Pipeline Risk Assessment Fundamentals

Banff Pipeline Workshop 2019

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Agenda

- Introductions
- Risk Definitions and Concepts
- Pipeline Risk Assessment Concepts
- Guidance from Standards
- Pipeline Risk and Reliability Modeling
  - Estimating Likelihood of Failure
  - Estimating Consequence of Failure
  - Case Studies
  - Societal Risk and Individual Risk
- Risk Presentation Methods
- Risk and Reliability Acceptance Criteria
- Integrating Risk Results into Integrity Management

Risk Definitions and Concepts

Risk Defined

- Risk is "The chance of loss"

(Concise Oxford Dictionary)

- This definition involves:

Loss → Adverse consequences

Chance → Uncertainty regarding the loss

Risk Defined

Risk of a person dying in a car accident	1 in 11,000 per year
Risk of a person dying in a plane crash	1 in 300,000 per year
Risk of a person dying by lightning strike	1 in 5,000,000 per year

- Recent 2018 Mariner East 2 Pipeline (NGL) report (public record) indicates that the average person's exposure to a fatal traffic accident is about 20 times greater than the fatality risk to someone standing above the pipeline 24/7 in Delaware County.

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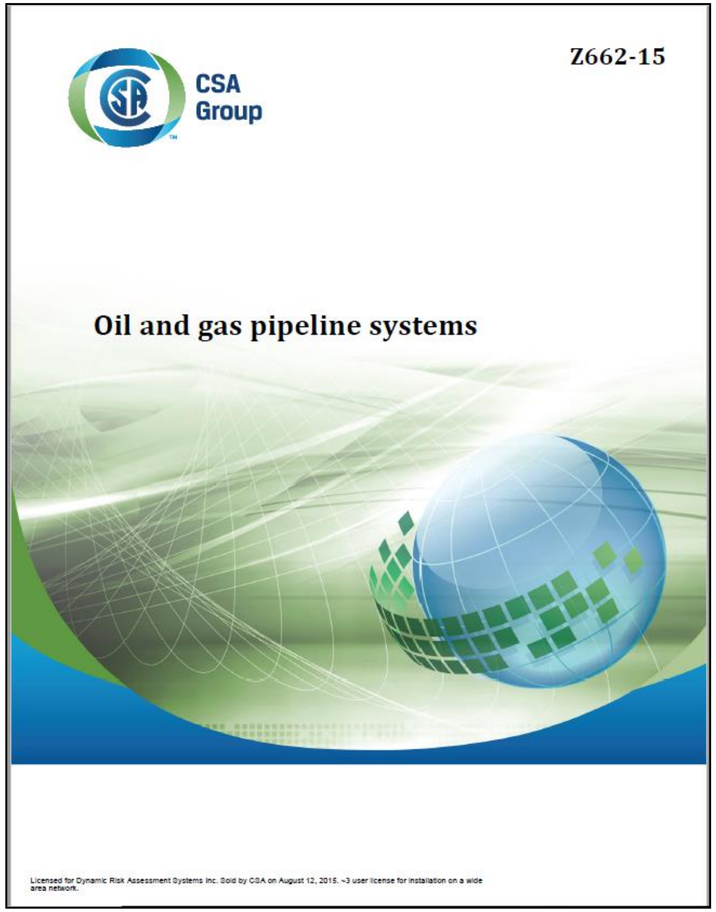
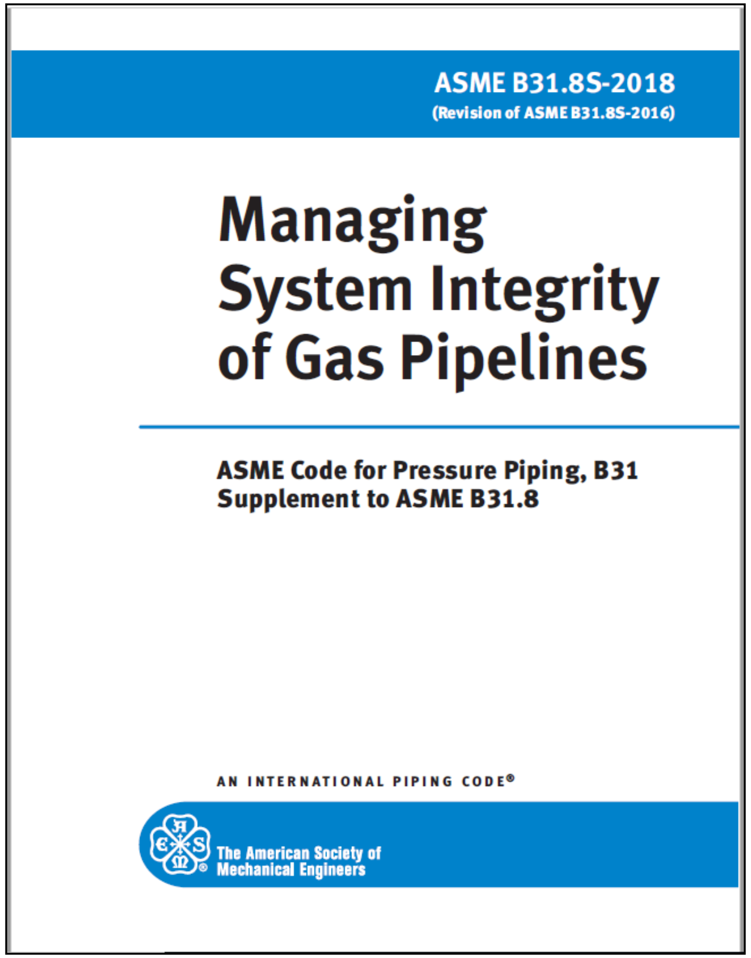
Risk as Defined in CSA Z662



- CSA Z662-15 – Annex B
  - **Risk:** a compound measure, either qualitative or quantitative, of the frequency and severity of an adverse effect.

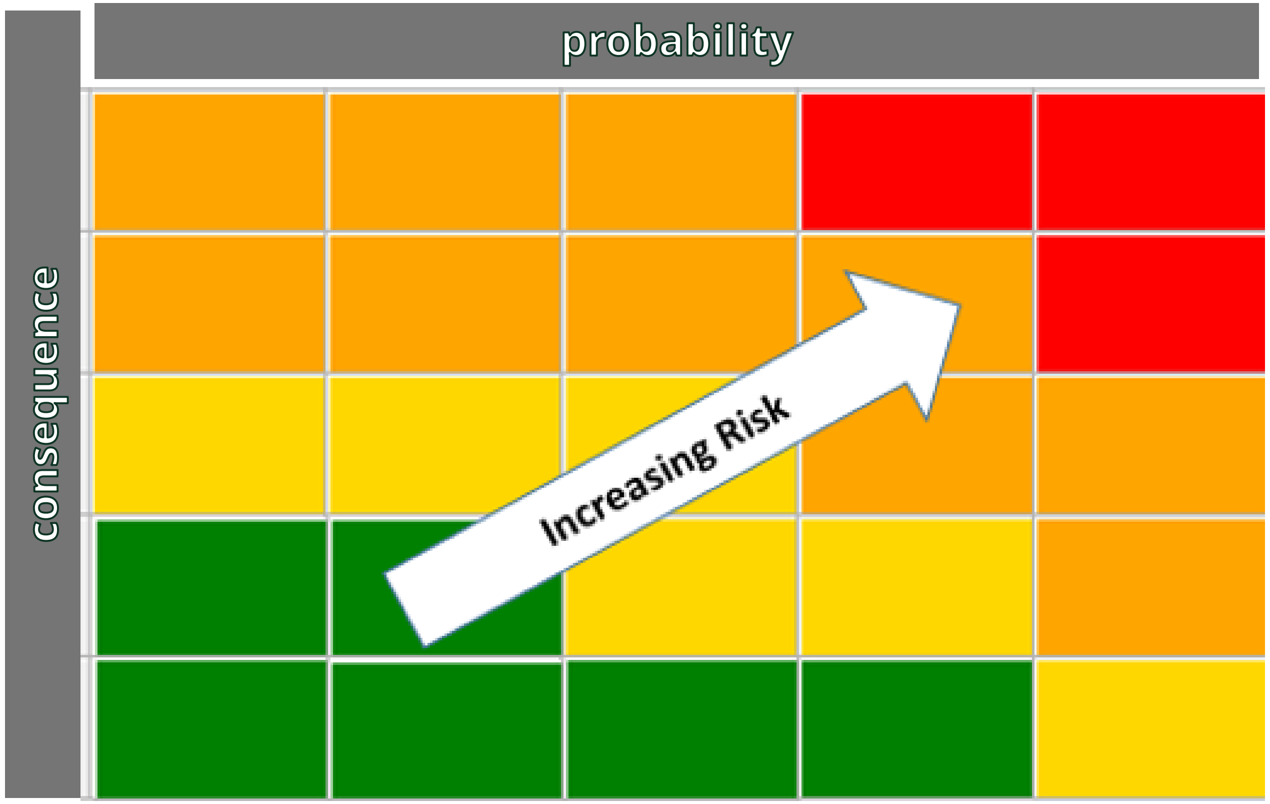
Risk as Defined in ASME B31.8S

- ASME/ANSI B31.8S
  - **Risk:** measure of potential loss in terms of both the incident probability (likelihood) of occurrence and the magnitude of the consequences.



Risk Measure

- Risk = <u>likelihood</u> of failure x <u>consequence</u> of failure



Likelihood of Failure

Likelihood: The chance of something happening, whether defined, measured, or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or frequency over a given time period).

PHMSA Draft Pipeline Risk Modeling Report 2018

- *Likelihood index*
- *Probability*
- *Frequency*
- *Reliability*

Likelihood: Probability & Frequency

- **Likelihood Index:** a non-quantitative relative ranking or rating number representing the likelihood of failure level
- **Probability:** likelihood, or measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty.
- **Frequency:** Number of events or outcomes per defined unit of time. Frequency can be applied to past events or to potential future events, where it can be used as a measure of likelihood / probability.

Likelihood: Probability & Frequency

- **Probability:**
  - 2/10 chance (0.2, 20%) of failing

- **Frequency:** 2/10 chance (0.2, 20%) of failing per year
  - 2/10 chance of failing per year per kilometer

Likelihood: Reliability

- **Reliability:** the probability that a component or system will perform its required function without failure during a specified time interval (usually taken as one year), equal to 1.0 minus the probability of failure.

- Reliability = 1- probability of failure
  - 8/10 chance (0.8, 80%) of not failing

Consequence of Failure

Consequence: Impact that a pipeline failure could have on the public, employees, property, the environment, or organizational objectives.

PHMSA Draft Pipeline Risk Modeling Report 2018

Pipeline Risk Assessment Concepts

Risk Assessment as Defined In CSA Z662-15

Annex B (informative)
Guidelines for risk assessment of pipeline systems

Note: *This Annex is an informative (non-mandatory) part of this Standard.*

There is a commentary available for this Annex.

B.1 Introduction

This Annex provides guidelines on the application of risk assessment to pipeline systems. These guidelines are intended to

a) identify the role of risk assessment within the context of an overall risk management process;
b) set out standard terminology that is consistent with existing Canadian standards in the field of risk management;
c) identify in general terms the components of the risk assessment process, the associated data requirements, and the requirements for documentation and records; and
d) where applicable, provide reference to methodological guidelines for risk assessment.

B.2 Applicability

B.2.1 General

This Annex applies to the risk assessment of all pipeline systems within the scope of this Standard.

B.2.2 Risk assessment process

B.2.2.1

Risk assessment forms a component of the broader process of risk management and includes the steps of risk analysis (hazard identification, frequency analysis, consequence analysis, risk estimation) and risk evaluation (risk significance and options). The function of risk assessment within the risk management process is shown schematically in Figure B.1.

B.2.2.2

Risk assessment is applicable to hazards affecting public and occupational safety and the environment and to hazards having economic consequences.

B.2.2.3

Risk assessment is applicable to the decision-making process in the design, construction, operation, inspection, monitoring, testing, maintenance, repair, modification, rehabilitation, and abandonment of pipeline systems.

B.3 Specific definitions

The following definitions apply in this Annex:

Hazard identification — the recognition that a hazard exists and the definition of its characteristics.

Risk — a compound measure, either qualitative or quantitative, of the frequency and severity of an adverse effect.

- CSA Z662-15 – Annex B
  - **Risk assessment**: the process of risk analysis and risk evaluation.

Risk Assessment as Defined in ASME/ANSI B31.8S

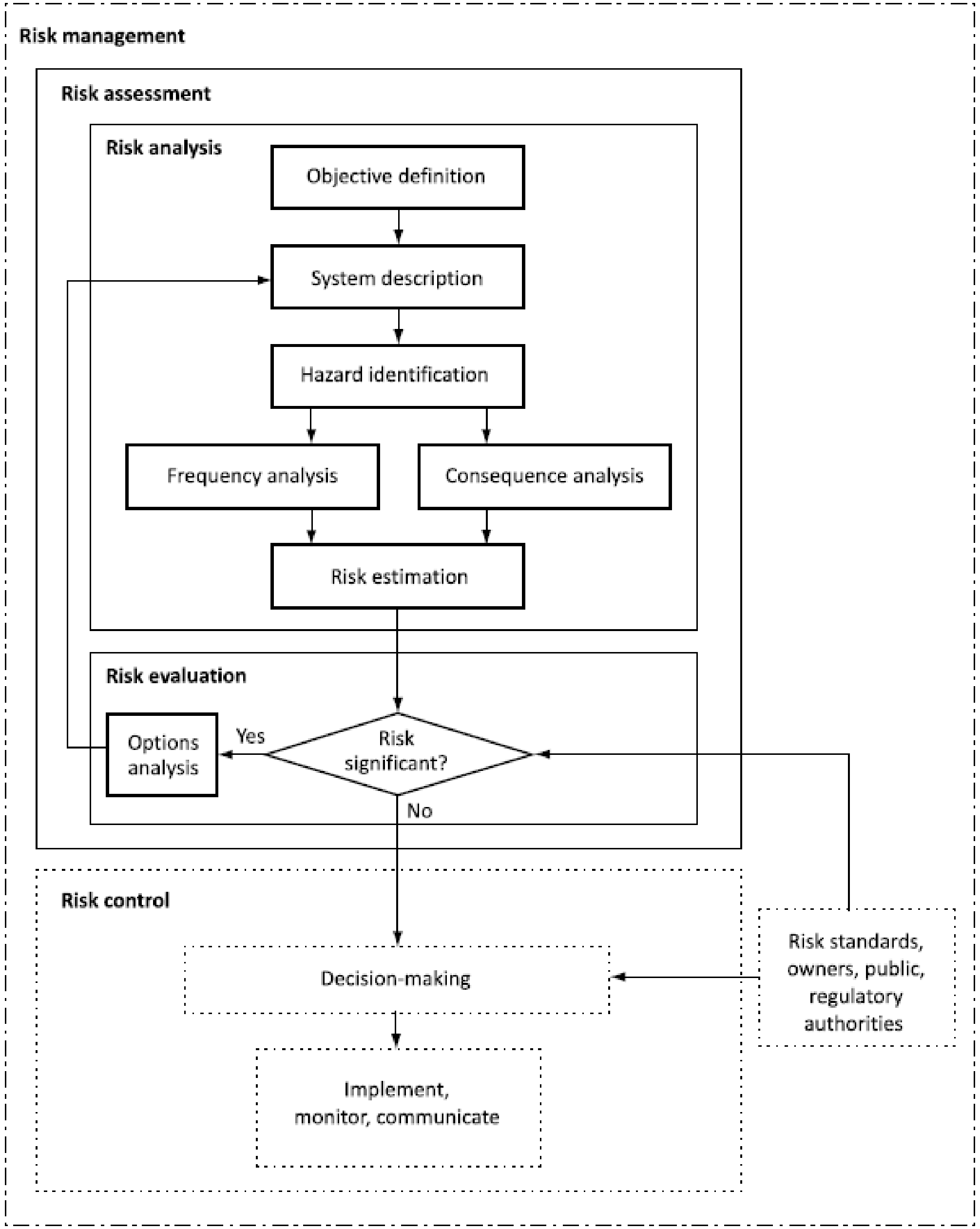
- ASME/ANSI B31.8S
  - **Risk assessment:** systematic process in which potential hazards from facility operation are identified, and the likelihood and consequences of potential adverse events are estimated. Risk assessments can have varying scopes, and can be performed at varying level of detail depending on the operator's objectives (see section 5).

