Manitoba Hydro

Marketing & Customer Service
Engineering and Construction Division
Gas Engineering & Construction Dept.

REPORT ON:

Pipeline Risk Methodology Version 1.0
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Executive Summary

This report outlines the methodology used to perform Manitoba Hydro's natural gas pipeline risk assessment as part of the risk management process. Risk management is a consistent and rational method of reducing overall risk to the pipeline system by identifying and focusing resources on pipe segments with the highest risk factors.

Risk assessment is composed of the risk analysis and risk evaluation processes. Risk analysis includes identifying the hazards, analyzing the frequency of hazardous events or incidents and their consequences, and estimating the overall risk. Risk evaluation is used to determine if the risk is significant and recommend options to reduce risk.

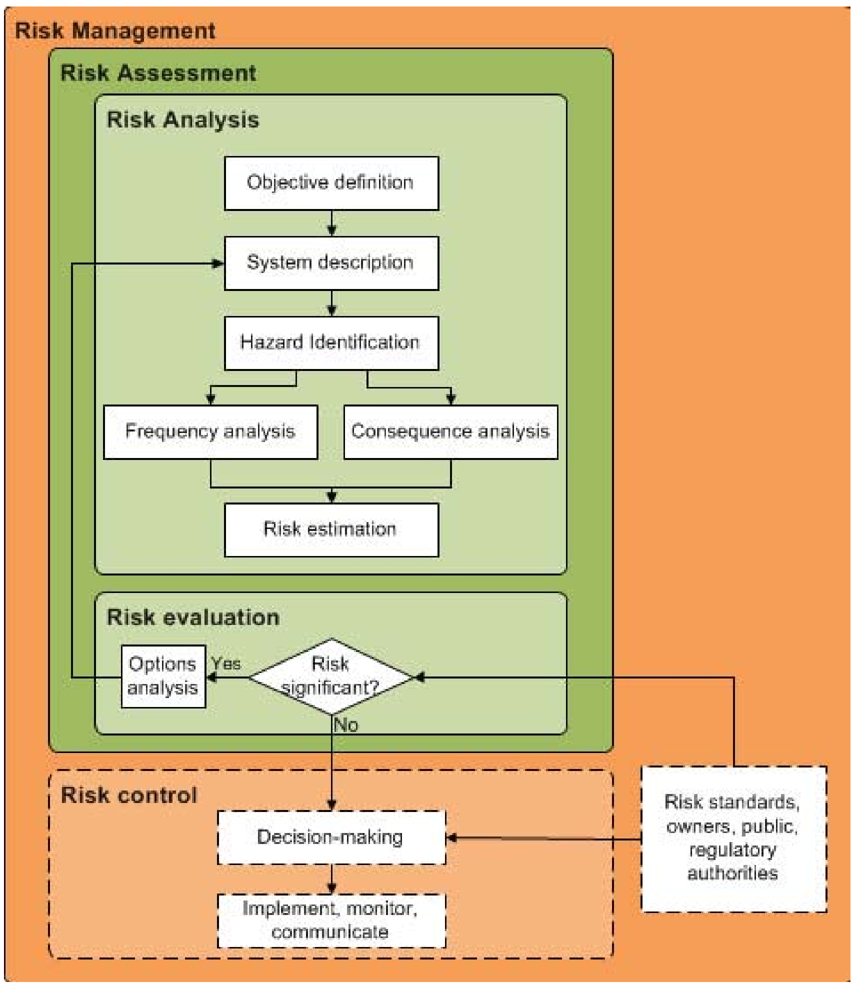

Figure 1: CSA Z662 Risk Management Process

To conduct the risk analysis, the Pipeline Integrity Engineer created a custom model using the software Smallworld GeoSpatial Analysis (GSA). GSA links together spatial and non-spatial data from multiple sources (ex. Smallworld eGIS, Banner, Microsoft Access and Excel, and AutoCAD) where it is then manipulated to suit our specific needs and concerns. Manitoba Hydro has complete control over the model inputs and parameters which is well suited to an evolutionary risk analysis approach.

The pipeline network is separated into two asset groupings for risk assessment. They are:

1. Distribution - Medium and High Pressure (≤ 1900 kPa)
2. Transmission Pressure (>1900 kPa)

The pipeline network is further separated into many small pipe segments sharing similar attributes (pipe material, internal pressure, cathodic protection, etc.).

Hazard Categories are as defined by the Canadian Gas Association (CGA) Asset and Integrity Management task force and are:

- External human interference (e.g. third party hits)
- Corrosion / degradation (age related failures)
- Natural Forces (e.g. slope failures)
- Material, manufacturing or construction defects
- Incorrect Operation

The likelihood of an incident (unintentional release of gas below grade) occurring is calculated using historical incident data as well as industry recognized risk determiners and expressed as a Frequency Score (incidents / 1000kmyr) for each pipe segment and each hazard category. The total Frequency Score is determined by summing the individual Frequency scores for each hazard category. The pipe segments are grouped for risk evaluation as follows:

Descriptor	Typical Frequency Score Characteristics
Almost Certain	• The event will occur on an annual basis • ≥ 80 incidents / 1000 kmyr
Likely	• The event might occur several times or more in a decade • ≥ 40 incidents / 1000 kmyr
Possible	• The event might occur once in a decade • ≥ 20 incidents / 1000 kmyr
Unlikely	• The event does occur somewhere from time to time. • ≥ 1 incidents / 1000 kmyr
Rare	• Have heard of something like this occurring elsewhere. • ≥ 0.5 incidents / 1000 kmyr
Very Rare	• Have never heard of this happening. • < 0.5 incidents / 1000 kmyr

The impact of an incident is calculated using industry recognized risk determiners such as the impact radius and building density of the pipe segment and expressed as a Consequence Score (units / incident) for each pipe segment. The pipe segments are grouped for risk evaluation as follows:

Descriptor	**Typical Consequence Score Characteristics**
High	• ≥ 60 units/incident • Multiple story buildings, dense neighborhoods • Large impact zone • Poor options for reliability during an emergency (transmission only)
Medium	• ≥ 45 units/incident • Suburbs, single family residential areas. • Medium impact zone • Potential source of energy during an emergency outage.
Low	• < 45 units/incident • Rural, farmland and low population areas. • Small impact zone • Reliable source of energy during an emergency outage (transmission only)

The results of the risk analysis are plotted on the Risk Matrix (Figure 2: Risk Evaluation Matrix) to evaluate the risk. The significance of the risk is determined as follows:

Colour:	Risk Evaluation:	Action:
Red	Significant	Refine analysis, evaluate options, and implement action.
Yellow	Less Significant	Refine analysis, consider options.
Green	Not Significant	Monitor

Risk Matrix

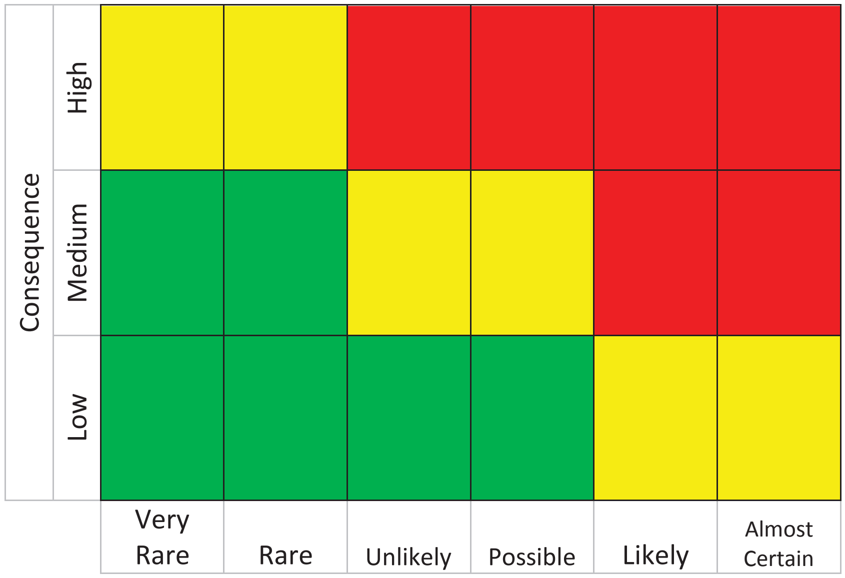

Figure 2: Risk Evaluation Matrix

The results of the Pipeline Risk Assessment are a valuable tool for:

- Making effective choices among risk-reduction measures;
- Supporting specific operating and maintenance practices for pipelines subject to integrity hazards;
- Assigning priorities among inspection, monitoring, and maintenance activities; and
- Supporting decisions associated with modifications to pipelines, such as rehabilitation or changes in service.

