Risk Modeling for Optimized Safety Decisions

(examples for Gas Transmission)

Shahani Kariyawasam

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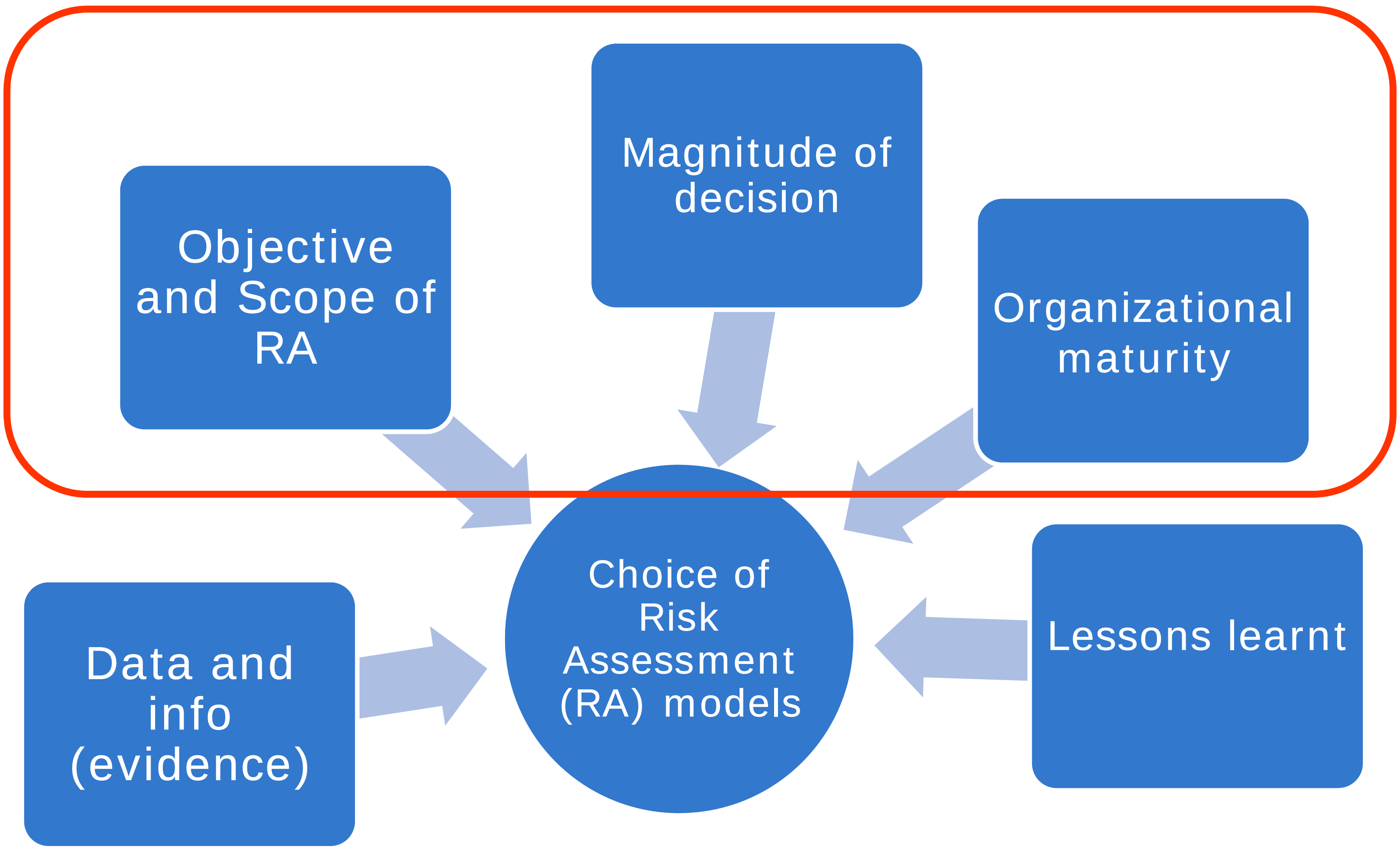
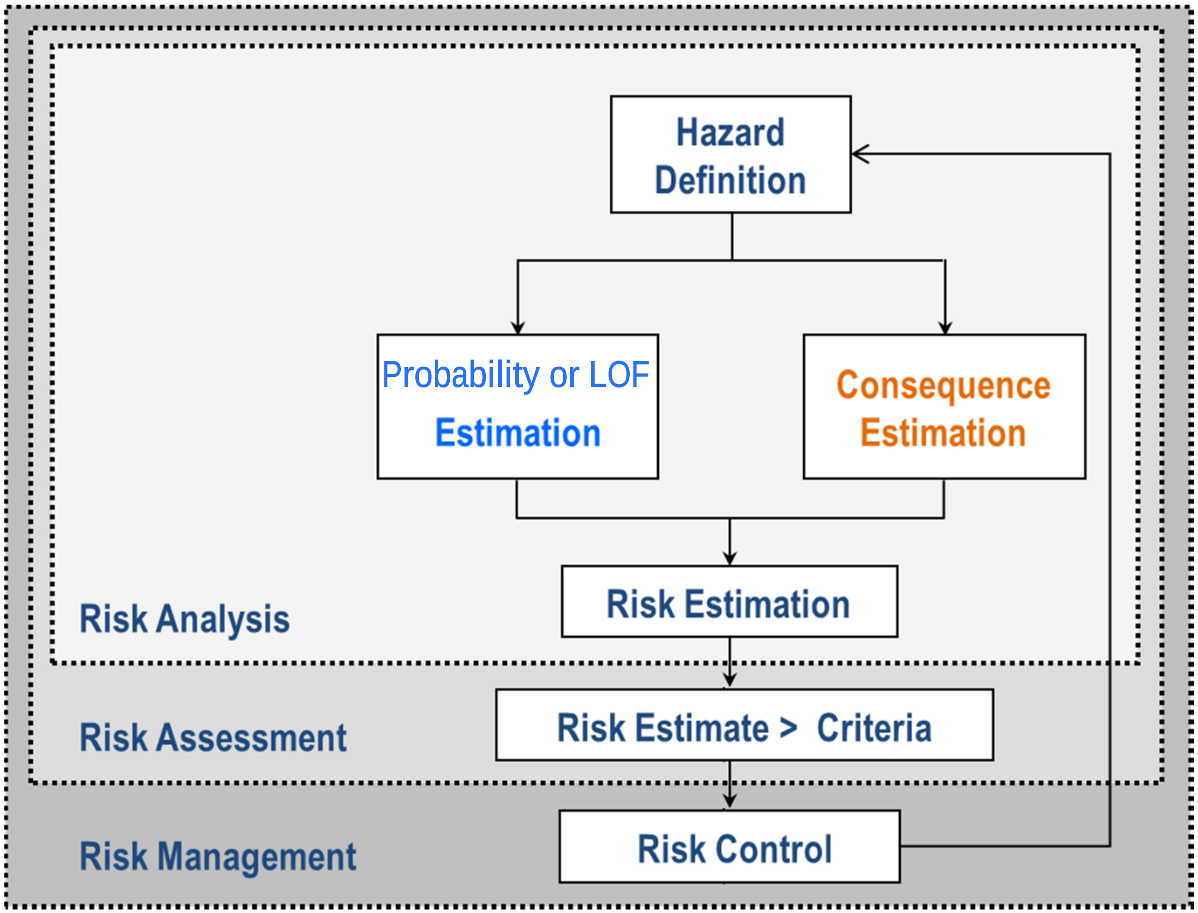
In business to deliver

Which Risk Model?



Risk Management

By managing risk (expected value of loss) below a tolerable level we optimize our decisions



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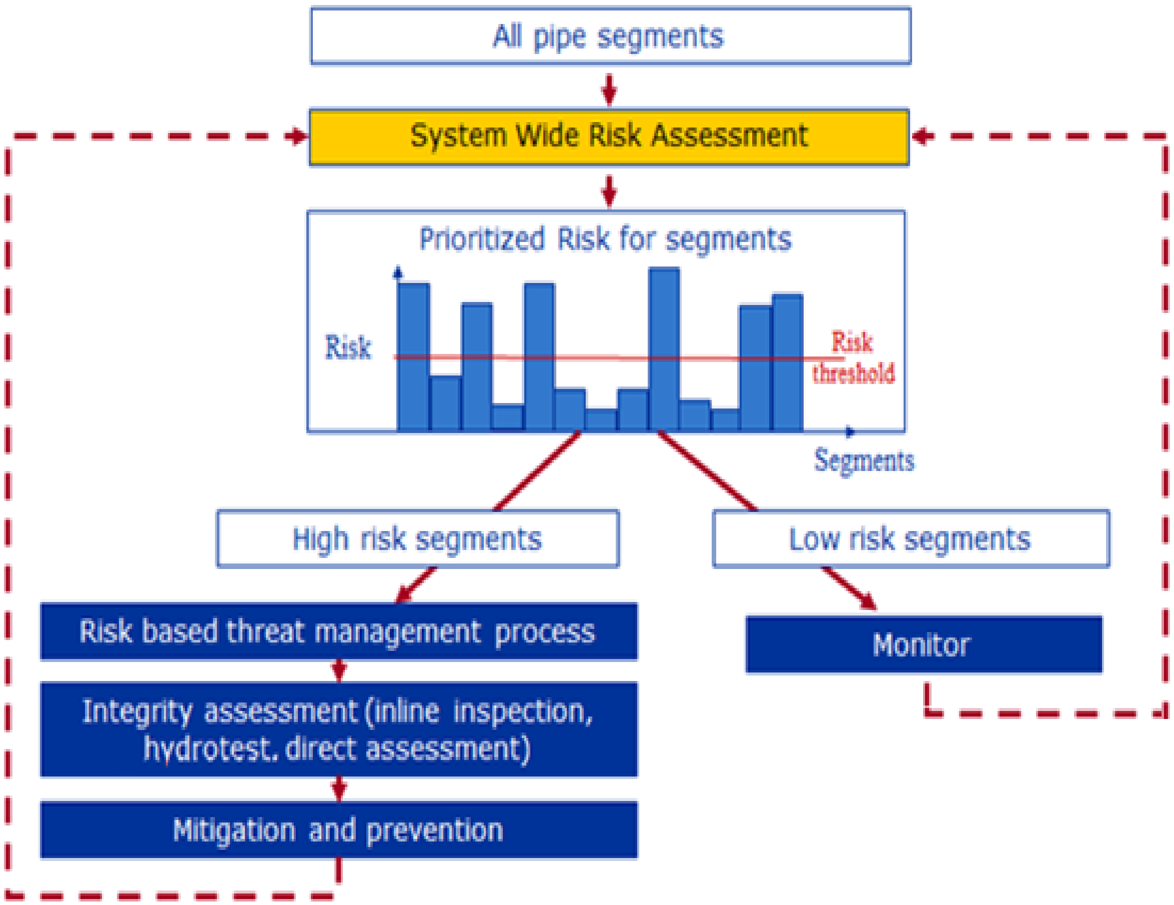
Objectives of SWRA

- Calculate likelihood of failure for all threats and interactions
- Combine Probability of failure and Consequence meaningfully
- Prioritize and drive assessment and mitigation activities
- Identify most effective mitigation or assessment

GOAL - PREVENT FAILURES AND REDUCE RISK



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Underlying needs to meet objectives

- **Combined view of threats, and prioritize P&M – Needs:**
  - ➢ systematic incorporation of all evidence of threats with disparate data sets
  - ➢ sensible comparison between threats
  - ➢ to account for threat interaction
  - ➢ to have the same framework for each threat (same basis and comparable between threats)
  - ➢ updateability and transparency

- **Combine Probability of failure and consequence**
  - ❖ articulate types of risk – to people, to individuals, to environment
  - ❖ Clear risk criteria and action

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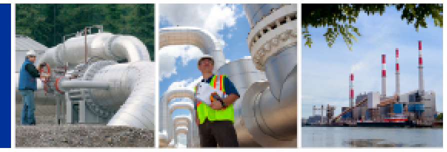
Essential characteristics - Effective risk management principles (CAN/CSA–ISO-31000)



- **<u>creates and protects value</u>** – safety, legal, environment, regulatory, public …

Consistent commitment to Risk based goals

- **<u>Integral</u>** part of **<u>all</u>** organizational processes
- **<u>optimizes decision</u>** making
- based on **<u>best available information</u>**
- **<u>explicitly</u>** addresses **<u>uncertainty</u>**

Grounded in reality

- systematic, structured and timely
- is **<u>tailored</u>** - transparent, inclusive, d<u>ynamic, iterative, and</u> **<u>responsive to change</u>**

Responsive and innovative

- Takes <u>human and cultural</u> factors into account
- <u>Facilitates</u> continual <u>improvement</u>

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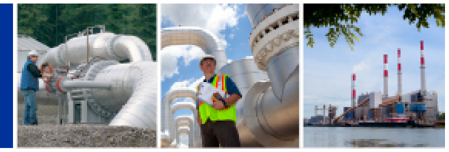
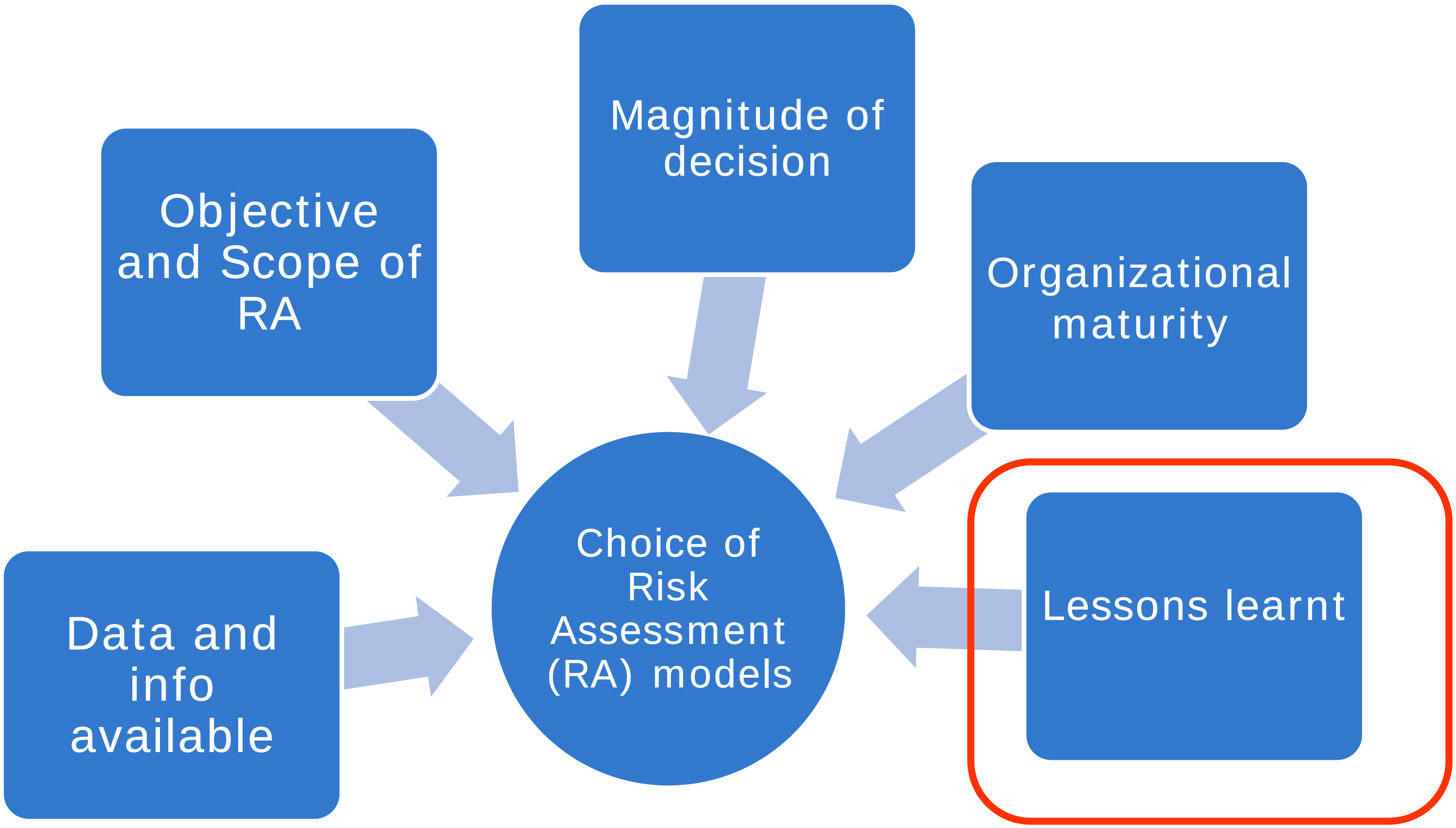
Which Risk Model?