Risk Assessment within Risk Management

- Risk Management is the integrated process of Risk Assessment and Risk Control

- Risk Assessment is a component of Risk Management

- Risk Assessment incorporates Risk Analysis and Risk Evaluation



Risk Assessment Objectives

- Identify highest risk pipeline segments
- Highlight pipeline segments where the risk is changing
- Identify gaps or concerns in data quality and completeness
- Support risk management:
  - Calculate the benefit of risk mitigation activities
  - Support decision making and program development
  - Improve system reliability
  - Minimize risk to as low as reasonably practicable and eliminate high impact events

Guidance from Standards

Guidance from Canadian Standards

Risk Assessment – Canadian Pipelines

- CSA Z662-15
  - Annex B – Guidelines for risk assessment of pipelines
  - Annex H - Pipeline failure records: provides a classification of the causes of pipeline failure incidents that can lead to hazards

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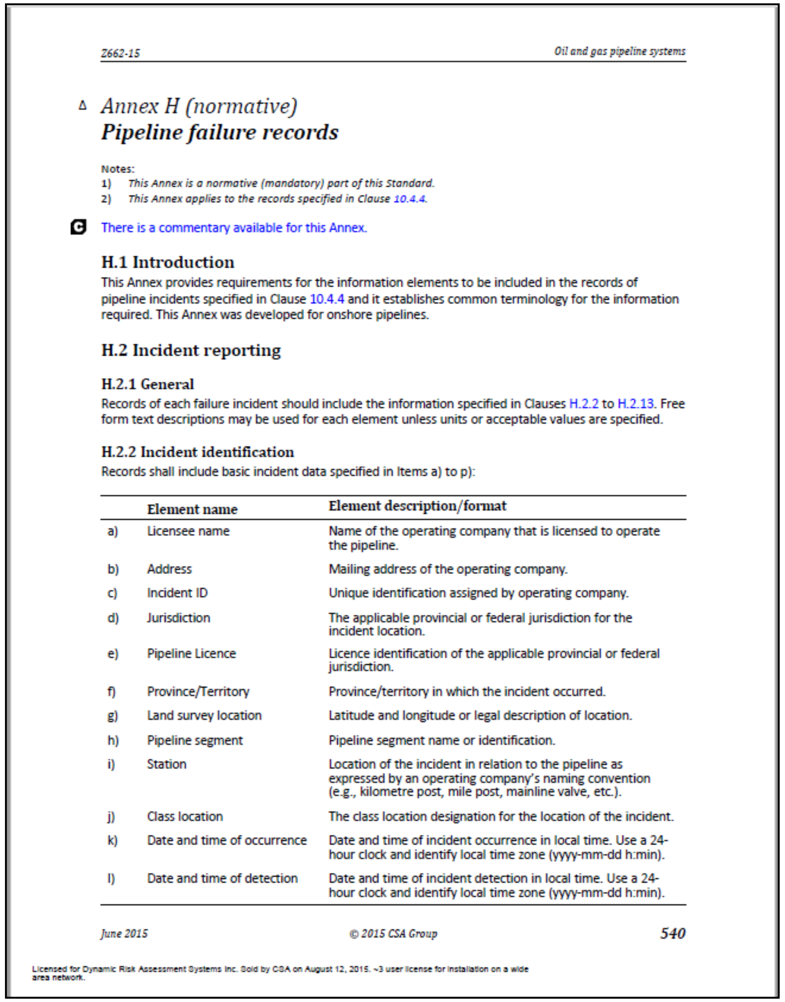
Guidance from Canadian Standards



Z662-15 — *Oil and gas pipeline systems*

Annex H (normative)
Pipeline failure records

Notes:
1) *This Annex is a normative (mandatory) part of this Standard.*
2) *This Annex applies to the records specified in Clause 10.4.4.*

There is a commentary available for this Annex.

H.1 Introduction

This Annex provides requirements for the information elements to be included in the records of pipeline incidents specified in Clause 10.4.4 and it establishes common terminology for the information required. This Annex was developed for onshore pipelines.

H.2 Incident reporting

H.2.1 General

Records of each failure incident should include the information specified in Clauses H.2.2 to H.2.13. Free form text descriptions may be used for each element unless units or acceptable values are specified.

H.2.2 Incident identification

Records shall include basic incident data specified in Items a) to p):

	Element name	Element description/format
a)	Licensee name	Name of the operating company that is licensed to operate the pipeline.
b)	Address	Mailing address of the operating company.
c)	Incident ID	Unique identification assigned by operating company.
d)	Jurisdiction	The applicable provincial or federal jurisdiction for the incident location.
e)	Pipeline Licence	Licence identification of the applicable provincial or federal jurisdiction.
f)	Province/Territory	Province/territory in which the incident occurred.
g)	Land survey location	Latitude and longitude or legal description of location.
h)	Pipeline segment	Pipeline segment name or identification.
i)	Station	Location of the incident in relation to the pipeline as expressed by an operating company's naming convention (e.g., kilometre post, mile post, mainline valve, etc.).
j)	Class location	The class location designation for the location of the incident.
k)	Date and time of occurrence	Date and time of incident occurrence in local time. Use a 24-hour clock and identify local time zone (yyyy-mm-dd h:min).
l)	Date and time of detection	Date and time of incident detection in local time. Use a 24-hour clock and identify local time zone (yyyy-mm-dd h:min).

June 2015 — © 2015 CSA Group — 540

- CSA Z662 Annex H
  - Hazard — a condition or event that might cause a failure or damage incident or anything that has the potential to cause harm to people, property, or the environment

Guidance from U.S. Standards

Risk Assessment - U.S. Pipelines

- 49 CFR Part 192 (Gas Pipelines)
  - Subpart O Section 192.917

(a) *Threat identification.* An operator must identify and evaluate all potential threats to each covered pipeline segment. Potential threats that an operator must consider include, but are not limited to, the threats listed in ASME/ANSI B31.8S (incorporated by reference, *see* § 192.7), section 2, which are grouped under the following four categories:

(1) Time dependent threats such as internal corrosion, external corrosion, and stress corrosion cracking;

(2) Static or resident threats, such as fabrication or construction defects;

(3) Time independent threats such as third party damage and outside force damage; and

(4) Human error.

Guidance from U.S. Standards

Risk Assessment - U.S. Pipelines

- 49 CFR Part 192 (Gas Pipelines)

  - Subpart O Section 192.917 (cont'd)

(c) *Risk assessment.* An operator must conduct a risk assessment that follows ASME/ANSI B31.8S, section 5, and considers the identified threats for each covered segment. An operator must use the risk assessment to prioritize the covered segments for the baseline and continual reassessments (§§ 192.919, 192.921, 192.937), and to determine what additional preventive and mitigative measures are needed (§ 192.935) for the covered segment.

Guidance from N.A. Standards

ASME/ANSI B31.8S – Managing System Integrity of Gas Pipelines

- Provides general guidance on risk assessment approaches
- Provides specific guidance on threats, safety consequences and data elements to consider
- Incorporated by reference in 49 CFR Part 192
- Referenced in API 1160 (Managing System Integrity for Hazardous Liquid Pipelines)

Guidance from U.S. Standards

Risk Assessment – U.S. Pipelines

- 49 CFR Part 195 (Hazardous Liquid Pipelines)
  - Subpart F Section 195.452 and Appendix C to Part 195
    - Provide guidance on risk factors to consider

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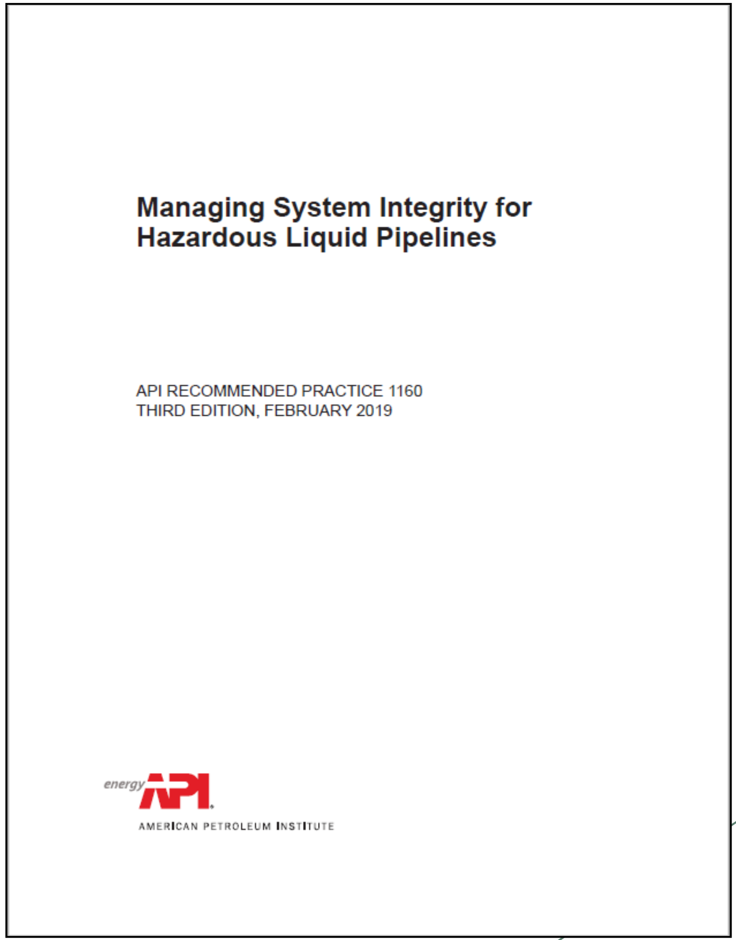
Guidance from N.A. Standards

API 1160 - Managing System Integrity for Hazardous Liquid Pipelines

- Provides general guidance on risk assessment approaches
- Provides specific guidance on threats, spill consequences and data elements to consider
- References ASME/ANSI B31.8S
- Much overlap with API 1160 and ASME B31.8S; however, the fact that there are both physical and regulatory differences between gas and liquid pipelines makes it necessary to alter the threat categories to some extent.


Managing System Integrity for Hazardous Liquid Pipelines

API RECOMMENDED PRACTICE 1160
THIRD EDITION, FEBRUARY 2019

energy API
AMERICAN PETROLEUM INSTITUTE

Guidance from International Standards

International - ISO Risk Assessment Standards

- ISO 31000:2018, *Risk management – Guidelines*, provides principles, framework and a process for managing risk. It can be used by any organization regardless of its size, activity or sector.
- Using ISO 31000 can help organizations increase the likelihood of achieving objectives, improve the identification of opportunities and threats and effectively allocate and use resources for risk treatment.

Guidance from Standards

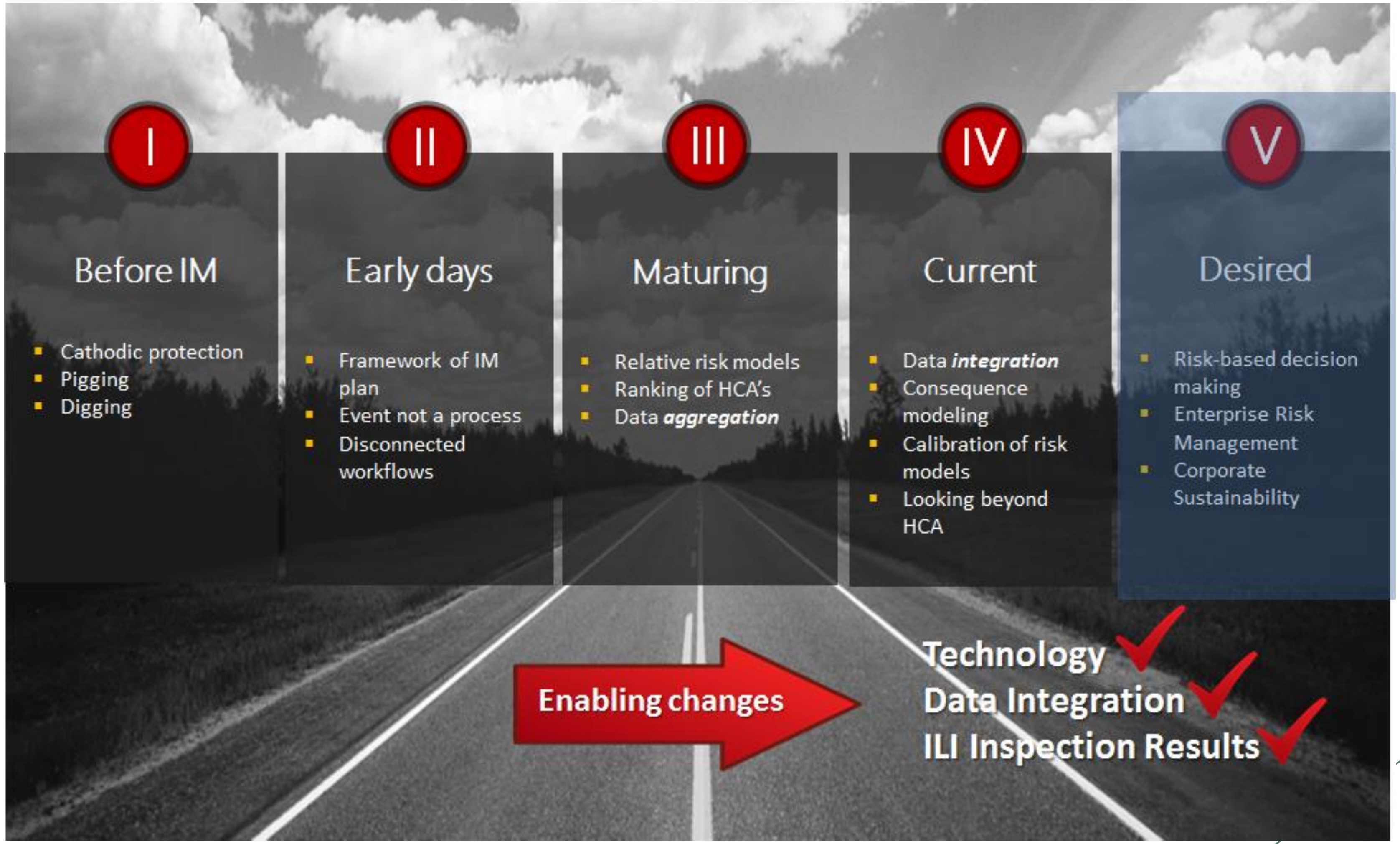
International - ISO Risk Assessment Standards (cont'd)

- IEC 31010:2009, *Risk management – Risk assessment techniques* focuses on risk assessment. Risk assessment helps decision makers understand the risks that could affect the achievement of objectives as well as the adequacy of the controls already in place. IEC 31010:2009 focuses on risk assessment concepts, processes and the selection of risk assessment techniques.

Questions?

Pipeline Risk and Reliability Modeling

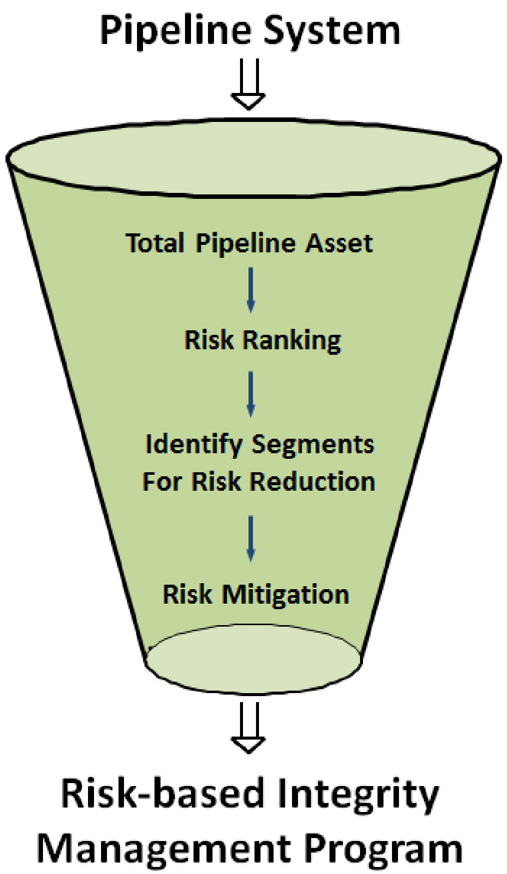
Pipeline Risk Modeling Evolution



Pipeline Risk Modeling Overview

General Process Overview

- Risk Evaluation
  - Determine failure modes which materially contribute to failure
  - Data collection, integration and analysis
  - Determine failure likelihood
  - Determine consequences
  - Conduct risk assessment
  - Prioritize where to conduct risk mitigation
- Risk Mitigation
  - Determine risk acceptability
  - Identify segments requiring risk reduction
  - Perform risk mitigation
  - Establish performance metrics
  - Measure performance of IMP



Pipeline Risk Modeling Overview

Risk = f(Failure Likelihood, Consequences)

- Failure Likelihood
  - Consideration of all viable threats
    - External corrosion
    - Internal corrosion
    - 3rd party damage
    - Manufacturing
    - Incorrect operations
    - Etc.
  - Establish failure likelihood for each viable threat as function of design, installation and operating environment
- Consequences
  - Types of consequences:
    - Safety
    - Economic
    - Environmental
    - Regulatory
    - Corporate Image
  - Utilize impact chart as means of equating consequences from various sources and establishing quantifiable impacts

Pipeline Risk Assessment Scope

- Types of Risk Assessment:
  - Site or project specific (QRA)
  - System wide
  - New construction; risk based design
  - Asset acquisition; due diligence
  - Support of engineering assessment

The risk assessment approach needs to align with the purpose of the assessment and the supporting data available.

Pipeline Risk Assessment Scope

10.1 Engineering assessments of existing pipelines

There is a commentary available for this Clause.