To complete the Risk Management Process, the results of the risk assessment are to be used to inform pipeline integrity activity owners and select risk control measures as applicable. The goal is to improve the overall integrity of pipelines while reducing the frequency and consequence of incidents.

In future risk methodology development, considerations include expanding the assets and including non-failure risk (e.g. third party damages that do not result in a release of gas).

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1. Changes from Previous Version

There have been a number of changes to the risk methodology since the last report in 2014. The pipeline risk assessment is a continually improving process and the changes reflect things that were learned since the previous version in 2014. The major changes include:

- The pipeline system has been divided into distribution and transmission pressures groups. These groups can have very different susceptibility factors which can now be analyzed separately.
- Equipment malfunction is no longer included as a hazard category. This change is consistent with the direction of the Canadian Gas Association (CGA) Asset and Integrity Task force. The task force determined that the Equipment Malfunction category was being selected to identify that the asset that leaked was a piece of equipment (e.g. valve) and not by the actual cause (hazard) of the incident. Hazards previously designated as Equipment Malfunction have been reviewed and assigned a new hazard category as appropriate.
- The Hazard susceptibility factors and weightings have been added and/or updated based on input from subject matter experts.
- This risk assessment includes the use of risk reduction measures. This was proposed in the 2014 Pipeline Risk Assessment, under the name of mitigation.
- The Construction / Material Defect hazard has been renamed the Material, Manufacturing or Construction Defect hazard.
- The Insufficient Cover susceptibility factor has been renamed the Depth of Cover susceptibility factor and includes expanded criteria.
- The Frequency scores are scaled against actual leak history data and reported in quantitative measurements.
- During risk evaluation, the risk significance is evaluated using a risk matrix format.

2. Pipeline Risk Assessment Report

The pipeline risk assessment report is a separate document that details the results of a risk analysis and evaluation using the methodology outlined in this document, at a specific point in time.

3. Pipeline Risk Management Overview

Risk management is a consistent and rational method of reducing overall risk to the pipeline system by identifying and focusing resources on pipe segments with the highest risk factors.

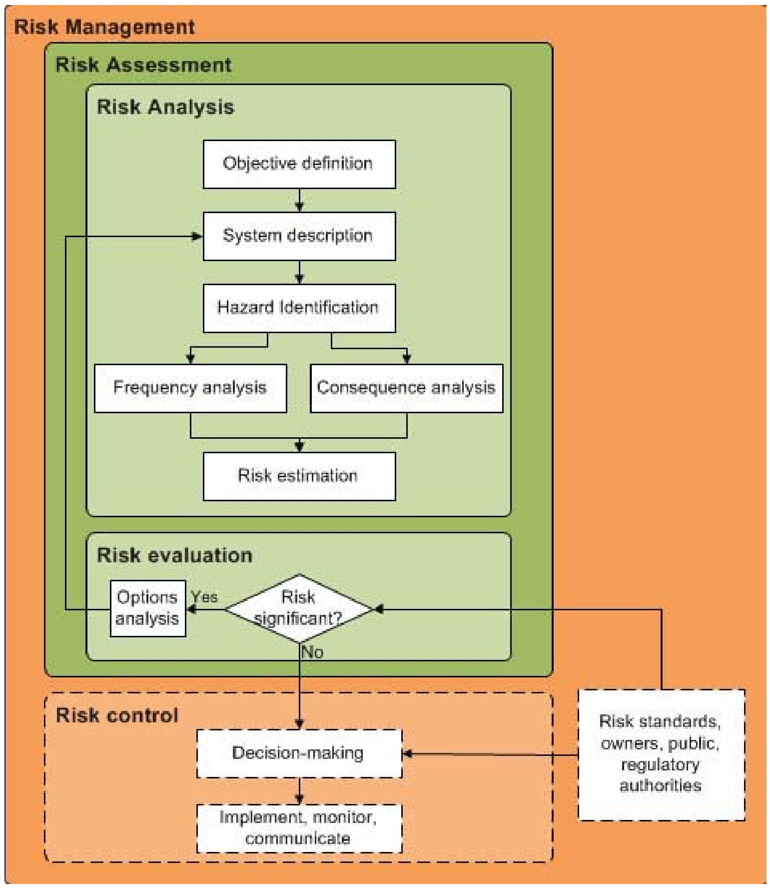

Figure 3: CSA Z662 Risk Management Process

Figure 1 from Annex B of CSA Z662 displays risk management as comprised of both the risk assessment process and implementing risk control measures.

The Pipeline Risk Assessment report satisfies the requirements for risk assessment as shown in Figure 1f. Risk assessment is composed of the risk analysis and risk evaluation processes. Risk analysis includes identifying the hazards, analyzing the frequency of hazardous events or incidents and their consequences, and estimating the overall risk. Risk evaluation is used to determine if the risk is significant and recommend options to reduce risk.

To complete the Risk Management Process, the results of this report are to be used to inform pipeline integrity activity owners and select risk control measures as applicable. The goal is to improve the overall integrity of pipelines while reducing the frequency and consequence of incidents.

4. Objectives and Scope

The objective of the Pipeline Risk Assessment is to identify pipeline segments with significant risk from a failure incident. A failure incident is defined in this report as an unintentional release of gas.

The results of the Pipeline Risk Assessment are a valuable tool for:

- Making effective choices among risk-reduction measures;
- Supporting specific operating and maintenance practices for pipelines subject to integrity hazards;
- Assigning priorities among inspection, monitoring, and maintenance activities; and
- Supporting decisions associated with modifications to pipelines, such as rehabilitation or changes in service.

The Pipeline Risk Assessment scope does not include pipe or assets associated with stations or services.

In future risk assessment development, considerations include expanding the assets and including non-failure risk (e.g. third party damages that do not result in a release of gas).

5. Network Description

Manitoba Hydro uses Natural Gas Standard 510.01 System Pressure Classifications to classify pipelines based on maximum operating pressure (MOP). This system is used primarily for internal corporate purposes and is denoted by:

- Medium Pressure (MP) class exists when MOP ≤ 700 kPa
- High Pressure (HP) class exists when 700 < MOP ≤ 1900 kPa
- Transmission Pressure (TP) class when MOP > 1900 kPa

Manitoba Hydro’s defines transmission pipelines as any pipeline with an MOP greater than 1900 kPa. The MOP is always greater than or equal to the actual operating pressure which is determined by customer demand, flow requirements for odourant, etc. The Canadian Standards Association Oil and Gas Pipeline Systems Standard (CSA Z662) defines distribution pipelines as pipelines operating at less than 30% of their specified minimum yield strength. Manitoba Hydro’s definition is always more conservative. See Figure 2: Manitoba Hydro Pipeline Network.

