nature, roles and interactions of the three main components of PIM - people, processes and technology - with the aim of improving the delivered value of the PIM program. Furthermore, it describes a software-aided process of this automated geographical pipeline centerline creation as the basis for a High Consequence Area Analysis and how it is finally utilized to provide the necessary input on immediate defect criticality prioritization and a risk-based mitigation strategy.

Keywords: Asset Integrity Management, Risk Management, ILI (In-Line Inspection) XYZ mapping, Data Management & Alignment, Centreline, High Consequence Area Analysis, Pipeline Repairs & Best practices.

1. Introduction

Many operators face time-consuming activities for developing an integrity management plan and a risk-based inspection strategy for their many kilometres of pipelines. They thus, require huge amounts of data input and its management to allow for reliable deductions on the safe and reliable use of their assets.

As an example, the US Electronic Code for Federal Regulations No. 49 CFR 192, for gas pipelines, states that an integrity management plan should include a process for the identification of all High Consequence Areas (HCAs) along the line, a baseline assessment plan, the identification of threats to each covered section, direct assessment plans, remediating conditions found during integrity assessments, a process for continual integrity assessment and evaluation, and a performance measurement plan. Further, the integrity assessment plan developed should define the credible threats to which a pipeline segment is susceptible, define the criticality of the features in the pipeline segment, include risk analysis and assessment results, tools recommended for assessing credible threats, and define the reassessment planning.

ASME B31.8S, for managing system integrity of gas pipelines, describes the two approaches an operator may use to develop and implement an effective integrity management plan; prescriptive approach and risk-based approach. The standard provides guidance on the process for managing the safety and integrity of pipeline systems in a systematic, integrated and comprehensive way. The integrity management plan should include a) the identification of potential threats to the pipeline especially in areas of concern, b) the definition, gathering, review and integration of data to understand the condition of the pipe, c) determine the location of threats and understanding the consequences of failure to different receptors, d) a risk assessment, e) an integrity assessment based on the risk assessment, f) mitigation and...
API Standard 1160 for managing system integrity for hazardous liquid pipelines, provides guidance to an operator on the key features an integrity management plan should include: a process for determining which segments could affect HCAs, a baseline assessment plan, a process for periodic integrity assessment and evaluation of segments that could affect an HCA, a process for integrating all pipeline integrity data and consequence of failure information, repair or mitigation plan, a process to identify and evaluate P&M activities used to protect HCAs, and provisions to measure the effectiveness of the integrity management plan.

Taking a look at all available data sources, inline inspection data is primarily considered as the solution for the assessing and understanding of the current condition on a particular segment of pipeline. On this matter, a combined XYZ mapping run during inline inspection (ILI) by pigging not only provides valuable information on the geographical location of individual features, but also provides information to prioritize those by their immediate potential environmental impact as well as gives the necessary input on a future consequence assessment, and thus, operators get the actual detailed pipeline route and its interaction with the environment and human settlements.

2. Description of XYZ Mapping

XYZ mapping was developed to determine 3-D geographical pipeline coordinates using inertial navigation. The XYZ mapping device is usually integrated in an ILI tool, e.g., CDP or XEGP. Mapping of the pipeline coordinates and gauging of the inner geometry and associated pipeline features are monitored simultaneously during the pig run. The survey results include information about the pipeline’s XYZ location, visualized by plan, elevation, and distance views. Pipeline alignment, direction, horizontal and vertical bend orientations with respect to angle, radius, direction and location are measured, computed, and reported accurately.

The pig’s translational and rotational movements are measured with the help of accelerometers and gyroscopes, which are the main components of this inertial system. After compensating for the earth’s rotation, gravitation and other forces, it determines orientations and velocities in X, Y and Z directions. By correlating the inertial system results with the data from dippers and odometer information, the pig computes the exact orientation and position of the pipeline in three dimensions. Known reference points are necessary to achieve sufficient accuracy of absolute measurements (in Differential GPS - DGPS - position and GPS time). For this purpose, the use of above-ground bench-markers placed at known GPS reference points are needed. The marker receiver is then activated by the on-board pig
transmitter system. The system records the GPS time of the pig’s passage, e.g. measuring the time GPS position of the trap stations and line valves, generates reference points. See schematic Figure 1 below.