10.1.1

Engineering assessments of existing pipeline systems shall be conducted and documented in accordance with the requirements of Clause 3.3 and the analysis shall include consideration of the following, as applicable:

a) design basis of the pipeline system, including service fluid, operating pressure and temperature range, and the general and site-specific loading and operating conditions that are anticipated throughout its design life;
b) material specifications and properties;
c) manufacturing process and installation method;
d) construction and testing specifications;
e) the physical configuration and constraints of the part of the pipeline system that are the subject of the engineering assessment;
f) condition of the piping, including types of imperfections, dimensions, and dimensional uncertainty;
g) mechanism or mode of imperfection formation, growth, and failure;
h) service, operating and maintenance history;
i) appropriateness of repair methods;
j) interaction of identified hazards; and
k) risk assessment.

Notes:

1) *Reference should be made to the records required in Clauses 5.7, 6.1.5, 7.6.3, 7.14.9, 7.15.11, 8.8.7, 9.9.4, 9.9.5, 10.4, and 16.5.2.*
2) *Risk assessment (see Annex B), pipeline system integrity management programs (see Annex N), and reliability-based design and assessment (RBDA) (see Annex O) can provide valuable information and guidance for the engineering assessment.*

- CSA Z662 requires consideration of risk assessment as part of engineering assessments for existing pipelines:

Pipeline Risk Modeling Continuum

Risk Modeling Continuum:

- Risk modeling is a continuum utilizing a range of qualitative and quantitative approaches and measures of risk
- Recent guidance on risk modeling (PHMSA Risk Modeling Work Group):

https://primis.phmsa.dot.gov/rmwg/docs/Pipeline_Risk_Modeling_Technical_Information_Document_05-09-2018_Draft_1.pdf

Pipeline Risk Modeling Continuum

- **Qualitative:**
  - Characterizes risk level without quantifying it
- **Quantitative**
  - Calculates risk level based on quantified estimates of probability and consequence
- **Semi-quantitative:**
  - One of either probability or consequence is based on quantified estimates while the other is not quantified

Pipeline Risk Modeling Continuum

Qualitative		Quantitative
Simple Subjective Relative Judgmental	*Increased accuracy requires increased data availability, accuracy, resolution* →	Detailed Objective Absolute Analytical

Index Methods → **Probabilistic Methods**

Pipeline Risk Modeling - Qualitative

Qualitative Methods:

- **Risk Indices or Categories**
  - Assign subjective scores based on pipeline attributes, e.g.:
    - **Failure Likelihood**:
      - Probability Score 1-10
      - Rare, Unlikely, Possible, Likely, Almost Certain
    - **Consequence**:
      - Impact Severity Score 1-10
      - Insignificant, Minor, Moderate, Major, Catastrophic
    - **Risk**:
      - Risk Score 1-100
      - Low, Moderate, High, Extreme

Pipeline Risk Modeling - Qualitative

- Advantages:
  - Easy to understand, use and communicate
  - Useful for prioritization
  - Readily accommodates a broad range of risk attributes

- Limitations:
  - Subjective assignment of attribute weights could be inaccurate
  - Difficult to establish acceptability thresholds
  - Provides relative measure only within a specific system; not comparable outside of the system

Pipeline Risk Modeling - Quantitative

Quantitative Methods:

- Failure Likelihood:
  - Failure Frequency (failures/km-yr or failures/yr)
- Consequences:
  - Numerical Consequences ($ Impact, Fatalities, etc.)
- Risk:
  - Numerical Impact ($/km-yr, fatalities/km-yr, barrels/km-yr)

Pipeline Risk Modeling - Quantitative

- Advantages:
  - Maximizes use of inspection data
  - Consistent basis for risk and feature response
  - Impact of design, material and mitigation measures on risk can be quantified
- Limitations:
  - Inaccurate or missing data has a large impact on results
  - Difficult to combine different measures of risk

Pipeline Risk Modeling - Quantitative

- Available approaches:
  - Reliability approaches
  - Fault-tree and event tree approaches
  - Incident data-based approaches
  - Exposure-mitigation-resistance approaches
  - Geohazard vulnerability approaches

Estimating Failure Likelihood

Pipeline Threats and Hazards

- **Threat:** Potential cause of failure, failure mechanism.
- **Hazard:** Hazard — a condition or event that might cause a failure or damage incident or anything that has the potential to cause harm to people, property, or the environment. [Used synonymously with “threat” by some references.]

Pipeline Threats and Hazards

Threats to Gas Pipelines (ASME B31.8S):

Time Dependent:

- External Corrosion
- Internal Corrosion
- SCC

Stable *(Resident)*:

- Manufacturing-Related Defects
- Construction-Related Defects
- Equipment

Time Independent:

- Third Party/Mechanical Damage
- Incorrect Operational Procedure
- Weather Related and Outside Forces

Pipeline Threats and Hazards

Threats to Gas Pipelines (ASME B31.8S):

- Interactive nature of threats shall be considered
- Pressure cycling and fatigue shall be considered

Interactive Threats - Gas

Gas: DOT Incidents from Interacting Threats

	Gas Transmission and Gathering Lines - DOT Incident Database 1984 - 2015																					
	EC	IC	SCC	DP	DPS	DFW	DGW	CD	MCRE	TSBPC	GF	SPPF	IO	TP	PDP	V	EM	HRF	LIGHT	CW	MISC	Total
EC			1	1	14		4	3	5	2	2		6		4		1	1		2		46
IC					11		8		3													22
SCC				1																		1
DP								2	1												1	4
DPS									1								1				1	3
DFW										1			1	2			5	1		1	2	13
DGW								1	1				1	2			19	11		2	3	40
CD										2							3	1				6
MCRE										5	4	1	11	2			1	5	7	33	3	72
TSBPC													6	11			17	18		3	1	56
GF													8	2		1	1	2	2		1	17
SPPF																						0
IO														7	1					2	1	11
TP															2		2	17				21
PDP																	1	1				2
V																						0
EM																		14		1		15
HRF																				2		2
LIGHT																						0
CW																						0
																						331

Pipeline Threats and Hazards

Threats to Hazardous Liquid Pipelines (API 1160):

- External corrosion
- Internal corrosion
- Selective seam corrosion
- Stress corrosion cracking (SCC)
- Manufacturing defects
- Construction and fabrication defects
- Equipment failure (non-pipe pressure containing equipment)
- Immediate failure due to mechanical damage
- Time-dependent failure due to resident mechanical damage
- Incorrect operations
- Weather and outside force
- Activation of resident damage from pressure-cycle-induced fatigue

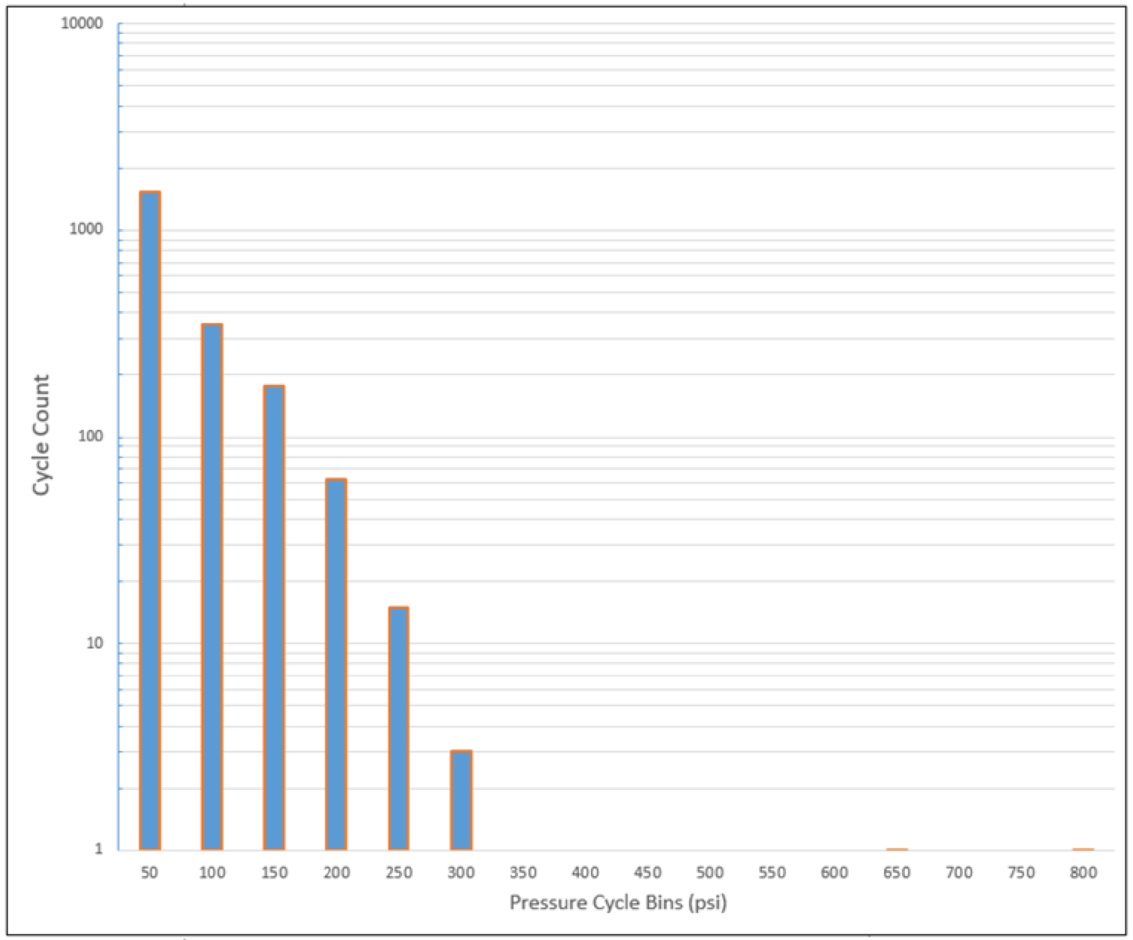
Interactive Threats - Liquids

Hazardous Liquids: DOT Incidents from Interacting Threats

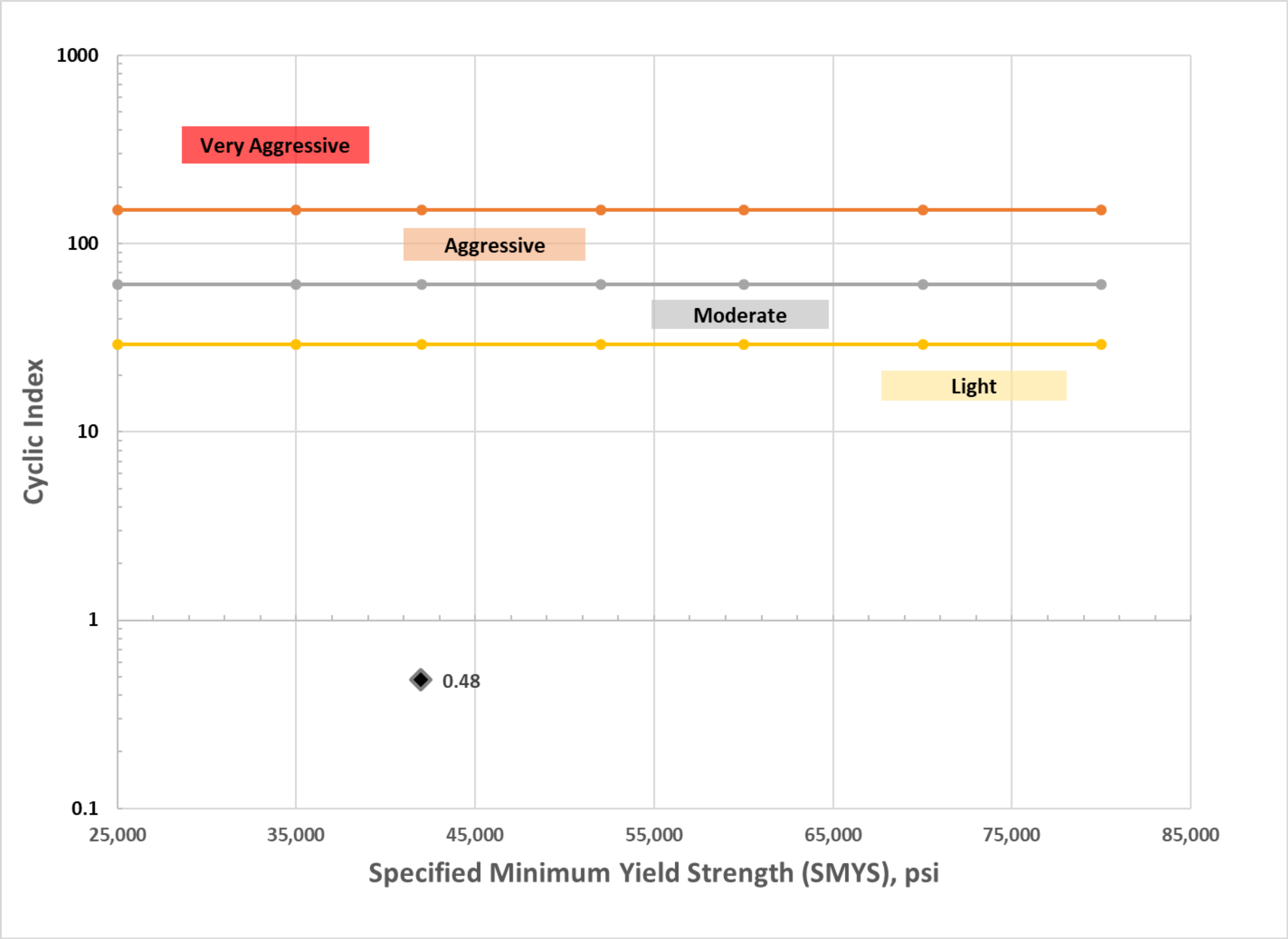
	Hazardous Liquids Transmission Lines - DOT Incident Database 1986-2015																					
	EC	IC	SCC	DP	DPS	DFW	DGW	CD	MCRE	TSBPC	GF	SPPF	IO	TP	PDP	V	EM	HRF	LIGHT	CW	MISC	Total
EC		2	1		31	4	6	49	2	3			21		11		1	2				133
IC					2	2	5		1	3	1		3									17
SCC					2	2	1	1					2		1		1					10
DP					1								5				2			1		9
DPS								1	1				11				1					14
DFW							1			1			17	1	1		1	1		1		24
DGW								1					5				10	7		1		24
CD										1			1				4			4		10
MCRE											1	1	18	3					1	27	1	52
TSBPC											2		47	36			14	14	1	14	1	129
GF													37					1		2	1	41
SPPF													7						1	1	1	10
IO														24	7		2	5	1	24	2	65
TP																	2	13				15
PDP																		1				1
V																						0
EM																		15		1		16
HRF																				1		1
LIGHT																						0
CW																						0
																						571

Pressure Cycling Considerations

- Impact on resident features
- Impact on crack growth



Pressure Cycling Considerations



Estimating Failure Likelihood

Threat Assessment:

- **Pipeline System Review**
  - System Maps (alignment, proximity to HCAs)
  - Installation Eras (modern vs. vintage materials)
  - Products Transported (liquid, gas, crude, refined, sour, sweet)
  - Design Variables (diameters, grades, w.t., stress levels)
  - Installation Procedures (welding, NDT, etc.)
  - Operating Factors (stress, pressure cycling, environmental conditions, Inspection data)

Estimating Failure Likelihood

Threat Assessment (cont'd):

- **Review Threat Attributes in Consideration of Data and System Review**
  - External Corrosion
    - Coating type, CP history, Inspection data, Interference, etc.
  - Internal Corrosion
    - Product composition, Hydraulic regime, Inspection data, etc.
  - Third Party Damage
    - Land use, patrol frequency, damage prevention measures, etc.
- **Quantitative**
  - Calculate risk level based on quantified estimates of probability and consequence

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Estimating Failure Likelihood

Case Study: Relative/Index Method for EC based on susceptibility factors (no ILI)

$$S = M \times \left\{ 1 - \left[1 - \left(\frac{B}{10} \right) \right] \times \left[1 - \left(\frac{C_F}{10} \right) \right] \times \left[1 - \left(\frac{FH}{10} \right) \right] \right\} \times A_F$$

Where,

M = Material Type Score (0 or 1);

S = External Corrosion Score (0-10);

B = Baseline Susceptibility Score (0-10);

C_F = Stray Current / Interference Factor (0-10);

FH = External Corrosion Failure History Score (0-10); and,

A_F = Integrity Assessment Mitigation Factor (1-10)

Baseline Score Weightings:

Variable	Factor	Fractional Weighting
Age	AF	0.20
Corrosion Allowance Factor	CAF	0.05
Coating System Type Score	MCT	0.30
CP Compliance Score	CP	0.20
Coating Condition Score	CC	0.20
Casings	CAS	0.05

Estimating Failure Likelihood

Case Study (cont'd): Relative/Index Method for EC based on susceptibility factors (no ILI)

CP Compliance

$$S_{CP} = \left\{1 - \left[1 - \left(\frac{\%NCR}{100}\right)\right] \times \left[1 - \left(\frac{\%NO}{100}\right)\right]\right\} \times 10$$

Coating Age

Coating Age (yrs)	<=3	>3 to <= 6	>6 to <=9	>9 to <=12	>12 to <=15	>15 to <=18	>18 to <=21	>21 to <=24	>24 to <=27	>27 to <=30	>30	Not Available
Age Score	0	1	2	3	4	5	6	7	8	9	10	10