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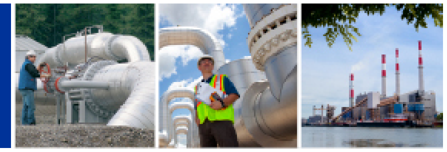
Recent Issues with Risk Management from Incident Reports



National Transportation Safety Board
Washington, D.C. 20594

NTSB Findings related Risk Management

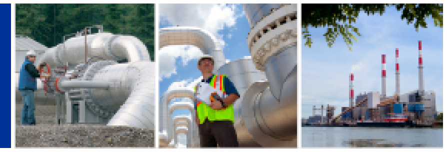
- "*Lack of a requirement to verify that all information is up to date prior to use in RA*" - Integrate all data including integrity assessment data

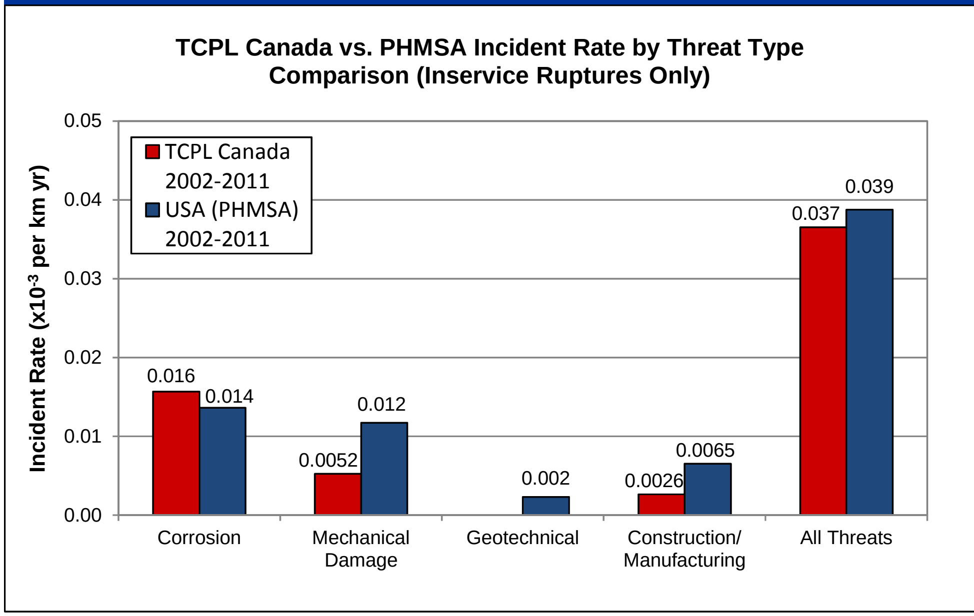
- "*Integration of information/risk analysis results did not appear to have a central role in the overall evaluation of integrity*" Integrate RA and IM

- "*Due to the limitation of the index modeling … model was not useful in giving risk acceptance criteria*" - Need models with explicit criteria

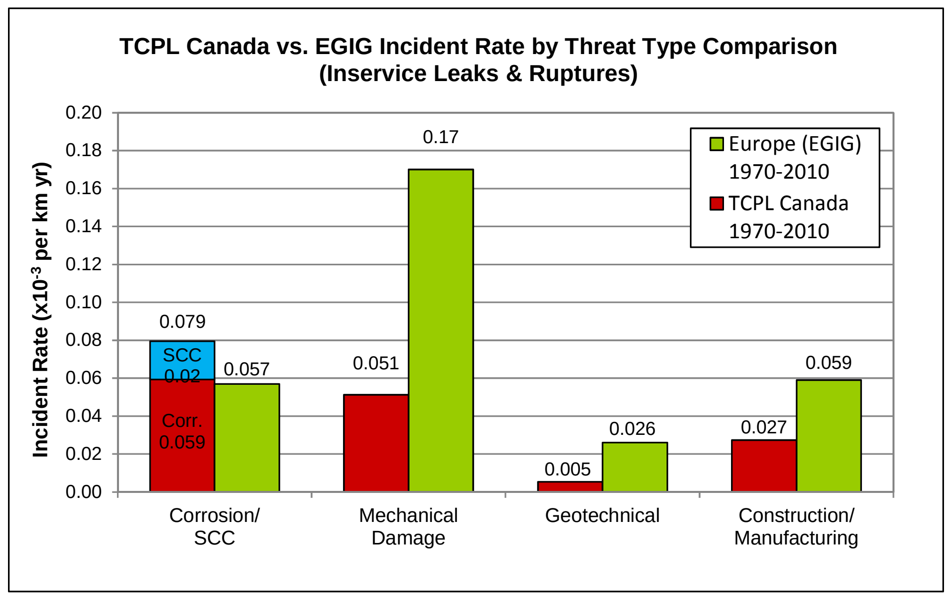
- "*Regions have made very limited use of risk model results*" - Integration of RA and P&M measures

Threats are system specific

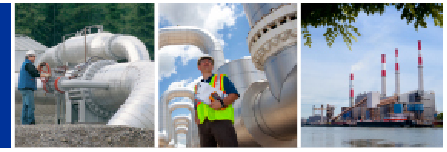


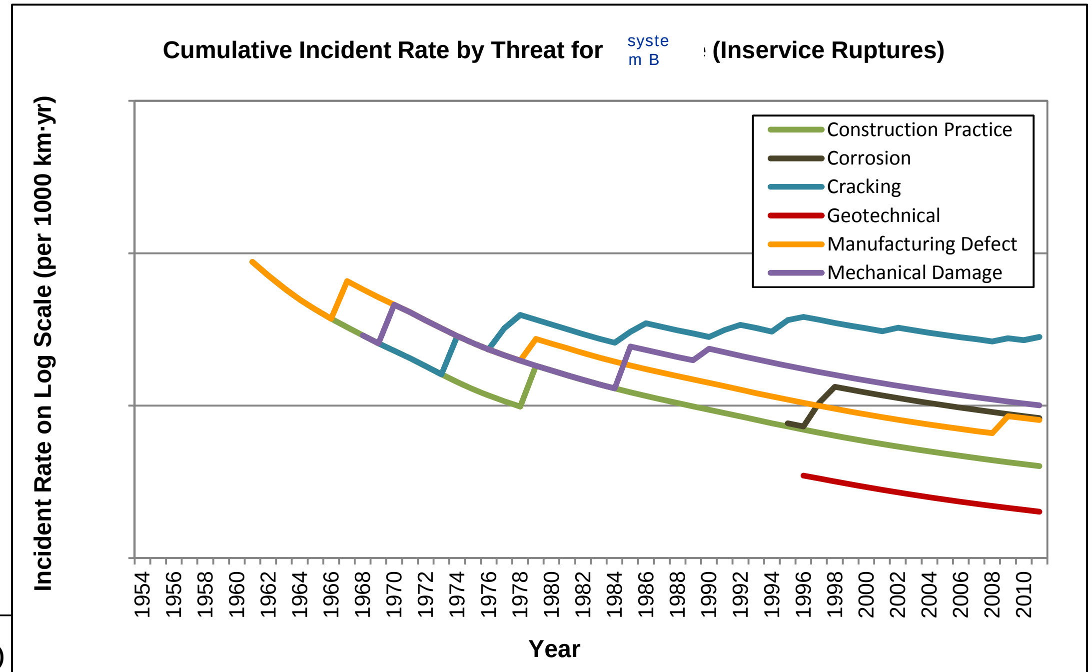


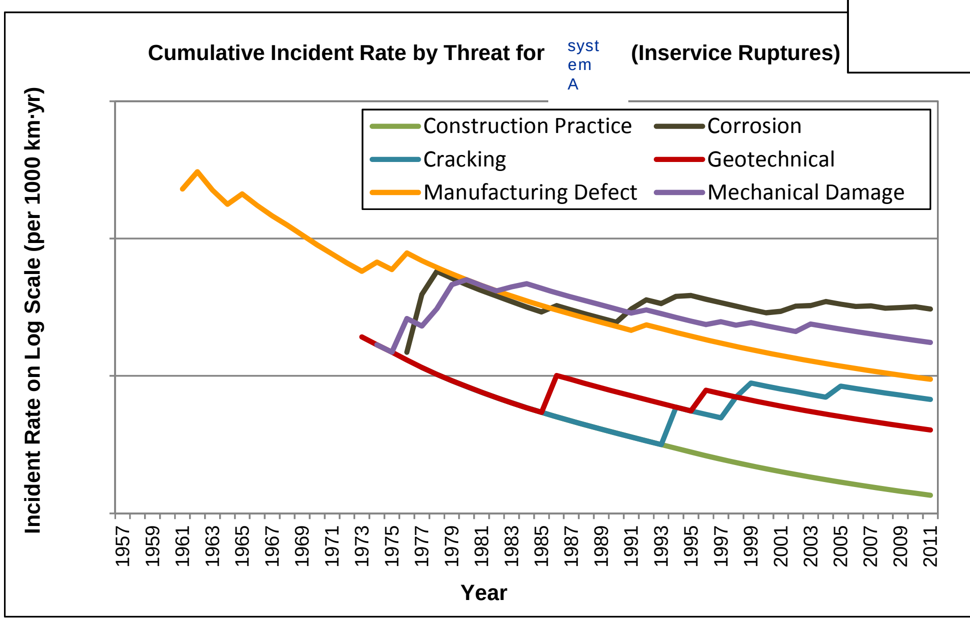
Highly system and segment specific



Threats are sub-system and time specific







Highly sub-system and time specific

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Consequences of Failures

- **Consequence aspects to consider**
  - Human safety (& Environmental)
  - Lethality zone - f(product, pD^3)
  - Prob. of ignition
  - Public perception
  - Security of service

San Bruno rupture NPS 30 8 fatalities (58 inj)

Rupture NPS 20

Rupture NPS 10

Leak, NPS 8

Some failures are more undesirable than others – should be reflected in risk criteria

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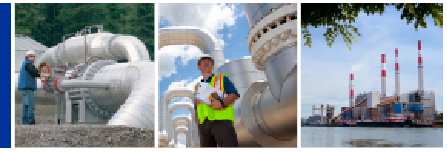
~~Failure to Learn~~ Learning from Failures



Andrew Hopkins on the sociology of accident prevention

+1 0

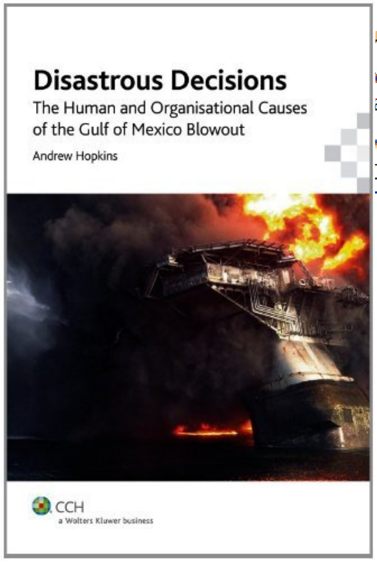
The Australian Pipeliner — July 2010

Professor Andrew Hopkins, a leading researcher in accident prevention, is assisting the pipeline industry in its venture to increase industry safety from a sociological viewpoint. Here, The Australian Pipeliner talks to Professor Hopkins about how the design of pipeline organisations can impact on the safety of its employees.

Accident prevention expert Professor Andrew Hopkins has written a number of books studying the cause and nature of industrial disasters. Professor Hopkins completed his first degree in science and mathematics and a Masters degree in Sociology at Australian National University. He then … his PhD in Sociology at the University of … t in the USA.

… ound in sociology has lead Professor Hopkins to consider how organisational … and social factors contribute to the safety – or lack of safety – of any operation.

… v been engaged with the newly formed Energy Pipelines Co-operative Research … RC) to facilitate its public safety division.



Actual Risk is often due to organizational or human error

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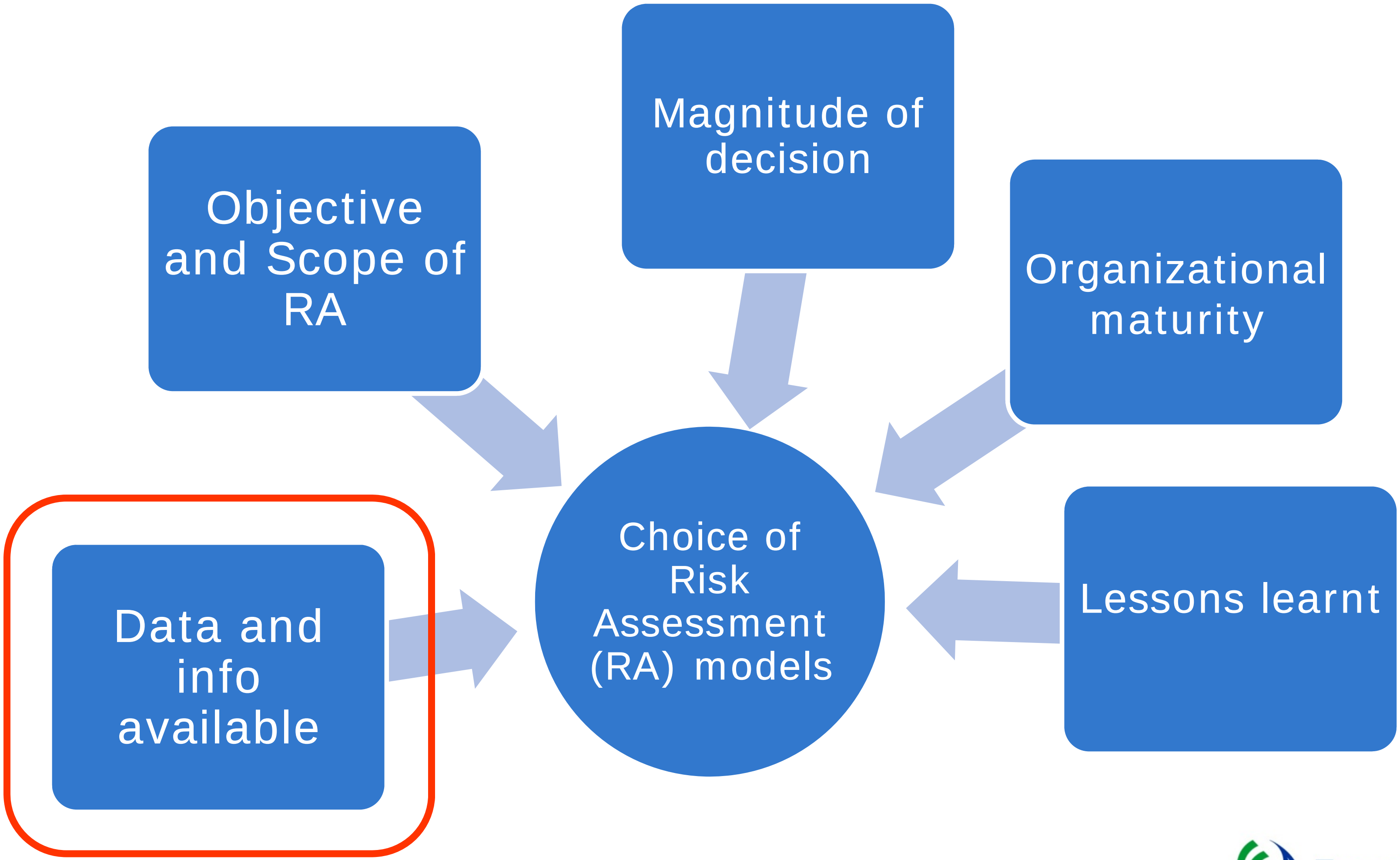
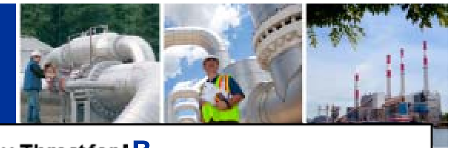
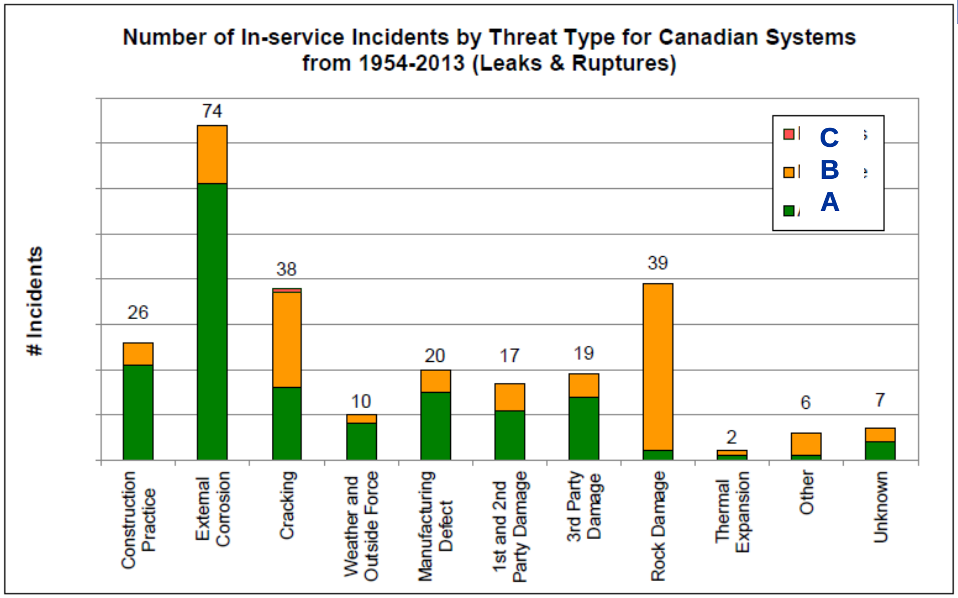
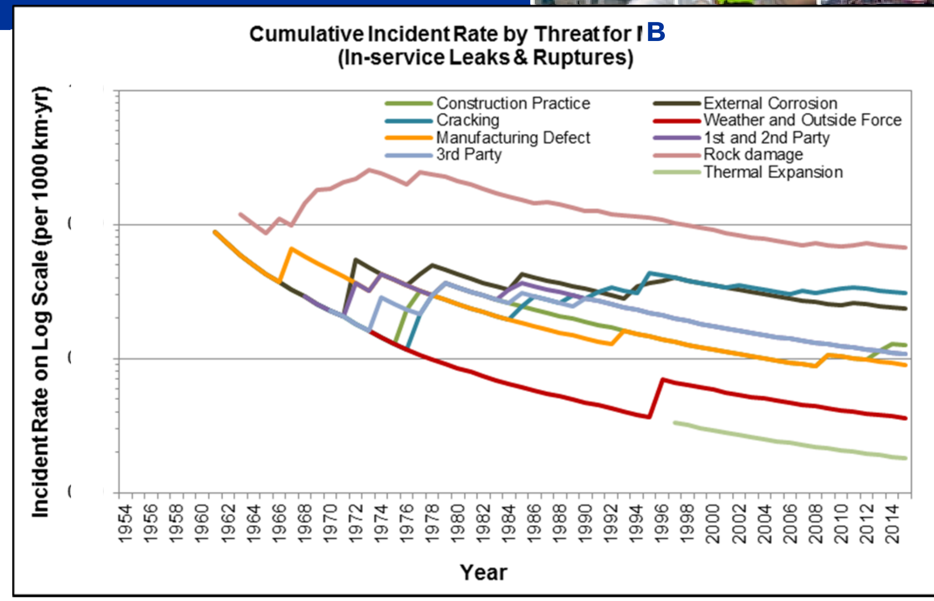
Which Risk Model?

Know your systems – subsystems - segments

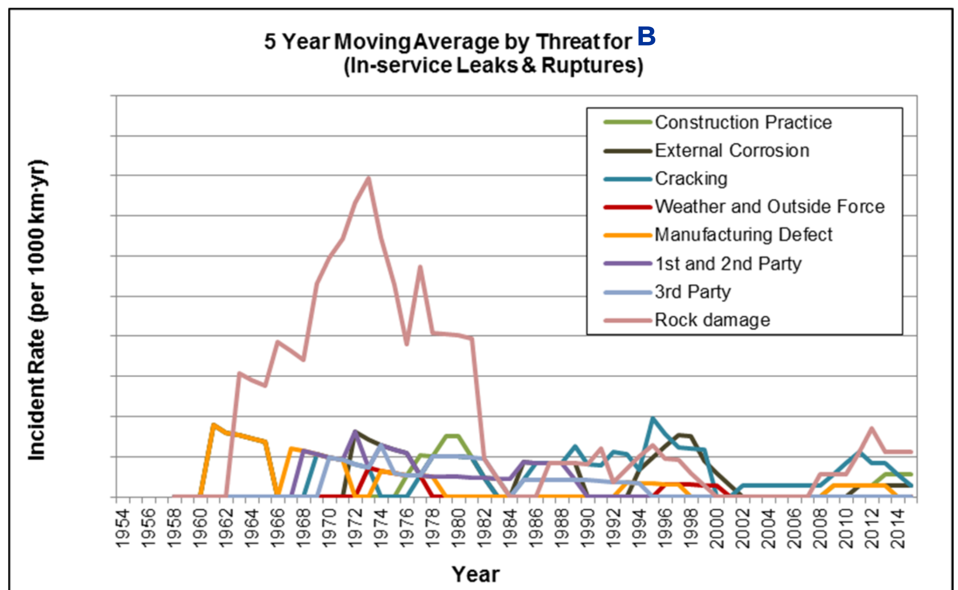




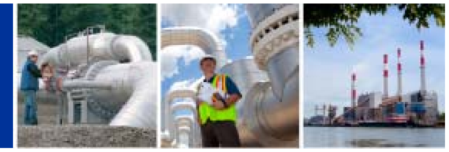


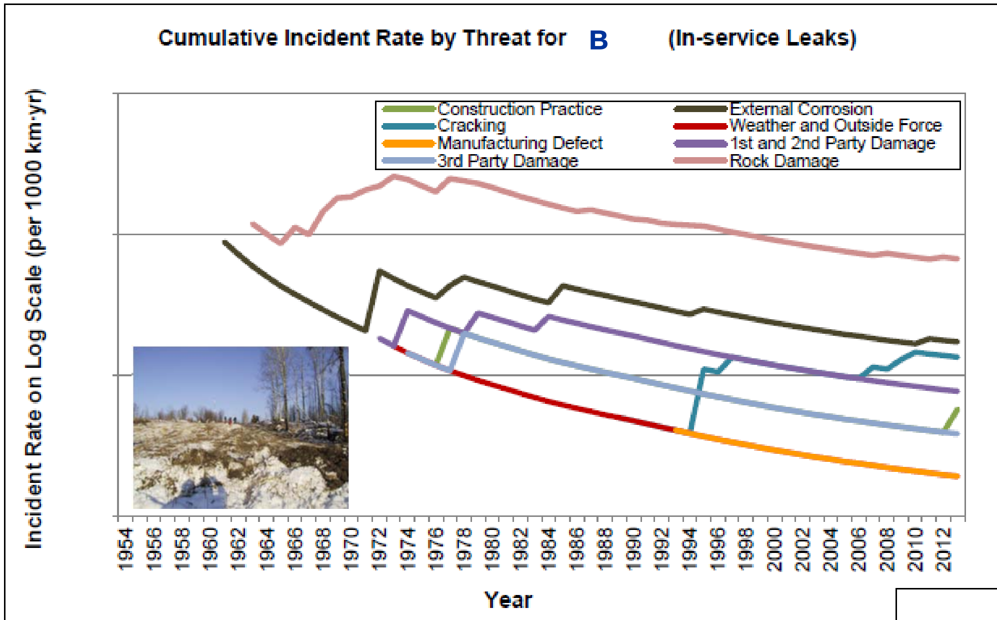
Highly sub-system and time specific –

- Global statistics do not represent local threats
- needs quantification
- qualitative/index based methods cannot capture