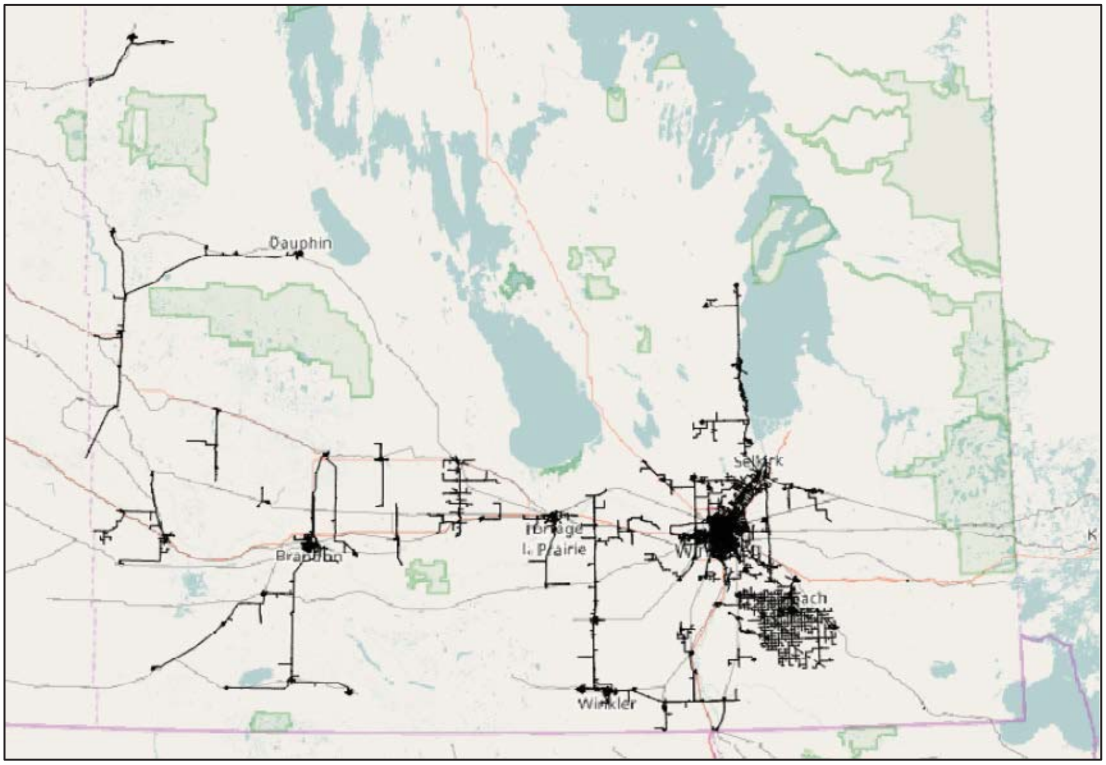

Figure 4: Manitoba Hydro Pipeline Network

6. Pipeline Risk Analysis Methodology

6.1. Introduction

To conduct the risk analysis, the Pipeline Integrity Engineer created a custom model using the software Smallworld GeoSpatial Analysis (GSA). GSA links together spatial and non-spatial data from multiple sources (ex. Smallworld eGIS, Banner, Microsoft Access and Excel, and AutoCAD) where it is then manipulated to suit our specific needs and concerns. Manitoba Hydro has complete control over the model inputs and parameters which is well suited to an evolutionary risk analysis approach.

The pipeline network is separated into two asset groupings for risk assessment. They are:

3. Distribution - Medium and High Pressure (≤ 1900 kPa)
4. Transmission Pressure (>1900 kPa)

The pipeline network is further separated into many small segments sharing similar attributes (pipe material, internal pressure, cathodic protection, etc.). Each of these segments is assigned a risk score. Since all of the segments are scored using the same criteria, the result is a relative risk ranking of the complete network. is a visual.

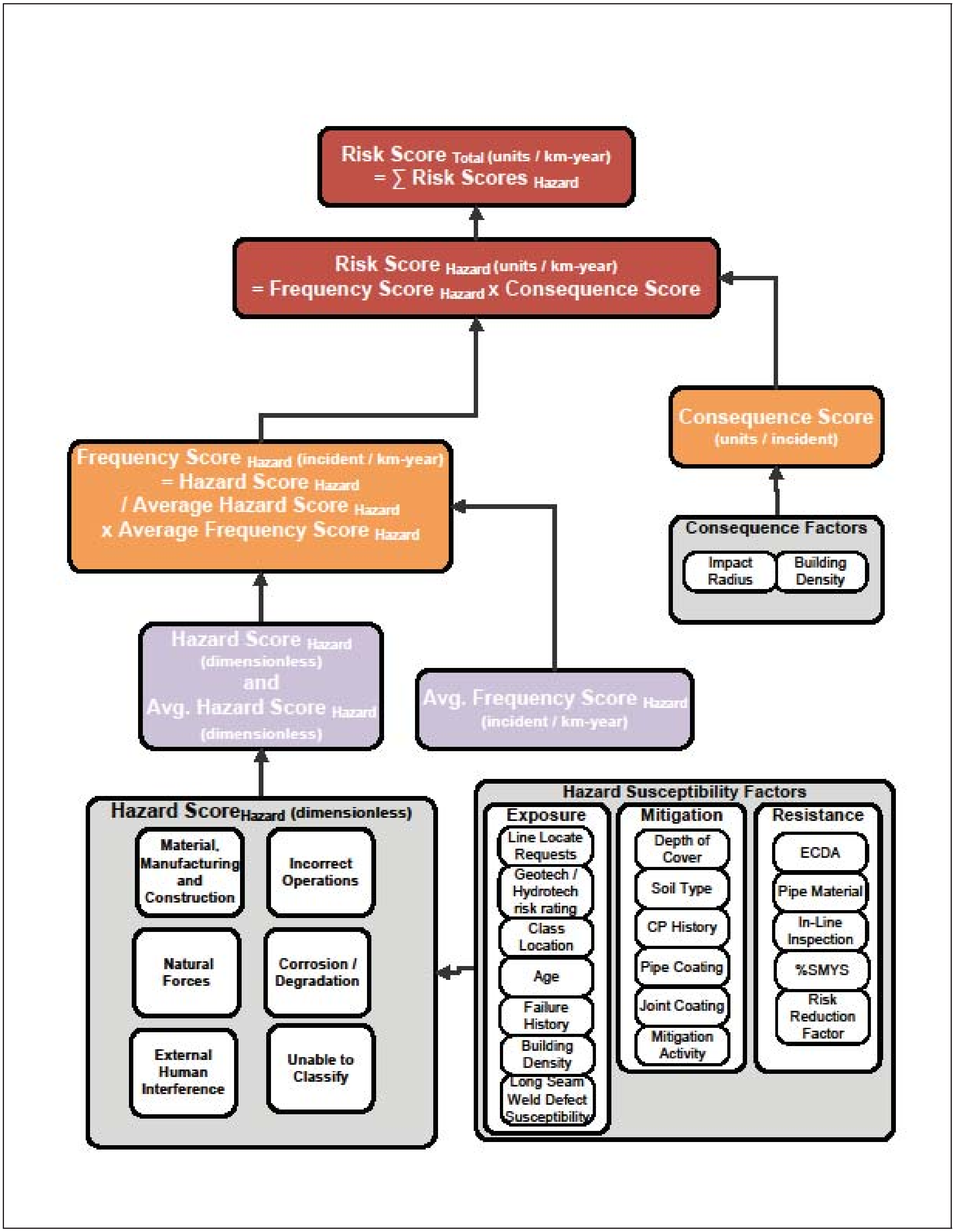

Figure 5: Pipeline Risk Analysis Structure

6.2. Limitations and Assumptions

The greatest limitation to the pipeline risk assessment is the number of unknowns which include:

- Unknown pipe attributes (blank fields) such as energized date, wall thickness, grade and/or coating. Unknown pipe attributes are either scored using tacit knowledge from subject matter experts or are assigned the maximum score possible.
- Unknown leak causes. An important factor in calculating the frequency of incidents is a review of the failure history. Since leaks with missing or unknown causes cannot be attributed to a specific hazard, that information is not used in the risk assessment. The Pipeline Integrity Group has been improving data quality by updating the below grade leak form, establishing contact with the maintenance groups that fill in the report and participating on the CGA Asset & Integrity Management Task Force. Data quality continues to be a work in progress.