Corrosion Allowance

$$t_{corr} = t_a - \left(\frac{PD}{2S}\right)$$

Calculated Value of t_{corr}	>0.250	>0.200 to <=0.250	>0.175 to <=0.200	>0.150 to <=0.175	>0.125 to <=0.150	>0.100 to <=0.125	>0.075 to <=0.100	>0.050 to <=0.075	>0.025 to <=0.050	<=0.025
Score	1	2	3	4	5	6	7	8	9	10

Coating Type

Pipe Coating Type	Score	SCC Susceptible (Y/N)
Bare	10	Y
Unknown	10	Y
Coated	7	Y
Coal Tar ("Enamel", "Hot Dope")	6	Y
Reinforced Coal Tar ("Enamel – reinforced")	4	Y
FBE	2	N
Thin Film	2	N
Pre-2000 Wax	6	Y
>= 2000 Wax	3	Y
Dual Coat	1	N
Paint (above ground paint)	2	Y
Paint – high temperature (above ground)	2	Y
Mastic	5	Y
Cold-applied PE tape with primer	4	Y
Liquid epoxy coating ("Powercrete")	1	N
Extruded Polyethylene ("Yellow Coat")	3	N
Line Travel PE Tape	7	Y

Estimating Failure Likelihood

Case Study: Relative/Index Method for EC based on ILI (Remaining Life)

- Use failure pressure criteria such as Modified B31G and wall thickness threshold to determine critical depth for failure at MOP or wall thickness threshold (eg. 80%)
- Can incorporate Safety Factor
- Apply growth rate to feature depth from time of ILI to current
- Calculate feature specific remaining life
- Determine % RL consumed since last assessment

Estimating Failure Likelihood

Case Study (cont'd): Relative/Index Method for EC based on ILI (Remaining Life)

$$\%Remaining\ Life\ Consumed = \frac{Y_{risk} - Y_{ILI}}{RL}$$

Where,
Y_{risk} = the current year
Y_{ILI} = Year of ILI run
RL = Remaining Life

Scores will be assigned using the following table:

% of Remaining Life Consumed Since ILI	Score
> 90%	10
> 80% to ≤ 90%	9
> 70% to ≤ 80%	8
> 60% to ≤ 70%	7
> 50% to ≤ 60%	6
> 40% to ≤ 50%	5
> 30% to ≤ 40%	4
> 20% to ≤ 30%	3
> 10% to ≤ 20%	2
≤ 10%	1
No anomalies	0

Estimating Failure Likelihood

Case Study: Quantitative Methods based on Incident Data

$$FF_{s,t,m} = FF_{Baseline} \times W_t \times W_m \times AF_{t,s}$$

Failure frequency for segment by threat and mode

Baseline failure frequency for type of asset (industry stats)

Weighting by threat (industry stats)

Weighting by mode [leak (size), rupture (industry stats)]

Adjustment Factor for segment and threat [algorithm-based]

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Estimating Failure Likelihood

Case Study (cont'd): Quantitative Methods based on Incident Data

Natural Gas Pipelines (PHMSA 2010-2017)

Threat	Failure Frequency (failures/km*yr) 2010-2017	Leak Fraction	Rupture Fraction
External Corrosion	1.347E-05	0.49	0.51
Internal Corrosion	5.844E-06	0.57	0.43
Stress Corrosion Cracking	5.082E-06	0.35	0.65
Manufacturing Defects	5.844E-06	0.43	0.57
Construction Defects	8.131E-06	0.69	0.31
Equipment Failure	1.575E-05	0.95	0.05
Third Party Damage	3.202E-05	0.87	0.13
Incorrect Operations	3.049E-06	0.92	0.08
Natural Forces	5.336E-06	0.76	0.24

Estimating Failure Likelihood

Case Study (cont'd): Quantitative Methods based on Incident Data

Hazardous Liquid Pipelines (PHMSA 2010-2017)

Threat	Failure Frequency (failures/km*yr) 2010-2017	Leak Fraction	Rupture Fraction
External Corrosion	5.897E-05	0.9437	0.0563
Internal Corrosion	3.281E-05	0.9873	0.0127
Stress Corrosion Cracking	3.738E-06	0.5556	0.4444
Manufacturing Defects	2.741E-05	0.8333	0.1667
Construction Threat	1.869E-05	0.9111	0.0889
Equipment Failure	1.059E-04	0.9922	0.0078
Third Party Damage	4.361E-05	0.9429	0.0571
Incorrect Operations	4.195E-05	0.9406	0.0594
Natural Forces	7.060E-06	0.8235	0.1765

Estimating Failure Likelihood

Incident Data Approaches:

- Useful when a reliability model cannot be employed or ILI cannot be leveraged
- Important to consider source of incident data
- Should match characteristics of system being modeled
  - Gas
  - Liquids
  - Products
  - Upstream/Midstream/Transmission/Distribution

Estimating Failure Likelihood

PoF approach from Exposure-Mitigation-Resistance:

- *"…**Exposure** (attack) –…defined as an event which, in the absence of mitigation, can result in failure, if insufficient resistance exists…*
- ***Mitigation** (defense) –…type and effectiveness of every mitigation measure designed to block or reduce an exposure.*
- ***Resistance** – measure or estimate of the ability of the component to absorb the exposure force without failure, once the exposure reaches the component…"*

Muhlbauer, *Pipeline Risk Assessment: The Definitive Approach and its Role in Risk Management*, 2015.

Estimating Failure Likelihood

Exposure-Mitigation-Resistance Example:

PoF_time-independent = exposure x (1 - mitigation) x (1 - resistance)

Data Category	Examples of Data/Information	Example Units of Measure
PoF: Exposure	excavator activity, mpy external corrosion, mpy fatigue cracking, human error rates, etc.	events/mile-year
PoF: Mitigation	depth of cover, patrol, signage, coatings, procedures, training, etc.	% reduction in damage potential
PoF: Resistance	wall thickness, SMYS, toughness, weaknesses (dents, gouges, seam issues, etc.), etc.	% of damage resisted without leak/rupture OR[87] effective wall thickness (inches)
CoF	population density, thermal radiation distance, dispersion distances, explosion potential, overland flow distances, soil permeability, etc.	Ft2, Count/ft2, value per unit (remediation costs), cost per incident, etc.

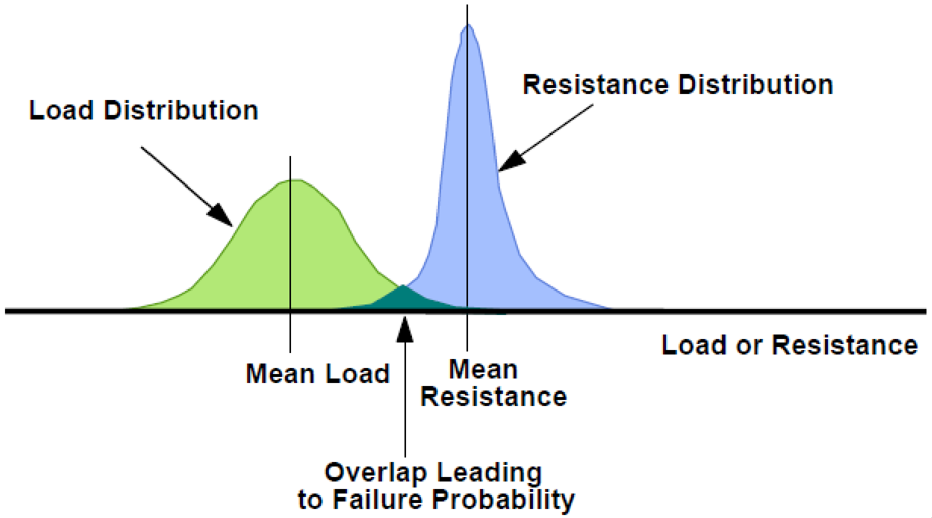
Estimating Failure Likelihood

Quantitative Methods based on Models

- Mechanistic models, combined with statistical analysis establishes probability of failure

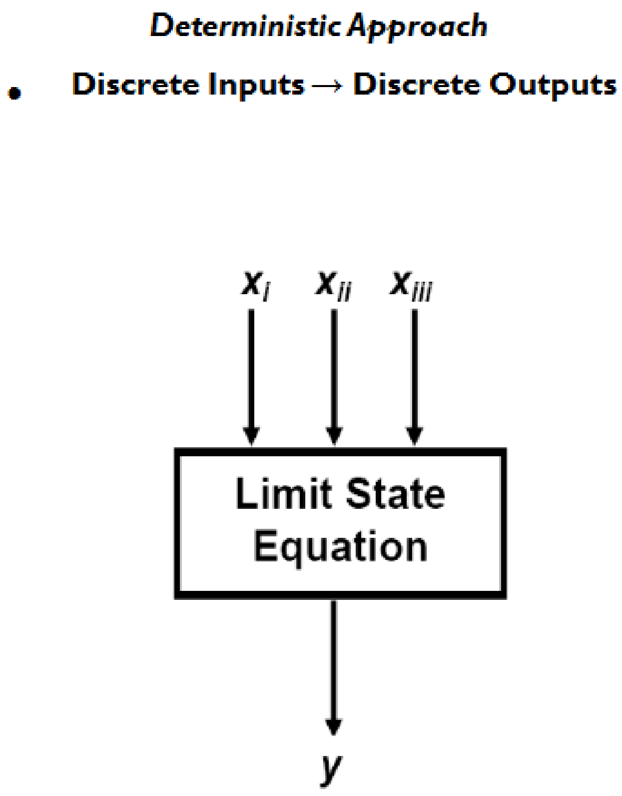
(Pdamage resistance < load)

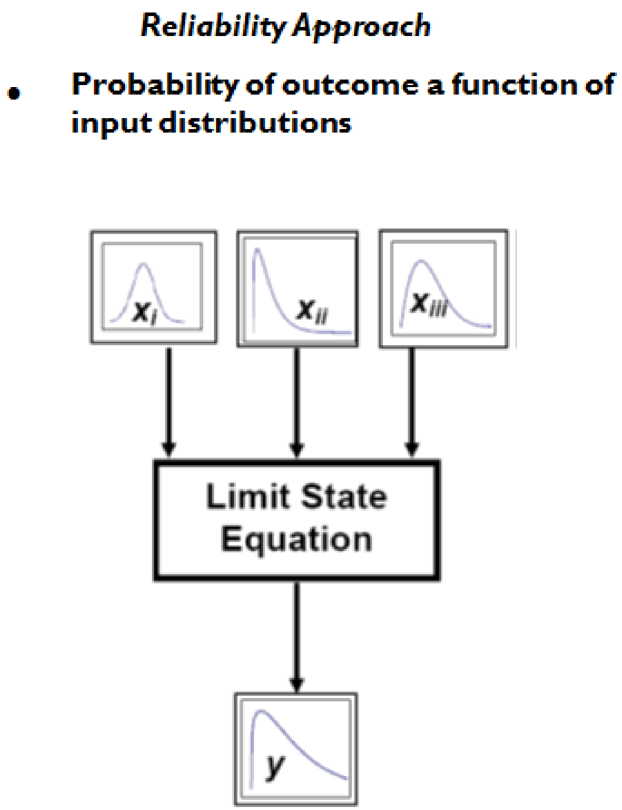
- Leverages ILI data, where available
- Often used in conjunction with Monte Carlo analysis



Estimating Failure Likelihood

Monte Carlo Analysis





- In Monte Carlo Analysis, mechanistic model is known as Limit State Equation

Estimating Failure Likelihood

Sample Limit State Equations:

- **Modified B31G Equation (Corrosion)**

$$\sigma_f = \bar{\sigma}\left[\frac{1-0{,}85\frac{d}{t}}{1-0.85\frac{d}{t}M^{-1}}\right]$$

- **NG18 Equation (Cracks)**

$$K_c^{\,2} = \frac{8\cdot c\cdot \sigma_{fl}^{\,2}}{\pi}\ln\sec\left(\frac{\pi\cdot M_T\cdot \sigma_h}{2\cdot \sigma_{fl}}\right)$$

- **Q-Factor Equation (3rd Pty Damage)**

$$\sigma_h = \sigma_{fl}\left[\frac{(Q-C_2)^{0.6}}{C_3}\right]$$

- **EGIG Equation (Dents)**

$$N_f = 5620\left(\frac{UTS}{\Delta\sum K_d K_g}\right)^{5.26}$$

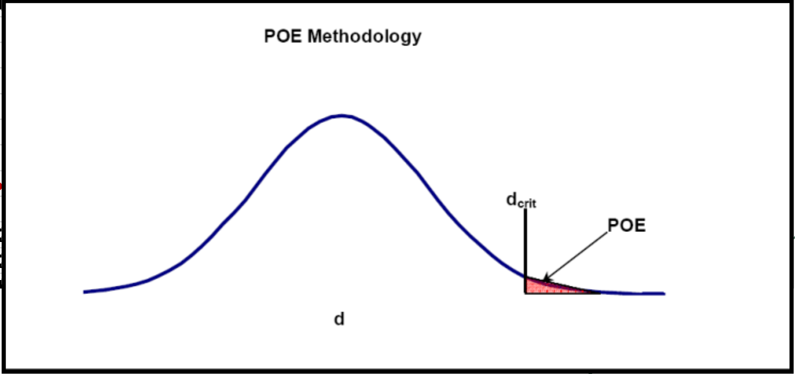
- ***All of these models support probabilistic analysis of ILI data***

Estimating Failure Likelihood

Risk Evaluation Consistent With Feature Response

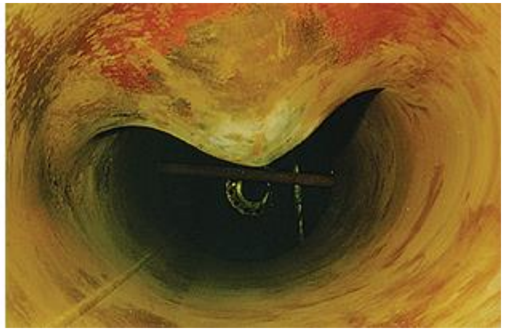
	J	K	L	M	N	O	P	Q
1	Callbox Id	YrExceedsCriteri	FailureModeAtYe	FailureProbability	LeakAtTimeOfLIT	RuptueAtTimeOfl	LeakOrRuptureAt	LeakOrRuptureAt
77	40000299	13	Rupture	0.0027	0	0	0	0
78	40000300			0	0	0	0	0
79	40000301	8	Rupture	0.003105	0	0	0	0
80	40000302	17	Rupture	0.00249	0	0	0	0
81	40000303	1	Leak	0.007905	710	0	710	0.00355
82	40000304	18	Rupture	0.002585	0	0	0	0
83	40000305	19	Rupture	0.002505	0	0	0	0
84	40000306			0	0	0	0	0
85	40000307			0	0	0	0	0
86	40000308	1	Rupture	**0.0208**	2125	1	2125	0.010625
87	40000309			0	0	0	0	0
88	40000310	4	Leak	0.002945	5	0	5	2.5E-05
89	40000311	2	Rupture	0.003405	79	1	79	0.000395
90	40000312			0	0	0	0	0
91	40000313	17	Rupture	0.00373	0	0	0	0
92	40000314	8	Rupture	0.0029	0	0	0	0
93	40000315	6	Rupture	0.003175	0	0	0	0
94	40000316			0	0	0	0	0
95	40000317			0	0	0	0	0
96	40000318			0	0	0	0	0
97	40000319	17	Rupture	0.00249	0	0	0	0
98	40000320	18	Rupture	0.0[illegible]				
99	40000321							
100	40000322							
101	40000323							

$$d_{crit} = \frac{\left[\left(\sigma_{MOP} - \overline{\sigma}\right)\cdot t\right]}{\left[0.85\cdot\left(\frac{\sigma_{MOP}}{M}\right) - \overline{\sigma}\right]}$$



Estimating Failure Likelihood

Quantitative Methods based on Geohazard Vulnerability



Geohazard Categories and Types Evaluated

Category	Geohazard Type	Identifier	Geohazard Description
Hydrotechnical	Lateral Migration	LM	Lateral movement of a stream related to stream bank losses
	Scour	SC	Downward erosion of the stream bed
	Buoyancy	UP	Uplift of a pipeline related to buoyant conditions
	Erosion	ER	Erosion of cover and/or confining materials around the pipe
Mass Movement	Deep-seated Landslide	DS	Deep landslide with rotational or complex slide surface
	Creep	CR	Gradual downslope movement of soil or rock
	Shallow Landslide	SL	Skin flows and shallow slides
Tectonics	Liquefaction	LQ	Loss of soil strength due to dynamic loading
	Shaking	SK	Ground shaking due to seismic activity
	Fault Displacement	FD	Differential movement of ground due to fault breaks
Geochemical	Acid Rock Drainage	ARD	Oxidation of sulphide bearing materials
	Karst Collapse	KC	Collapse of ground into bedrock solution cavities
Freeze / Thaw	Frost Action	FA	Ground heave due to excess ice formations in frozen ground

Estimating Failure Likelihood

Geohazard FLOC Calculation

FLOC = Frequency of Loss of Containment

= I x F x S x V x M

F – If so, how often?(/yr)