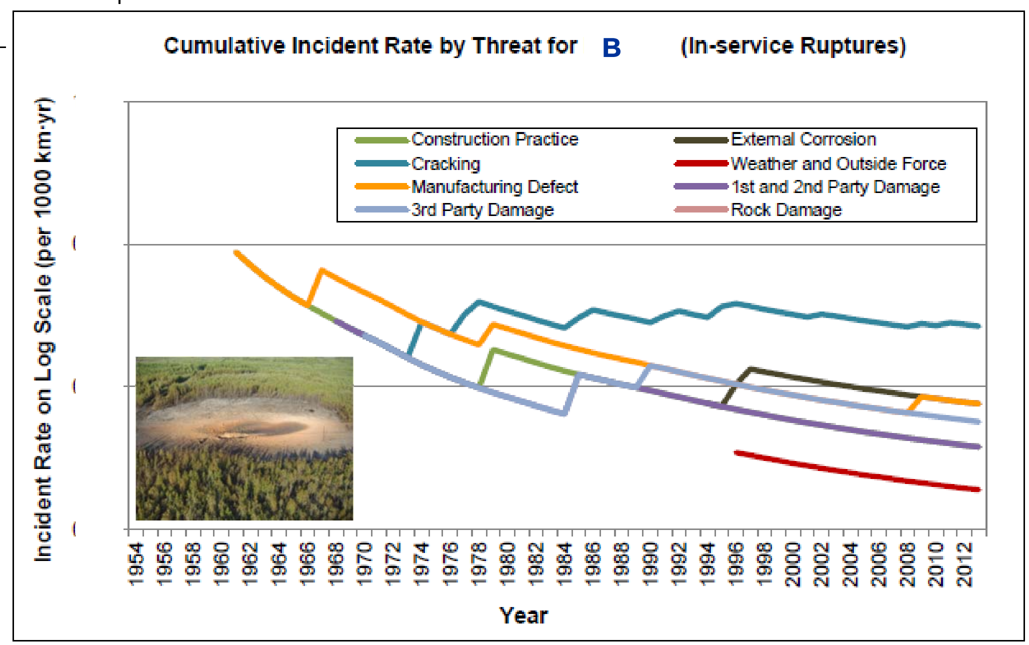


Know your threats and failure modes

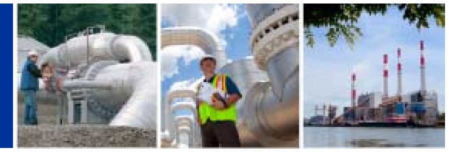




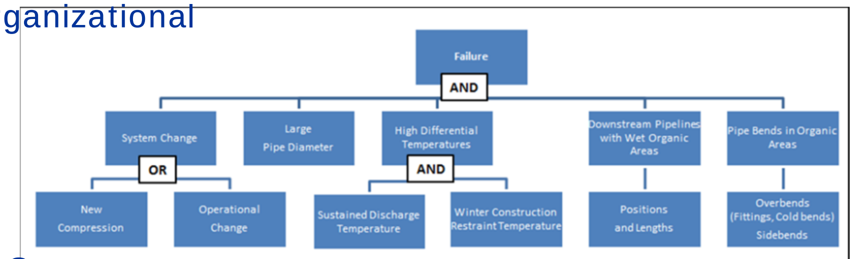
Consideration of threat and system specific failure modes necessary to represent risk



System Wide Response to Incidents(SWRI)

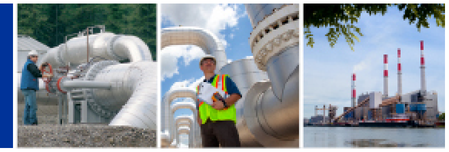


- **Initiative since 2014**
- **Objectives:**
  - Formal procedure to learn from incidents (failures and other events)- Failure investigation – contributing factors – similar incidents – focused review list (technical and organizational causes)
  - Investigate and refine
  - Incorporate into relevant programs and EAs



- **2013 incident thermal expansion**
  - **stress analysis and mitigation / verification**
  - **New threat added to SWRA and EAs**
- **Inc near valve – proximity to valves, Ts, and transition welds added to SWRA**
- **Corrosion on wrinkle – process change for ILI reporting and internal**

Explicitly Considered Threat categories



1. External Corrosion
2. Internal Corrosion
3. A) Cracking - SCC
3. B) Cracking - CSCC
4. A) Manufacturing – Long Seam and Material
4. B) Manufacturing - Hardspots
5. A) Construction – Girth weld
5. B) Construction - Rock Damage
6. Weather and Outside Force
7. First and 2nd Party Damage
7. Third Party Damage
8. Equipment
9. Incorrect Operations
10. Thermal expansion

Added in response to failure root cause analysis

LOF Algorithm developed for each threat and each subsystem

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Available data

- **Threats –**
  - **Failure causes are complex – primary/secondary**
  - **Interactive threats**
- **Evidence of threats come in many disparate data forms**
- **Use all available evidence from:**
  - Failure/incident history,
  - Observations/assessments using ILI, HT history, excavations
  - Mechanistic or scientific understanding of the threat and its causal and preventative actions (data and metadata)

Evidence/Data →Model

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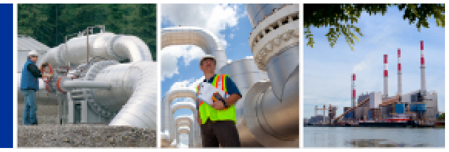
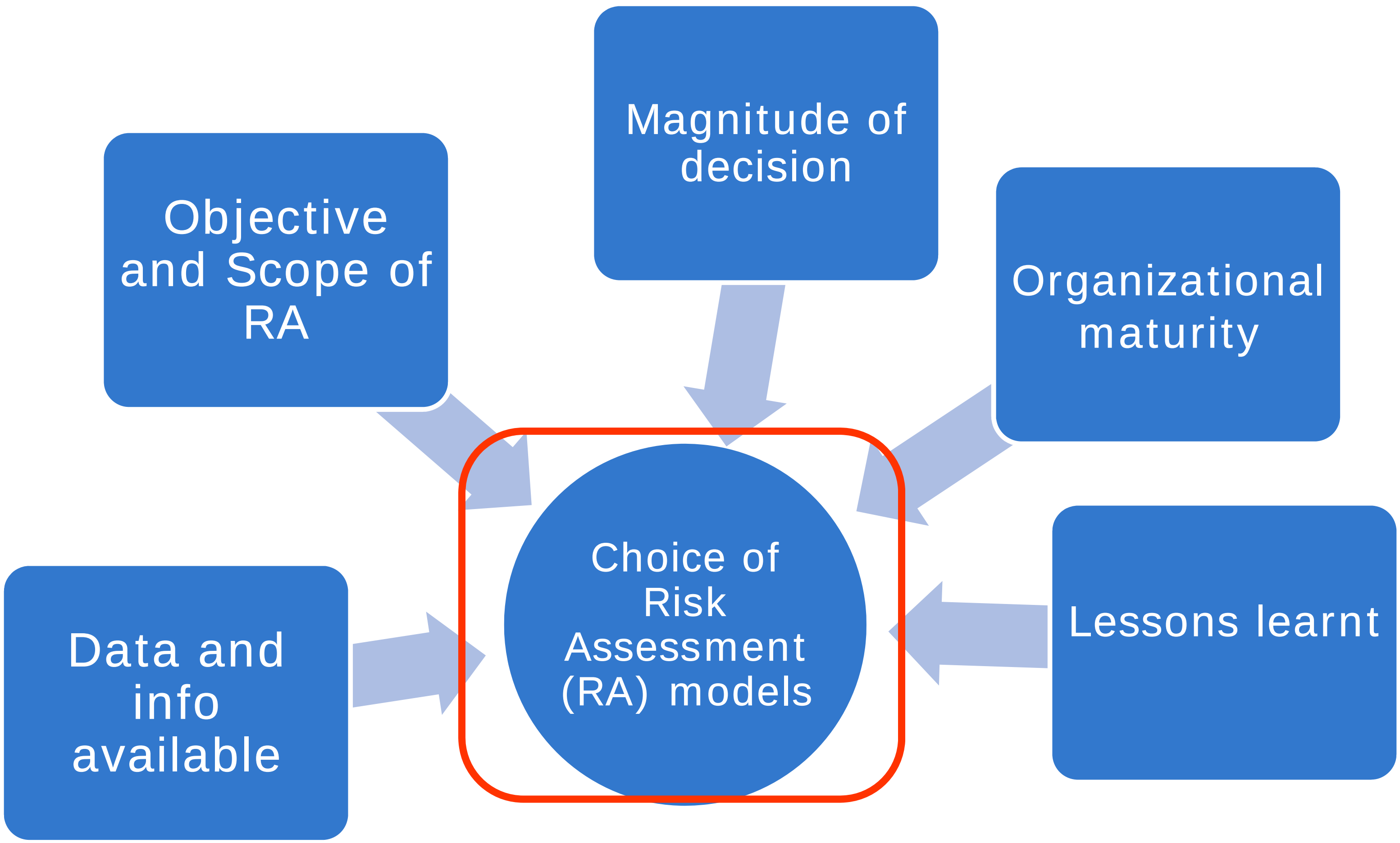
Which Risk Model?





Structure / defined logic Types

Qualitative

- SME based – Muhlbauer 1, Bass-trigon/American innovation, DRA
- Relative risk based - Muhlbauer 2, Kiefner, GE PII 1, DRA
- Questionnaire based (guilty until proven innocent) – Rosen, B318s

Quantitative

- Mechanistic equation based – PRIME, British Gas, scenario based
- Historical failure rate based – C-FER, GE PII 2
- Reliability based – C-FER, ***TC for ILI and site- specific***

- Many combinations of above – mix and match

Format best for purpose and able to accommodate all data

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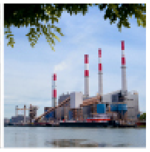
Choice of Algorithm for Likelihood of Failure (LOF)





- **Qualitative methods –**
  - Simple to implement
  - no sensible comparison between threats
  - Cannot account for local threats and address actual threats
  - Cannot validate against actual rates
  - No meaningful risk measure or criteria
- **Quantitative – mechanistic/physical process based –**
  - Each causal/mechanistic process represents one threat mechanism
  - Mechanism does not fully capture all evidence – e.g., ILI data
  - Assumes adequate mechanistic predictability
  - Performance not fully explainable mechanistically – e.g., regional failure rates

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Choice of Algorithm for LOF (cont..)

- **Historical failure rate based**
  - Gives a means of quantification – universal base rates not system dependent
  - Dialed based on known parameters but many unknown parameters
- **Reliability based**
  - Uses quantified condition data (ILI, activity rates, fault trees), considers uncertainties, and quantify location specific LOF
  - Quantified condition data does not exist for each threat on each pipeline
- **Hybrid model – <u>use best data and best model available at each location</u>**
  - Use reliability models for the threats where condition data exists
  - If not - Historical failure rate based model but with subsystem specific rates
  - Regress historical rates against mechanistic factors to quantify better (less subjectively)
  - Enables use of all data that shows evidence of threat

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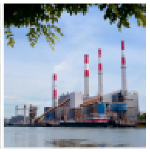
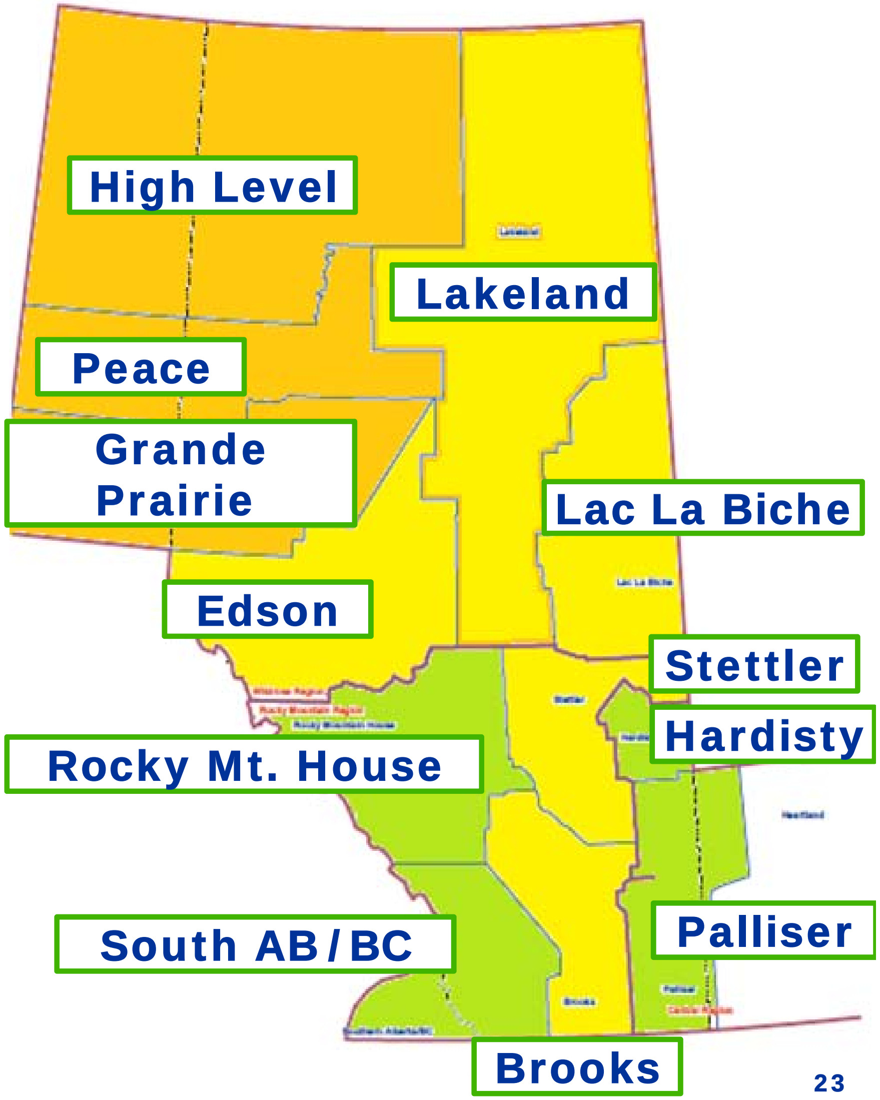
Subsystems for distinct performance and behaviour





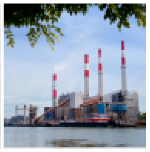
- **Subsystems for P-Tape & Asphalt Coated Lines of AB**

PIPELINE_AREA	**Subsystem**
High Level	**AB-1**
Peace	
Grande Prairie	
Lakeland	**AB-2**
Edson	
Stettler	
Brooks	
Lac La Biche	
South Alberta/BC	**AB-3**
Palliser	
Rocky Mountain House	
Hardisty	



SWRA– Threat Identification





- **Evidence based framework for all threats**
- **Use of all available evidence from:**
  - Failure/incident history,
  - Observations/assessments using ILI, HT history, excavations
  - Mechanistic or scientific understanding of the threat and its causal and preventative actions
- **Subsystem specific - consider unique aspects of certain populations**
- **All 9 categories (and 14 with sub categories) of threats**
- **Interaction of threats**

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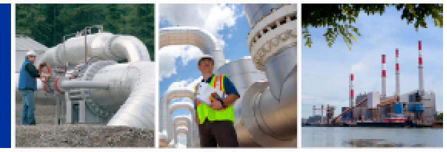
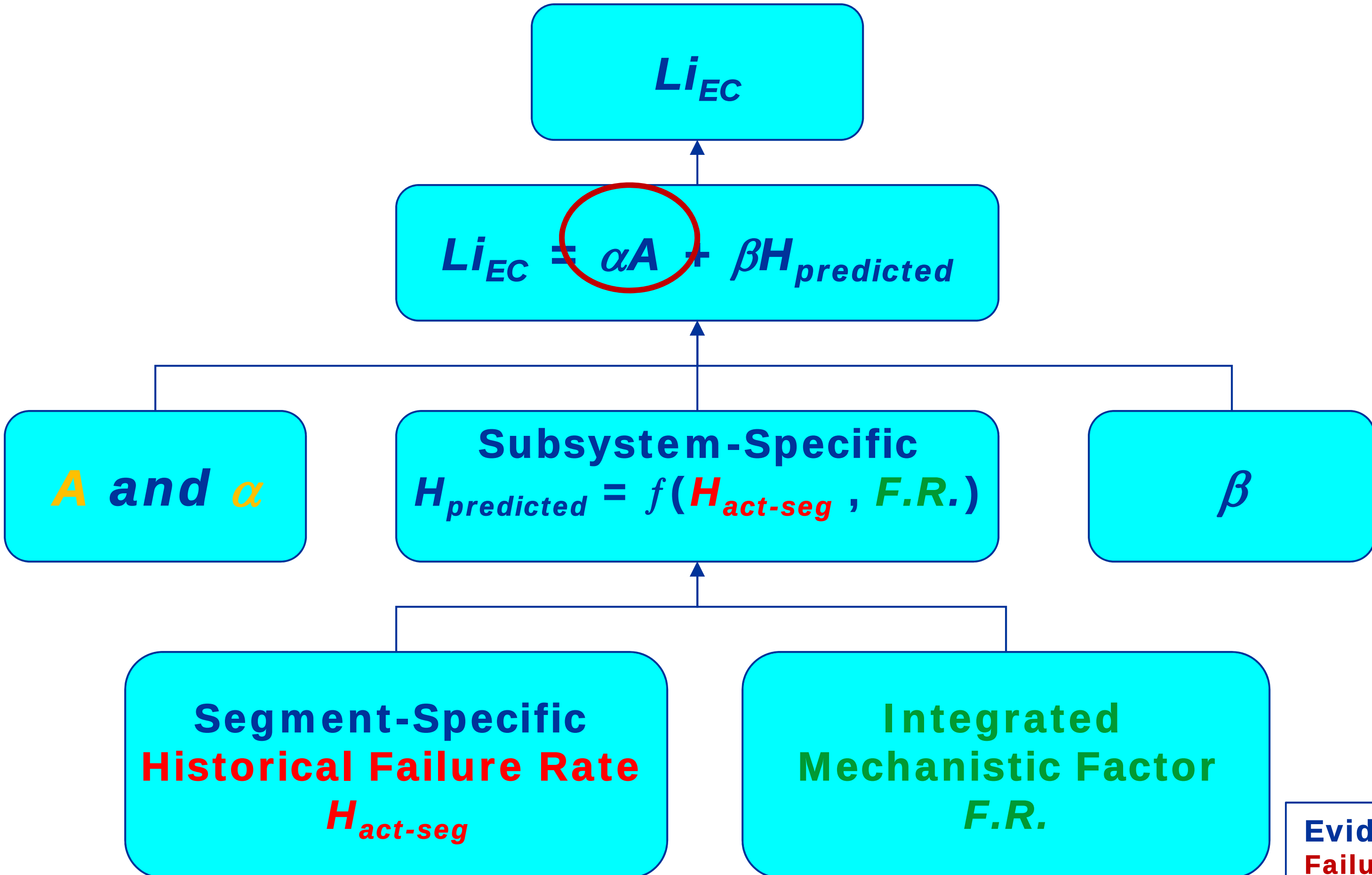
Likelihood Model – for each threat and subsystem – e.g., EC





