RISK ANALYSIS & RARE-EVENTS DATA

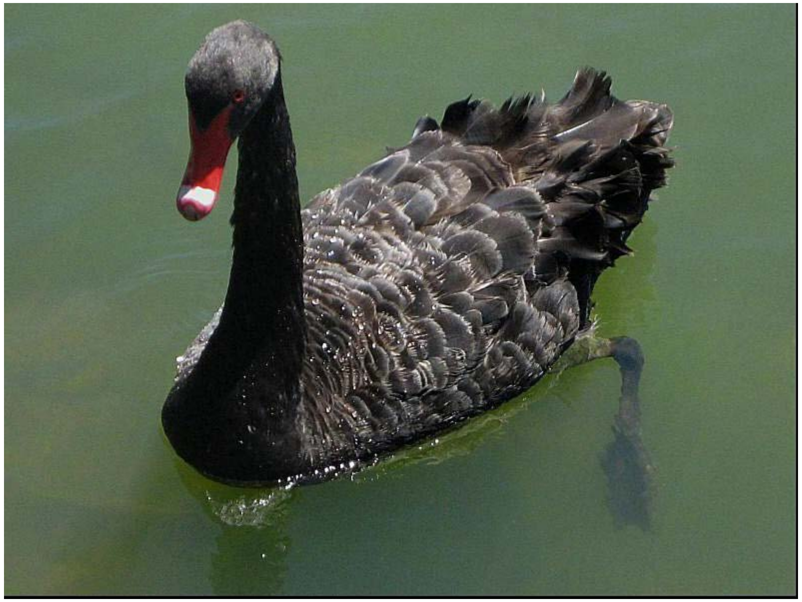
Andrew Kendrick
Kendrick Consulting LLC

Objective -

- To extend the dialogue regarding our current approaches to assessing pipeline risk.

Focus -

- Approaches to Risk
- Critical Pipeline Failures
- Rare-Events Data



Back in the Day -

PHMSA 49-CFR-195, Appendix C

Leak History	
High	>3 Spills in last 10 years
Low	<3 Spills in last 10 years
Line Size/Volume	
High	≥18″
Moderate	10”–16” nominal diameters
Low	≤8″ nominal diameter
Age of Pipeline	
High	>25 years
Low	<25 years
Product Transported	
High	HVLs, NGLs, Ammonia, Benzene, High H2S Crude
Medium	Gasoline, JP4, Low Flashpoint Crude Oils
Low	Diesel, Fuel Oil, Kerosene, JP5, Most Crude Oils

The Risk Matrix

5	Very High	Decreasing Likelihood	5	10	15	20	25
4	High		4	8	12	16	20
3	Medium		3	6	9	12	15
2	Low		2	4	6	8	10
1	Very Low		1	2	3	4	5
Consequence Indices			Decreasing Consequence				
			Very Low	Low	Medium	High	Very High
			1	2	3	4	5