I - Can it happen? (0 or 1)

S – When it happens, can it hit the pipe?(0-1)

V – Will it cause the pipe to fail?(0-1)

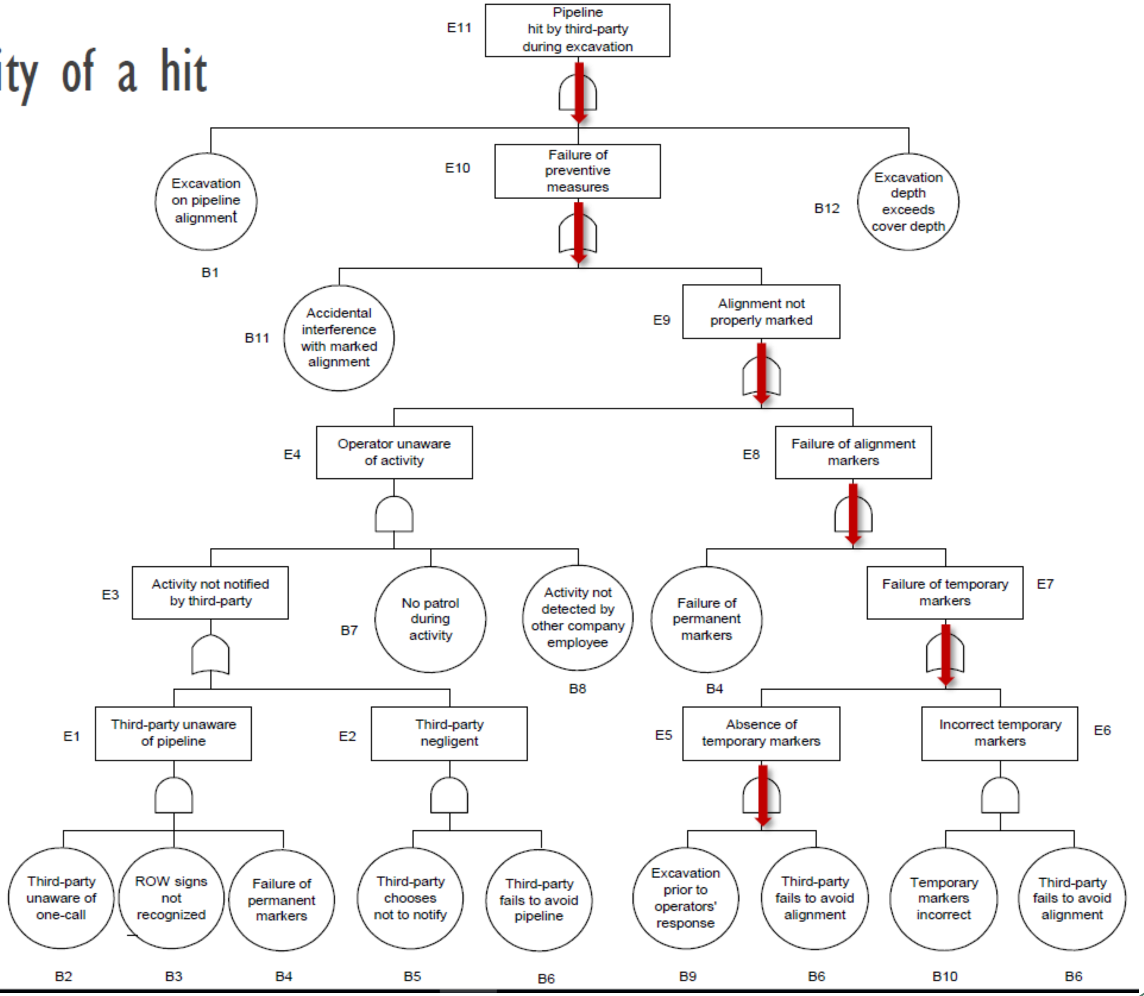
M – How will mitigation help? (0-1)

Estimating Failure Likelihood

Fault Tree Model for Third Party Damage

External Interference

- Probability of a hit



Estimating Failure Likelihood

No	Event	Conditions	Probability
B1	*Excavation on pipeline alignment (function of land use)	Commercial/Industrial	0.52
		High density residential	0.26
		Low density residential	0.36
		Agricultural	0.076
		Remote/Water Body	0.06
B2	Third-party unaware of one-call (function of method of communicating one-call system)	Advertising via direct mail-outs and promotion among contractors	0.24
		Above + Community meetings	0.10
		Community meetings only	0.50
B3	Right-of-way signs not recognized (function of placement frequency for signs)	Signs at selected crossings	0.23
		Signs at all crossings	0.19
		All crossings plus intermittently along route	0.17
B4	Failure of permanent markers (warning tape)	No buried markers	1.00
		With buried markers	0.10
B5	Third-party chooses not to notify (function of type of penalty for failure to advise of intent to excavate)	Voluntary	0.58
		Mandatory	0.33
		Mandatory plus civil penalty	0.14
		Right-of-way agreement	0.11
B6	Third-party fails to avoid pipeline	Default value	0.40
B7	ROW patrols fail to detect activity (function of patrol frequency)	Semi-daily patrols	0.13
		Daily patrols	0.30
		Bi-daily patrols	0.52
		Weekly patrols	0.80
		Biweekly patrols	0.90
		Monthly patrols	0.95
		Semi-annual patrols	0.99
		Annual patrols	0.996
B8	Activity not detected by other employees	Default value	0.97
B9	Excavation prior to operator's response (function of response time following advice of intent to excavate)	Response at the same day	0.02
		Response within two days	0.11
		Response within three days	0.20
B10	Temporary mark incorrect (function of marking method)	By company records	0.20
		By magnetic techniques	0.09
		By pipe locators/probe bars	0.01
B11	Accidental interference with marked alignment (function of means of conveying information pertaining to location of pipeline during excavation by others)	Provide route information	0.35
		Locate/mark	0.17
		Locate/mark/site supervision	0.03
		Pipe exposed by hand	0.06
B12	Excavation depth exceeding cover depth (function of depth of cover)	Cover depth <= 0.8 m (2.5 ft)	0.42
		0.8 m (2.5 ft) < Cover depth <=0.9 m (3 ft)	0.25
		0.9 m (3 ft) < Cover depth <=1.2 m (4 ft)	0.08
		1.2 m (4 ft) < Cover depth <=1.5 m (5 ft)	0.07
		Cover depth > 1.5 m (5 ft)	0.06

Questions?

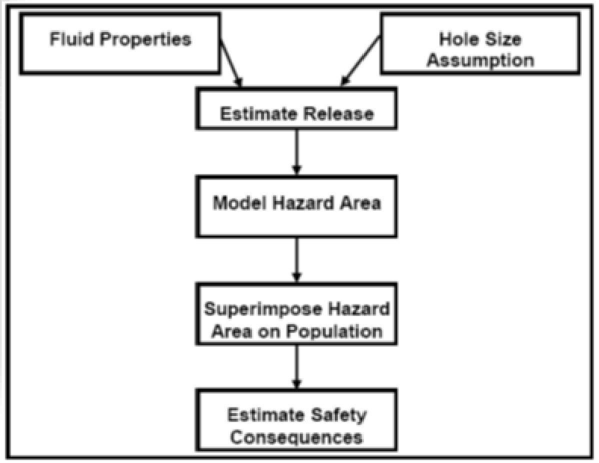
Estimating Consequence of Failure

Estimating Consequence of Failure

- Consequence factors most commonly modeled
  - Safety
  - Economic
  - Environmental
  - Regulatory
  - Corporate Image
  - Outage
- Computer models/empirical relationships to establish
  - Release Rate
  - Hazard Area
  - Spill Area
  - Damage Area
- Consideration of failure mode:
  - Small Leak
  - Large Leak
  - Rupture

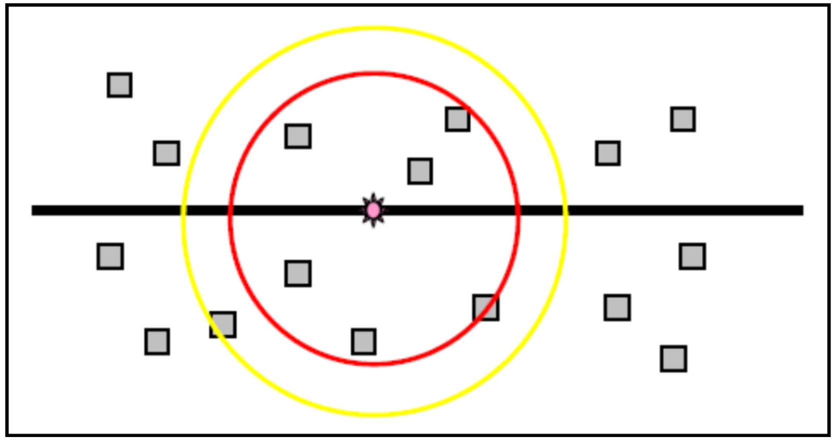
Estimating Consequence of Failure

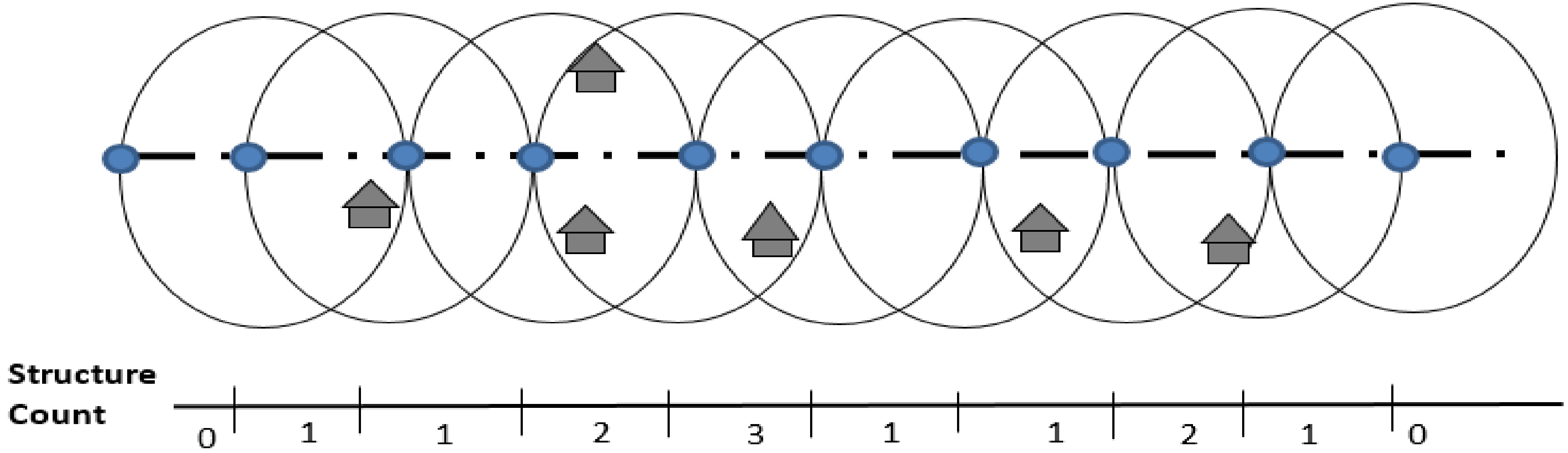
- Main Steps
  - Identify fluid properties and parameters
  - Estimate release rate
  - Model hazard area and probability of hazard (ignition)
  - Establish public impact



Estimating Consequence of Failure

$$PIR = 0.69\sqrt{P.D^2}$$





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Estimating Consequence of Failure

- Environmental impact determined by modelling liquid outflow and overland spill
- Spill plume intersects are identified
  - HCAs, ESAs
  - Waterbodies
  - Areas of Habitation
  - Native territorial lands and reserves

Estimating Consequence of Failure

No regulatory body or standard has adopted a means to quantify environmental impact

No acceptance criteria based on quantitative end points

Challenges*:

- Limits on ability to accurately model complex ecosystems
- Temporal / seasonal impacts
- Lack of agreement on assumptions
- Lack of data on response of environmental receptors to toxic loads
- Appropriate units to quantify ecosystem value
- Variability in perception of value (native / non-native / commercial / recreational user)
- Social / cultural considerations in valuation
- Intangible value of habitat preservation among species

** European Commission Land Use Planning Guidelines*

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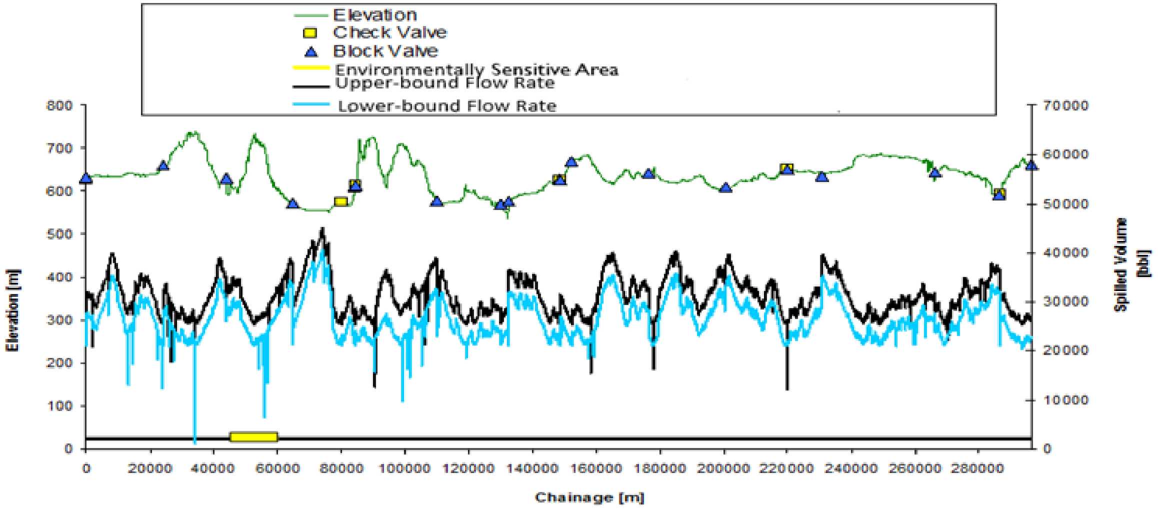
Estimating Consequence of Failure

Consequence Assessment; Environmental Consequence

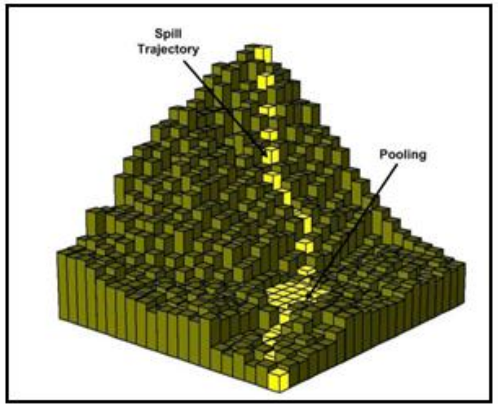
- **Outflow volume**
  - Product type
  - MOP
  - Flow rate
  - Hole size
  - Leak detection capabilities
  - Pump shutdown time
  - Valve design & configuration
  - Valve actuation time
  - Valve section profile

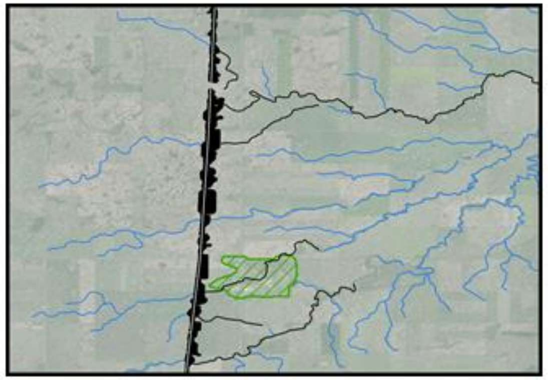


Estimating Consequence of Failure

Consequence Assessment; Environmental Consequence

Overland spill potential (direct / indirect intersect)





Practical solution is employment of consequence index that accounts for above factors

$$CI_{Watercourse} = F_{W1}S_{V,Watercourse} + F_{W2}S_{SR} + F_{W3}S_{DW}$$

Where,

$CI_{Watercourse}$	= Consequence Index for Watercourse Intersects (10-100)
F_{W1}, F_{W2}, F_{W3}	= Weighting Factors (0-1)
$S_{V,Watercourse}$	= Outflow Volume Score for Watercourse Intersects (10-100)
S_{SR}	= Watercourse Sensitivity Rating Score (10-100)
S_{DW}	= Drinking Water Source Score (10-100)

$$CI_{Nonwatercourse} = F_{N1}S_{V,Nonwatercourse} + F_{N2}S_{LS}$$

Where,

$CI_{Nonwatercourse}$	= Consequence Index for Non-Watercourse Intersects (1-10)
F_{N1}, F_{N2}	= Weighting Factors (0-1)
$S_{V,Nonwatercourse}$	= Outflow Volume Score for Non-Watercourse Intersects (1-10)
S_{LS}	= Land use Severity Score (1-10)