Evidence used:
Failure history,
Observations / assessments
Mechanistic or scientific understanding

A and α

- ***A* is the assessment factor (failures per km-yr)**
- **Assessment techniques:**
  - In-line Inspection – detects and assesses imm and future threat
  - Hydrostatic Pressure Test – detects and remediates near term threat
  - Excavations – detects, asseses, and remediates locally
- α **indicates the reliability of the assessment, depends on**
  - Methodology used (e.g. HT vs EMAT)
  - Tools used (e.g. 2^{nd} vs 3^{rd} generation ILI tool)
  - Year of assessment (e.g. 5 yrs old vs 10 yrs old HT)

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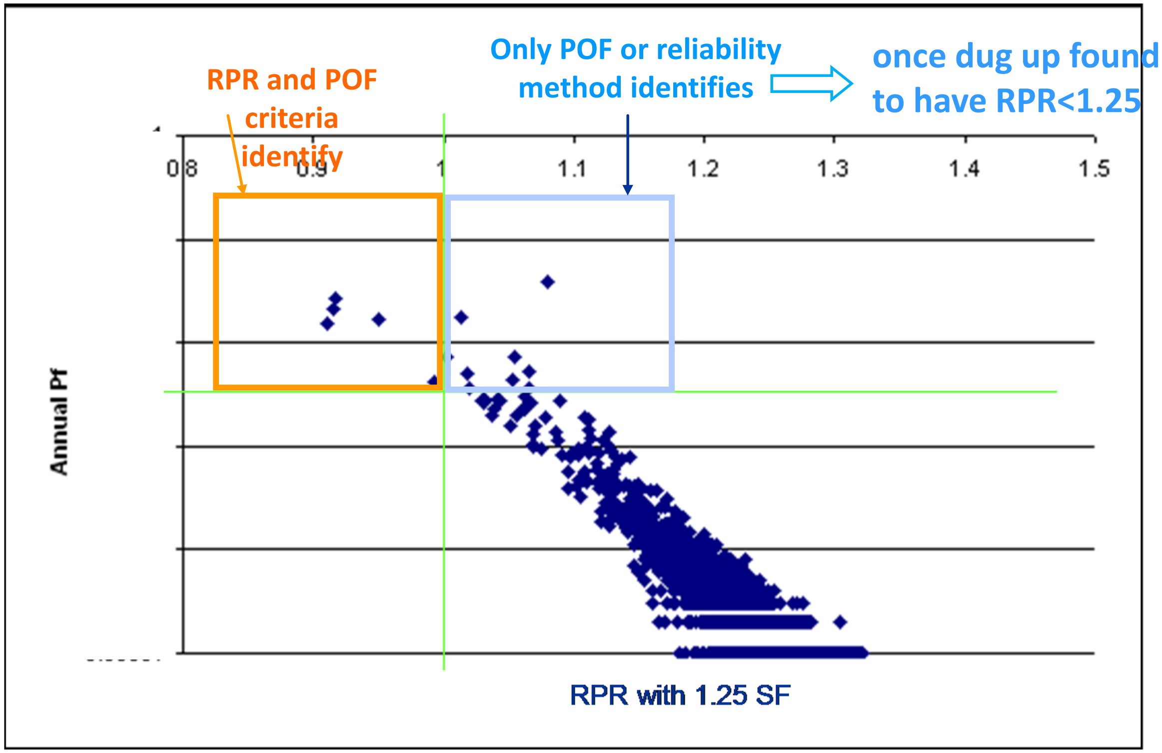
A for Corrosion ILI Reliability Assessment



- Probability of failure and RPR for each ILI anomaly

- Reliability methods provides more consistent safety
- These defect specific POF values are fed into SWRA for each dynamic segment

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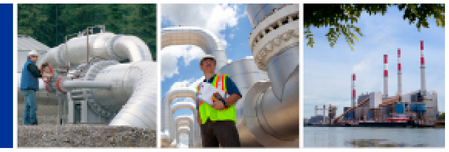
Likelihood Model – for each threat and subsystem – e.g., EC



Li_{EC}

$$Li_{EC} = \alpha A + \beta H_{predicted}$$

A and α

Subsystem-Specific
$H_{predicted} = f(H_{act\text{-}seg}, F.R.)$

β

Segment-Specific
Historical Failure Rate
$H_{act\text{-}seg}$

Integrated
Mechanistic Factor
F.R.

Evidence used:
Failure history,
Observations / assessments
Mechanistic or scientific understanding

Causal and Resistance factor, F.R.

- Captures the mechanistic aspects
- Parameters that cause and resist the threat
- for example,

  $$F.R. = f(X_i)$$

  where

  X_i parameters or combinations for mechanisms
- Considers values (e.g. clay, sand etc.) of a given parameter (e.g. soil) or combination (e.g., soil, coating, vintage)
- Developed by SME input and correlation to assessment data and performance

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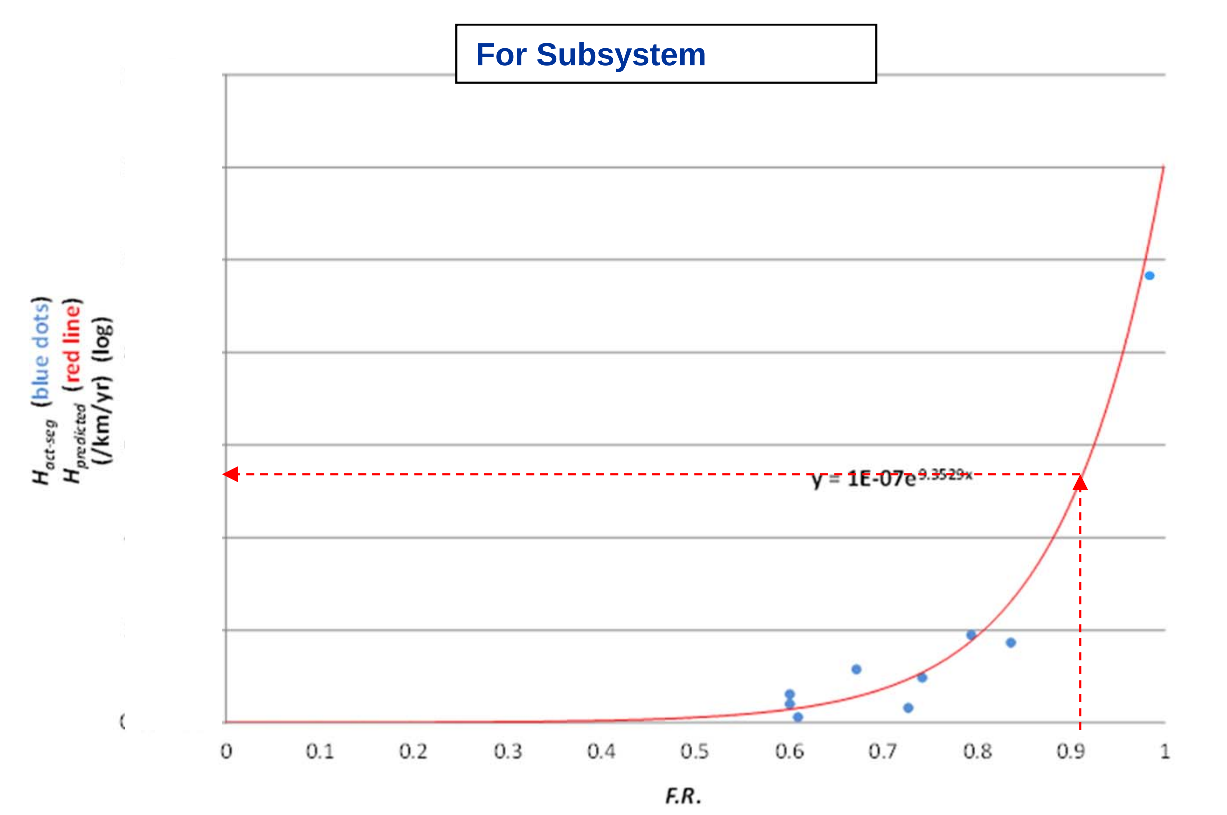
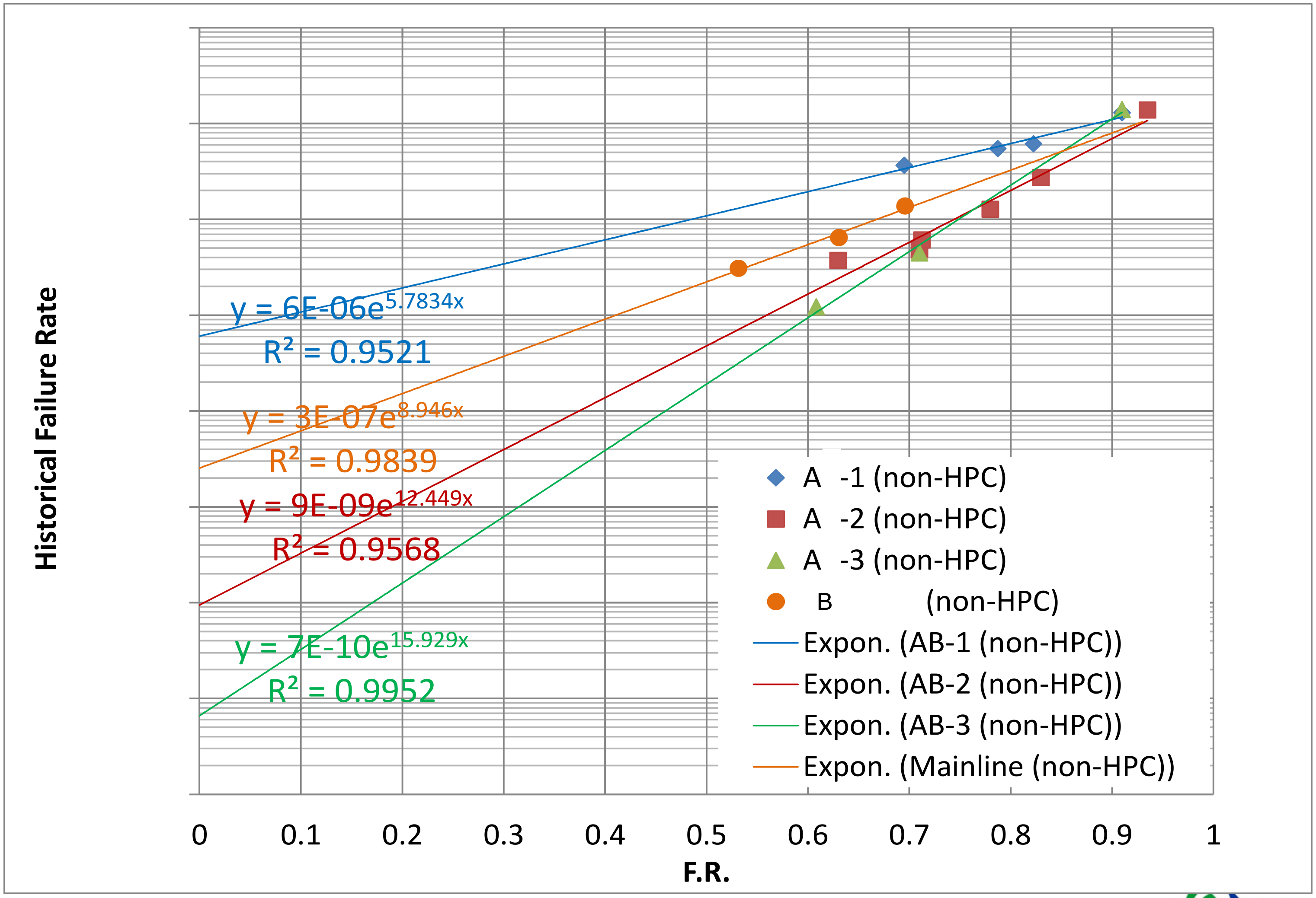
Predicted Failure Rate, $H_{predicted}$

- Segment-specific failures rates, $H_{act\ seg}$ are regressed against F.R. values to obtain subsystem-specific relationship between FR and $H_{predicted}$
- F.R. scores refined for better fit

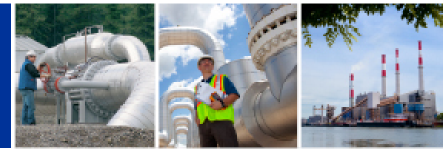


Curve Fitting - $H_{predicted}$ Equation

- **Non-HPC A-1, A-2, A-3, B**



Likelihood Model – for each threat and subsystem – e.g., EC



Li_{EC}

$$Li_{EC} = \alpha A + \beta H_{predicted}$$

A and α

Sub system-Specific
$$H_{predicted} = f(H_{act\text{-}seg}, F.R.)$$

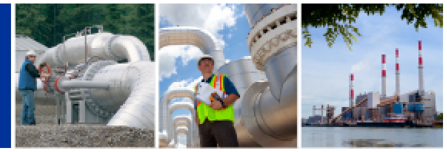
β

Segment-Specific Historical Failure Rate $H_{act\text{-}seg}$

Integrated Mechanistic Factor F.R.

Evidence used:
Failure history,
Observations / assessments
Mechanistic or scientific understanding

Likelihood of Failure (LOF) – Third Party EI



$$LOF = \alpha A + \beta H_{pred}$$

- o **3rd Party Activity rate**
  - ➢ **Unauthorized Activities – Critical, Major, Minor, Near Hit**
  - ➢ **Authorized Activities - One-Call Data**
  - ➢ **Top side dent density from ILI**
- o **3rd Party Hit given Activity**
  - ➢ **Fault Tree Model**
- o **3rd Party Failure given Hit**
  - ➢ **Monte Carlo Simulation – CSA Z662-15 Annex O**

$$H_{pred} = \text{P of Hit} \times \text{P of Failure given Hit}$$

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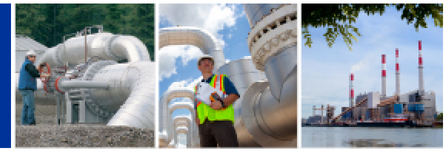
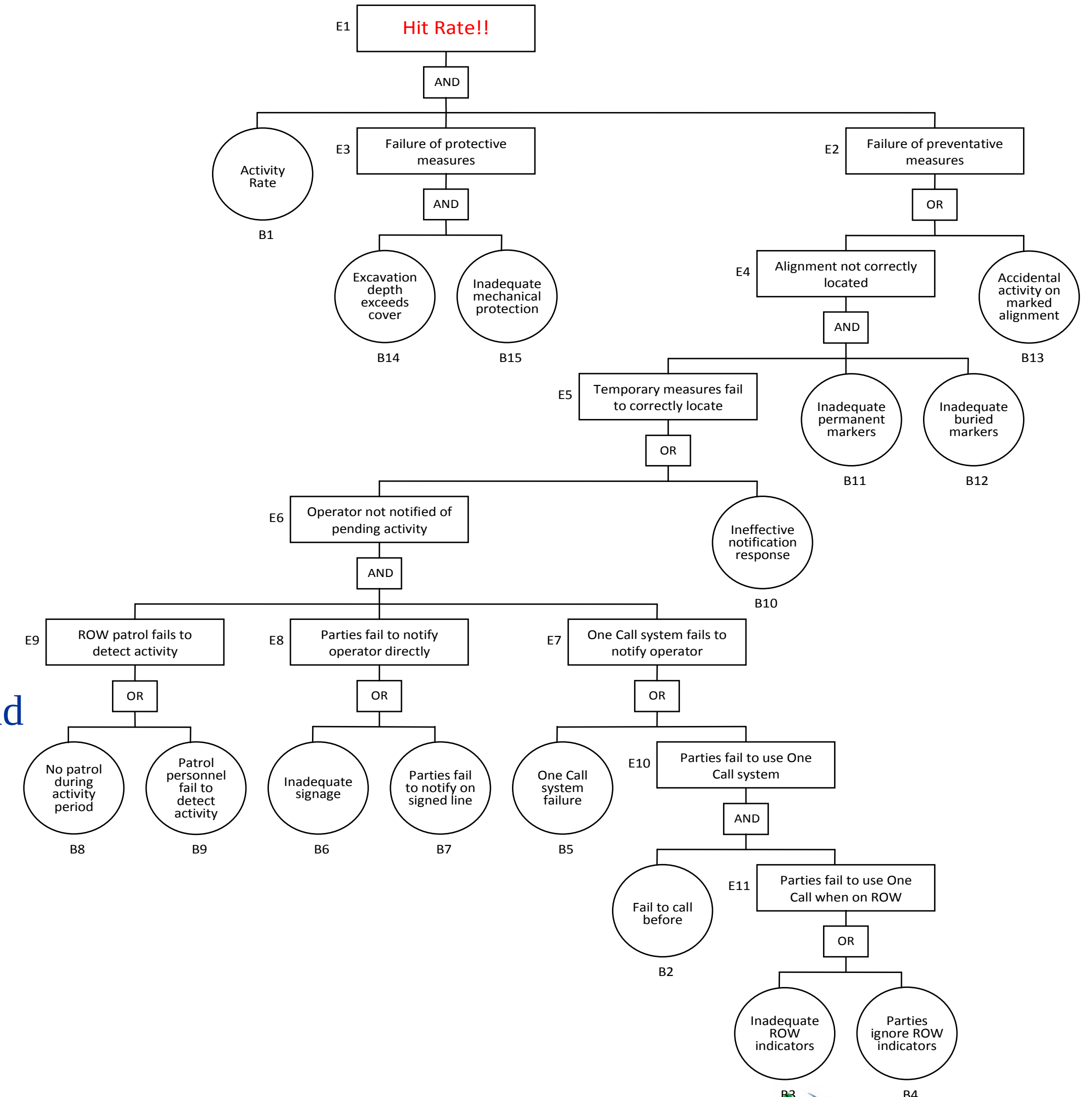
Probability of Hit (Fault Tree Inputs)



1. Activity Zone (MD region, Class)
2. Crossings & Terrain
3. Dig Notification Requirement
4. Public Awareness Level
5. ROW Indication
6. One-Call System Type
7. ROW Markers - Explicit Signage
8. Surveillance Interval
9. Surveillance Method
10. Alignment Markers - Above Ground
11. Alignment Markers - Buried
12. Dig Notification Response
13. Dig Notification Response Time
14. Depth of Burial (m)
15. Mechanical Protection



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POF given a Hit (Monte Carlo Simulation)

- **Annex O.2.6.3 Model for Monte Carlo Simulation**
- **Probability of Failure given a hit = *f* (OD, WT, Grade, Pressure)**