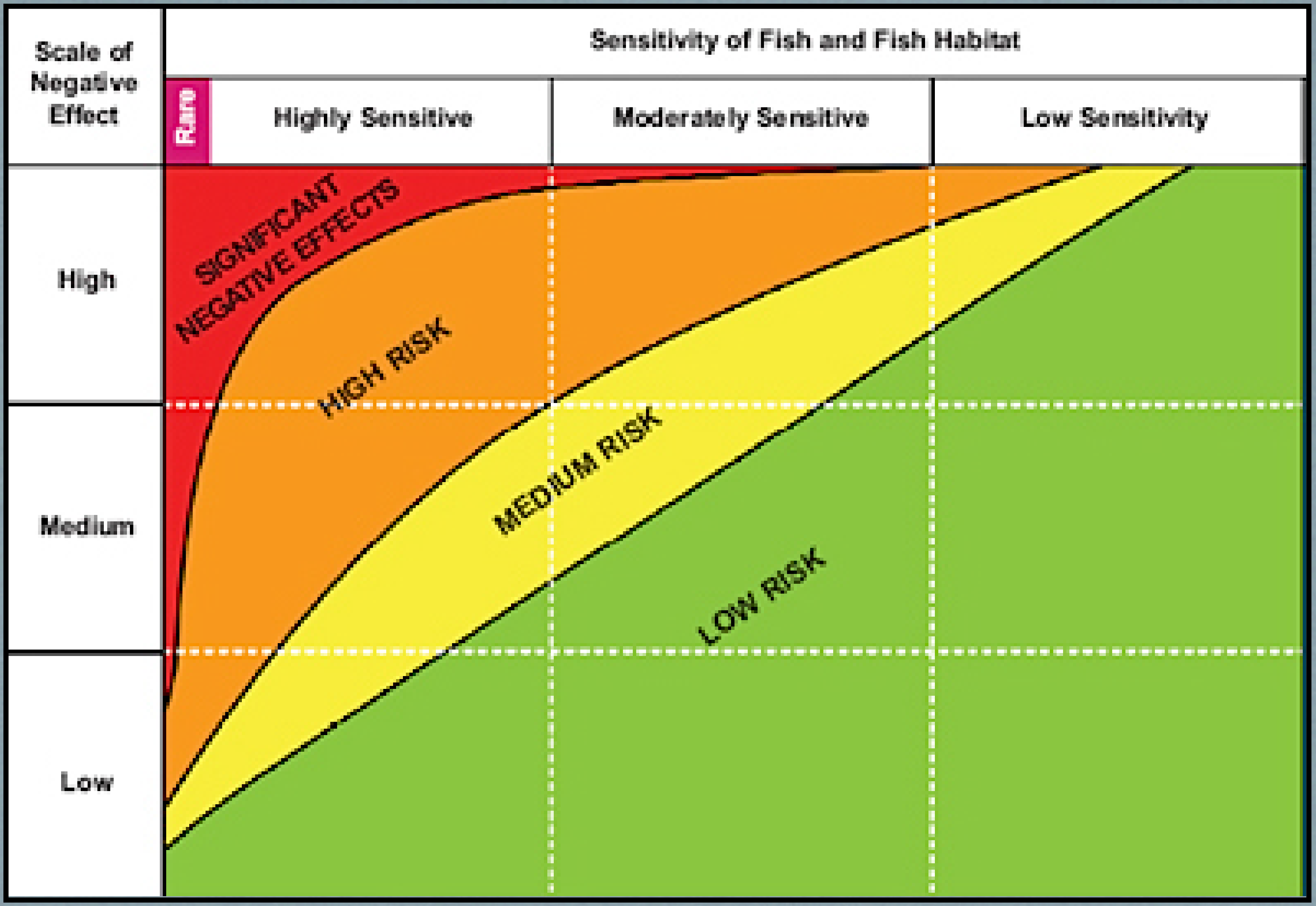
Army Risk Assessment Matrix

SEVERITY		PROBABILITY: Frequent (A)	Likely (B)	Occasional (C)	Seldom (D)	Unlikely (E)
Catastrophic	I	Extremely High	Extremely High	High	High	Moderate
Critical	II	Extremely High	High	High	Moderate	Low
Moderate	III	High	Moderate	Moderate	Low	Low
Negligible	IV	Moderate	Low	Low	Low	Low

Marine Corps Risk Assessment Matrix

			PROBABILITY			
			Likely	Probably	May	Unlikely
			A	B	C	D
Catastrophic	SEVERITY	I	1	1	2	3
Critical		II	1	2	3	4
Moderate		III	2	3	3	5
Negligible		IV	3	4	5	5