![D-GPS and Benchmark Receiver](image)

Figure 1: XYZ principal.

3. Centralized Integrity Management Systems

ROSEN Asset Integrity Management Software (ROAIMS) for pipelines is a collection of inter-operable software tools for maintaining and managing assets in a reliable, safe and cost-effective condition. The key objective of ROAIMS is to enable an efficient, auditable and well-structured integrity process to support operators in their day-to-day work.

The software was designed to follow ROSEN’s unique “control loop” approach to asset integrity. The integrity loop used as part of this approach is broken down into the following major steps:

- Processing
- Inspection & Testing
- Asset Integrity Management
- Rehabilitation

ROAIMS allows users to visualize, explore, and analyse complex information, systems and processes and additionally acts as a storage facility enabling you to manage large amounts of data quickly. ROAIMS can optimize clients’ integrity spend by not only identifying the most significant immediate and future threats, but also by allowing virtually any mitigation action to be captured/applied and comprehensive scenarios to be automatically and/or manually constructed and compared. The flexibility of the software allows users to individually select relevant modules to create their own personalized software system.

Industry standards are considered in the specification phase of the general software concept (e.g. AS2885, API 1160, ASME B31.8s) down to each specific algorithmic implementation (e.g. defect assessment based on ASME B31.G, RStreng).

4. Centreline Creation Based on Inertial ILI Data

Using the Inertial In-Line Inspection (ILI) recorded data, the immediate necessity is the creation of two combined, consistent and accurate reference systems, the coordinate system in combination with the stationing system. These are commonly combined to create the “XYZ + M” centreline environment used in the latest standardized data models.
The software-based process utilizes a spatial alignment method, “linear referencing”, to combine the most accurate XYZ information – coming from in-line inspections – with the stationing values mainly historically defined in the pipeline design data documentation. The pre-condition for this type of data alignment is the identification of identical reference objects in both datasets as the basis for an accurate calculation. In most cases, pipeline facilities like valves, taps, tees or makers are identified in the technical sheets as well as in the in-line inspection data, so that the matching can be performed.

As a result, the pipeline and its installations are brought into a global spatial context allowing the user to analyse the pipeline route and its installations together with various additional aspects like terrain, water resources, roads, populations distribution, soil characteristics, or datasets coming from other external inspection activities.

The whole workflow of centreline creation is digitally implemented as an automated Extract-Transform-Load (ETL) process that directly writes the centreline representation into a common database system (e.g. Pipeline Open Data Standard “PODS”). Following the alignment procedure, the sources are merged and the PODS database is automatically filled with the stationed centreline, the pipeline facilities as well as their properties and the respective geographical location of each object. See Figure 2 below.

![Figure 2: ROAIMS ETL Process to PODS.](image)

### 5. High Consequence Area Analysis

The aim of a High Consequence Area (HCA) analysis is to identify all segments of a pipeline system having the potential to affect an HCA either directly or indirectly. Regulations require integrity management in all HCAs therefore, it is necessary for the operator to identify all of the pipeline segments that can affect an HCA. Depending on the product and the pipeline transportation characteristics, different methods apply for the determination of regions that could be influenced by a pipeline failure. See schematic given in Figure 3 below.

![Figure 3: High Consequence Area Evaluation.](image)
The US regulations specify High Consequence Areas for liquid pipelines in CFR 49 § 195.450 and CFR 49 § 195.6. For liquid transmission pipelines, an HCA can be determined by performing a direct analysis, indirect analysis or terrain analysis. HCAs for liquid lines are high population areas, busy commercial navigable waterways, or environmentally sensitive areas. Parameters that need to be taken into account to determine which HCA could actually be influenced by pipeline rupture or leak scenarios are defined in US CFR 49 § 195.452.

For gas pipelines, the model for determining high consequence areas considers – apart from transportation characteristics – mainly population data situated in a certain distance around the pipeline centreline (US CFR 49 § 192.903). Therefore, a HCA is determined either by Class Location along the pipeline or by the assessment of an area of a circle of threshold radius (termed the ‘potential impact circle’) along the pipeline. ASME B31.8S provides guidelines on calculating the refined potential impact radius for different gas fluid types. In ASME B31.8S four location classes are defined with regards to the building and population densities.