Marlo POFH MC Simulation		Unit	Distribution Type	Mean	Standard Deviation	Standard Deviation	Source
Outside diameter	D	mm	Deterministic	Nominal value	0	0	Annex O
Wall thickness	t	mm	Normal	Nominal value	0.25	0.25	Annex O
Yield strength	Sigma_y	MPa	Normal	1.11 X SMYS		Mean x 3.4%	Annex O
Tensile strength	Sigma_u	MPa	Normal	1.12 X SMTS		Mean x 3.0%	Annex O
Young's modulus	E	MPa	Normal	210000	8400	Mean x 4%	Annex O
Charpy energy	Cv	Joule	Lognormal	30	3.20	0.0223 x Mean^1.46	Annex O
Gouge length	lg	mm	Weibull	249	311.25	Mean x 125%	Annex O
Gouge depth	dg	mm	Weibull	1.2	1.104	Mean x 92%	Annex O
Excavator bucket tooth length	lt	mm	Uniform	90	28.8	Mean x 32%	Annex O
Excavator bucket tooth width	wt	mm	Uniform	3.5	0.875	Mean x 25%	Annex O
Indenting Force	q	kN	Gamma	133	72	72	C-FER Report
Pressure	P	MPa	Deterministic	MOP	0	0	

Threat interaction

Entail three notions about the relationship (Bullock, 2011):

1. Interacting Defects / Coincident defects:

- **Multiple defects exist in a pipe at the same location and at the same time. E.g., Corrosion and Mechanical damage**

2. Interacting / activating Threats:

- **Involves a causal mechanism that couples one threat to the other**
- **One threat activates the other E.g., CSCC (SCC environment and materials with ground movement) and WB with ground movement, L of F with fatigue**

3. Interacting and Common Mode Conditions:

- **Multiple environmental and operational conditions lead to the concurrent presence of multiple threats. E.g., Corrosion and SCC, SCC and CSCC**

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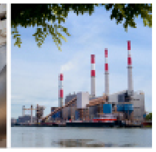
Threat Interaction considerations



- **All threats can coincide (Category 1) –handled by quantitative total risk**
- **Additional measures are required for Category 2 and 3 – explicitly accommodated in algorithm**

		External corrosion	Internal corrosion	Stress corrosion cracking	Circumferential Stress Corrosion Cracking	Manufacturing related defects long seam and material	Manufacturing related defect - Hardspot	Welding and fabrication (Construction) related	Wrinkle Bend	Rock Damage	Equipment failures	Thermal Expansion	Third party external interference	First and second party external interference	Incorrect operations – human error	Weather-related and outside force
a) Time Dependent	External corrosion															
	Internal corrosion	1														
	Stress corrosion cracking	1, 3	1													
	Circumferential Stress Corrosion Cracking	1, 3	1	1, 3												
b) Static or Resident	Manufacturing related defects - long seam and material	1	1	1, 3	1											
	Manufacturing related defect - Hardspot	1	1	1, 3	1	1										
	Welding and fabrication (Construction) related	1	1	1	1, 3	1	1									
	Wrinkle Bend	1	1	1	1, 3	1	1	1, 3								
	Rock Damage	1	1	1	1	1	1	1	1							
	Equipment failures	1	1	1	1	1	1	1	1	1						
	Thermal Expansion	1	1	1	1	1	1	1	1	1	1					
c) Time Independent	Third party external interference	1	1	1	1	1	1	1	1	1	1	1				
	First and second party external interference	1	1	1	1	1	1	1	1	1	1	1	1			
	Incorrect operations – human error	1	1	1	1	1	1	1	1	1	1	1	1	1		
	Weather-related and outside force	1	1	1	1, 2	1	1	1, 2	1, 2	1	1	1	1	1	1	

LOF VALIDATION

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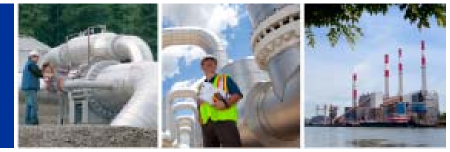
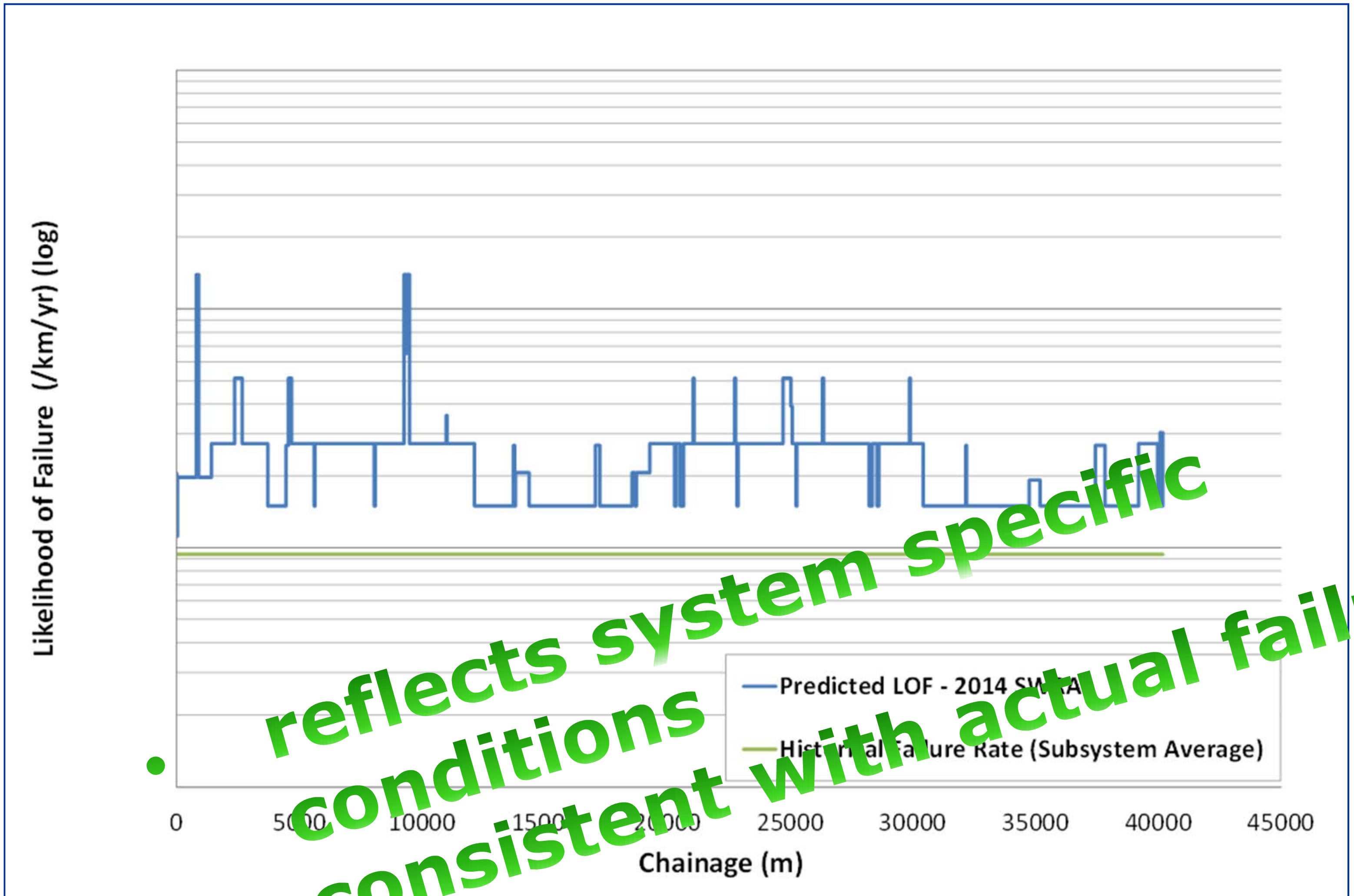
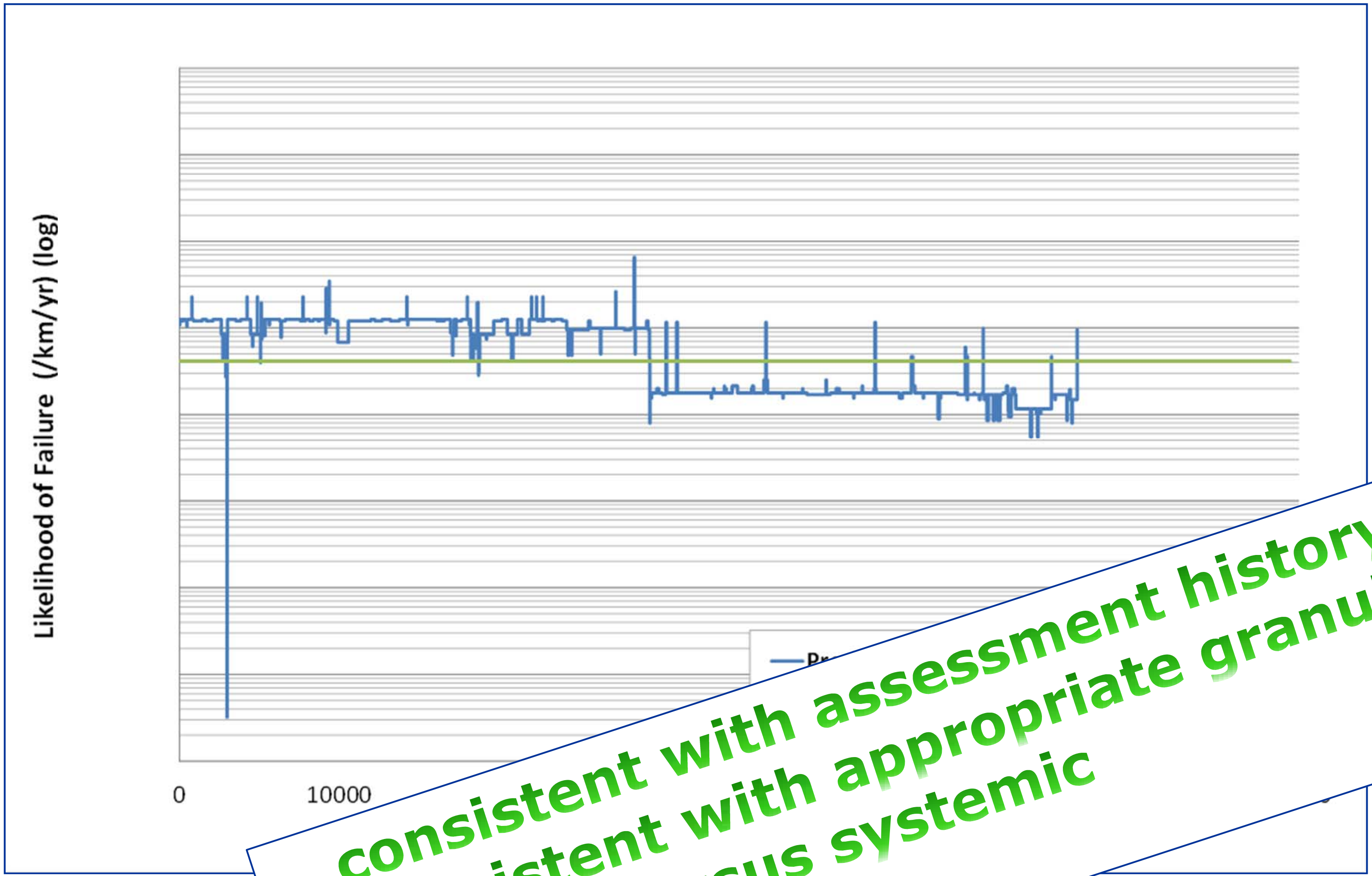
Validation - POF_{EC} & historical -unpigged, NPS 10 1970, A-2 Subsystem, Ptape





- reflects system specific conditions
- consistent with actual failure rates

Validation - POF_{EC} & historical - unpigged, partially hydrotested , Ptape, NPS 18 1969, A-1 subsystem



- consistent with assessment history
- consistent with appropriate granularity –
  - local versus systemic

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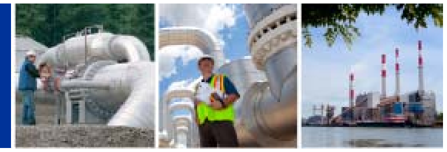
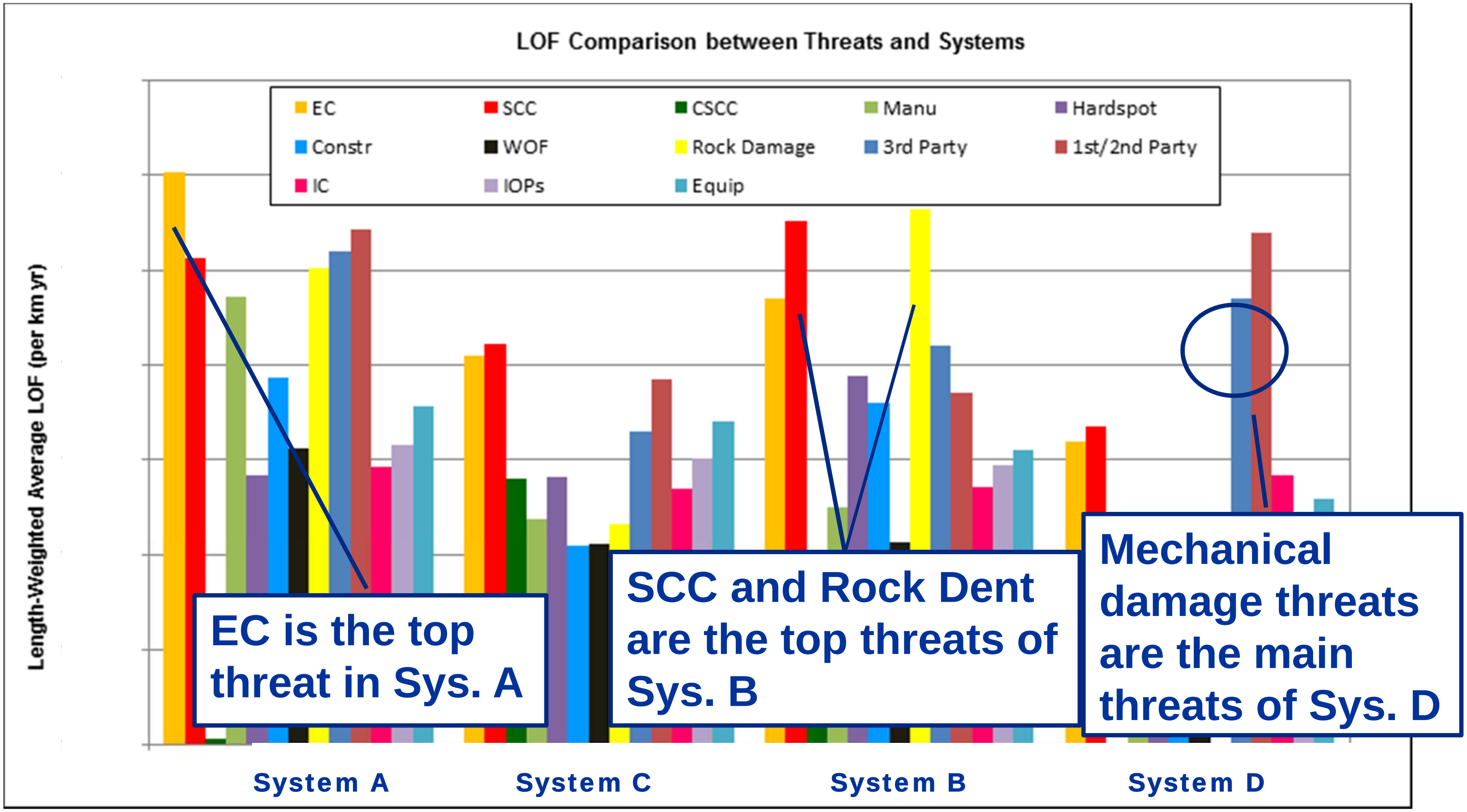
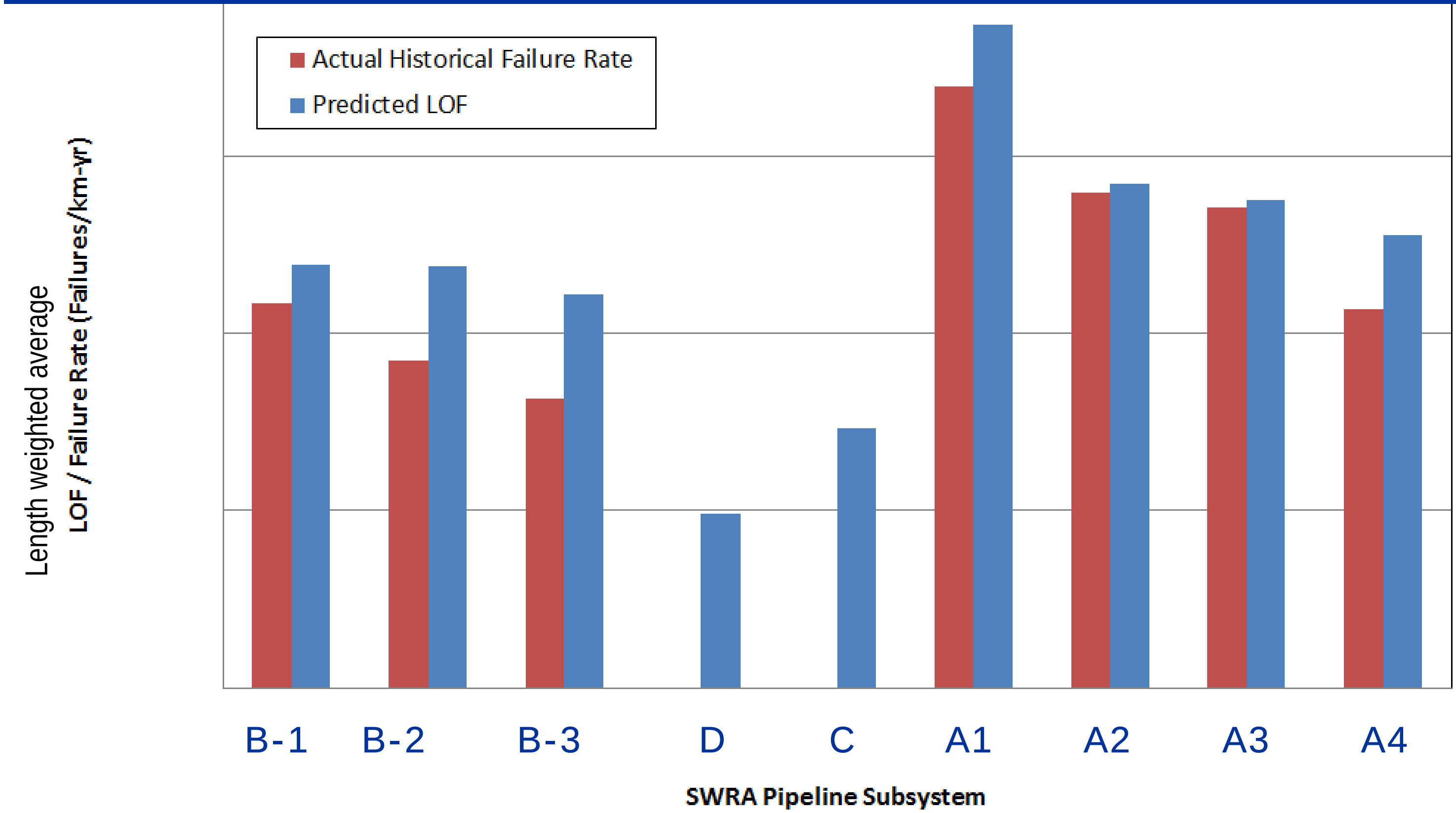
Validation