Fisheries and Oceans Canada



Index-Based Assessment

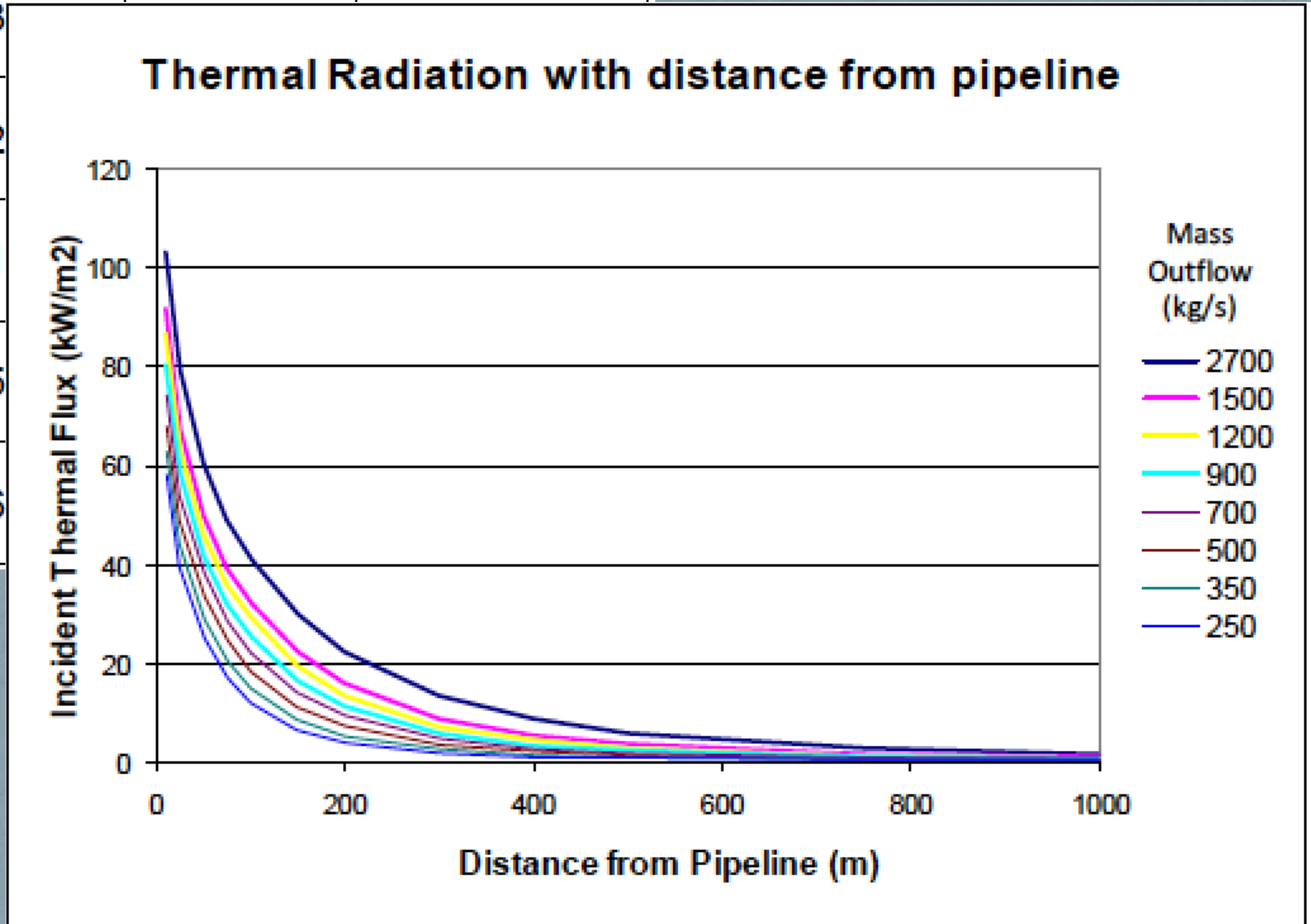
	Segment A	Segment B	Segment C
Overal Rank:	**#1**	**#2**	**#3**
Average Likelihood:	**3.3**	**4.6**	**5.7**
Consequence:	**4**	**4**	**5**
Total Risk	**13.1**	**18.3**	**28.6**
Ext. Corrosion	**3**	**3**	**5**
Coating Condition	Good (somastic)	Average (heat damage, brittle FBE at the beginning)	Good-Average (replacing coating and pipe, ongoing, reduced operating temperature)
CP Efectiveness	Average (low CP spot exists)	Average (low CP spot exists)	Good
Atmospheric coating	Excellent	Excellent	good
Severity of Amonalies	<50%	<50%	<50%
Int. Corrosion	**3**	**5**	**5**
Product	Jet-A	Refined (mogas, diesel)	LSFO
Corrosion Monitoring	Yes	Yes	No
Inhibitors/Process Measures	No	Yes	No
Severity of anomalies	<50%	none	<15%
TPD	**4**	**4**	**5**
Depth of Cover	Over 3 feet	Over 3 feet	Under concrete, near RR, all developed
Signage	Adequate, line of sight	Adequate, line of sight	Adequate, line of sight
Row/Land Use	Utility coridoor, residential	Utility coridoor, residential	Agriculture, resorts
One-calls	1/week	1/week	1/quarter
Dents >2%	No new dents	No new dents	1 dent in 2005
PA Program	Effective	Effective	Effective
Incidents (damage, no one-call)	No	No	No

