<u>Selected Excerpts</u>

Enbridge Gas Transmission

Dynamic Risk Semi-Quantitative Risk Algorithm

09/20/2019

1 Calculating and Communicating Risk Results

This document describes how failure frequency and consequence are calculated as part of a semi-quantitative risk analysis for Enbridge Gas Transmission pipelines.

Quantitative values of failure likelihood and qualitative (severity index) values of consequence will be calculated for each pipeline dynamic segment, where a dynamic segment is defined as a discrete, contiguous segment of pipeline in which all variables that are used in calculating either failure likelihood or consequence are constant. Risk will be expressed as the product of failure likelihood and consequence, and alternately, as a compound measure represented within a risk matrix.

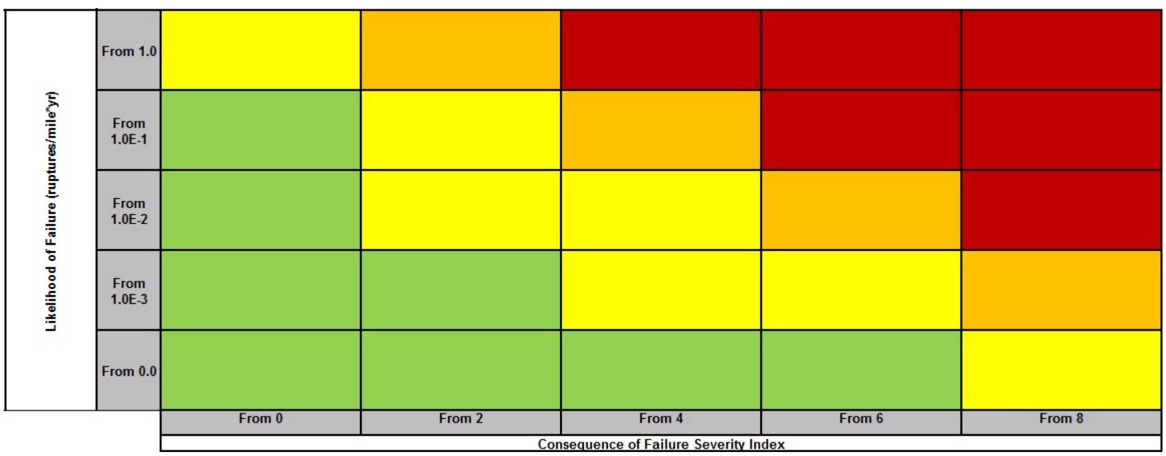

Figure 1: Semi-Quantitative Risk Matrix

2 Risk Methodology

There are a small number of risk models that are purely “qualitative” or purely “quantitative” in their approach. Most have some elements of both:

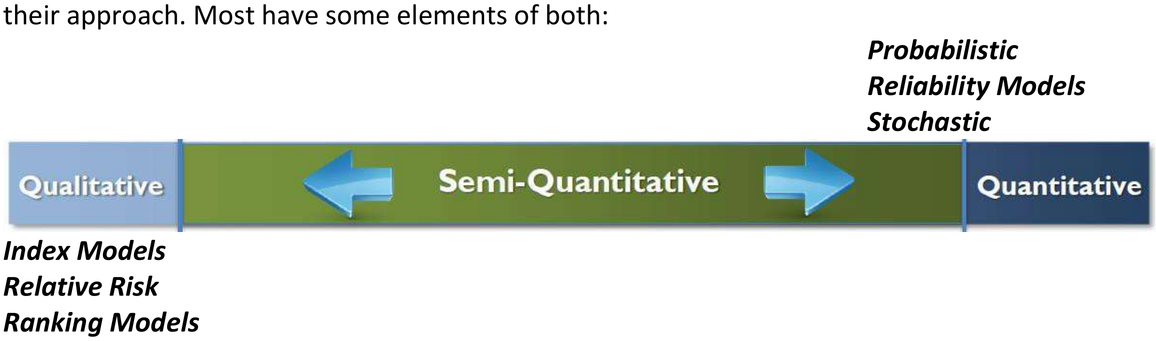

Figure 2: Continuum of Risk Model Approaches

Note that any ellipses (“…”) indicate redacted language, tables, or figures. Some of the material contained in the full procedure is proprietary and/or not relevant to this case and thus has been redacted from these excerpts accordingly.

Risk will be calculated on a semi-quantitative basis, defined as the product of quantitative estimates of Likelihood of Failure (LOF in ruptures/mi-yr) and qualitative (severity indices) estimates representing Consequence of Failure (COF Severity Index from 1-10).

$$ROF = LOF \cdot COF$$

Equation 1 - Risk of Failure

In Equation 1, risk is calculated for each of three measures of consequence:

1. Safety;
2. Economic; and,
3. Environment

In regards to the above measure of consequences, ruptures have a far more significant level of impact for gas transmission pipelines. Therefore, risk (both failure likelihood and consequence) is modeled on the basis of rupture failure modes.