Reflects known system specific aspects

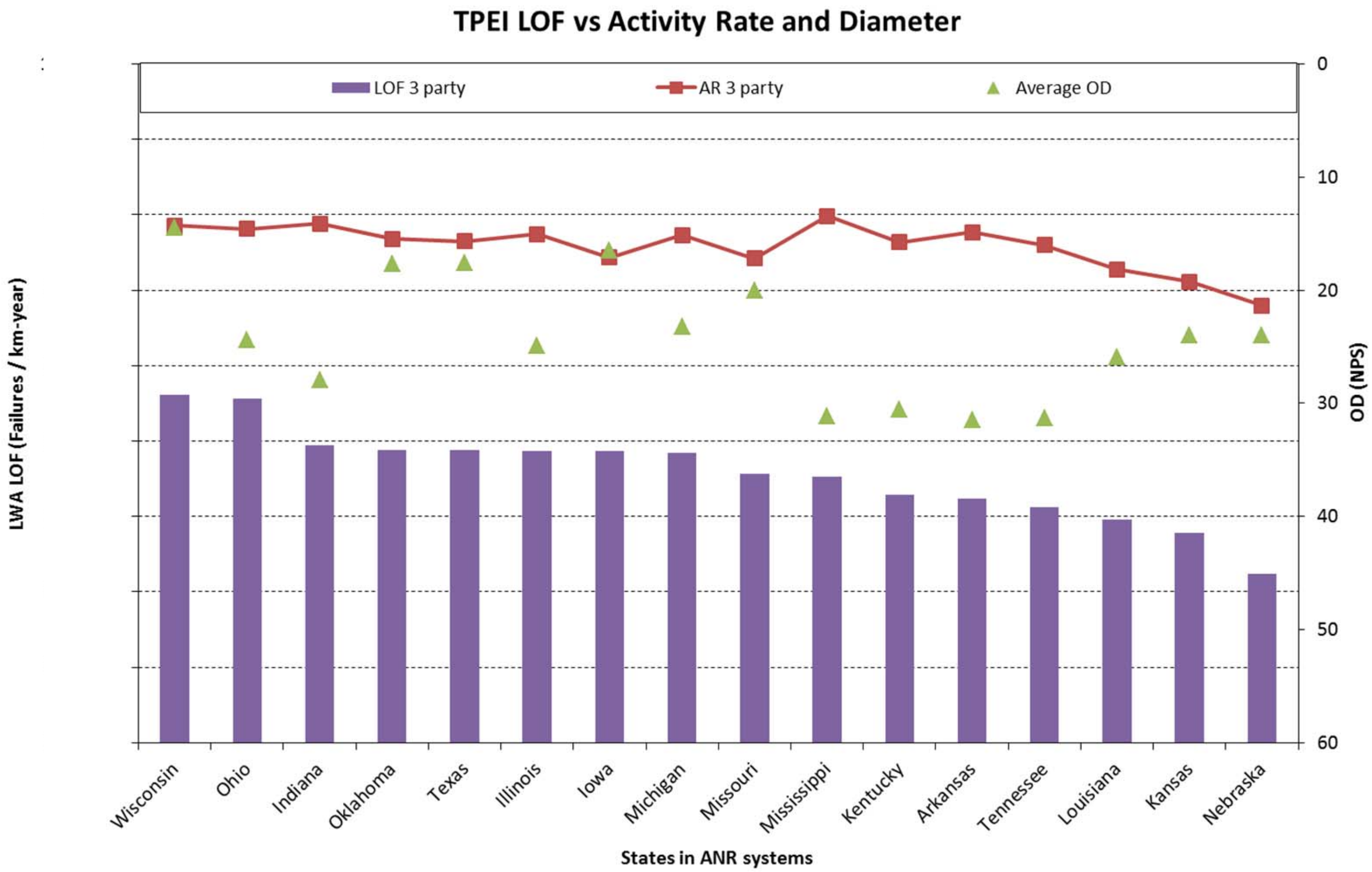
Validation - and historical Failure rates



System A	Predicted Failures (leaks and ruptures) / year	Reality Check (in last 5 years)
All Threats	5.0	20 (i.e. 4.0 / yr)
Ext. Corrosion	3.65	12 (i.e. 2.4 / yr)
SCC	0.46	1 (i.e. 0.2 / yr)

Sub-system in XX by State
3rd Party Damage

- **XX system- 16 states**
- Activity rate – from Unautorized activity, one calls and top side dents
- P of failure given hit f(OD, wt, grade …)



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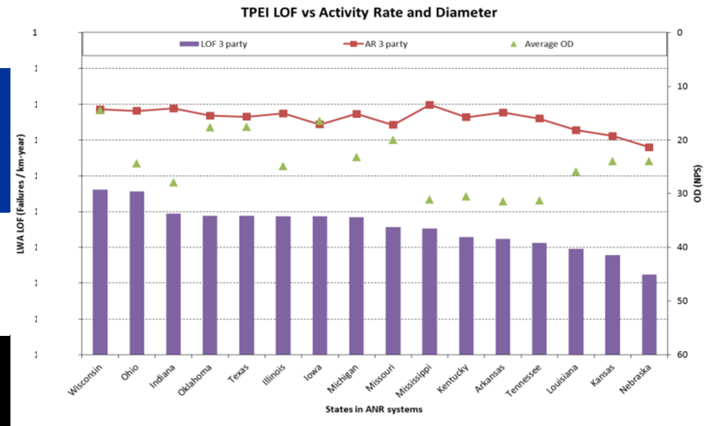
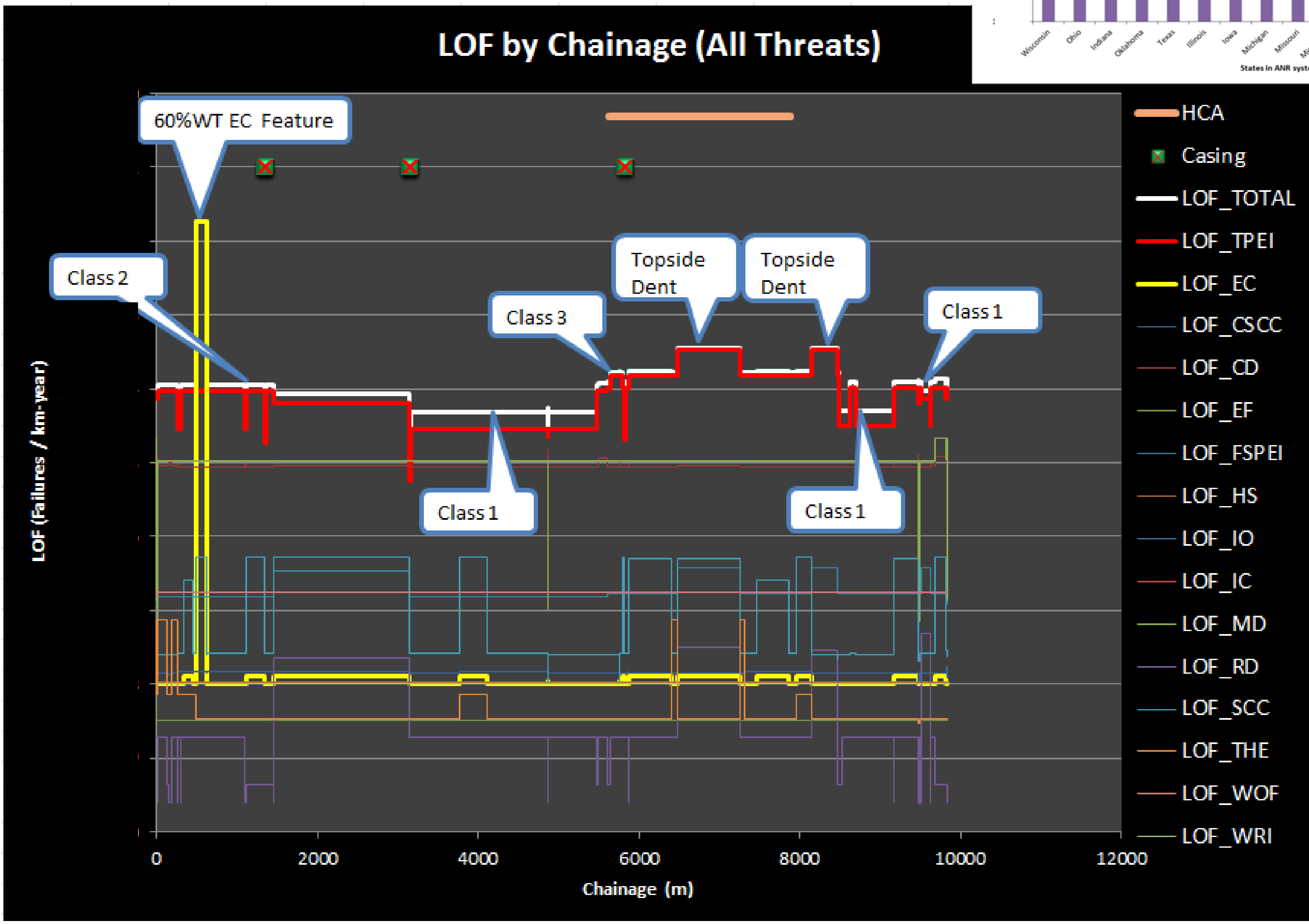
3rd Party Damage LOF

- **Wisconsin - Highest LOF_{TPEI}**





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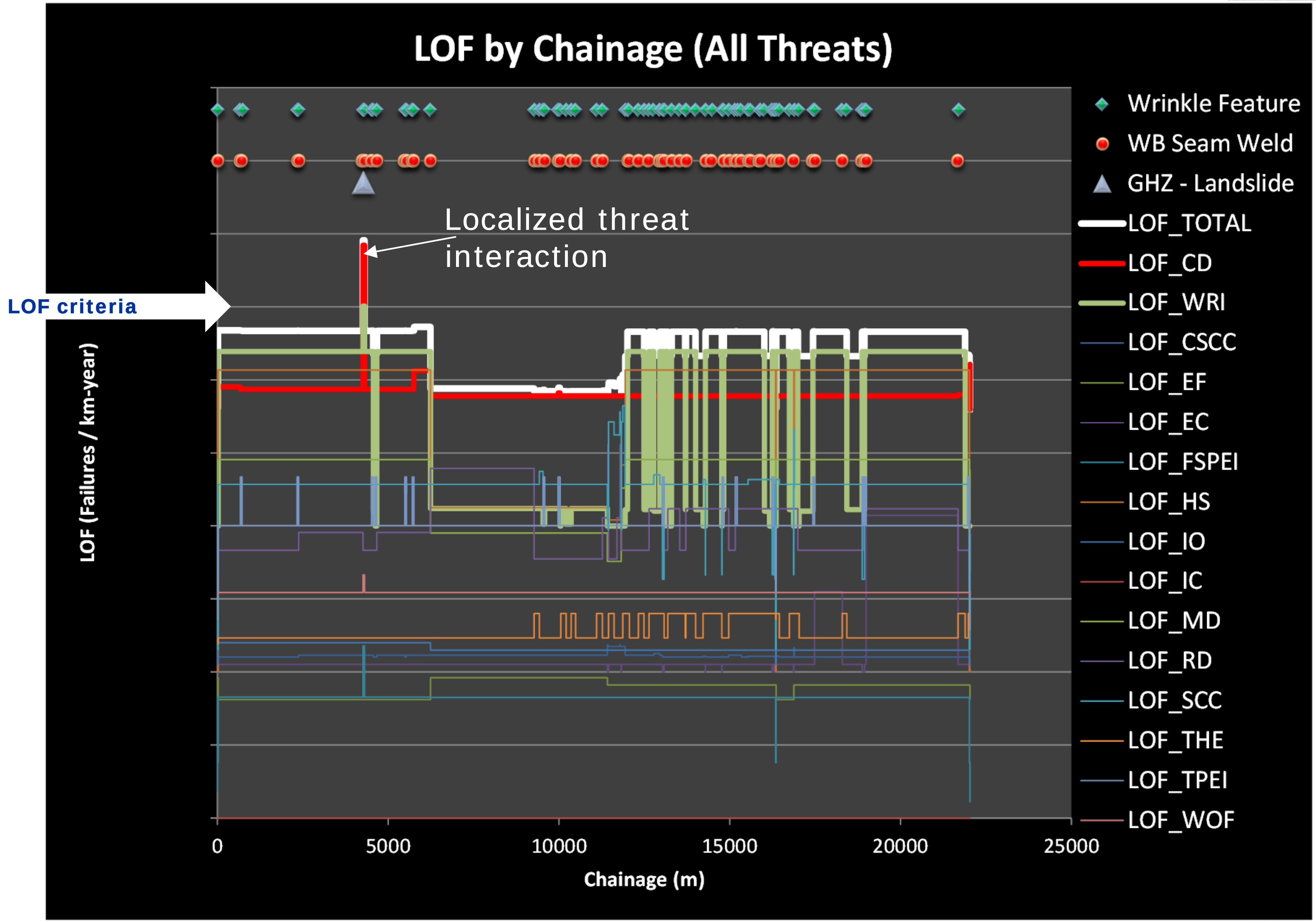
Construction and Wrinkle Bends LOF



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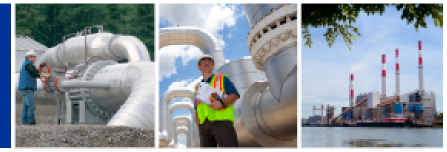
General Validation



- **Failures/Year prediction should be realistic**
- **Failures = In-service Leaks + Ruptures**

EC Prediction for XX		**XX System Length**		**EC XX Predicted Failures/Year**
9.19E-6 Fail/km-yr	**x**	14700 km	**=**	0.14 Fail/Yr

(1 failure last 10 years)

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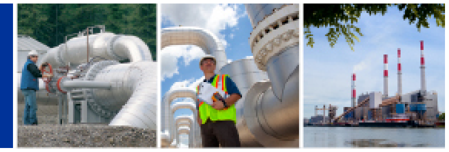
General Validation



For XX:

Prediction:

Threat	Failures/Yr
Construction	0.43
Manufacturing	0.45
3rd Party	0.18
EC	0.14
IC	0.24
SCC	0.02
Hardspot	0.05
1st & 2nd Party	0.001
CSCC	6.42E-04
IOPs	8.94E-05
Rock Damage	0.01
Thermal Exp	3.69E-03
WOF	6.75E-04
Equip	1.91E-04
Wrinkle Bend	0.02
Total	1.54

Actual:

Threat	Failures/Yr
Const	4 failures in the last 10 yrs = 0.4
Manuf	2 in last 10 yrs = 0.2
3rd Party	1 in last 5 years = 0.2
EC	1 in last 10 years = 0.1
IC	4 in last 10 years = 0.4
Total	16 in last 10 years = 1.60

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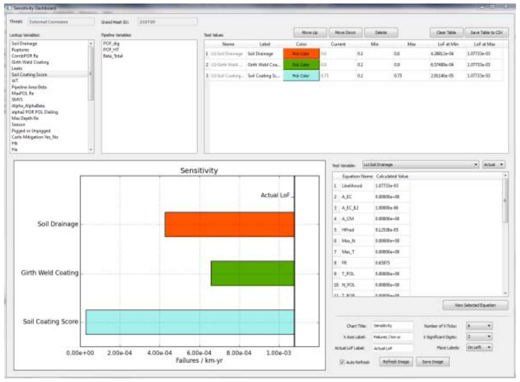
Sensitivity analysis

- Separate work is done on sensitivity studies
- Corrosion reliability – IPC papers
- Mechanical damage model - NEB website – EA s and IRs
- Mechanistic factors SWRA tool
- Shows which data collection efforts to focus on



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Consequence and Risk aspects

1. **Failure – leak / Rupture**
2. **Gas Outflow f(P,D,..)**
3. **Ignition**
4. **Thermal Radiation**
5. **Thermal Radiation Effect**
6. **Probability of Casualty (Risk)**

San Bruno rupture
NPS 30
8 fatalities (58 inj)

Rupture NPS 20

Rupture NPS 10

Leak NPS 8

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Risk Criteria – HCA & non HCA

Based on Objectives

Risk measures and thresholds

- **Individual Risk (IR)**
- **Societal Risk (SR)**

To Avoid failures

- **Limits on Total LOF**

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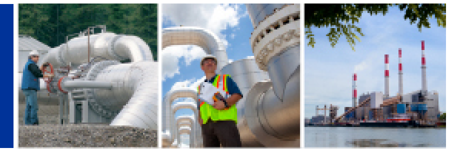
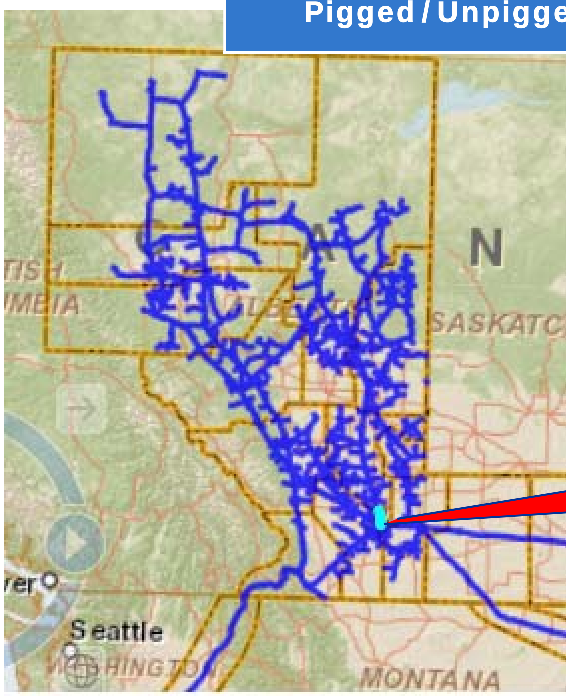
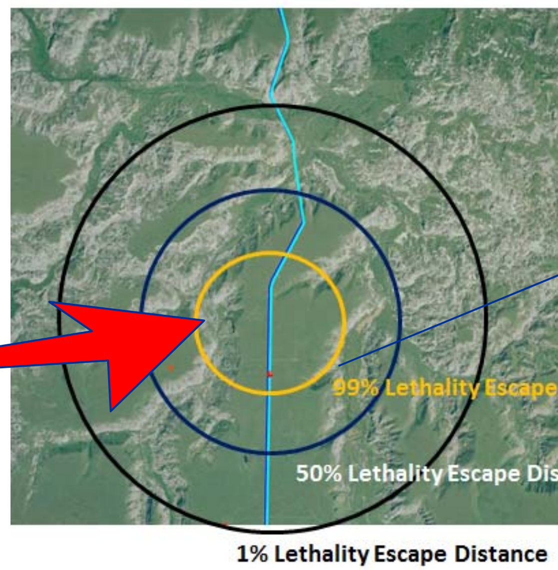
SWRA Results – Individual risk criteria

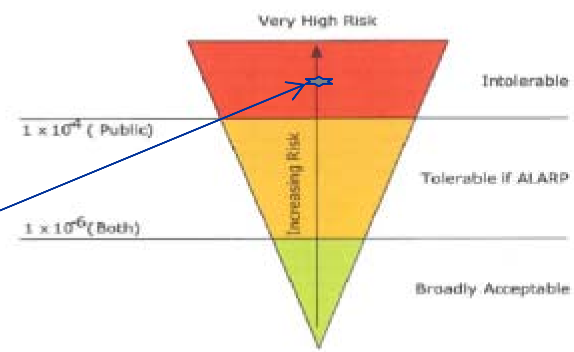


Pipeline	Loop N(NPS 30 1975)
Diameter	30
MAOP	8455 kPa
% SMYS	60
Coating	PTape2
Construction Year	1975
Pigged / Unpigged	Partially (30 inch section not pigged)