Subject-Matter Expert (SME)

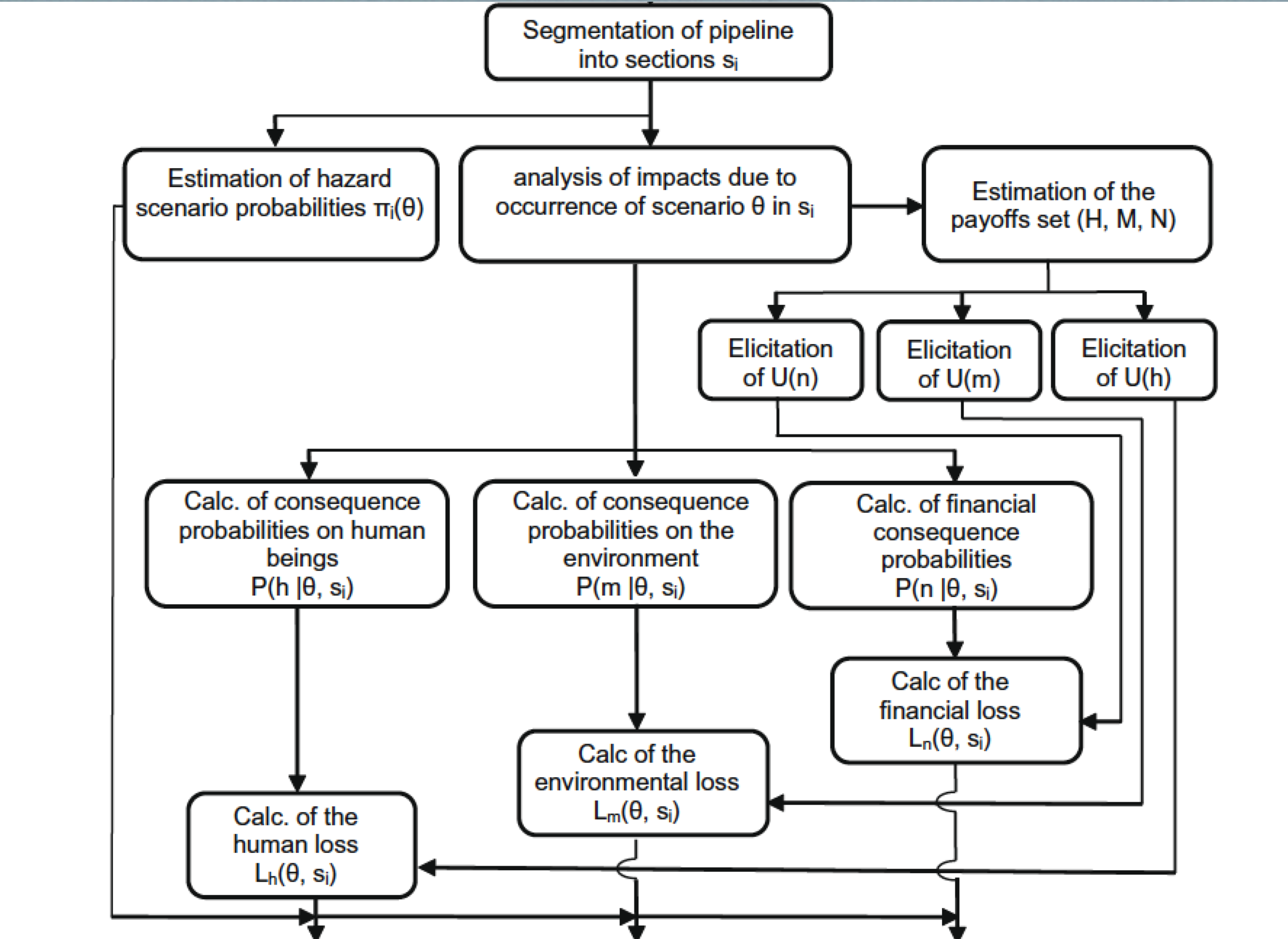
THIRD PARTY DAMAGE - Risk Factors				
Evaluation of risk factors (exposure and resistance)	**Is there a potential risk increase or exposure due to this factor?**			
	Yes	**No**	**N/A**	**Comments**
Excavation activity level	☐	☒	☐	Low excavation activity. Static over past 5 years. No change in number of one-calls or locate frequency.
Damaging farming activities in the area	☐	☐	☒	No farming or tiling activities along pipeline. Pasture land only. No plowing. Only surface cutting.
Depth of cover (DOC)	☒	☐	☐	Approx. 5 ft. along entire system. One area east of Houser Rd. in road ditch is 2.5 ft.
Spans or above-ground pipe	☐	☒	☐	Only above ground pipe; located in the pump station and at the intermediate block valve (MP-22).
Above ground valves or other components	☐	☒	☐	One at MP-22. Manual block valve located 2 miles west of I-35 along Rte. 432.
Traffic damage potential (vehicle, rail, marine) or vandalism	☒	☐	☐	MP-22 has chain link fence and barbed wire. Approximately 15 ft. from Rte. 432. No bollards or pipe-rail fence. Snow could cause a car/truck accident.
Diameter/Wall thickness	☐	☒	☐	0.322" (8.625" Grade B = 52% SMYS) 8.625"/ 0.322" Ratio = 26.8
Operating stress	☐	☒	☐	Max NOP = 200 psig (avg. 120 psig) with MOP = 1350 psig NOP/MOP = 15% (8.625" Grade B = 52% SMYS)
Other (describe)	☒	☐	☐	Proposed extension of bike path south of Clifford.