6.3. Frequency Analysis

Frequency analysis is a measure of the likelihood of a pipeline failure occurring due to known hazards.

6.4. Hazard Identification and Score

Within the frequency algorithm, factors such as historical incident data as well as industry recognized risk determiners are used to calculate:

- The average hazard scores for the whole pipeline system.
- The individual hazard scores for each pipeline segment.

Manitoba Hydro participates on the Canadian Gas Association (CGA) Asset and Integrity Management task force. This task force is comprised of a number of local distribution companies working together to understand hazards that can result in failures directly and compile annual incident data. The CGA Incident Cause Guideline (Appendix A) is used to identify hazards in the Pipeline System Risk Assessment. The 6 hazards are:

- External Human Interference (e.g. Third party hits)
- Corrosion / Degradation
- Natural Forces
- Material, Manufacturing or Construction (MMC) Defect
- Incorrect Operation
- Other / Unable to Classify

The hazard scores are created by combining hazard susceptibility factors that demonstrate the exposure, mitigation, or resistance of the pipe segment to the hazard in question:

- Exposure (attack) is the relative number of events which, in the absence of any mitigation, can result in failure, if insufficient resistance exists. For example, Line Locates Requests are used as a proxy to demonstrate increased exposure to excavation activities.
- Mitigation (defense or barrier) is the type and effectiveness of the mitigation measures designed to block or reduce an exposure. For example, adequate depth of cover is a defense against excavation activities.
- Resistance is a measure or estimate of the ability of the component to absorb the exposure without failure. For example, an in-line inspection survey can locate corrosion so that it is remediated before leading to an incident.

6.4.1. External Interference

A significant hazard to the pipeline network is external interference. Incidents in this category are usually attributed to unintentional third party, company employee or company contractor damages. They may also be caused by intentional vandalism damages.

Different factors and weightings are selected for either distribution or transmission based on their applicability or availability. For example, line locate requests are available on distribution pipelines because they are attributed to a customer service tee which is attached to the distribution main. Another example, Pipe material is not applicable to transmission since all of the pipelines are metal.

The External Interference score is the sum of the Hazard Susceptibility Factors multiplied by their percentage weighting:

Hazard Susceptibility Factor	Hazard Aspect	Weighting (Distribution)	Weighting (Transmission)
Line Locate Requests	Exposure	60%	
Building Density	Exposure		60%
Depth of Cover	Mitigation	15%	30%
Soil Type	Mitigation	5%	5%
Pipe Material	Resistance	20%	
Percentage Specified Minimum Yield Strength	Resistance		5%
Risk Reduction Factor	Resistance	Multiplier	Multiplier

6.4.2. Corrosion / Degradation

Corrosion and degradation are both time dependent hazards to the pipeline system. Corrosion has the potential to affect metal pipelines by resulting in metal loss and a reduction in wall thickness of pipe. Degradation affects some aging plastic pipelines. The Corrosion / Degradation score is the sum of the Hazard Susceptibility Factors multiplied by their percentage weighting:

Distribution Segments:

Hazard Susceptibility Factor	Hazard Aspect	Weighting Metal Distribution	Weighting Plastic Distribution	Weighting (Transmission)
Failure History (Corrosion Volume)	Exposure	25%		45%
Failure History (Corrosion concentration)	Exposure	25%		
Failure History (Corrosion Trend)	Exposure	25%		
Failure History (Degradation)	Exposure		100%	
Cathodic Protection History	Mitigation	25%		45%
Pipe Coating	Mitigation			5%
Joint Coating	Mitigation			5%
ILI metal loss tool or ECDA Survey	Resistance	Multiplier		Multiplier
Risk Reduction Factor	Resistance	Multiplier	Multiplier	Multiplier

6.4.3. Natural Forces

Failures associated with the hazard Natural Forces are either weather or geotechnical related. Causes include riverbank instability, soil erosion and frost heave. The Natural Forces score is the sum of the Hazard Susceptibility Factors multiplied by their percentage weighting:

Hazard Susceptibility Factor	Hazard Aspect	Weighting (Distribution)	Weighting (Transmission)
Failure History (Natural Forces)	Exposure	40%	
Geotechnical or Hydrotechnical risk rating	Exposure	55%	95%
Soil Type	Resistance	5%	5%
Risk Reduction Factor	Resistance	Multiplier	Multiplier

6.4.4. Material, Manufacturing or Construction Defect

Material, manufacturing and construction defects are those that are created during construction or due to material defects and defective manufacturing. Examples include leaks cause by improper welds, fusion, and mechanical fittings (improper installation), not following procedures during construction, cross bores, loose cap or cracked tee cap due to over tightening. The Construction / Material Defects Score is the sum of the Hazard Susceptibility Factors multiplied by their percentage weighting.

Hazard Susceptibility Factor	Hazard Aspect	Weighting (Distribution)	Weighting (Transmission)
Failure History (MMC Defect Volume)	Exposure	50%	50%
Failure History (MMC Defect Trend)	Exposure	50%	45%
Long Seam Weld Defect Susceptibility	Exposure		5%
Risk Reduction Factor	Resistance	Multiplier	Multiplier

6.4.5. Incorrect Operations

The susceptibility of a failure attributed to the incorrect operation of the pipeline network post-commission is calculated in the Incorrect Operations Hazard Score. Examples include not following procedures or not having competency/training.

Improvements in reporting methods are being undertaken to track failures resulting from incorrect operations for future reporting consideration however at this time, no leaks have been directly attributed to incorrect operations.

6.4.6. Other / Unable to Classify

The other / Unable to classify category is in place to track failures that do not fit into any of the other hazard categories and for historical leaks where the cause is unknown. Currently, when a leak is reported unable to classify, the Pipeline Integrity Technologist follows up with the operational staff to determine the correct cause and the leak record is updated.