Risk Assessment Case Studies

Quantitative Risk Analysis - Case Study

Straits of Mackinac Enbridge Line 5 Study

- Client: State of Michigan contracted study (public record)
- Project: detailed assessment of alternatives to controversial oil pipeline crossing
    - 64-year-old twin 20-inch diameter lines on bottom of the straits
    - Transporting ≈540,000 bbl/day of light crude oil/natural gas liquids
- Alternatives analyzed
    - Construction of a new pipeline along a different route
    - Moving oil by rail
    - A new "trenched" crossing
    - Tunnel under the straits
    - Outright closure and decommissioning of Line 5
- Assessment included
    - Design-based cost estimates
    - Economic feasibility, socioeconomic and market impacts
    - Operational risk including consequences associated with an oil spill

Risk-based Design - Case Study

QRA for Planned Pipeline Interconnect

- Client: Diversified energy company operating more than 18,000 miles of liquids and natural gas pipelines
- Project: quantitative risk assessment for planned pipeline project
- Threat Assessment
  - Reviewed design, materials, construction, operating practices, and environment
  - Identified principal failure threats
  - Identified data to support failure frequency analysis
- Failure Frequency Analysis
  - Developed threat-based calculation of probability of failure per year of operation
- Consequence Analysis
  - Overland spill modeling and spatial assessment of impact
  - Safety, Environment, Economic impacts considered
- Risk Analysis
  - Developed a compound measure of likelihood and consequences
  - Recommended risk mitigation options to achieve acceptable risk level

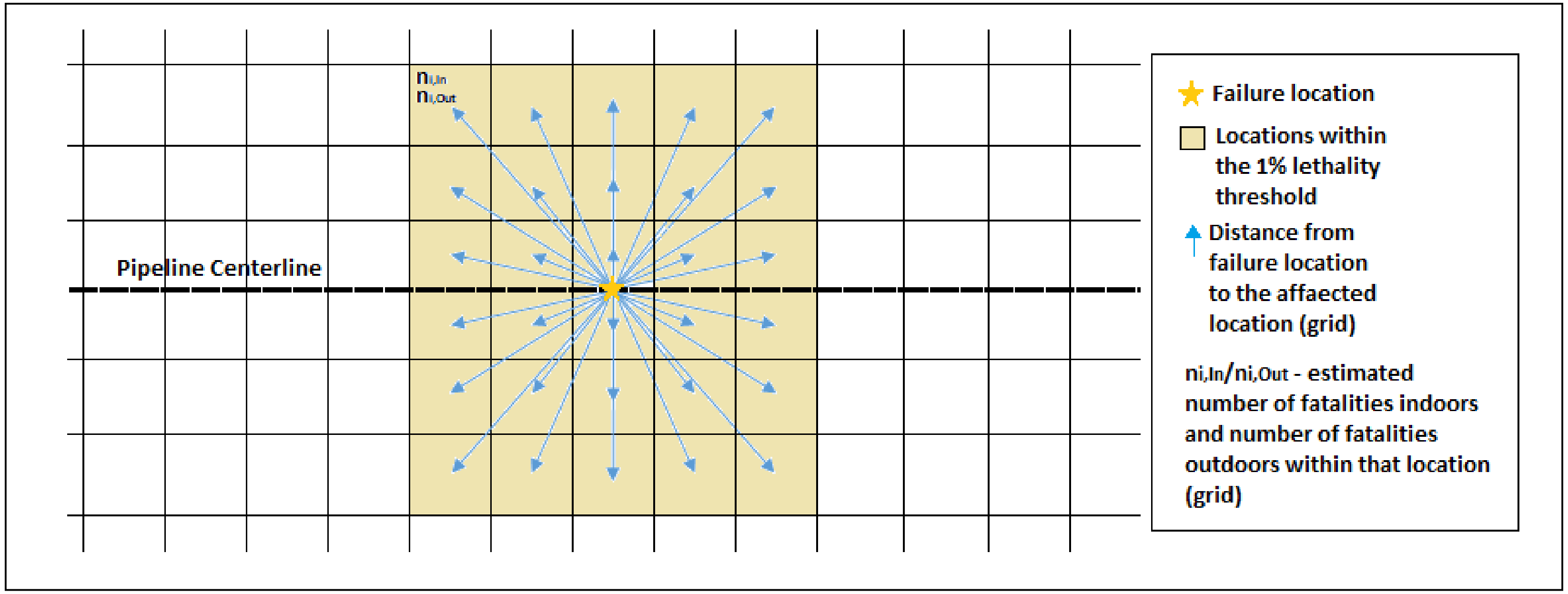
Societal Risk and Individual Risk

Societal Risk

- Represented by an F-N curve, which is a plot of the frequency F, of incidents resulting in N or more fatalities
- An F-N curve is associated with a specified length of pipeline

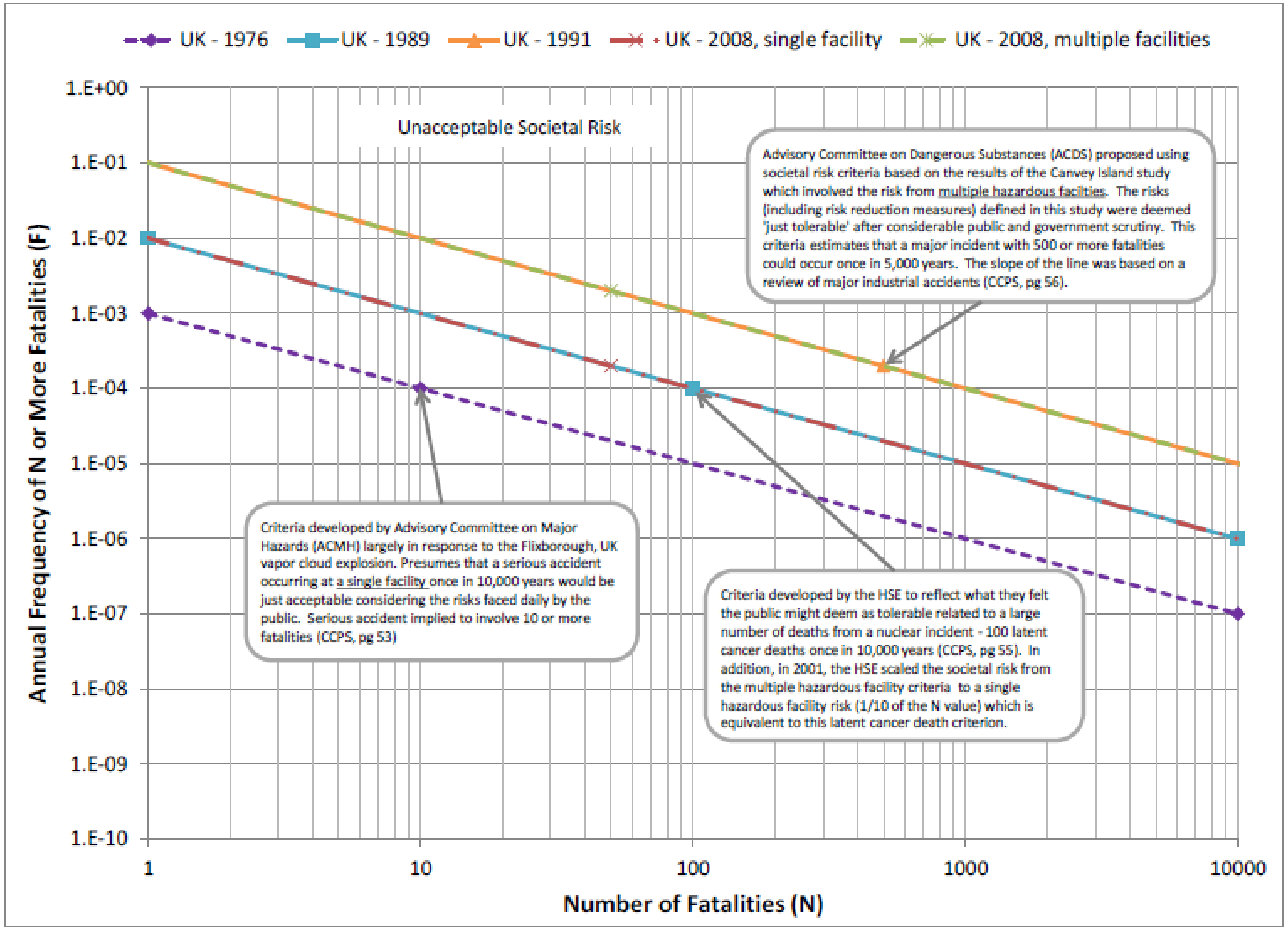
Societal Risk

- Probability of failure
- Probability of ignition
- Probability of fatality



Societal Risk

F-N Curve:



Societal Risk

- CSA Z662-15 Annex O: Reliability Targets for Ultimate Limit States:

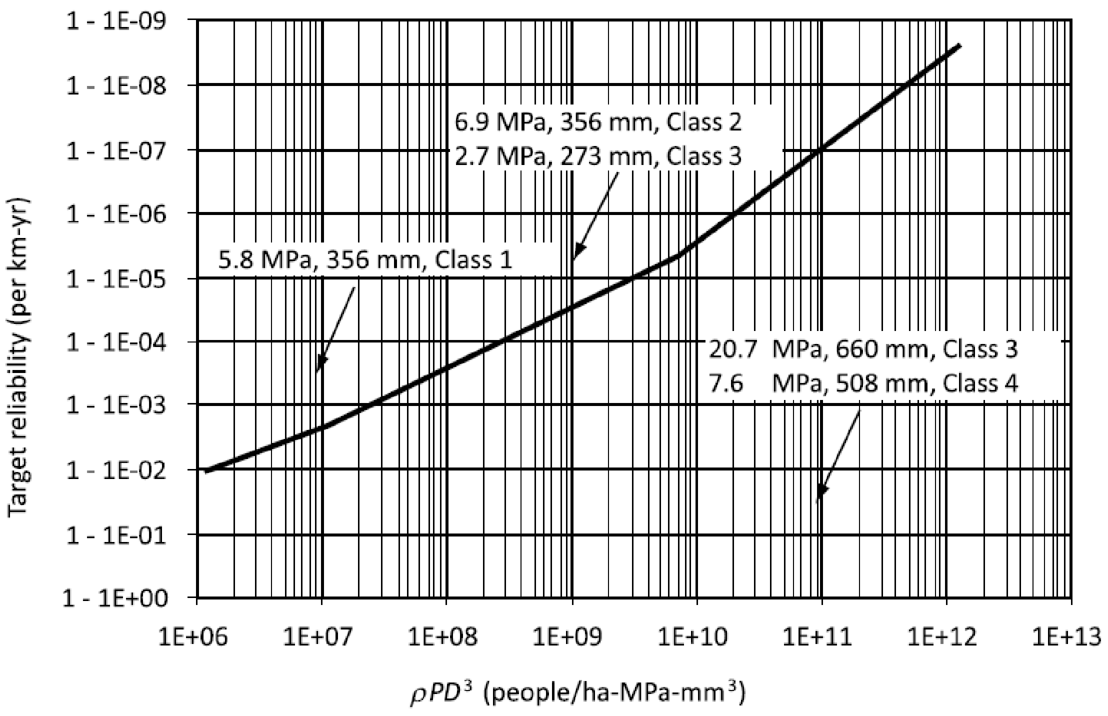
$$R_T = \begin{cases} 1 - \dfrac{1650}{(PD^3)^{0.66}} & \text{for } \rho = 0 \\ 1 - \dfrac{197}{(\rho PD^3)^{0.66}} & \text{for } 0 < \rho PD^3 \leq 1.16 \times 10^7 \\ 1 - \dfrac{49\,700}{\rho PD^3} & \text{for } 1.16 \times 10^7 < \rho PD^3 \leq 7.1 \times 10^9 \\ 1 - \dfrac{4.05 \times 10^{10}}{(\rho PD^3)^{1.6}} & \text{for } \rho PD^3 > 7.1 \times 10^9 \end{cases}$$

where
ρ = the population density (people per hectare)
P = the pressure, MPa
D = the diameter, mm

Societal Risk

- CSA Z662-15 Annex O: Reliability Targets for Ultimate Limit States:

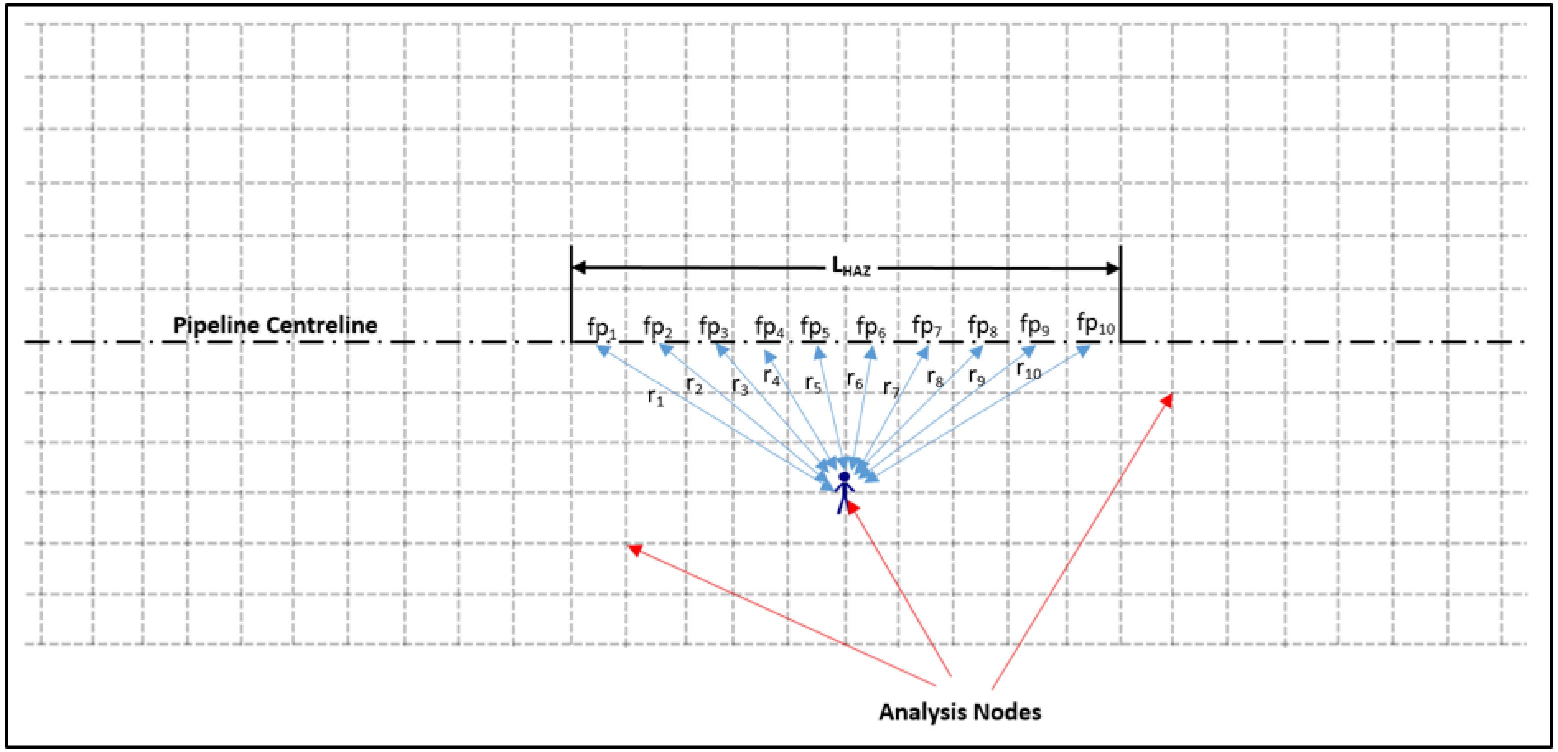
Figure O.2
Reliability targets for ultimate limit states
(See Clauses O.1.5.2.1 and O.1.5.2.4.)



Individual Risk

- Defined as the probability of fatality for a person at a particular location due a to a pipeline failure.
- Calculated for locations where individuals can be present for extended periods of time.
- Varies with the distance from the pipeline and the likelihood of individuals being present.

Individual Risk



$$IR = [(fp_1 \times pfat_1) U (fp_2 \times pfat_2) U (fp_3 \times pfat_3) U \ldots U (fp_n \times pfat_n)]$$

Individual Risk

- CSChE Guidelines:

APPENDIX A1 – COMMON RISKS

In evaluating levels of individual risk, and putting the risk acceptability criteria into perspective, it is useful to keep in mind the risk levels encountered in other activities. Some common risks are presented in Table A1.1 for this purpose.

