Bowtie Risk Assessment of Electrofusion Fitting Installations

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Abstract

Risk modeling is typically applied in the process of Integrity Management (IM) for existing, in-the-ground pipeline assets. Risk modeling, however, can also play a valuable role in examining the potential risk and identifying and assessing the value of potential mitigations in the acquisition or installation phase of new pipeline assets - prior to their going into the ground. An example bowtie risk assessment for electrofusion fitting installations based on the Bowstar™ bowtie risk analysis software is presented to demonstrate this approach. Based on historical failure modes and data, a foundational bowtie risk model is developed. Possible mitigations, such as training and inspection, are assessed to examine their potential impact on reducing risk. The process is seen to provide valuable insights into the potential value of different mitigations on risk reduction, This provides operators with a valuable tool for reducing risk in new pipeline installations. For the example case of electrofusion fitting installations, the analysis highlights the potential risk reduction benefits of training and inspection.

Risk Modeling Applied to the Pipeline Installation Phase

There is rapid evolution in the risk modeling approaches that gas distribution and transmission pipeline operators apply in their integrity management efforts[1]. Risk modeling, however, is most typically applied to existing, in-the-ground assets. Risk modeling can also be applied to assess potential risks and possible mitigations prior to assets being installed, in what is termed the 'acquisition' phase in the PAS-55[2] and ISO 55000[3] asset management frameworks.

As for buried pipeline assets a significant component of the future risk profile is cast when these go into the ground. Therefore, when combined with a systematic asset management approach, significant improvements in overall pipeline integrity can be obtained through assessing risk in the installation phase. Specifically, risk modeling in this stage is targeted towards reducing infant mortality and extending pipeline longevity. For example, the American Gas Association (AGA) Plastic Pipe Data Collection (PPDC) findings support that there are issues with recently installed distribution pipelines[i]. Of gas distribution pipeline joint leaks experienced within the first 5 years of installation, 58% of leaks are due to installation errors, some 18% of fitting leaks are due to material defects and over 20% of the leaks have unattributed causes (unknown, not recorded or other), as shown in Table 1 and Figure 1. Similarly elevated numbers exist for pipe and fitting leaks. What is not known is how these systems will perform over the long-term. It is certain that product design and quality issues or poor installation issues can take years to present themselves.

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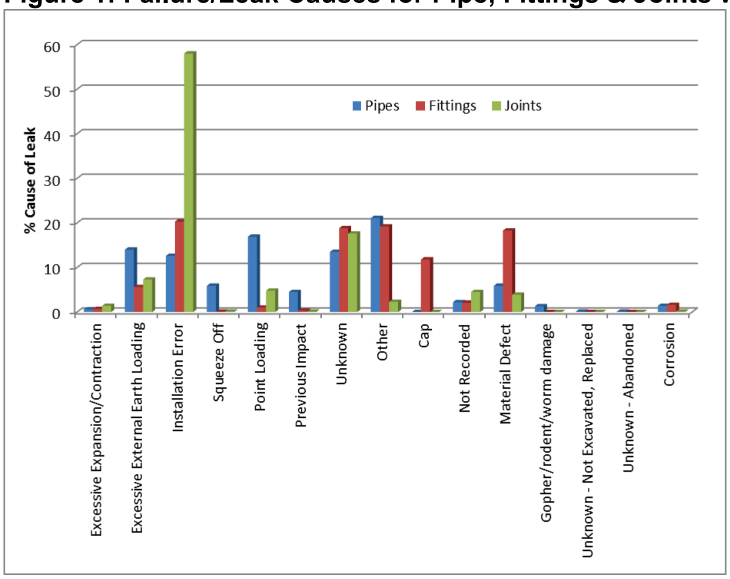
[1] Reference JANA Absolute Risk Paper and Consequences paper…
[2] Add ref
[3] Add ref

Table 1: Failure/Leak Causes for Pipe, Fittings & Joints within 5 Years of Installation

Cause	% of Total Pipe Failures/Leaks	% of Total Fitting Failures/Leaks	% of Total Joint Failures/Leaks
Excessive Expansion/Contraction	0.6	0.7	1.4
Excessive External Earth Loading	14.0	5.6	7.3
Installation Error	12.6	20.3	58.0
Squeeze Off	5.9	0.1	0.1
Point Loading	16.9	1.0	4.8
Previous Impact	4.5	0.3	0.1
Unknown	13.5	18.8	17.6
Other	21.1	19.2	2.3
Cap	0.0	11.8	0.0
Not Recorded	2.2	2.1	4.5
Material Defect	5.9	18.3	3.9
Gopher/rodent/worm damage	1.3	0.0	0.0
Unknown - Not Excavated, Replaced	0.1	0.0	0.0
Unknown - Abandoned	0.1	0.0	0.0
Corrosion	1.4	1.6	0.1
Total	100.0	100.0	100.0

Figure 1: Failure/Leak Causes for Pipe, Fittings & Joints within 5 Years of Installation



Hand in hand with gas utilities, JANA has developed the JANAcquire55™ approach that specifically addresses the risks through the entire asset lifecycle by ensuring the right decisions, methods and products are employed in the construction of new or replacement pipelines, e.g. the asset acquisition phase.