The outcomes of the High Consequence Area calculation, is the segmentation of a pipeline centreline based on area categories, which depends on the type of area they are intersecting (e.g. census population, river network, road network, natural parks, water intakes, environmentally sensitive areas) as well as on the amount of areas they influence either directly or indirectly. These segments are then made available in the overall software context to later on directly influence defect assessment and risk assessment calculations.

6. Immediate Defect Prioritization

In order to prioritize defects, the operator defines certain rules depending on isolated defect characteristics, e.g. “general corrosion features with peak depth greater than or equal to 60 % wall loss” as well as on calculated properties considering additional pipe and environmental characteristics, e.g. “features with an Estimated Repair Factor (ERF) greater than or equal to 1”. The determination of the ERF requires the Maximum Allowable Operating Pressure (MAOP), which itself depends on the class location. The characteristics of this parameter should be reviewed occasionally as population density changes overtime.

The defined procedure and software-based process takes into account these possible changes. Using the coordinated information coming from the XYZ mapping run allows for overlaying feature information with the results coming from HCA evaluation, and the revised MAOP is facilitated to calculate the ERF. Considering a high amount of features of the same criticality, i.e. with an identical prioritization based on the previously described rules, the software allows to consider the defects’ geographical location directly. This consequentially follows the guidance for prioritizing and scheduling anomalies based on for example API 1160: “Anomalies located in or near casings, near foreign pipeline crossings, areas with suspect cathodic protection, or HCAs should take precedence over other pipeline locations with similar indications.”

Furthermore, within this sophisticated software environment, users have various advanced filter mechanisms, allowing to query the defect data in combination with the HCA outcomes for data crosschecking. As API 1160 outlines, examples for such capabilities of comprehensive data management software are as follows:

- Information and data can be sorted, filtered, or searched (e.g., list all corrosion defects with depths > 40% in HCAs).
• Anomalies can be prioritized based on combined information (e.g., a corrosion spot in a specific location and in conjunction with a gouge). Figure 4 shows example high consequential area evaluation.

![Figure 4: High Consequence Area evaluation.](image)

7. Risk Model Designer

The Risk Model Designer (RMD) is an application within ROAIMS for pipelines, which allows the user to design and develop new risk models, or to make changes to existing risk models in accordance with the current risk model framework.

Two sections are available in the RMD application, the Modelling section: ability view, develop and edit the risk model (questions, answers, values, dependencies, equations etc.) and the Validation section: able to view the algorithms (e.g. for a particular threat) and test the algorithm by entering answers and assessing the estimated result.

The ability to alter existing risk models or develop new risk models enables flexibility which could help the operator to obtain a more realistic and site-specific understanding of the risk profile of the pipeline and assist in optimizing risk-based mitigation strategies.

8. Risk Assessment

Using a function of the probability of failure due to a certain credible threat and the consequences in case of a failure, the risk in a specific segment of pipeline is evaluated. When deciding on the methodology to be used for the risk assessment exercise, an operator should decide on the approach to follow, e.g.:

- Qualitative Risk Assessments
- Semi-Quantitative Risk Assessments
- Quantitative Risk Assessments

The main difference between these methods is the amount and detail of pipeline information needed to fulfil a certain assessment. When evaluating the different models against each other, an operator should try to find the best balance between the complexity of the model, the available pipeline information and the effort required to populate the risk model with data and perform the assessment. For the risk model developed, a combination of a qualitative questionnaire approach and the input of “real” absolute data was chosen for implementing in the software environment; and thus, the model has been defined as ‘semi-quantitative’.
The Risk Assessment module is an integrity management application which allows the user to estimate and manage the risk level along the pipeline. In performing the risk assessment, one has to a) initially segment the pipeline based on different threat and consequence parameters, b) perform the threat susceptibility and severity assessment, c) perform the consequence of failure assessment and d) perform the risk analysis.