Individual risk criteria



Identifies segments that are more likely to fail and cause risk to people on the ROW and puts them in a IM program

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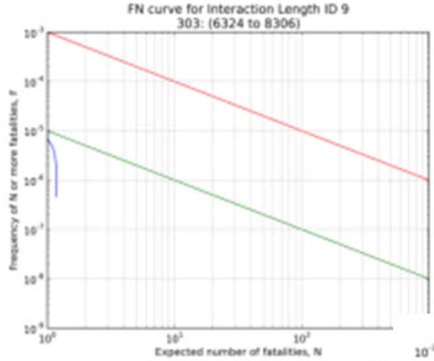
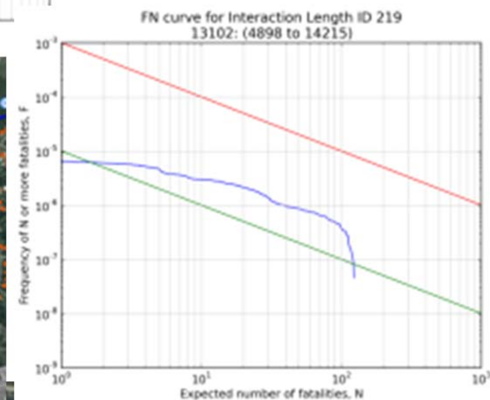
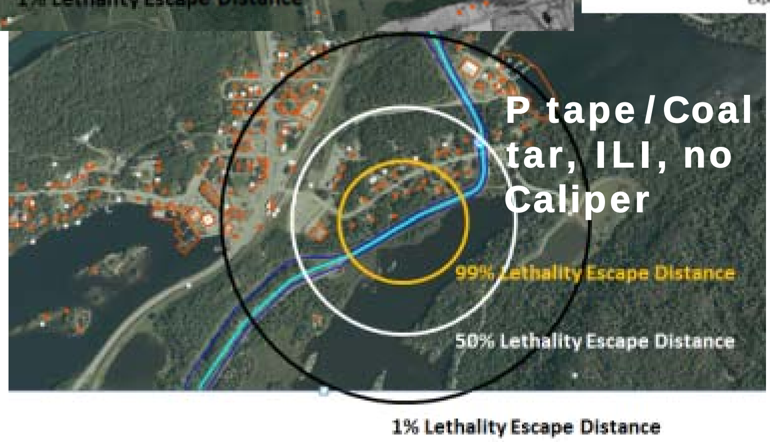
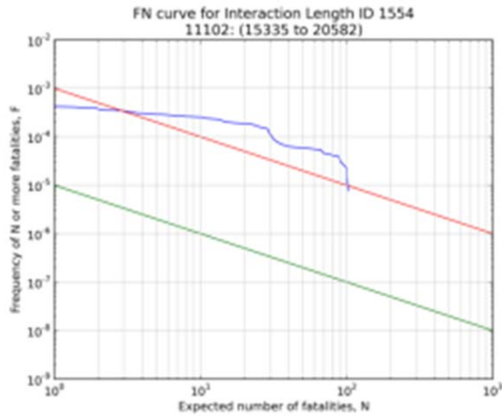
SWRA Results - Societal Risk Criteria

identifies higher consequence segments that need prevention or mitigation



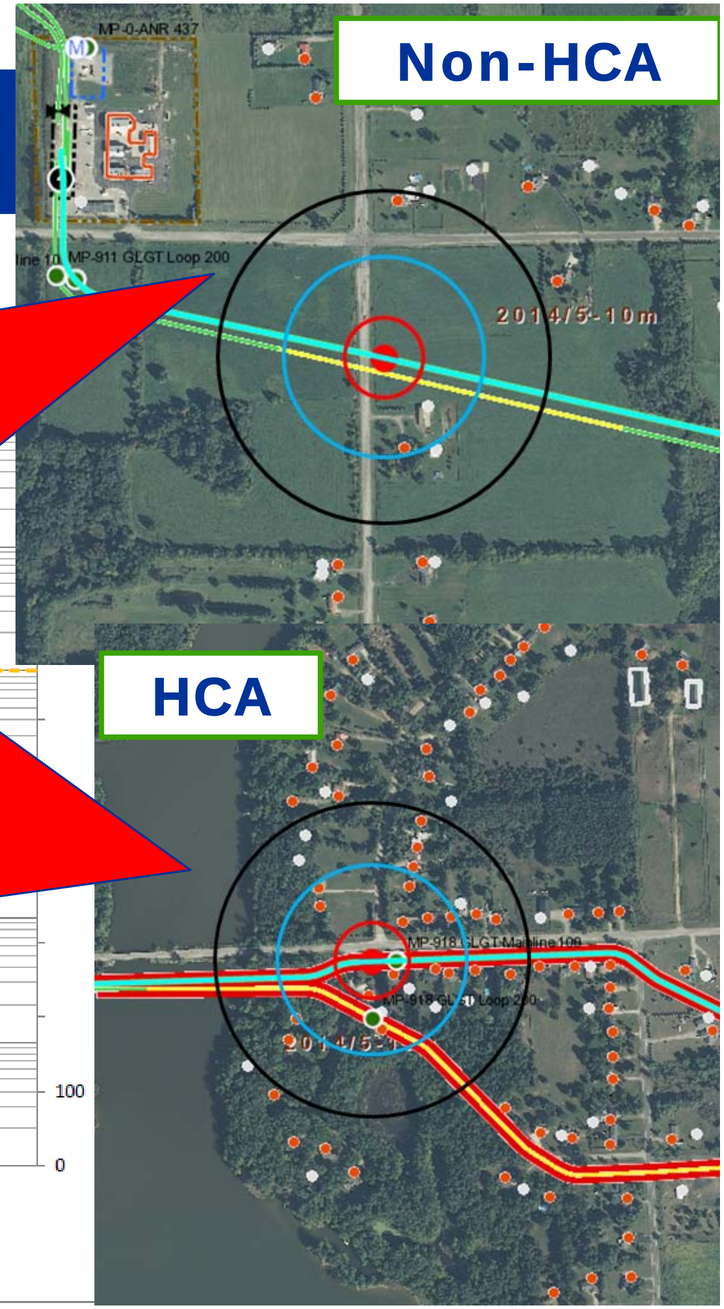






IR Exceedance Driven by External Corrosion

External Corrosion Features > 50 % WT



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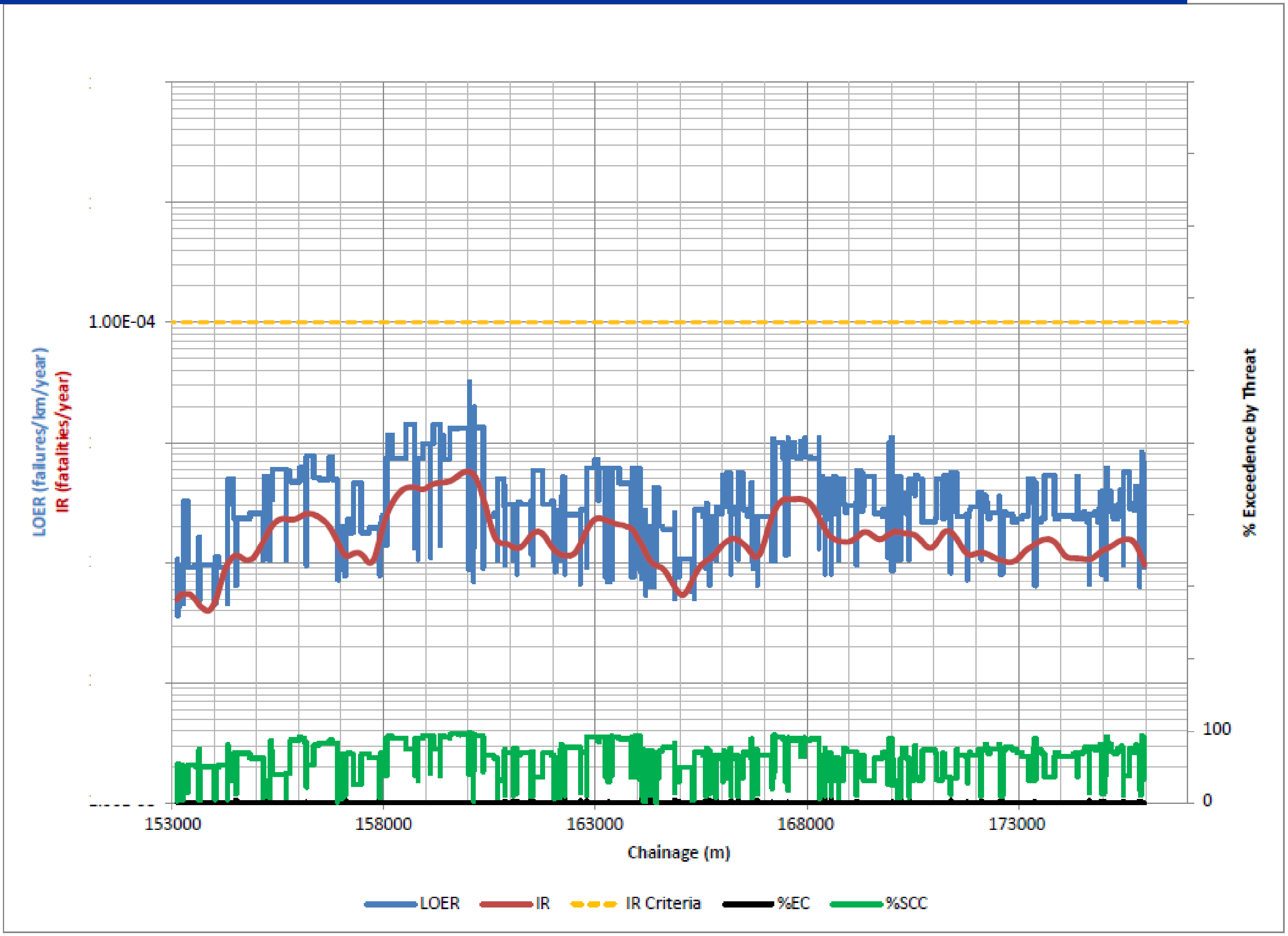
Reducing IR by Defect Remediation



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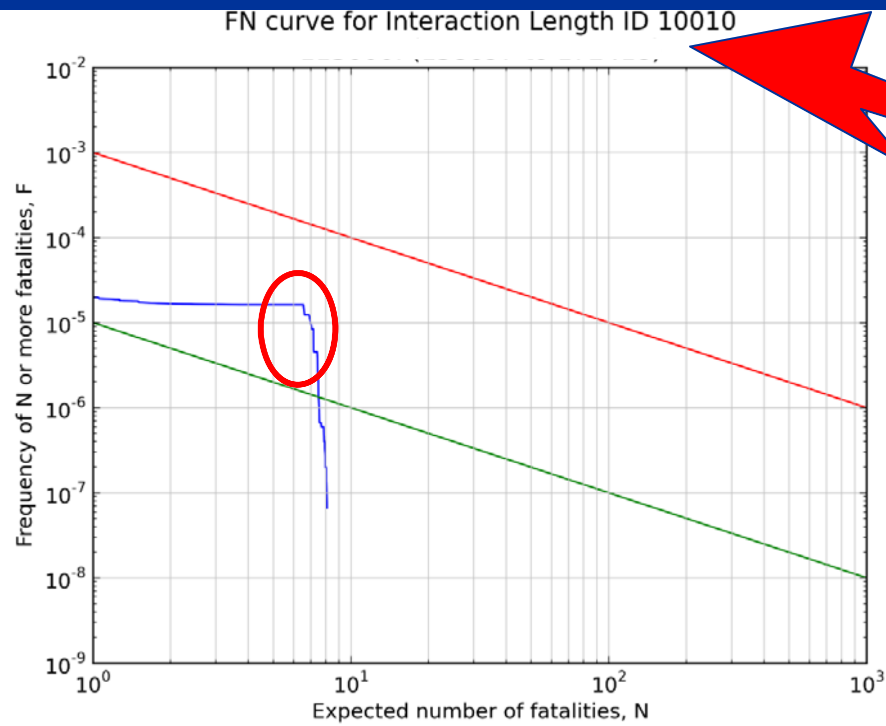
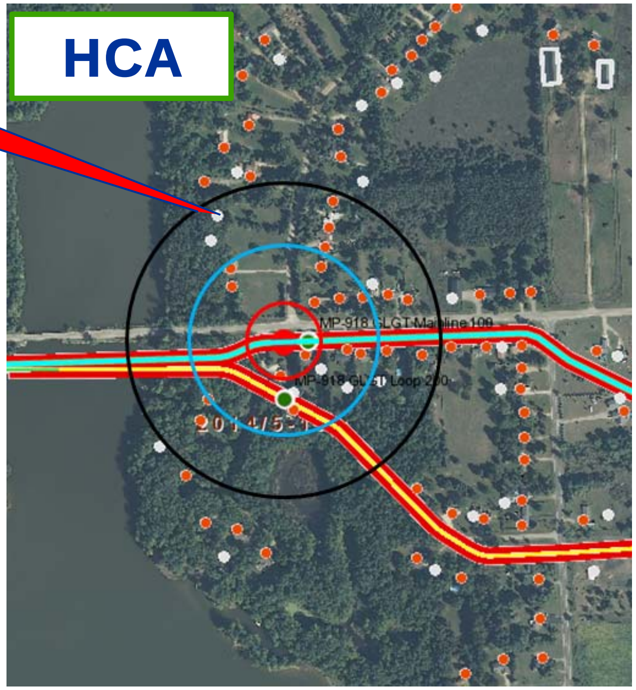
SR ALARP Driven by External Corrosion





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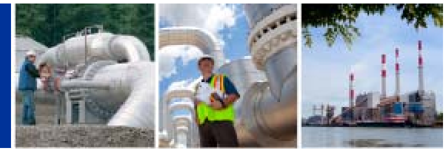
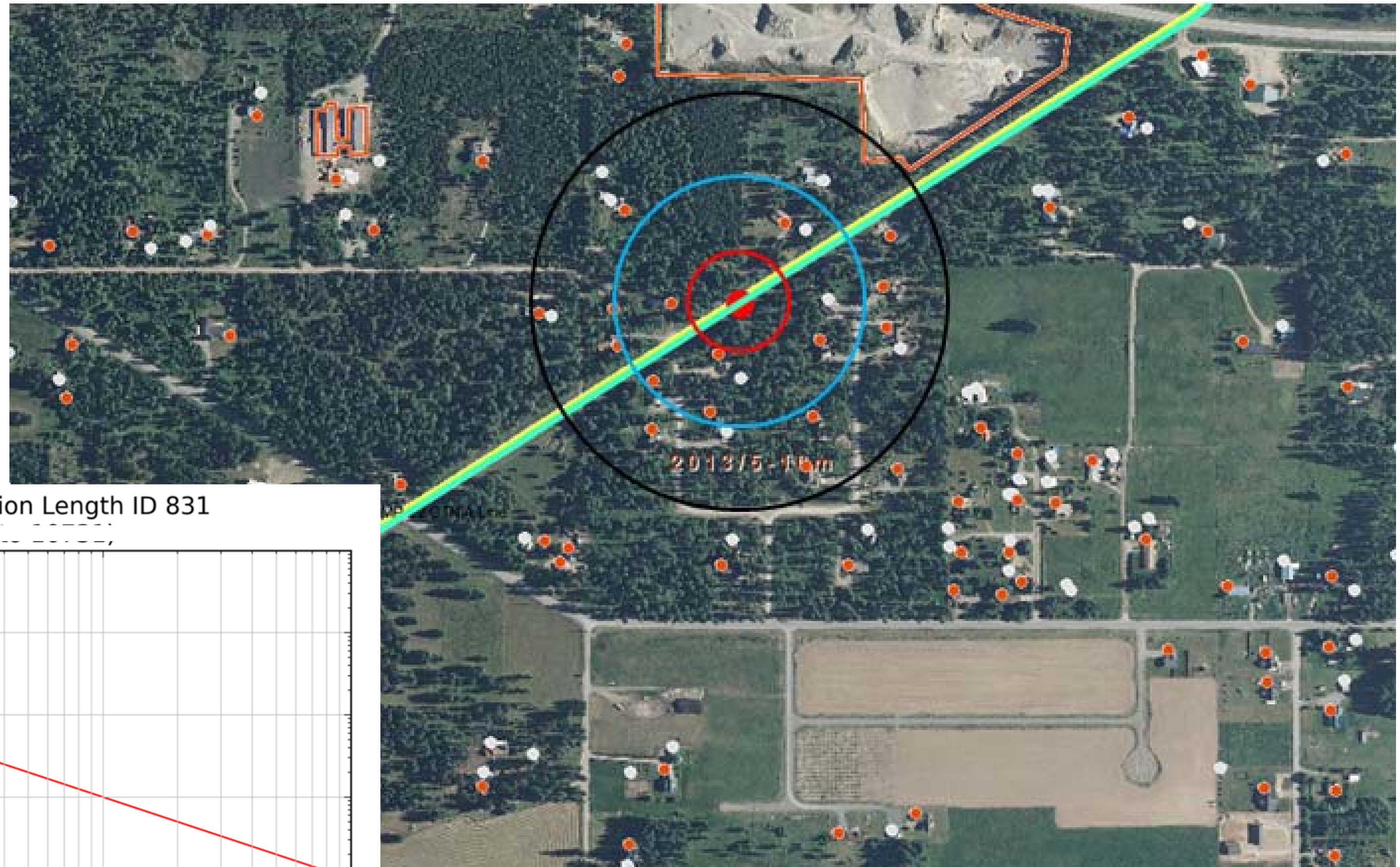
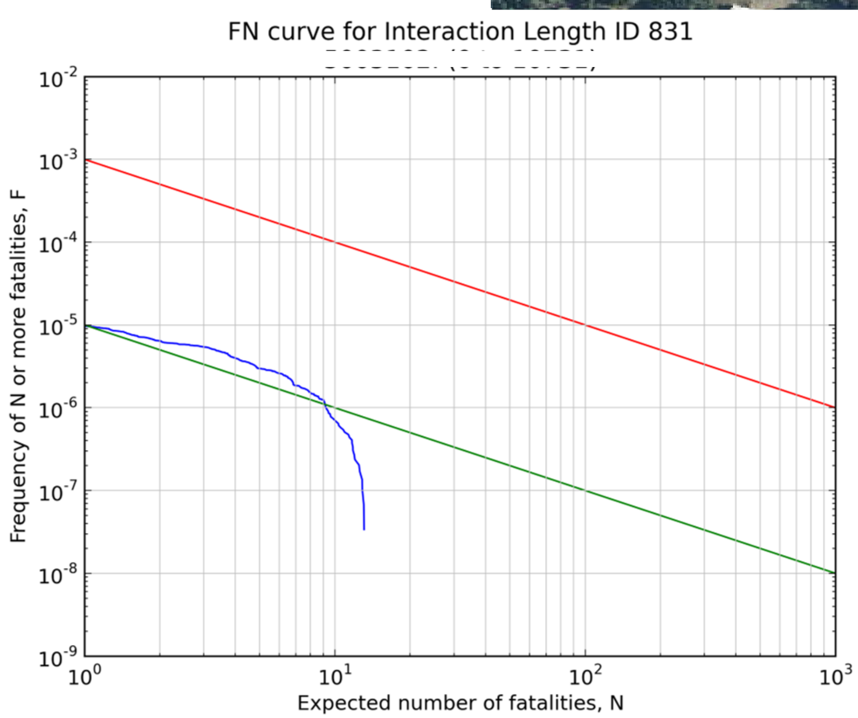
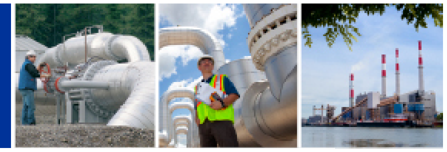
SR ALARP in Non-HCA