Table A1.1 Common Risks in Canada[a]

Cause	Individual Risk[b] (Chances in a million of death per year)
Motor Vehicle Accident	109
Falls	82
Poisoning[c]	25
Dwelling Fires	7.9
Water Transport Accidents	3.6
Air & Space Transport Accidents	3.2
Excessive Cold	3
Electrical Current	1.1
Railway Accidents	1.1
Drowning in Bathtub	0.8
Earth Movements	0.4
Lightning	0.2
Cataclysmic Storm	0.03

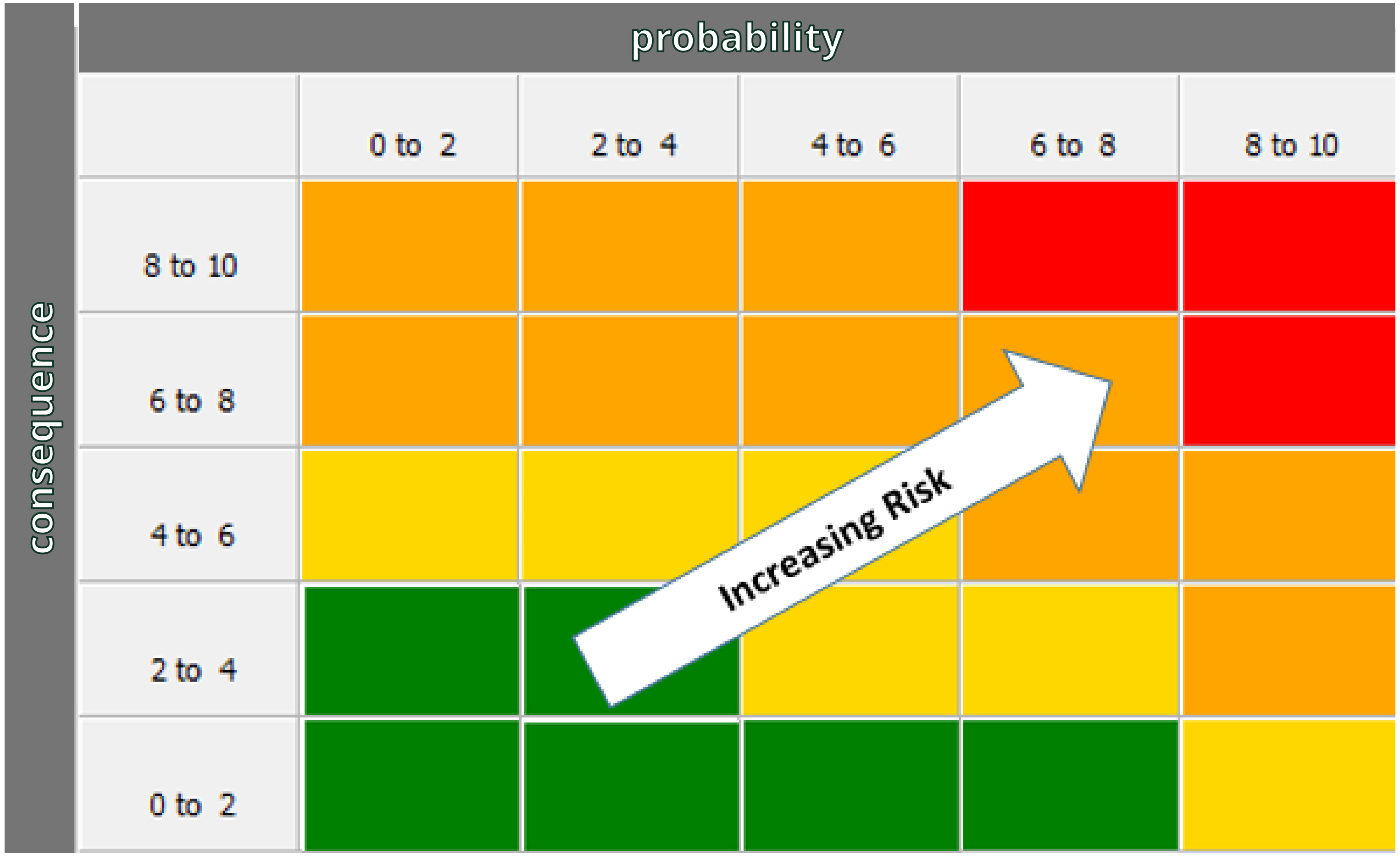
(a) Data are Canada-wide and were derived from information in "Causes of Death" Statistics Canada Publication #84-208 (1995).

(b) These are average individual risk values, based on a population of ~29,600,000. Data are rounded.

(c) Poisoning includes accidental poisoning due to poisonous and other substances, surgical complications and misadventures to patients.

Presentation of Risk Results

Qualitative Risk Matrix Examples



Qualitative Risk Matrix Examples

		Consequence level				
		1	2	3	4	5
Likelihood level	Descriptor	Insignificant	Minor	Moderate	Major	Catastrophic
5	Almost certain	5	10	15	20	25
4	Likely	4	8	12	16	20
3	Possible	3	6	9	12	15
2	Unlikely	2	4	6	8	10
1	Rare	1	2	3	4	5

Risk rating
Extreme
High
Moderate
Low

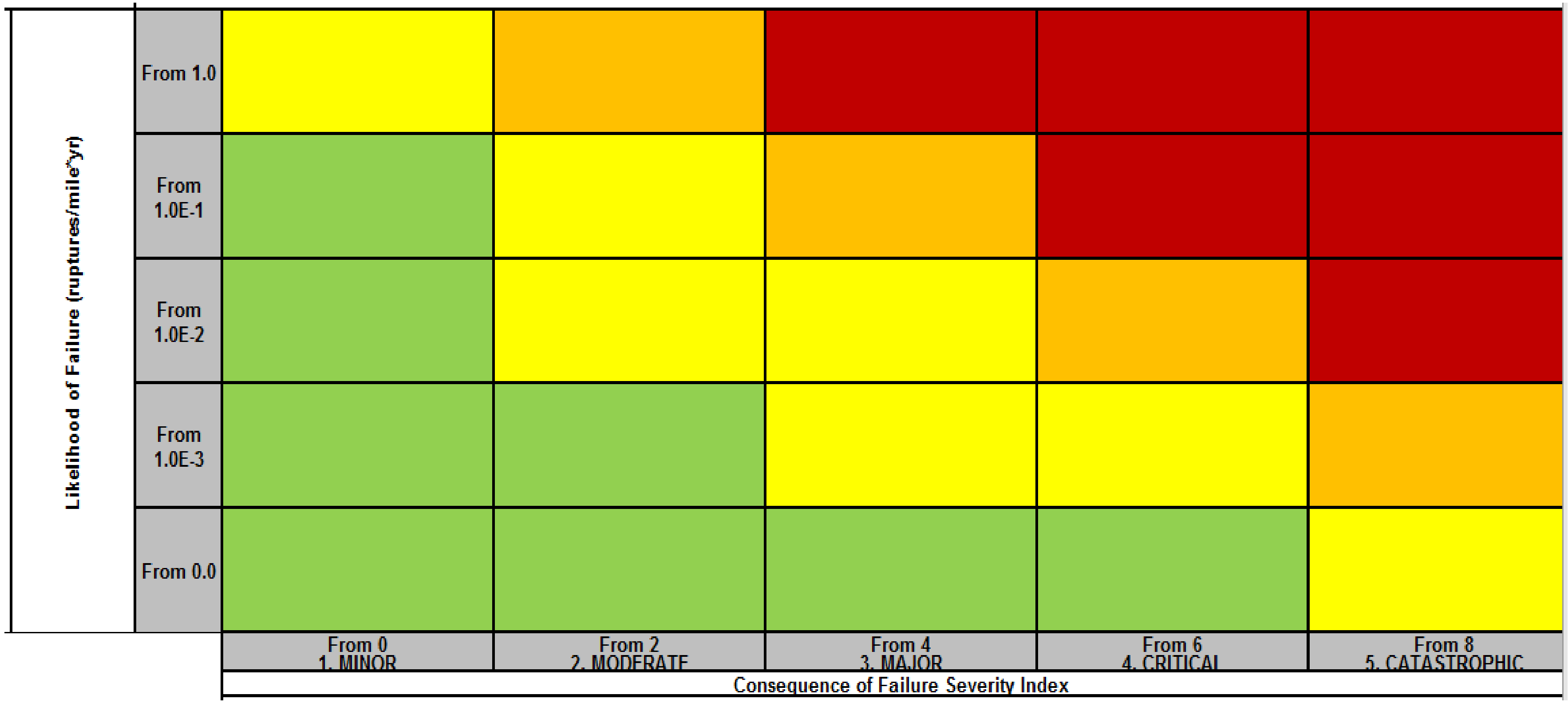
Qualitative Risk Matrix Examples

Consequence Category	Frequency Category 1	2	3	4
4	IV	II	I	I
3	IV	III	II	I
2	IV	IV	III	II
1	IV	IV	IV	III

Category	Description
1	No injury or health effects
2	Minor to moderate injury or health effects
3	Moderate to severe injury or health effects
4	Permanently disabling injury or fatality

Category	Description
1	Not expected to occur during life of process/system/facility
2	May occur once during life of process/system/facility
3	May occur several times during life of process/system/facility
4	Expected to occur more than once in a year

Semi-Quantitative Risk Matrix Example



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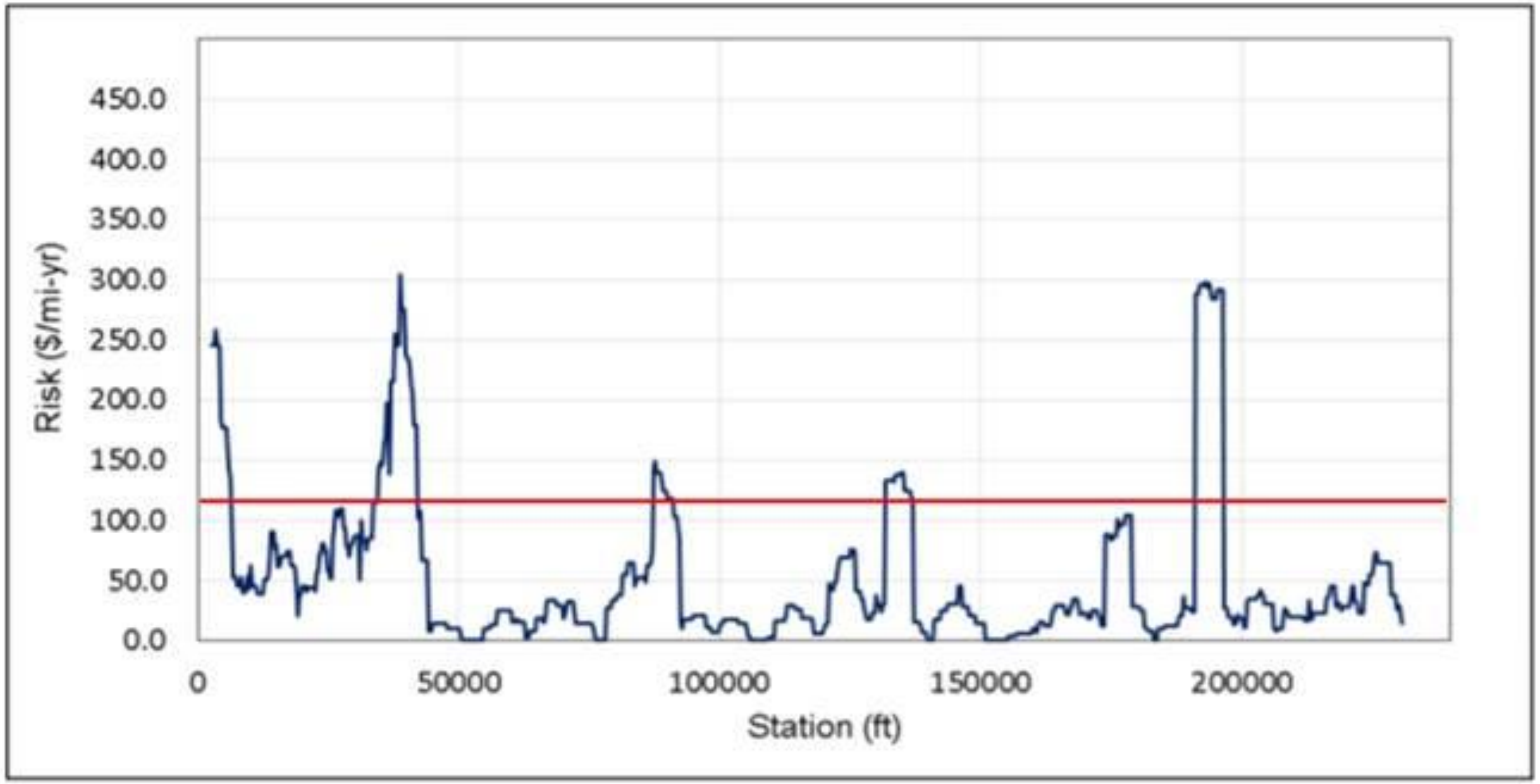
Quantitative Risk Matrix Example

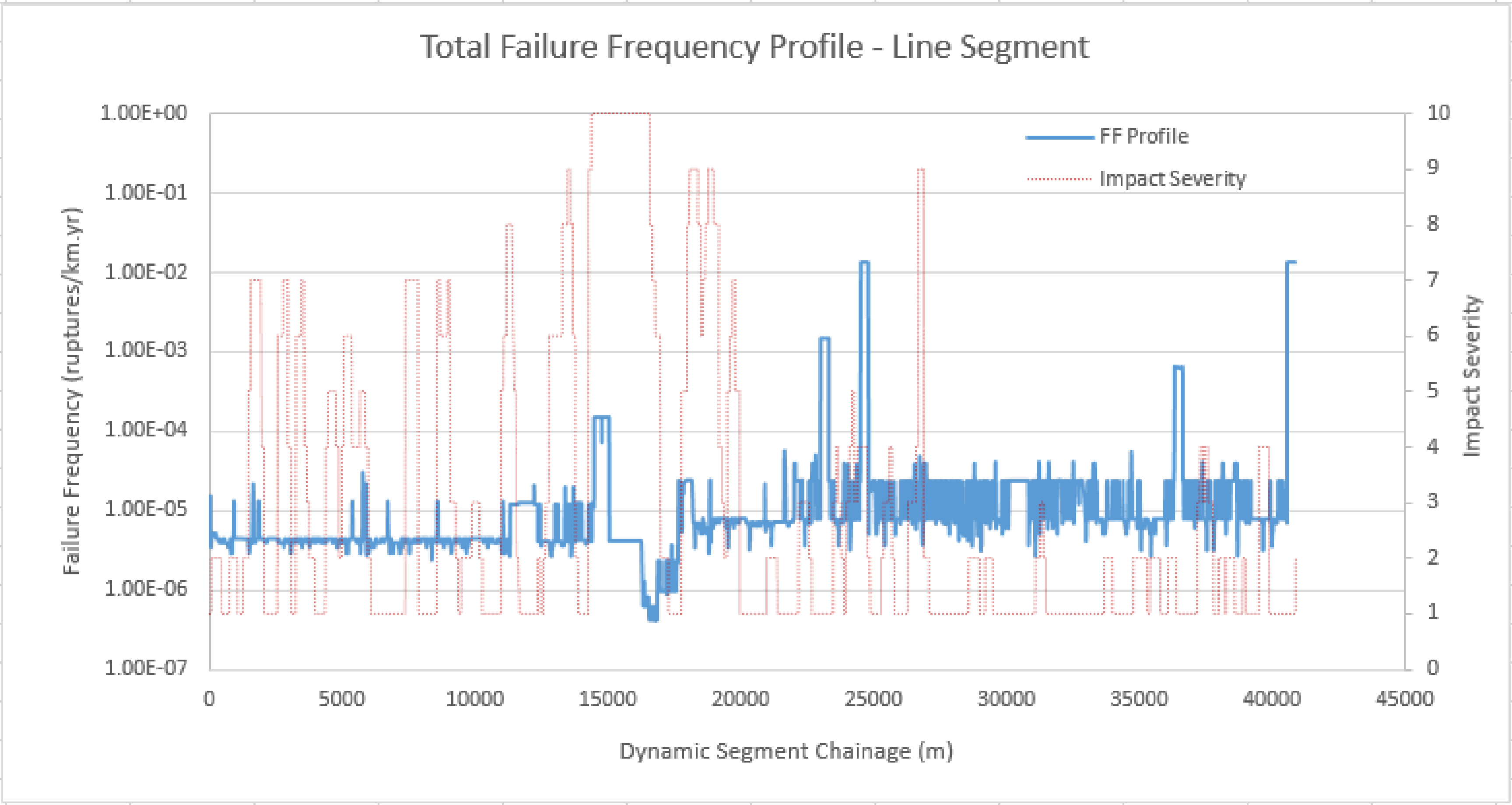
Increasing Likelihood of Occurrence	≤$100,000	$101,000 up to $1,000,000	$1,000,001 up to $10,000,000	$10,000,001 up to $100,000,000	>$100,000,000
From 1×10^{-1}					
From 1×10^{-2}					
From 1×10^{-3}					
From 1×10^{-4}					
From 0.0					