The JANAcquire55™ process and the resulting 'toolbox' that is derived from it eliminate the causes of infant mortality and prolong the time before the wear-out stage of a pipeline asset begins. This approach brings together some of the tools and methods used in the nuclear, automotive and aerospace industries to address critical risk. The process presented has been adapted to address the specific needs and constraints of gas distribution pipelines.

The JANAcquire55™ process involves:

1. Identification of the component or operational process to be assessed
2. Collection and review of all related information
3. Detailed analysis of all the potential root causes of failure
4. Mapping of all current mitigations via a fault tree analysis

5. Risk assessment of failure rate and mitigation effectiveness
6. Gap analysis to identify where additional risk mitigation is required
7. Development of appropriate corrective action to reduce risk

Key to this process is modeling the potential risk in future pipeline installations. In this paper, an example modeling approach for electrofusion fitting installations is presented based on a bowtie risk modeling approach.

Electrofusion Fitting Installation

Electrofusion fittings are seeing increased use in gas distribution pipelines. While electrofusion (EF) joints can be highly reliable, quality components and installation techniques are necessary for ensuring the long-term integrity of the joints. As discussed previously, the Plastic Pipe Database Committee (PPDC) has identified infant mortality failures in electrofusion joints[4]. Similarly, a comprehensive study of electrofusion joints in the UK water industry[5] found that 20% of field EF joints sampled failed in destructive testing. The primary causes of failure in this study were identified as:

- Inadequate clamping or misalignment: 34%
- Contamination: 29%
- Poor scraping: 26%
- Other: 11%

In root cause analysis (RCA) and field studies with clients, JANA has observed similar issues in US gas distribution systems and similar or higher failure rates for destructive testing on installed fittings. Assessing the risks mitigations in the electrofusion fitting installation process, therefore, has the potential to provide significant enhancements to pipeline integrity.

Bowtie Risk Assessment

A bowtie type risk assessment was constructed for the electrofusion fitting installation process based on the Bowstar™ bow tie risk assessment software. Bowstar™ employs an advanced bowtie method to complete a risk inventory, which allows definition of a mitigation plan that enables pipeline operators to optimize the lifecycle of their assets and facilitate decision-making in the most economical way to manage risk and integrity. Bowstar™ is a process model software demonstrating the transparency of all integrity related operational activities and the way the cycle of improvement has been embedded into daily practice. It provides an enhanced bowtie risk assessment technique with a highly structured inventory of threats, consequences, escalations and mitigations throughout the lifecycle of a pipeline asset, including effectiveness and cost. Algorithms enable the economic evaluation of mitigations and quantification of the effect of new mitigations can be visualized. This approach allows a pipeline operator to balance between preventive and repressive mitigations to find the most economical solution to managing its risk.

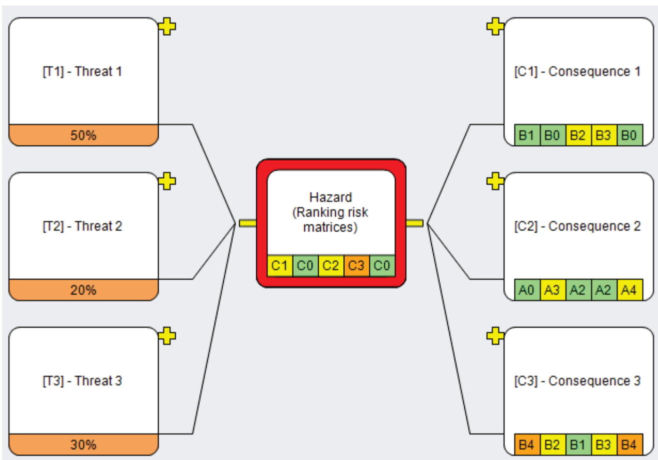
[4] Plastic Piping Data Collection Initiative Status Report, December 2014.
[5] UK WIR Report Ref No 10/WM/08/43, "Leakage from PE Pipe Systems", 2011

Bowtie Model

The goal of a Bowtie Model is to create an overview that includes the risks an organization needs to mitigate, the effectiveness of mitigation measures, possible improvements and the costs involved. The results can be used to ensure the integrity and security of the assets in place, as well as to motivate investment policy and improving continuity.

As inspection data, historical leak data, etc. are not available for uninstalled assets (as they are for existing assets), the data used for assessments in the acquisition phase is based on data for similar past components combined with SME (Subject Matter Expert) input.