Statistics & Numerical Models

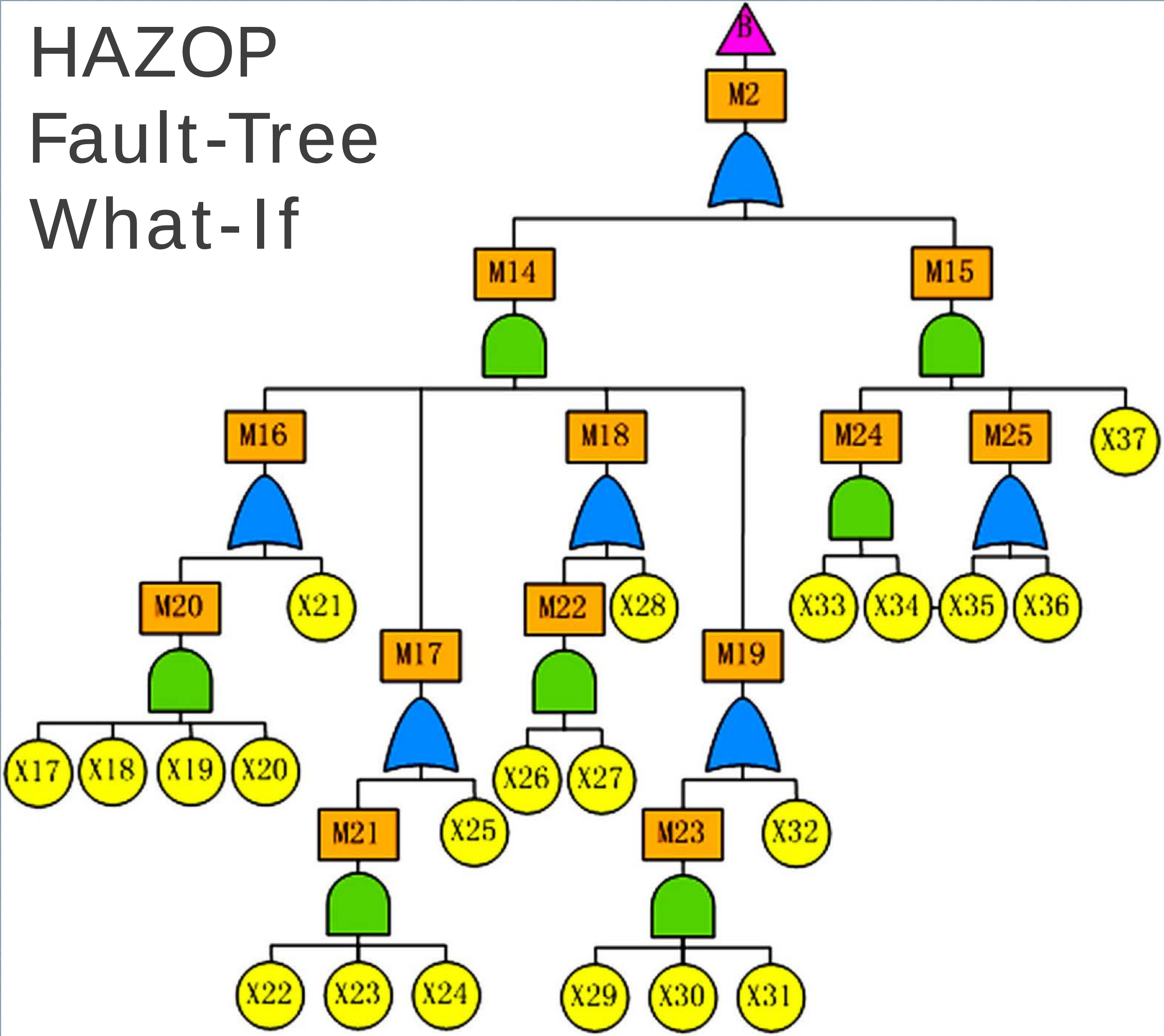
Source	Period	Exposure (10^6 kmyr)	No. of Incidents	Frequency (x 10^{-3} kmyr)
PHMSA	1992 - 2010	9.01	1383	0.153
	2006 - 2010	2.3		
NEB	2000 - 2009	0.2		
	2005 - 2009	0.1		
EGIG	1970 - 2010	3.5		
	2006 - 2010	0.6		