6.5. Calculating Hazard and Average Hazard Scores

The Hazard Score is calculated individually for each pipe segment and for each of the hazards using the following algorithm:

$$Hazard\ Score_{Hazard} = Risk\ Reduction\ Measures\ Factor_{Min.} \times \left\{ \sum Hazard\ Susceptibility\ Factors \times Weightings \right\}$$

For example, the External Interference Hazard Score for each distribution pipe segment is calculated as follows:

$$Hazard\ Score_{External\ Interference}\ (\%) = Risk\ Reduction\ Measure\ Factor\ x\ \{[Line\ Locate\ Request\ Factor\ \times\ 60\%] + [Depth\ of\ Cover\ Factor\ \times 15\%] + [Soil\ Type\ Factor\ \times 5\%] + [Pipe\ Material\ Factor\ \times 20\%]\}$$

The Average Hazard Score is calculated for each Hazard by adding the individual pipe segment hazard scores and dividing by the number of pipe segments.

$$Average\ Hazard\ Score_{Hazard} = \sum \frac{Hazard\ Score_{Hazard}}{\#\ Pipe\ Segments}$$

6.6. Calculating Average Frequency Score

The Average Frequency Score for each Hazard type is calculated from the number of historical below grade leaks attributed to the hazard over a study period and the total length of pipe.

$$Average\ Frequency\ Score_{Hazard}\left(\frac{incidents}{1000km \times year}\right) = \frac{Below\ Grade\ Leaks_{Hazard}\ (incidents)}{(Length\ of\ Pipe\ (km))(Study\ Period\ (years))}$$

The results from the study period are as follows:

Hazard Type	Average Frequency Score (incidents/1000km-year)	
	Distribution	Transmission
External Human Interference	9.671	0.073
Corrosion / Degradation	3.140	0.077
Natural Forces	0.359	0.085
Material, Manufacturing and Construction	4.719	0.338

A six year study period (2011 to 2016) was chosen for analyzing the distribution leaks since the leak survey has historically been conducted on a three year basis and this provided two complete survey cycles. Leak reporting prior to 2010 is questionable and therefore disregarded. There is a delay between when a leak occurs and when the reporting is complete. For this reason the 2017 leaks were disregarded as well.

Transmission pipeline leaks on Manitoba Hydro pipelines are rare. The following adjustments were necessary to make the results useful in hypothesizing future risk frequency:

- 0 corrosion leaks were reported on the transmission system during the 2011 to 2016 study period. However, a corrosion leak was found at Moore Park station in June 2017. Therefore, the study period was extended to include this leak.
- 0 external human interference leaks were reported on the transmission system during the study period. However, multiplying the risk model relative hazard scores by an average frequency score of 0 would show that there is no likelihood of future external human interference and therefore no risk. Of course this is unrealistic because even if an incident has not occurred in can always occur tomorrow. Additionally, a severe damage that very likely could have resulted in a leak did occur on the Altona system. For these reasons, the Average Frequency Score for External Human Interference is calculated as one incident from 2011 to present.

6.7. Calculating Frequency Score

The Frequency Score is calculated for each pipe segment and each hazard type by taking the ratio of the pipe segments Hazard Score, divided by the Average Hazard Score and multiplying it by the Average Frequency Score.

$$Frequency\ Score_{Hazard}\left(\frac{incidents}{1000km \times year}\right) = \frac{Hazard\ Score_{Hazard}}{Avg.Hazard\ Score_{Hazard}} \times\ Avg.Freq.\ Score_{Hazard}\left(\frac{incidents}{1000km \times year}\right)$$

The resulting Frequency Score is an estimate of the likelihood that an incident will occur on the pipe segment in the following year.

6.8. Hazard Susceptibility Factors

6.8.1. Line Locate Requests

Data Sources:	Smallworld energized date, Banner line locates
Hazard Susceptibility type:	Exposure

The External Human Interference Hazard Score considers that a location with a higher number of line locate requests has an increased susceptibility to being unintentionally damaged. It could also be suggested that in an area with a large number of line locate requests, there would be a number of excavations where line locate requests were never made.

In the 5 years after a new distribution main is energized it has an elevated risk of third party damage because it is often located in a new development where landowners are planting trees, shrubs, fences, etc.

The Line Locate Request factor (0.1-1) is a combination of the age of the main and the number of line locate requests within 200 metres of a gas main received by Manitoba Hydro.

Energized < 5 years ago	***Minimum Requests (>=)***	***Maximum Requests (<)***	***Line Locate Request Factor***
TRUE	250	10000	1
TRUE	100	250	0.5
TRUE	50	100	0.25
TRUE	0	50	0.1
FALSE	250	10000	0.25
FALSE	100	250	0.18
FALSE	50	100	0.13
FALSE	0	50	0.1

6.8.2. Building Density

Data Sources:	Electrical Service Points
Hazard Susceptibility type:	Exposure

The External Human Interference Hazard Score considers that an increased building density around the gas main is representative of greater population density and greater exposure to human activities which may cause damage.

The building density is estimated using the electrical service points around the pipeline. First, the building density at each electrical service point is calculated by counting the total number of all service points within a 200 metre radius of the original service point. Finally, the pipeline is assigned the value of the highest density that it interacts with along its route. The building density is expressed in buildings/km^2.

The service points 100m on either side of the line and along the length of the segment are counted. The results are then adjusted to estimate the building density (points/hectare).

The Building Density factor (0.1-1) is determined as follows:

Minimum Building Density	***Maximum Building Density***	***Building Density Factor***
2500	5000	1.0
1500	2500	0.8
500	1500	0.6
100	500	0.4
10	100	0.2
0	10	0.1

It is recognized that the population density is not a direct relation to the electrical demand points as there would be multiple residents in one home and largely populated buildings may be serviced by one point (ex. Offices). For this reason, the downtown area with distribution facility code D3008 is given an elevated building density factor of 1.0.

6.8.3. Depth of Cover

Data Sources:	Smallworld Gas Main Anomaly object type insufficient cover, Depth of Cover survey results
Hazard Susceptibility type:	Mitigation

The External Human Interference Hazard Score considers that adequate depth of cover has a mitigating effect by reducing the likelihood that human activities will result in contact to the buried gas main.

The Depth of cover factor (0.1-1) is a combination of whether or not a depth of cover survey has been completed and by the presence of insufficient cover on the gas main. Only unmitigated insufficient covers are included for analysis.

Depth of Cover Survey completed	***Insufficient Cover on Gas Main***	***Depth of Cover Factor***
True	True	0.5
True	False	0.1
False	True	1.0
False	False	0.5

6.8.4. Soil Type

Data Sources:	Regional Surficial Geology Maps
Hazard Susceptibility type:	Mitigation

The External Human Interference Hazard Score and the Natural Forces Hazard Score consider the soil type to be a susceptibility factor.

An external human interference failure is considered more likely in denser soils like rock and clay and less likely in looser sands.

Natural forces such as erosion are more likely in water or eroded soil types. Pipe segments are more susceptible to frost heaving in soils with higher moisture holding capabilities like clay.

The Soil Type Factor (0.1-1) is determined by interpreting the regional surficial geology maps:

Soil Types	***Soil Type Factor***
Unknown	1.00
Eroded Slopes	1.00
Water	1.00
Marsh	1.00
Unclassified	1.00
Clayey	0.9
Loamy	0.30
Coarse Loamy	0.50
Sands	0.1
Coarse Sands	0.1
Organic	0.3
Rock	1

6.8.5. Pipe Material

Data Sources:	Smallworld Gas Main Pipe Type
Hazard Susceptibility type:	Resistance

The External Human Interference Hazard Score considers that the pipe material affects the extent of damage incurred. For example, plastic pipe is more likely to leak than steel pipe when damaged with the same force, etc.

The Pipe Material Factor (0.1-1) is determined from the eGIS Pipe Type.

Pipe Material	***eGIS Pipe Type***	***Pipe Material Factor***
Other / Unknown*	Other	0.50
Plastic	PE	0.50
High Density Plastic	PE-100	0.50
High Density Plastic	PE-HD	0.50
Steel	Stl	0.25
Aluminum	Alum	0.25

*Pipe segments with a pipe material field of other or unknown are assigned the highest pipe material factor that exists in the network, 0.5. Higher values are reserved for materials that do not exist in the MB Hydro network like cast iron (0.75), poly vinyl chloride (0.8) wrought iron (1.0).