Increasing Severity of Consequence

Other Displays of Risk

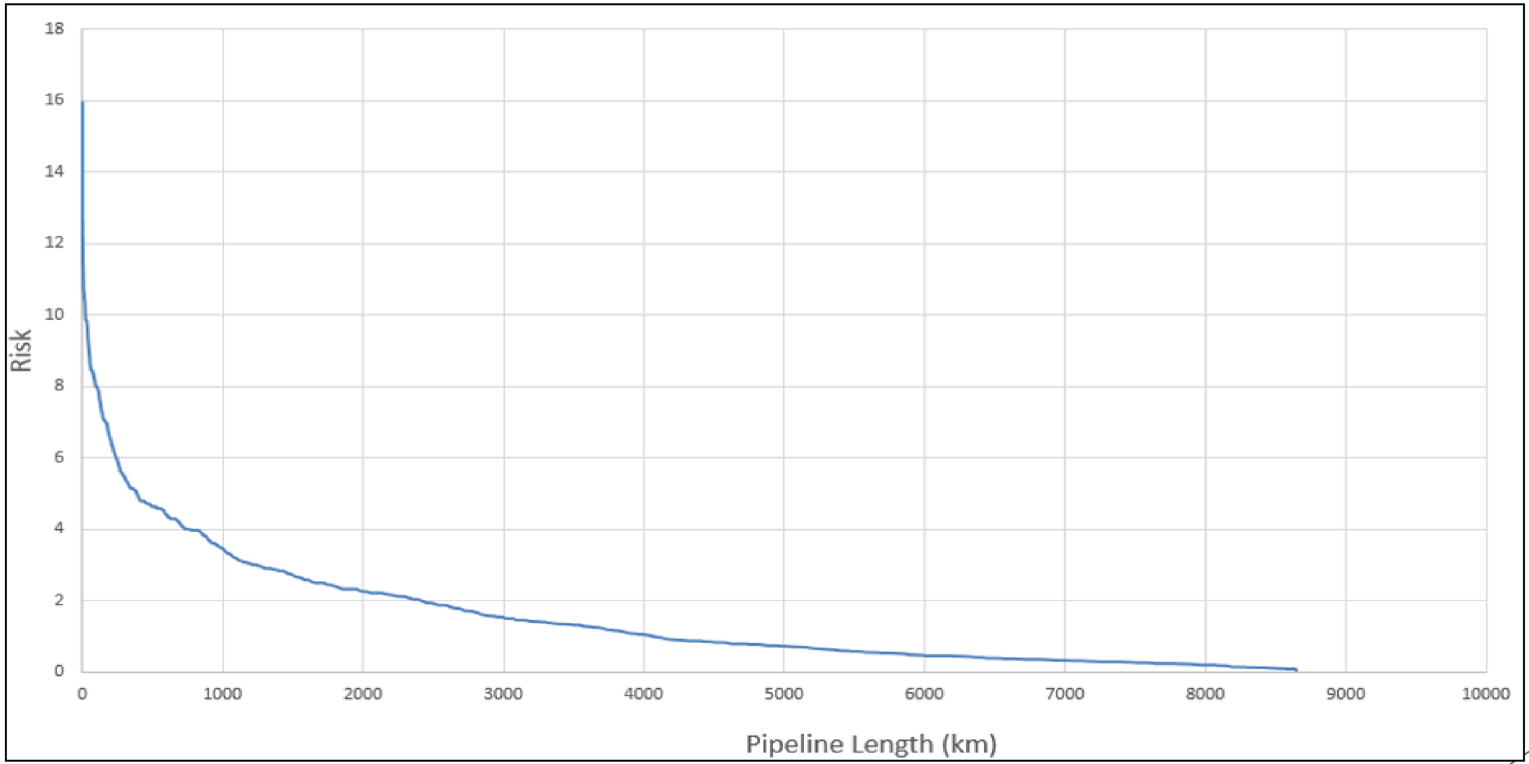


Failure Frequency and Impact Severity



Risk Distribution

- Useful tool for testing and calibrating risk assessment approach
- Need an approach that provides for focused risk reduction



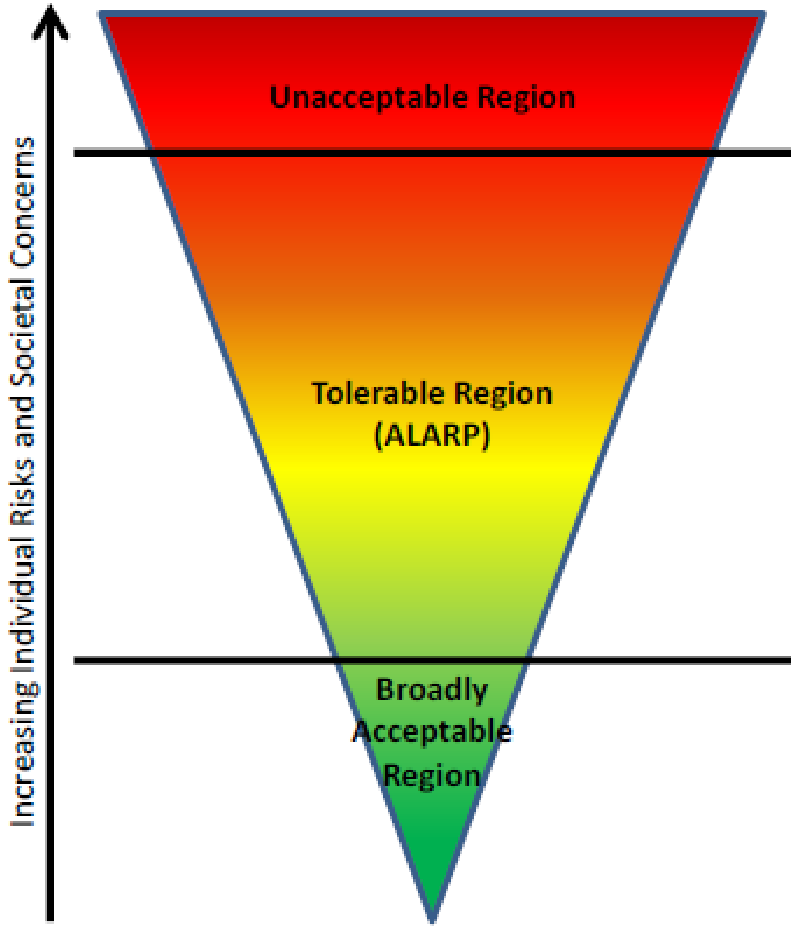
Risk Acceptance Criteria

Risk Acceptance Criteria

- Industry Activities:
  - PHMSA Paper Study on Risk Tolerance
  - CSA Annex B Risk Management Task Force (proposed updates for 2023 standard)
  - Operators developing their own reliability targets
  - Comparison to other industries that have criteria:
    - Nuclear
    - Aeronautical
    - Aerospace
    - Chemical
  - Employing ALARP principles

Risk Acceptance Criteria

- ALARP (as low as reasonably practicable):



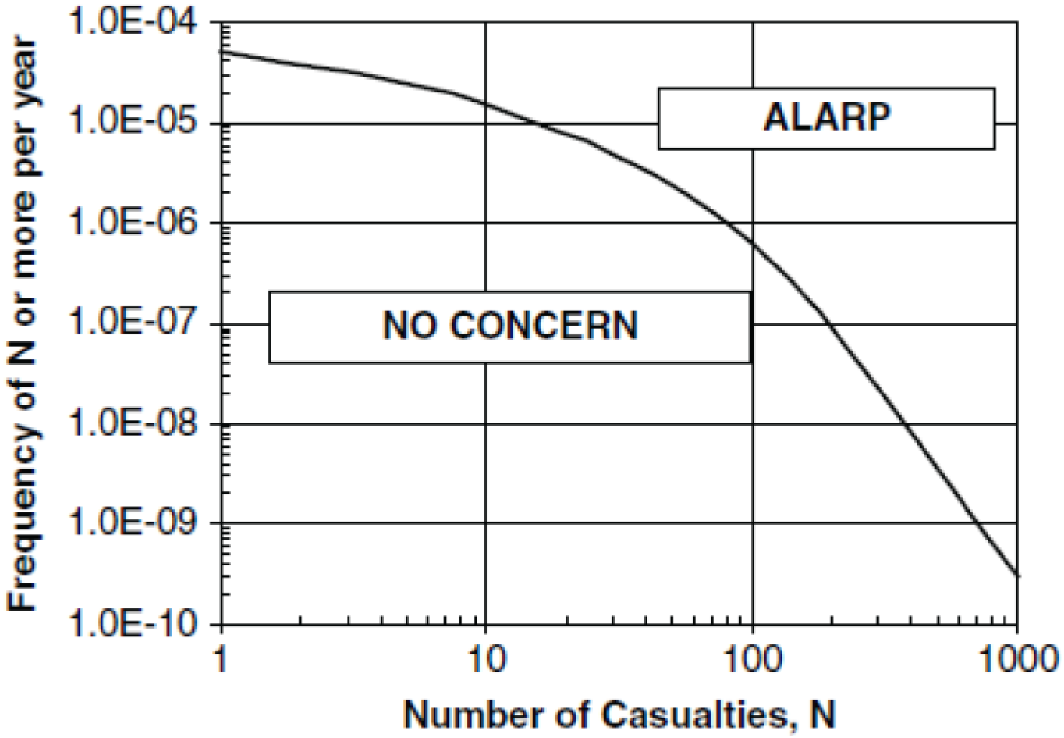
Risk Acceptance Criteria

- ALARP: As Low as Reasonably Practicable is the level of risk that represents the point, objectively assessed, at which the time, difficulty and cost of further reduction measures become unreasonably disproportionate to the additional risk reduction obtained.

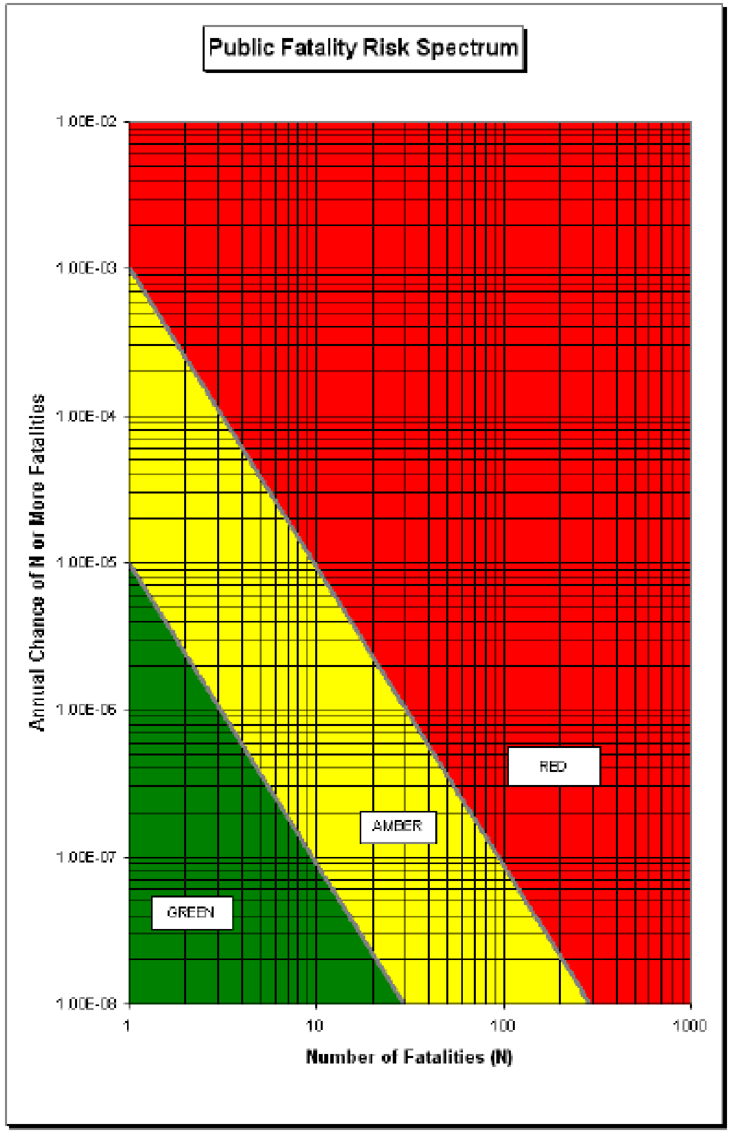
  (ref. CSA Z276-15 LNG)

Risk Acceptance Criteria

- IGEM/TD/1 Sample F-N curve criteria for natural gas pipelines (1.6 km):

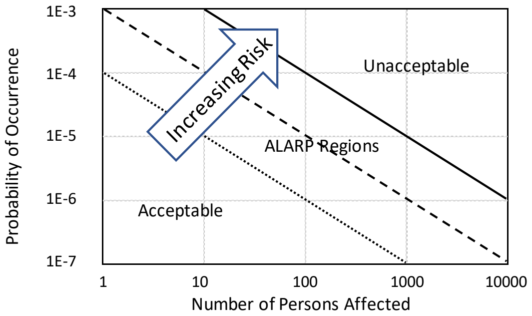


Risk Acceptance Criteria

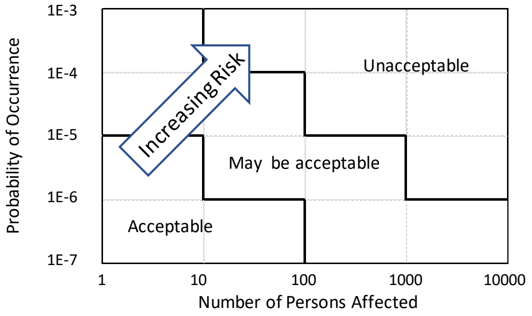


- County of Santa Barbara County Planning and Development Department criteria

Risk Acceptance Criteria



Continuous Quantitative Risk Criteria



Discrete (step-wise) Quantitative Risk Criteria

	Minor	Moderate	Major	Critical	
Likely	High	Extreme	Extreme	Extreme	Extreme - unacceptable
Possible	Medium	[illegible]	Extreme	Extreme	High - may be acceptable
Unlikely	Low	Medium	High	Extreme	Medium - may be acceptable
Very Unlikely	Low	Low	Medium	High	Low - acceptable

Increasing Risk

Consequences

Discrete (step-wise) Qualitative Risk Matrix

- Thresholds in F-N curve and risk matrices

Using the Risk Results

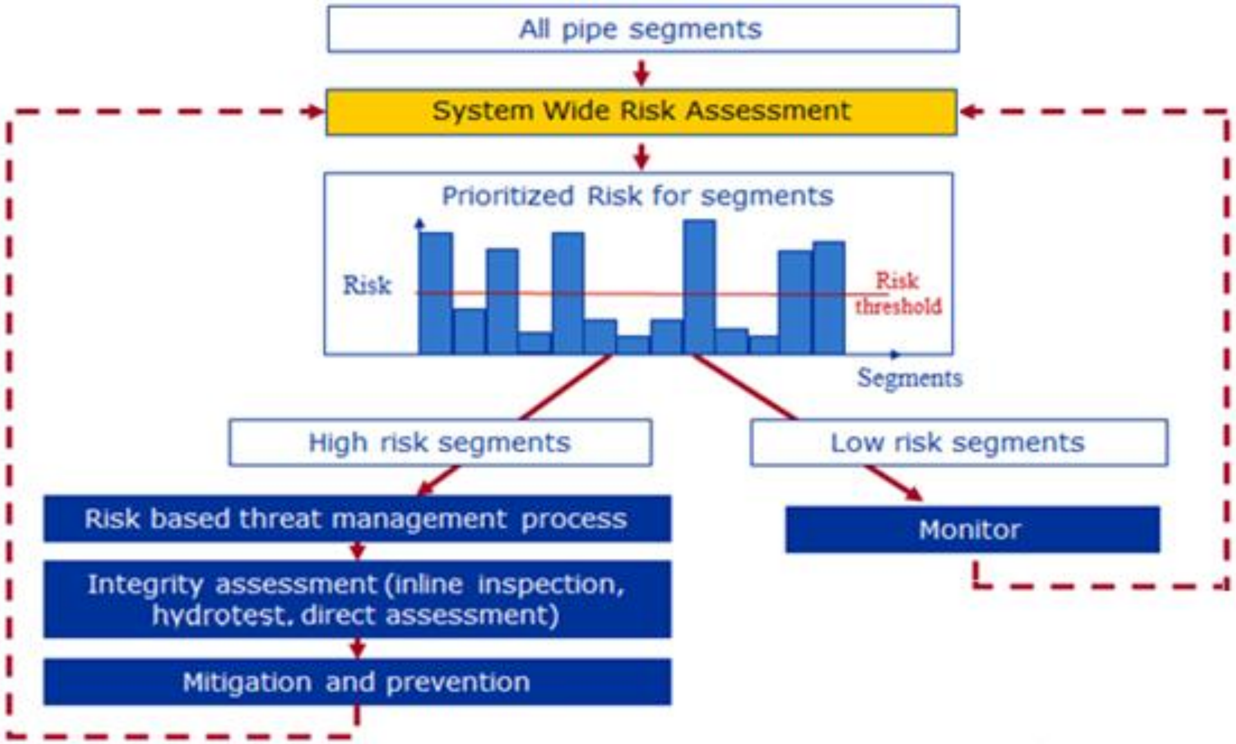
Using the Risk Results

- Goal: risk-based decision making
- Supports integrity management activities and prioritizations
- Eliminate high consequence events
- Regulatory expectation to integrate risk results
- Recognize that integrity management and risk assessment approaches may not always be aligned
- Need to gain trust in the results across the organization

Integration of Risk Assessment into IMP

- Compares the calculated risk to established measures
- Combines Probability of failure and Consequence meaningfully
- Prioritizes preventative & maintenance (P&M) activities

PREVENT FAILURES AND REDUCE COMPANY RISK



Questions?