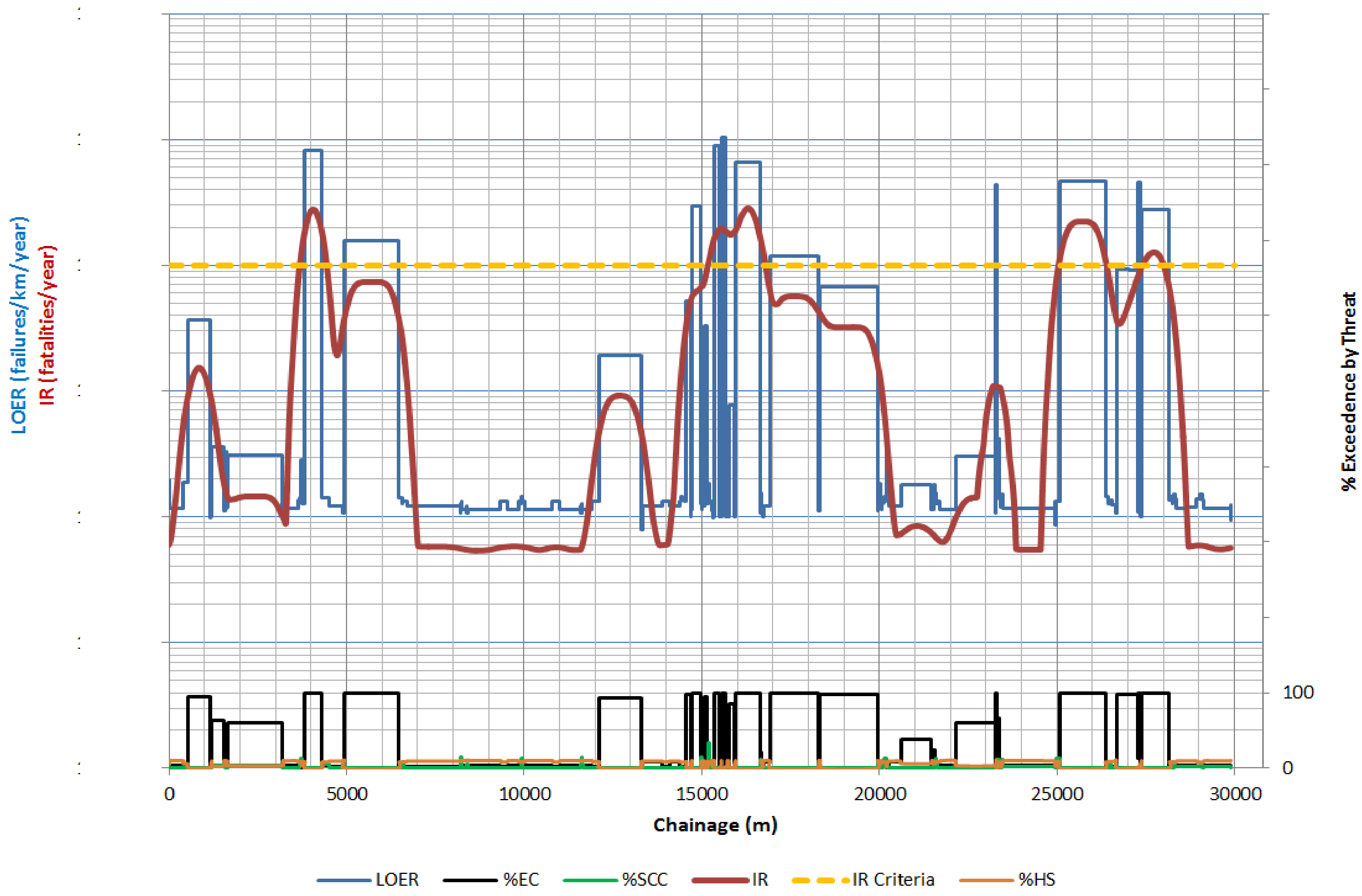




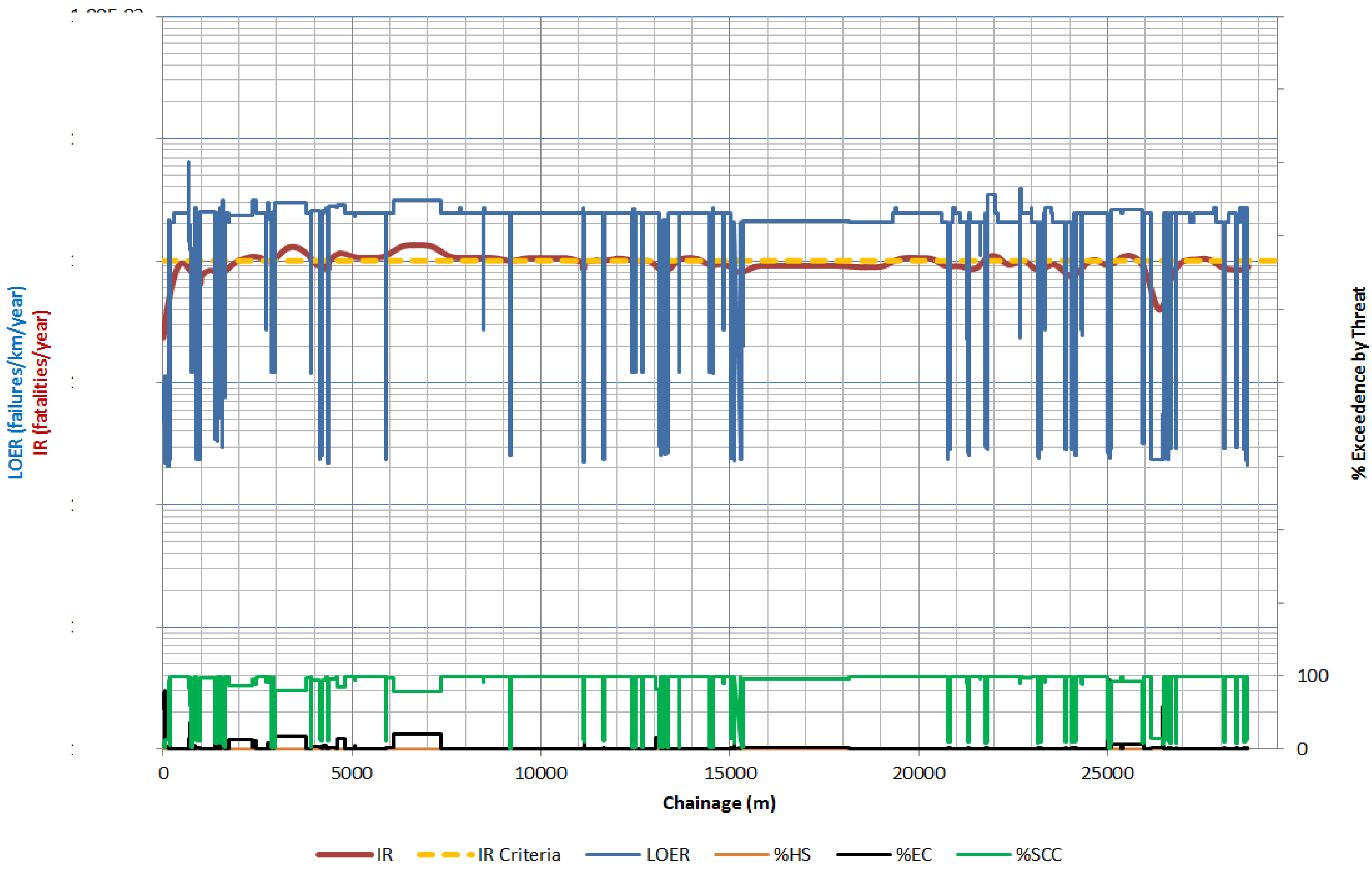


IR and LOER Plot User Guidance

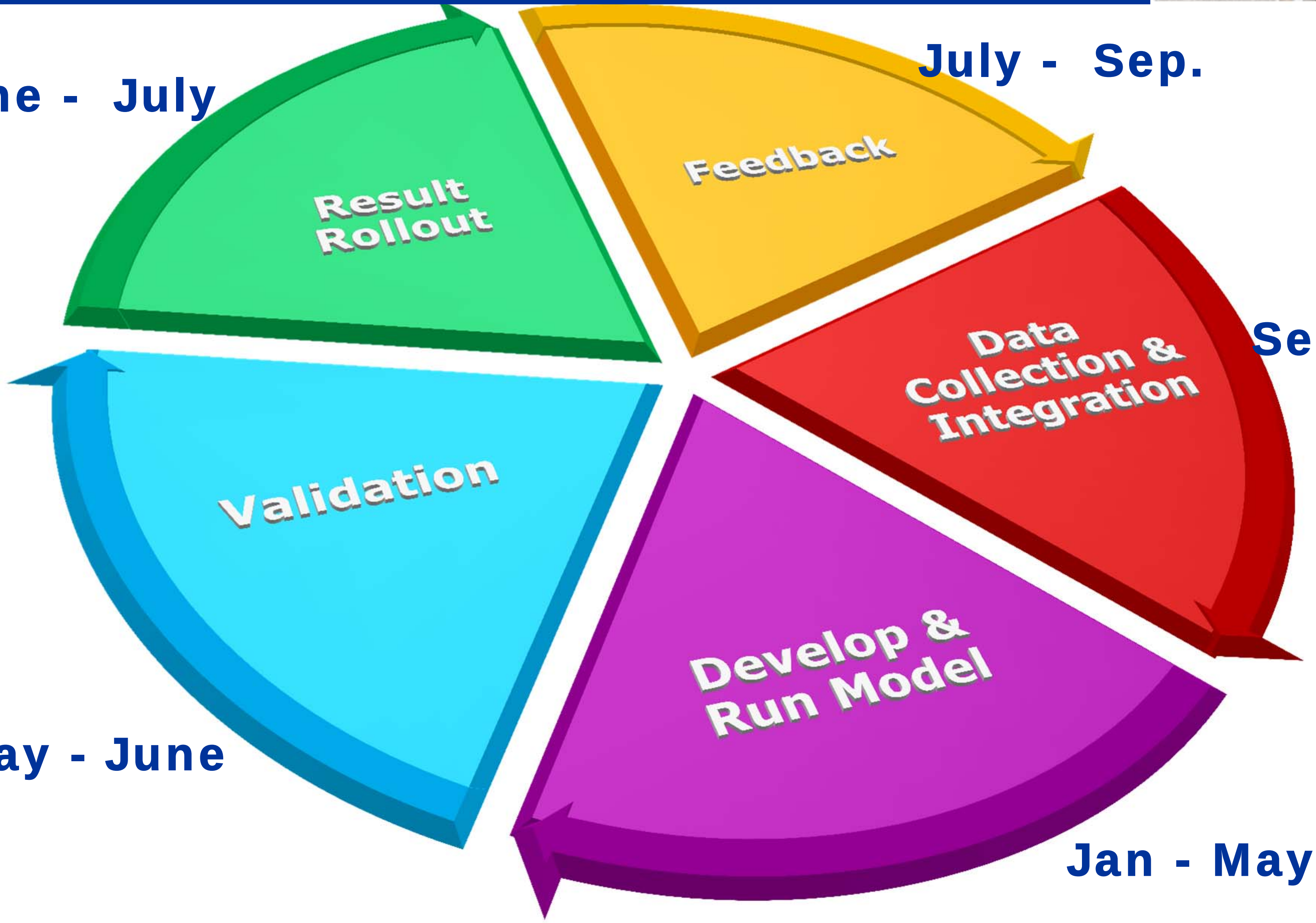




IR and LOER Plot User Guidance



Annual Continuous Improvement Cycle



Follows CSA/API1173 Safety Management - Plan- Do-Check-Act

Which LOF/Risk Models for SWRA?

Magnitude of decision:

System wide

but remediation is local - need appropriate granularity

Objective: Drive assessment and mitigation activities that reduce risk and prevent failures - combine all threats and consequences and criteria

Organizational maturity: Acknowledge current state but build a framework for continuous improvement

Data and info available:

Many disparate data sets, consider all evidence for all threat types, SME input should be backed by data

Models: Use best quantified model with best quantified data for each threat and subsystem with continuous improvement

Lessons learnt: Integrate Risk and IM, learn from failures, threat dominance- time and subsystem specific, predictive models do not have all the data necessary for accuracy.....

QUESTIONS?

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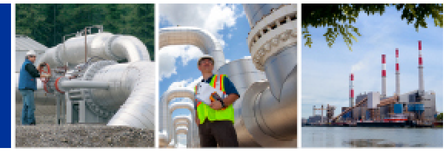
BACK UP

ASME B31.8s – Characteristics of Effective Risk Assessment



a) **Attributes/defined logic** – structured consistent framework

b) **Resources** – dedicated resources

c) **Operating Mitigation history** – used as input, for updating, and drive action

d) **Prediction capability** – predicts using all evidence data

e) **Risk confidence** – confidence factors use best evidence available

f) **Feedback** – annual structured feedback

g) **Documentation** – extensive annual documentation

h) **What if** - Recalculation of results based on actions taken

i) **Weighting factors** – calculated by using quantitative factors

j) **Structure** – structured, documented, and verified

k) **Segmentation** – dynamic segmentation

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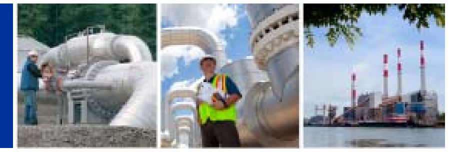
NPRM – characteristics of a mature risk program



(1) Identifying risk drivers;

(2) evaluating interactive threats;

(3) assuring the use of traceable and verifiable information and data;

(4) accounting for uncertainties in the risk model and the data used;

(5) incorporating a root cause analysis of past incidents;

(6) validating the risk model in light of incident, leak and failure history and other historical information;

(7) using the risk assessment to establish criteria for acceptable risk levels;

(8) determining what additional preventive and mitigative measures are needed to achieve risk reduction goals

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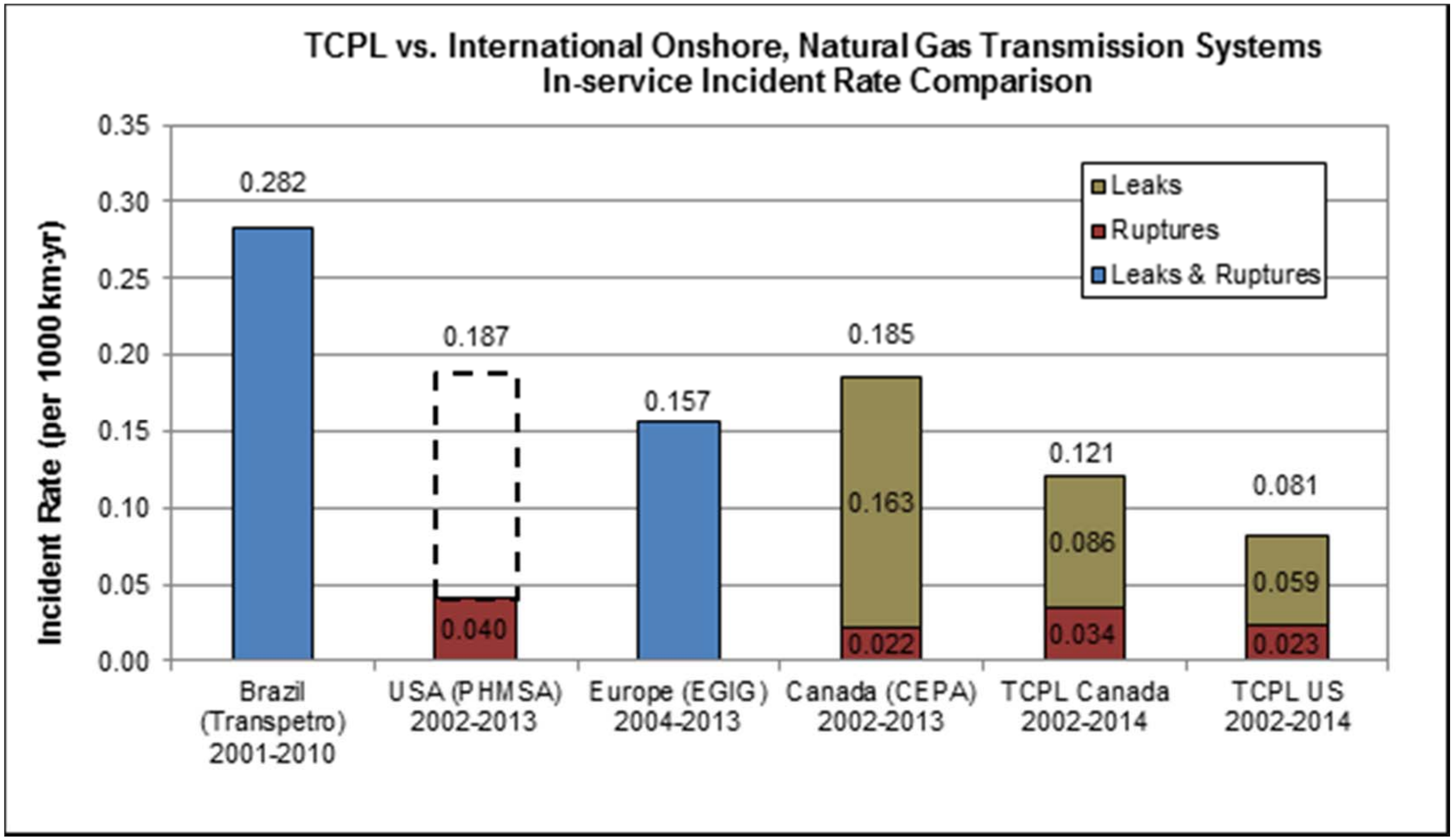
Performance



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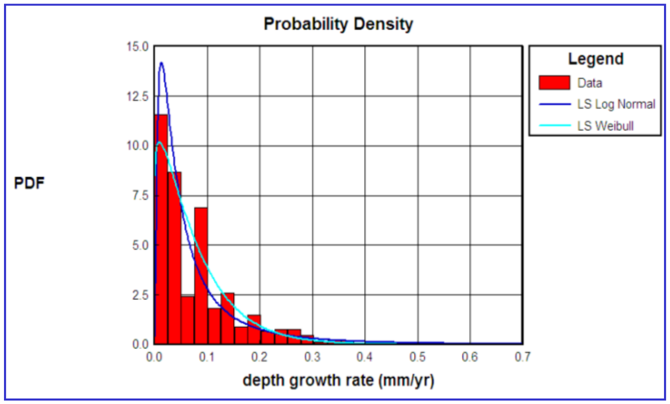
Acknowledge uncertainty - POF due to Uncertainty/errors

- **Uncertainty? Common attitude ->**
- Many types of uncertainty
  - Measurement, Material, Dimensional, growth, model
  - E.g., "Corrosion is not growing" – true for ~90% anomalies!! 10% do!! Similarly using extremes for growth is unrealistic as most do not



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