6.8.6. Percentage Specified Minimum Yield Strength (%SMYS)

Data Sources:	Smallworld Gas Main
Hazard Susceptibility type:	Resistance

The External Human Interference Hazard Score considers that transmission pipelines operating closer to their percentage specified minimum yield strength (%SMYS) are more likely to leak from an impact.

$$\%SMYS = \frac{Pressure\ x\ Pipe\ Diameter}{2\ x\ wall\ thickness\ x\ Pipe\ Grade}$$

The %SMYS factor (0.1 – 1) is determined as follows:

Minimum %SMYS	Maximum %SMYS	%SMYS factor
0	<25	0.1
25	<30	0.2
30	<35	0.4
35	<50	0.6
50	<70	0.8
70	<100	1.0

6.8.7. Failure History (Corrosion Volume)

Data Sources:	Smallworld Below Grade Leak Objects
Hazard Susceptibility type:	Exposure

The Corrosion/Degradation Hazard Score considers that gas mains located in the same cathodic section will have similar cathodic protection history. Therefore, recent historical failures are considered a good predictor of the likelihood of future failure incidents. The number of leaks reported in the gas main's cathodic section in the last 15 years is counted. This highlights the cathodic sections which have the highest number of leaks in the given study period.

The Failure History (Corrosion Volume) Factor (0.1-1) is determined based on the number of leaks that have occurred in the cathodic section.

Min Leak History	*Max Leak History*	*Failure History (Corrosion Volume) Factor*
10	Unlimite d	1
6	< 10	0.75
3	< 6	0.5
1	< 3	0.25
0	< 1	0.1

6.8.8. Failure History (Corrosion Concentration)

Data Sources:	Smallworld Below Grade Leak Objects
Hazard Susceptibility type:	Exposure

The Corrosion/Degradation Hazard Score considers the number of leaks in the last 15 years present in a concentrated area around each leak.

In this method, a buffer zone with a 200 m radius is created for each leak located on a given gas main. The reported leaks are counted in each buffer zone. The pipe is assigned the value with the highest number of leaks. This approach highlights the area with higher concentration of leaks in an area.

The Failure History (Corrosion Concentration) Factor (0.1-1) is determined based on the number of leaks that have occurred in the buffer zone.

Min Leak History	***Max Leak History***	***Failure History (Corrosion Volume) Factor***
10	Unlimite d	1
6	< 10	0.75
3	< 6	0.5
1	< 3	0.25
0	< 1	0.1

6.8.9. Failure History (Corrosion Trend)

Data Sources:	Smallworld Below Grade Leak Object
Hazard Susceptibility type:	Exposure

The Corrosion/Degradation Hazard Score considers the trend of leaks occurring recently as a signifier that corrosion is active and more leaks are likely to occur .

The Failure History (Corrosion Trend) Factor (0.1-1) is determined based on the number of leaks that have occurred on the cathodic section in the past 5 years.

Min Leak History	***Max Leak History***	***Failure History (Corrosion Volume) Factor***
5	Unlimited	1
3	< 5	0.75
2	< 3	0.5
1	< 2	0.25
0	< 1	0.1

6.8.10. Failure History (Degradation)

Data Sources:	Smallworld Below Grade Leak Object
Hazard Susceptibility type:	Exposure

The Corrosion/Degradation Hazard Score considers leaks attributed to degradation. Degradation leaks include any time-dependent plastic pipe failure. Manitoba Hydro's plastic pipe is considered in good condition and efforts to track this hazard are pro-active.

The Failure History (Degradation) Factor (0.1-1) is determined based on the number of leaks that have occurred on the gas main with a degradation cause listed.

Min Leak History	***Max Leak History***	***Failure History (Degradation) Factor***
5	Unlimited	1
3	< 5	0.75
2	< 3	0.5
1	< 2	0.25
0	< 1	0.1

6.8.11. Cathodic Protection History

Data Sources:	Smallworld CP Manager - export
Hazard Susceptibility type:	Mitigation

The Corrosion/Degradation Hazard Score considers the cathodic protection downtime, where cathodic protection values were less than target levels of 1.0V, to be a susceptibility factor. Corrosion is a time dependent hazard meaning that the longer corrosion is active, the more likely it will result in a defect or incident.

The Corrosion prevention group, which manages the cathodic protection data, has indicated that records prior to 2006 are questionable. Therefore, the cathodic protection downtime factor is calculated based on records from 2006 to present.

The Cathodic Protection History Factor (0.1-1) is determined based on the cathodic protection downtime of the cathodic section it is in.

Min. Cathodic Protection Downtime (months)(>=)	***Max. Cathodic Protection Downtime (years)(<)***	***Cathodic Protection History Factor***
60	unlimited	1
40	<60	0.75
20	<40	0.5
10	<20	0.25
0	<10	0.1

6.8.12. <u>Pipe Coating</u>

Data Sources:	Smallworld Gas Main Pipe Coating
Hazard Susceptibility type:	Mitigation

The Corrosion Hazard Score considers that the type of coating on the pipeline will affect its susceptibility to corrosion. The following factors are applied to the pipe segments based on their pipe coating type:

Pipe Coating	***Coating Type***	***Pipe Coating Factor***
Unknown*	Unknown	0.75
Asphalt Enamel	Coated	0.75
Tape	Coated	0.75
Coal Tar Wrap	Coal Tar	0.75
Coal Tar	Coal Tar	0.75
DPAR	Epoxy	0.25
Dual Layer Abrasion Resistant FBE	Epoxy	0.25
Epoxy	Epoxy	0.25
FBE	Epoxy	0.25
Wax Coatings	Coated	0.75
Yellow Jacket	Poly	0.5

*Pipe segments with a pipe coating field of missing or null are assigned the highest pipe coating factor that exists in the network, 0.75. Higher values are reserved for bare pipe (1.0) of which MB Hydro has none.

6.8.13. <u>Joint Coating</u>

Data Sources:	Smallworld Gas Main Joint Coating
Hazard Susceptibility type:	Mitigation

The Corrosion Hazard Score considers that the type of coating on the joint connections will affect its susceptibility to corrosion. The following factors are applied to the pipe segments based on their joint coating type:

Joint Coating	***Coating Type***	***Joint Coating Factor***
Bare	Bare	1.0
Unknown*	Unknown	0.75
Tape	Coated	0.75
Wax Tape (Denso or Petrolatum)	Coated	0.75
Shrink Sleeves	Poly	0.5
Dual Powder Abrasion Resistant	Epoxy	0.25
Field Applied FBE	Epoxy	0.25
Liquid Epoxy Coating	Epoxy	0.25

Note*: Pipe with an unknown or missing joint coating is given a joint coating factor of 0.75 as it is almost certainly tape. Bare joint coating is not found on the Manitoba Hydro pipeline system.

6.8.14. Failure History (Natural Forces)

Data Sources:	Smallworld Below Grade Leak Object
Hazard Susceptibility type:	Exposure

The Natural Forces Hazard Score considers the number of leaks in the vicinity of the gas main attributed to natural forces as a predictor for ground movement in the area.

In this method, a buffer zone with a 200 m radius is created, for each leak located on a given gas main. The reported leaks are counted in each buffer zone. This approach highlights the area with higher concentration of leaks in an area.

The Failure History (Natural Forces) Factor (0.1-1) is determined based on the number of leaks that have occurred in the buffer zone.

Min Leak History	***Max Leak History***	***Failure History (Natural Forces) Factor***
10	Unlimited	1
6	< 10	0.75
3	< 6	0.5
1	< 3	0.25
0	< 1	0.1

6.8.15. Geotechnical / Hydrotechnical

Data Sources:	Smallworld geotechnical and hydrotechnical objects, Geotechnical Monitoring Program tracker, Hydrotechnical Monitoring Program tracker
Hazard Susceptibility type:	Exposure

The Natural Forces Hazard Score considers the pipe segments geotechnical and hydrotechnical susceptibility.