In the threat assessment model, the threats are differentiated and grouped as being either time-dependent or time-independent. See table below:

<table>
<thead>
<tr>
<th>Time-dependent</th>
<th>Time-independent</th>
</tr>
</thead>
<tbody>
<tr>
<td>• External Corrosion</td>
<td>• Third party damage</td>
</tr>
<tr>
<td>• Internal Corrosion</td>
<td>• Sabotage</td>
</tr>
<tr>
<td>• Erosion</td>
<td>• Operating Faults</td>
</tr>
<tr>
<td>• External Stress Corrosion Cracking</td>
<td>• Ground Movement (e.g. ground collapse)</td>
</tr>
<tr>
<td>• Fatigue</td>
<td></td>
</tr>
<tr>
<td>• Slow Ground Movement (e.g. slow subsidence)</td>
<td></td>
</tr>
</tbody>
</table>

ILI data gives significant input on the presence of external and internal corrosion threats. The information gathered during those steps previously described in this document, helps extensively to obtain an indication on the impact on the different consequence categories. See table below:

<table>
<thead>
<tr>
<th>Direct input</th>
<th>Indirect input</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Impact of a failure on local population</td>
<td>• Legal impact</td>
</tr>
<tr>
<td>• Consequence of a failure on local environment</td>
<td>• Impact on company image</td>
</tr>
<tr>
<td></td>
<td>• Economic costs to the company</td>
</tr>
</tbody>
</table>

The modes of pipeline failure – whether a leak or a full bore rupture – are considered when conducting a consequence assessment.

During the evaluation of the consequence model for the different consequence categories, the most important factors to be considered are the HCAs, the estimated spill amount as well as additional environmental factors that can be put into the model based on some relative and absolute input fields.

The results derived from HCA analyses are incorporated for deriving the impact of a pipeline failure on the local population as well as the local environment.

During a Risk Assessment exercise, the probability of a pipeline failure derived from the threat assessment is combined with the consequence of a pipeline failure derived from the consequence assessment, and their results can, in most cases, be represented in a matrix visualization.

Within the sophisticated software environment, users can visualize and relatively rank each segment against each other with regards to the probability of a failure, the consequences should a failure be realized and the risk profile. These results are the valuable input for recommending verification and mitigation tasks. Figure 5 below shows risk assessment results.
8. Conclusion

The use of a XYZ run as a combined tool provides many cost effective advantages for many operators, especially in areas where the spatial component is not fully leveraged and the pipeline reference system is mainly distance-based.

The first step of gathering and ordering data is key in enabling a cost effective Pipeline Integrity Program along with prioritizing engineering decisions and accelerating the next phase of the integrity program. Considering vast amounts of information are generated during the integrity management process, software tools become a necessity to aid the engineer in its practical implementation. This includes essential elements such as effective data integration and management, appropriate assessment tools, documentation of the integrity assessments conducted, risk assessments, and data crosschecking.

Performing a risk assessment is an important phase in an integrity management program and is essential to assess identified threats to the pipeline, understand the consequences of failure and estimate the risk of failure (or loss of integrity) of the pipeline to the identified threats. Furthermore, having a flexible risk model designer capability can benefit the user/operator with the ability to develop new or edit existing risk models, which could enable the operator to obtain a more realistic understanding of the risk profile of the pipeline and assist in optimizing risk-based mitigation strategies.

As a final conclusion, a centralized approach for managing integrity data and assessing integrity and safety matters of a pipeline system can minimize operators’ efforts during their daily decision making activities. Looking not only at the immediate defect prioritization, but also at the future rehabilitation planning and inspection schedules, the assessment of defect growth mechanisms (e.g. corrosion) and the application of appropriate (agreed) rates of growth (for both internal and external corrosion) will help to estimate budgets on required upcoming integrity matters. Furthermore, preventative and mitigation activities coming as a result of both risk assessments and integrity assessments, can be controlled and tracked in a software added process allowing users to keep a record of the activities done, and thus, create and manage an auditable process.
References

1. API 1160, Managing System Integrity for Hazardous Liquid Pipelines
2. ASME B31.8S; Supplement to B31.8 on Managing System Integrity of Gas Pipelines
4. The Pipeline Open Data Standard Association (www.PODS.org)
5. G.Weigold, C.Argent, J.Healy, I.Diggory, A Semi-Quantitative Pipeline Risk Assessment Tool for Pig-gable and Un-Pig-gable Pipelines, IPC06-10280, Proceedings of IPC2006,