2.1 Baseline Threats and Threat Interaction

Baseline (un-interacted) values of LOF are determined in accordance with Section 3. Interacted threat values of LOF for each threat are calculated by multiplying the baseline (un-interacted) value of LOF for each threat by the Threat Interaction Factor for that threat, as illustrated below.

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Values of TIF_i are determined separately based on the threat interaction approach developed on behalf of the Northeast Gas Association[1]. The magnitudes of individual values of TIF_i are dependent on the magnitudes of contribution to the base threat, derived from an evaluation of incident data.

…

Table 1 - Threat Interaction Factors

Interacting Threat Failure Frequency (ruptures/mi.yr)	Base Rupture Frequency (ruptures/mi.yr)	TIF_i
Manufacturing Defect Susceptibility (See Section 3.5)	External Corrosion (See Section 3.1)	…
Construction Defects (See Section 3.6)		…

[1] Morris, W.G., Mackenzie, J.D., Haines, H.H. , and Kiefner, J.F., "Development of a Methodology for Incorporating Interacting Threats into Risk Models", Northeast Gas Association Final Draft Report, November 25, 2015.

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Interacting Threat Failure Frequency (ruptures/mi.yr)	**Base Rupture Frequency (ruptures/mi.yr)**	**TIF_i**
…	…	…
Manufacturing Defect Susceptibility (See Section 3.5)	Internal Corrosion (See Section 3.4)	…
Construction Defects (See Section 3.6)		…
…		…
…		…
…		…
…	…	…
…		…
…	…	…
…		…
…		…
…	…	…
…		…
…		…

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3 Failure Likelihood Assessment

Failure likelihood is measured in units of ruptures/mi-yr. Failure Likelihood, as it relates to pipeline integrity, is the relative measure of the likelihood of a breach in the pipeline's pressure membrane as a result of a design or operating condition. The intent of the Failure Likelihood assessment is to provide quantitative estimates of rupture frequency, based on the threat environment that the pipeline is exposed to along its length.

Using the guidance of ASME B31.8S, threats to pipelines can be classified in terms of "Time Dependent", "Stable" and "Time Independent" categories.

Time Dependent Threats include:

1. External Corrosion;
2. Internal Corrosion; and,
3. Stress Corrosion Cracking (SCC);

Stable Threats include:

4. Manufacturing Defects;
5. Welding / Fabrication Related; and,
6. Equipment Failure;

Time Independent Threats include:

7. Third Party / Mechanical Damage;
8. Incorrect Operations; and,
9. Natural Forces

The failure likelihood algorithm addresses the likelihood of failure due to each of the nine threats listed above.

…

3.5 Manufacturing Defects

The primary manufacturing defect – related threats on natural gas pipelines are Hard Spots and Seam Defects. Therefore, the Manufacturing Defect Score is derived on the basis of the Hard Spot Score (H_S) (0-10) and the Seam Defect Score (S_S) (0-10) in accordance with the following Relationship:

…

Where,

MD	= Manufacturing Defect Score (0-10);
M	= Material Type Score (0 or 1);
H_s	= Hard Spot Score (0-10); and,
S_s	= Seam Defect Score (0-10)

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3.5.1 Material Type Score

The Material Type Score is equivalent to the Material Type Score defined in Section 3.1.1.1.

3.5.2 Hard Spot Score - [H_S (0-10)]

…

3.5.2.1 Hard Spot Susceptibility Score (S) (0-10)

The Susceptibility Score is an indication of the susceptibility of a pipeline segment to failure due to hard spots. This is taken as a function of the following factors, and their assigned scores:[26]

i. Susceptibility of the pipe to having hard spots (M) (0-10);

ii. Coating Condition (C) (0-1);

iii. Operating Stress level (OS) (0-1); and,

iv. Cathodic Protection levels (P) (0-1).

…

The form of the above equation is consistent with the findings of Reference 26, in that it suggests that in order to have a hard spot failure, all of the following conditions must be present:

- Pipe susceptible to hard spots;
- Poor coating condition;
- Sufficiently high stress levels; and,
- Cathodic Protection "on" values that are more negative than –1.25 v.

If any of the above conditions are absent or insignificant, so that a zero is returned for the score associated with that condition, the above equation would calculate a Susceptibility Score of zero.

[26] Report on Integrity of Vintage Pipelines – Material and Construction Threats, Draft INGAA Report, August, 2003.