A Bowtie Model can be visualized as follows:



Bowtie Models include the following:

- Unwanted Event: Hazard that needs to be controlled; sometimes referred to as the 'top event'
  - It is situated in the center of the bowtie model
- Threats: Threats that could cause the unwanted event to occur
  - Threats are visualized in the model on the left side and show a direct relationship between the causes of the unwanted event and the unwanted event itself
- Consequences: Possible outcomes should the unwanted event occur
  - Consequences are displayed at the right side of the model and show a direct relationship between the unwanted event and the consequences of the unwanted event
- Lifecycle Barriers: Barriers for each threat and consequence, based on the asset lifecycle phases
- Escalation Factors: Threats which could erode the degree of effectiveness of each lifecycle barrier
- Mitigation Measures: To minimize the chance that an escalating factor causes damage, a mitigation measure should be applied. Often, multiple mitigation measures are applied concurrently. Several types of mitigating measures can be defined:
  - Mitigation measures which are already in place
  - Improvements for existing mitigation measures
  - New mitigation measures

Electrofusion Fitting Bowtie Risk Assessment

The Bowstar™ risk assessment software was used to conduct a bowtie risk assessment for electrofusion fitting installations. A simplified version of the overall JANA EF Bowtie Risk Analysis is presented below. Overall the analysis highlights the benefits of improved training and inspection in the EF installation phase in reducing pipeline risk.

A simplified version of the JANA EF Bowtie for the primary hazard of 'leak' is shown in Figure 2. Similar bowtie diagrams are developed for each of the primary hazards (e.g. pinhole, leak, rupture, loss of service, etc.) in a complete analysis.

For the leak hazard, the primary threats are based on historical EF failure types:

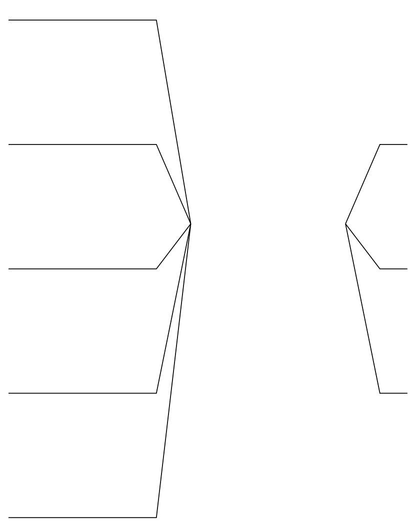
- Faulty EF Fitting
- Contamination
- Misalignment (or poor clamping)
- Poor Scraping
- Interrupted (or incomplete) fusion

The primary consequences included are:

- No ignition
- Ignition
- Explosion

Probabilities and potential consequences have been assigned based on general historical data (the analysis is customized for a given utility based on historical data, an audit of existing practices, SME input, etc.).

Figure 2: Simplified Base Electrofusion Bowtie



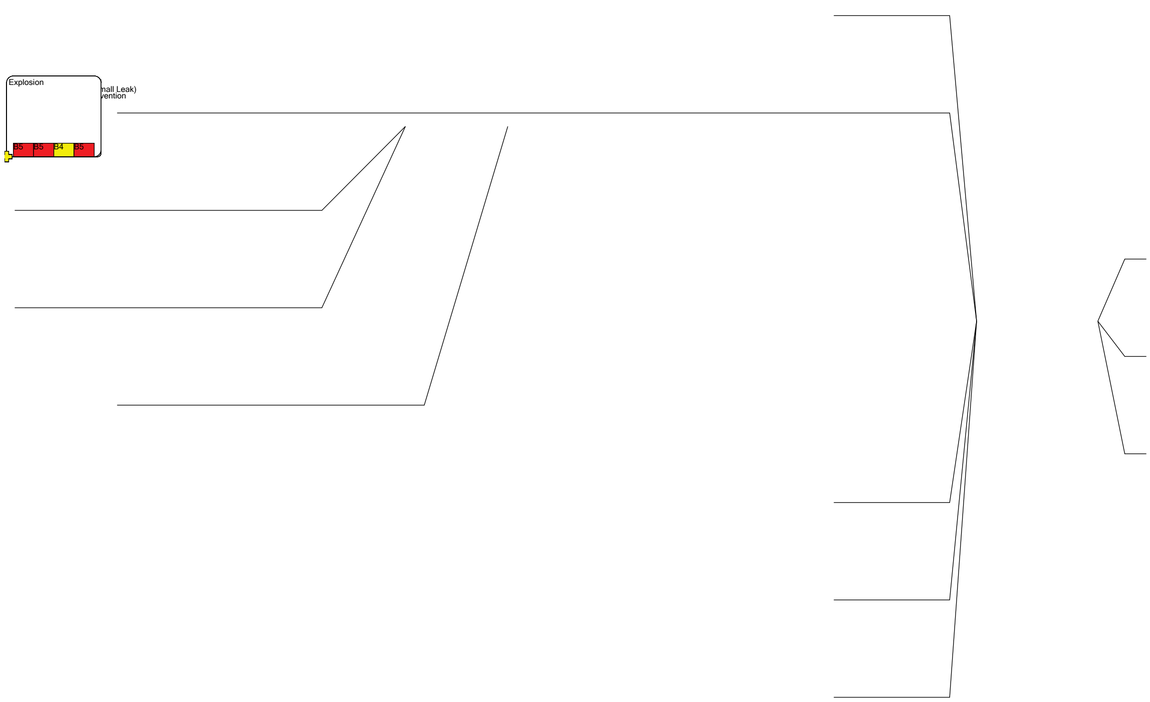
For each threat the lifecycle phases of: design, construction, commissioning, operations, maintenance, 3rd party interference and mothballing/removal, are examined to identify potential escalating factors and existing or potential barriers for each of these escalating factors. As the current risk analysis is focused on the acquisition phase, the assessment is conducted for only the design, construction and commissioning phases. A complete lifecycle analysis would include all phases.