The geotechnical/hydrotechnical factor (0.1 – 1.0) is the greater of the geotechnical factor and hydrotechnical factor for the gas main.

Transmission pipelines are rated during the geotechnical monitoring program. Distribution pipelines were not originally assessed under the geotechnical monitoring program however some locations have been added due to geotechnical concerns raised.

The geotechnical factor is determined by whether or not the site is identified as a geotechnical site, and what the current hazard likelihood score is (from the geotechnical monitoring survey).
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Geotechnical Site	***Highest Geotechnically Unstable Area Rating***	***Geotechnical Factor***
True	HIGH	1
True	MODERATE	0.75
True	LOW	0.5
True	VERY LOW	0.25
True	<null>	0.25
False	n/a	0.1

The hydrotechnical factor is determined by whether or not the pipe segment crosses a watercourse, whether or not that watercourse has been surveyed, what the most likely installation is (HDD or trench) and the size of the river.

Watercourse Crossing	***Watercourse Crossing Survey completed***	***HDD (installed >1990)***	***River Class***	***Hydrotechnical Factor***
False	n/a	n/a	n/a	0.1
True	True	n/a	n/a	0.2
True	False	True	Tiny	0.2
True	False	True	Minor B	0.22
True	False	True	Minor A	0.24
True	False	True	Major	0.26
True	False	False	Tiny	0.4
True	False	False	Minor B	0.6
True	False	False	Minor A	0.8
True	False	False	Major	1.0

6.8.16. Failure History (MMC Defect Volume)

Data Sources:	Smallworld Below Grade Leak Object
Hazard Susceptibility type:	Exposure

The Material, Manufacturing or Construction Defect Hazard Score considers that gas mains located in close proximity will share similar design and construction details. Therefore, recent historical failures are considered a good predictor of the likelihood of future failure incidents. The number of leaks reported within a 200 metre buffer in the last 15 years or since the gas main was installed, whichever is less, is counted. This highlights areas which have the highest number of leaks in the given study period.

In this method, a buffer zone with a 200 m radius is created for each leak located on a given gas main. The reported leaks with matching facility codes are counted in each buffer zone. The pipe is assigned the value with the highest number of leaks. This approach highlights the area with higher concentration of leaks in an area.

The Failure History (MMC Defect Volume) Factor (0.1-1) is determined based on the number of leaks that have occurred within a 200 meter buffer in the last 15 years.

Min Leak History	***Max Leak History***	***Failure History (MMC Defect Volume) Factor***
10	Unlimited	1
6	< 10	0.75
3	< 6	0.5
1	< 3	0.25
0	< 1	0.1

6.8.17. Failure History (MMC Defect Trend)

Data Sources:	Smallworld Below Grade Leak Object
Hazard Susceptibility type:	Exposure

The Material, Manufacturing or Construction Defect Hazard Score considers the trend of leaks occurring recently as a signifier that more failures are likely in the near future.

The Failure History (MMC Defect Trend) Factor (0.1-1) is determined based on the number of leaks that have occurred within a 200 metre buffer in the past 5 years.

Min Leak History	***Max Leak History***	***Failure History (MMC Defect Trend) Factor***
5	Unlimited	1
3	< 5	0.75
2	< 3	0.5
1	< 2	0.25
0	< 1	0.1

6.8.18. Long Seam Weld Defect Factor

Data Sources:	Smallworld Gas Main Energized Date
Hazard Susceptibility type:	Exposure

The Material, Manufacturing and Construction Defects Hazard Score considers the age of the pipeline to be a susceptibility factor for long seam weld defects.

Defects are considered to be dependent on advancements in manufacturing and construction practices over time. Metal pipe segments energized prior to 1971 are considered susceptible to long seam weld defects. All plastic and metal segments energized in 1971 or later are not considered susceptible to long seam weld defects. (Baker, 2004)

Metal	***Energized Date <1971***	***Age (Long Seam Weld Defect) Factor***
True	True	1
True	False	0.1
False	n/a	0.0

6.8.19. ECDA Survey, ILI Survey and Risk Reduction Factors

Data Sources:	ECDA Program Results, In-Line Inspection Program results, various integrity assessments
Hazard Susceptibility type:	Resistance

Risk can be reduced in a number of ways including performing:

- ECDA Survey
- ILI Survey
- Hydrostatic Retest
- Integrity Assessment including implementing recommendations
- Other Risk Reduction Activities

The ECDA Survey factor, ILI Survey factor or Risk Reduction factor with the least value is applied in the form of a credit to the Hazard Score. The overall Hazard Score is reduced based on the time since the risk reduction activity was completed as follows:

Minimum Time	***Maximum Time***	***Risk Reduction Factor***
0	3	0.125
3	6	0.250
6	9	0.375
9	12	0.500
12	15	0.625
15	18	0.750
18	21	0.875
21	100	1.000

6.9. Consequence Analysis

Consequence analysis is an estimate of the severity of an incident. Industry recognized risk determiners are used to represent the effect of an incident on safety and economic loss.

The Consequence Score for each segment is calculated by adding the Consequence Score factors by their weighting.

$$Consequence\ Score\ \left(\frac{units}{incident}\right) = \sum Consequence\ Factors\ \times Weightings$$

6.10. Consequence Identification and Score

Within the Consequence Score algorithm, pipe segment attributes and building density data were used to calculate Consequence Category Scores for each individual pipeline segment:

Consequence Factor	Weighting (Distribution)	Weighting (Transmission)
Impact Radius	60%	50%
Building Density	40%	40%
System Reliability		10%

6.10.1. Impact Radius

The Impact Radius is a function of the pipe's network MOP (maximum operating pressure) and diameter (ASME B31.8S-2012):

Impact Radius (metres) = 0.00315 • (Pipe Diameter (mm)) (√MOP (kPa))

The following factors are applied to the pipe segments based on their Impact Radius:

Minimum Impact Radius	***Maximum Impact Radius***	***Impact Radius Factor***
80	1000	1
60	80	0.8
40	60	0.6
20	40	0.4
0	20	0.2

6.10.2. Building Density

The building density is estimated using the electrical service points around the pipeline. First, the building density at each electrical service point is calculated by counting the total number of all service points within a 200 metre radius of the original service point. Finally, the pipeline is assigned the value of the highest density that it interacts with along its route. The building density is expressed in buildings/km^2.

The service points 100m on either side of the line and along the length of the segment are counted. The results are then adjusted to estimate the building density (points/hectare).

The Building Density factor (0.1-1) is determined as follows:

Minimum Building Density	***Maximum Building Density***	***Building Density Factor***
2500	5000	1.0
1500	2500	0.8
500	1500	0.6
100	500	0.4
10	100	0.2
0	10	0.1

6.10.3. System Reliability

The System Reliability Factor is determined from the results of the Isolation and Return to Service Documentation. The analysis in this documentation looked at what was required to maintain consumption at -10C should the primary station be lost.

Results of the IRS study	System Reliability Factor
Looped System	0.1
Emergency Interruption to Industrial Customer	0.2
2 CNG trailers	0.2

3 CNG trailers	0.4
4 CNG trailers	0.6
5 CNG trailers	0.7
6 CNG trailers	0.85
CANNOT be supported by CNG	1

6.11. Calculating Total Frequency Score

The total frequency score for each pipe segment is the sum of the individual hazard frequency scores.

$$Frequency\ Score_{Total}\left(\frac{incidents}{km \times year}\right) = \sum Frequency\ Score_{Hazard}\left(\frac{incidents}{km \times year}\right)$$

7. Risk Evaluation Methodology

Risk evaluation is the process of judging the significance of the estimated risk values, including the identification and evaluation of options for managing risk.