3.5.2.1.1 Susceptibility to Hard Spots (M) (Score Range: 0 – 10)

According to Reference 26, the susceptibility to hard spots is confined to a limited subset of pipe manufacturers and eras. Therefore, in accordance with the findings of that reference, the Susceptibility to Hard Spots is assigned scoring on the following basis:

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Table 27 - Pipe History Score

Pipe History	Score
Any pipe for which prior ILI or excavation assessments have indicated a presence of hard spots (where hard spots are defined as regions of pipe having a hardness of Rockwell C22 or higher) • Apply history to like kind pipe (same manufacturer and vintage on the same assessable segment)	10
Like kind pipe on which a previous hard spot failure has occurred.	10
AO Smith pipe manufactured Prior to 1953	10
AO Smith pipe manufactured in the years 1953 to 1960	2
DSAW seam pipe manufactured by Bethlehem, Kaiser, or Republic prior to 1961	2
ERW Youngstown pipe manufactured prior to 1961	2
Unknown manufacturer prior to 1953	3
Unknown manufacturer ≥1953 to ≤1961	2
All other pipe (Default)	0

3.5.2.1.2 Coating Condition (C) (Score Range 0 –1)

In order for hard spots to fail, atomic hydrogen must be cathodically charged into the steel at locations where the environment has come into contact with the surface of the pipe. This can only occur at areas where the coating has degraded and is allowing cathodic currents to access the pipe. Therefore, the coating condition score is assigned a value between 0 and 1.

Where metal loss ILI data is available, the coating condition score is assigned based on external metal loss ILI feature count density as follows:

Table 28 – Coating Condition Score from ILI

Average Feature Density in Segment (Based on Clusters)	Coating Condition Score (C)
≥ 50 features per mile	1.0
≥ 45 to < 50 features per mile	0.9
≥ 40 to < 45 features per mile	0.8
≥ 35 to < 40 features per mile	0.7
≥ 30 to < 35 features per mile	0.6
≥ 25 to < 30 features per mile	0.5
≥ 20 to < 25 features per mile	0.4
≥ 15 to < 20 features per mile	0.3
≥ 10 to < 15 features per mile	0.2
< 10 features per mile	0.1

…

3.5.2.1.3 Stress Level (OS) (Score Range 0 – 1)

As indicated in Reference 26, higher operating stress levels have greater potential for hard spot failure, and based on regulatory limits to maximum allowable operating pressures, the stress levels associated with Class 3 and 4 locations are too low to precipitate hard spot failures. Therefore, the Stress Level Score is assigned on the following basis.

Table 29 - Operating Stress level Score

Operating Stress Level Range (% SMYS)	Score
≥ 70.8	1.0
≥ 69.6 to < 70.8	0.9
≥ 68.4 to < 69.6	0.8
≥ 67.2 to < 68.4	0.7
≥ 66.0 to < 67.2	0.6
≥ 64.8 to < 66.0	0.5
≥ 63.6 to < 64.8	0.4
≥ 62.4 to < 63.6	0.3
≥ 61.2 to < 62.4	0.2
≥ 60.0 to < 61.2	0.1
< 60.0	0.0

3.5.2.1.4 Cathodic Protection (P) (Score Range 0 – 1)

Reference 26 indicates that in order to have cracking cathodic charging must occur, and that

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sufficiently high levels of cathodic charging are only associated with CP "instant off" potentials of –1.2 v or more negative. Assuming a 50 mv IR drop in the soil, this is commensurate with "on" potentials that are more negative than –1.25 v.

Because atomic hydrogen diffuses from steel over time, pipeline potentials that may have exceeded this criterion at some time in the past do not contribute to an increase in risk to hard spot failure provided that recent pipe potentials are below the –1.25 mv "on" criterion. Therefore, only the most recent CP survey data is assessed for the purposes of assigning the Cathodic Protection Score.

…

Where CP data is not available, the Cathodic Protection Score is assigned a value of 1, which is a conservative assumption that reflects the risk associated with uncertainty.

3.5.2.2 Repair Score (0-1)

The potential for hard spot failure is a function of the repair status of any existing hard spots. Therefore, a Repair Score (0 – 1) is assigned on the following basis:

Table 30 - Repair Score

Repair Status	Score
Inspection for hard spots has been performed, and hard spots have been identified, and all hard spots in a segment are repaired.	0.0
Inspection for hard spots has been performed, and hard spots have been identified, and some but not all hard spots in the segment have been repaired.	0.5
Inspection for hard spots has been performed, and hard spots have been identified, but no hard spots in the segment have been repaired.	1.0
Inspection for hard spots has occurred, but no hard spots have been found	0.0
No inspections completed (default)	1.0

…

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