Figure 3 provides a simplified version of the full bowtie analysis, showing for each threat the lifecycle barriers, escalating factors and existing or potential mitigations. For existing mitigations, both the current mitigation effectiveness and potential mitigation effectiveness are estimated, enabling the assessment of, for example, the potential risk reduction benefit of additional training or improved supplier controls.

Figure 3: Simplified Electrofusion Bowtie

To illustrate the analysis approach, Figure 4 provides the details of the bowtie for the contamination threat. In the construction lifecycle phase the escalating factors have been identified as poor procedures and poor installation practices. For poor procedures procedural verification has been identified as an existing barrier with an existing mitigation effectiveness of 50%. A potential mitigation effectiveness of 80% was assigned by SME assessment. Inspection was identified as a potential mitigation with a potential effectiveness of 90% (based on NDE inspection of the EF joints on installation[6]). Similarly, for the escalating factor of poor installation practices, training and operator certification were assigned existing and potential mitigations of 60% and 80% respectively and inspection was again identified as a potential (i.e. not currently existing) mitigation barrier.

Figure 4: Detail of Contamination Threat - Simplified Electrofusion Bowtie



On the consequence side, for each identified consequence (i.e. no ignition, ignition and explosion), the potential magnitude and frequency are defined for the identified primary consequence categories (e.g. health and safety, environment, economic cost and reputation).

Once all the escalating factors and potential and existing mitigations in the simplified bowtie were identified and probabilities assigned, an overall risk analysis was run. The resulting risk matrix is shown in Figure 5. The current risk is identified by the black circles and the potential risk reduction on implementation of the additional identified mitigation improvements or new mitigations by the dashed arrows. The analysis highlights the benefits of improved training and inspection on reducing risk in EF installations.

[6] Ref JANA NDE papers

Figure 5: Risk Matrix - Simplified Electrofusion Bowtie

Company value (KPI): All Customer - Assets: PE Joints - Unwanted event: Small Leak - Analysis: 4/1/2016 1:39 PM - impact of life cycles: All 1-2-3-4-5-6-7

	P	A	E	R	A	B	C	D	E	F	G
	People	Asset	Environment	Reputation	Unlikely, never heard of	Possible heard of in industry (10-5 - 10-4)	Sometimes in organisation (10-4 - 10-3)	Regurarly, several times per year (10-3 - 10-2)	Often, several times per month (> 10-2)	Happens several times per month in location	Happens Daily
0	No health effect / injury	No damage	No Impact	No Impact							
1	Minor health effect of injury	Minor damage < 10 K	Minor Impact	Individual Concern							
2	Moderate health effetc / injury	Moderate damage, Costs<50K	Moderate Impact	Local public concern - regional echoes							
3	Serious health effect	Serious damage.Costs<100K	Serious Imapct	Regional concern. National echoes							
4	Major health effect or fatality	Major damage.Costs<1M	Major Impact	National public concern. International echoes							
5	Catastrophc health effect / Multiple fatalities	Catastrophic damage. Costs>1M	Catastrophic Impact	International public attention							

● Original situation

Conclusions

While risk modeling is typically focused on existing, in-the-ground assets, significant opportunities for identifying enhancements to pipeline integrity can be derived by assessing risk in the acquisition phase of an asset, prior to assets being installed in the ground. By way of example, a simplified bowtie analysis for electrofusion fittings highlights the potential risk reduction benefits of improved training and inspection during the EF installation phase. When combined with a systematic asset management approach, such as the JANAcquire55™ approach, and applied across the asset base, such tools have the potential to significantly mitigate infant mortality failures and extend the safe operating life of gas pipelines.