7.1. Frequency Criteria

The likelihood of an incident (unintentional release of gas below grade) occurring is calculated using historical incident data as well as industry recognized risk determiners and expressed as a Frequency Score (incidents / 1000kmyr) for each pipe segment and each hazard category. The total Frequency Score is determined by summing the individual Frequency scores for each hazard category. The pipe segments are grouped for risk evaluation as follows:

Descriptor	Typical Frequency Score Characteristics
Almost Certain	• The event will occur on an annual basis • ≥ 80 incidents / 1000 kmyr
Likely	• The event might occur several times or more in a decade • ≥ 40 incidents / 1000 kmyr
Possible	• The event might occur once in a decade • ≥ 20 incidents / 1000 kmyr
Unlikely	• The event does occur somewhere from time to time. • ≥ 1 incidents / 1000 kmyr
Rare	• Have heard of something like this occurring elsewhere. • ≥ 0.5 incidents / 1000 kmyr
Very Rare	• Have never heard of this happening. • < 0.5 incidents / 1000 kmyr

7.2. Consequence Criteria

The impact of an incident is calculated using industry recognized risk determiners such as the impact radius and building density of the pipe segment and expressed as a Consequence Score (units / incident) for each pipe segment. The pipe segments are grouped for risk evaluation as follows:

Descriptor	Typical Consequence Score Characteristics
High	• ≥ 60 units/incident • Multiple story buildings, dense neighborhoods • Large impact zone • Poor options for reliability during an emergency (transmission only)
Medium	• ≥ 45 units/incident • Suburbs, single family residential areas. • Medium impact zone • Potential source of energy during an emergency outage.
Low	• < 45 units/incident • Rural, farmland and low population areas. • Small impact zone • Reliable source of energy during an emergency outage (transmission only)

7.3. Risk Evaluation and Significance

The results of the risk analysis are plotted on the Risk Matrix (Figure 4) to evaluate the risk. The significance of the risk is determined as follows:

Colour:	Risk Evaluation:	Action:
Red	Significant	Refine analysis, evaluate options, and implement action.
Yellow	Less Significant	Refine analysis, consider options.
Green	Not Significant	Monitor

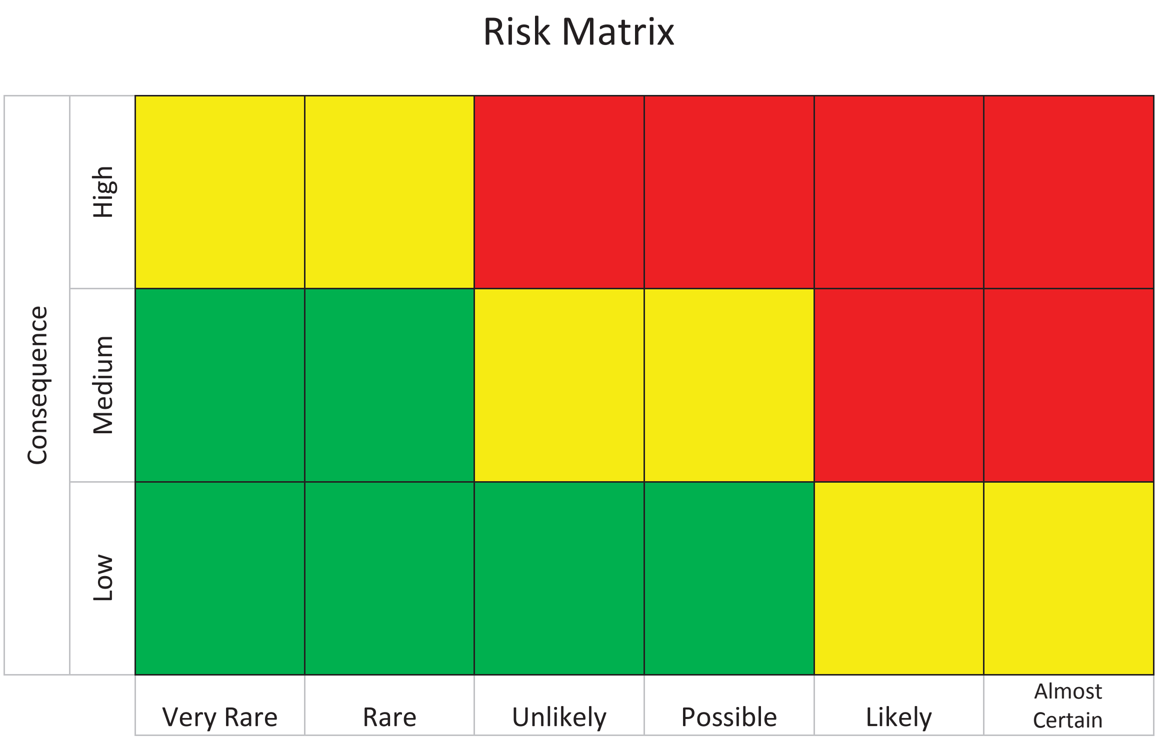

Figure 6: Risk Evaluation Matrix

7.4. Options analysis

If a pipe segment has a significant risk, the pipeline integrity engineer will perform an options analysis to determine what activities could be performed to reduce the risk. Decreasing either the frequency or the consequence score will decrease the risk.

8. Risk Control

The pipeline risk assessment is intended to inform management and pipeline integrity activity owners so that appropriate risk control measures can be implemented.

This is performed by communicating the results of the risk assessment and working together to select appropriate risk control options.

Appendix A: CGA Incident Cause Guidance (2017)

Cause	Sub-Cause	Guidance Notes
Corrosion / Degradation	Metal Loss	Wall thickness reduction e.g. corrosion leaks
	Metal Cracking	Mechanically driven or environmentally assisted cracking e.g. stress corrosion cracking, hydrogen-induced cracking
	Plastic Degradation	any time-dependent plastic pipe failure - e.g. split pipe, cracking, "1st generation" PE pipe with splitting tendency during squeeze-off
External Interference	1st or 2nd Party	1st Party - Company Employee
		2nd Party - Company Contractor
	3rd Party	3rd Party - Contractor, Homeowner, Landowner, Other Utility, etc. Includes acts of terrorism, vandalism, etc.
Incorrect Operation	Improper Operation	post-commission: not following procedures, not having competency/training
	Insufficient Procedures	post-commission: insufficient procedure provided, inadequate documentation and/or records
Material, Manufacturing or Construction Defect	Defective Pipe Body	leaks caused by manufacturing or delivery of the pipe
		(e.g. laminations, seam weld defects)
	Defective Joining Method	leaks caused by improper welds, fusion, and mechanical interference fit joints (improper installation).
	Other Improper Construction	leaks caused by pre-commission construction issues
		(e.g. not following procedures, not having competency/training, over-bending, wrinkle or buckling pipe, loose tee cap, cracked tee cap due to over tightening, homemade couplings)
Natural Forces	Geotechnical	includes soil erosion, ground movement, , frost heave, soil subsidence or slope movement
	Weather Related	includes lightning, flooding
	Weather and Fire	Failure due to lightning, flooding or fire (excluding arson).
	Wildlife / Animal	
Unable to Classify	Unable to Classify	includes incidents that were either 'unable to be classified' at the time of reporting due to lack of information, or the cause of the incident was indeterminable

Reference Publications

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Peabody, A.W. Peabody's Control of Pipeline Corrosion. 2nd ed. U.S.A: NACE Press, 2001.

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