Bayesian Inference



HAZOP
Fault-Tree
What-If



So what's the Best Approach?

- Risk Matrix?
- Index-Based?
- Fault-Tree?
- Subject-Matter Expert?
- Classical Statistics and Models?
- Bayesian/Monte Carlo Simulation?

So what's the Best Approach?

- ✓ Risk Matrix
- ✓ Index-Based
- ✓ Fault-Tree
- ✓ Subject-Matter Expert
- ✓ Classical Statistics and Models
- ✓ Bayesian/Monte Carlo Simulation

There is no single correct way

- Depends entirely upon what you're trying to accomplish.
- The source data type, population, uncertainty, etc. should drive the approach.
- The method needs to be valid in its application and execution.

Risk Matrix

- Very rapid analysis
- Easily understood
- Comparing simple relationships
- Visualize and communicate results
- Very subjective and high-level

5	10	15	20	25
4	8	12	16	20
3	6	9	12	15
2	4	6	8	10
1	2	3	4	5

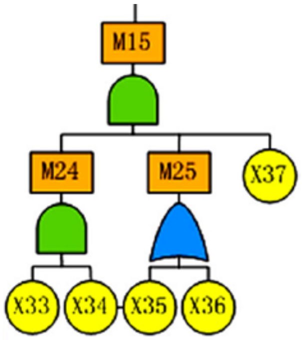
Index Model

- Can aggregate large amounts of data
- Subjective factors applied to threats
- Rapid means of aggregating data
- Very subjective
- No interactive threats

	Segment A	Segment B	Segment C
Overal Rank:	#1	#2	#3
Average Likelihood:	3.3	4.6	5.7
Consequence:	4	4	5
Total Risk	13.1	18.3	28.6
Ext. Corrosion	3	3	5
Coating Condition	Good (somastic)	Average (heat damage, brittle FBE at the beginning)	Good-Average (replacing coating and pipe, ongoing, reduced operating temperature)
CP Efectiveness	Average (low CP spot exists)	Average (low CP spot exists)	Good
Atmospheric coating	Excellent	Excellent	good
Severity of Amonalies	<50%	<50%	<50%
Int. Corrosion	3	5	5
Product	Jet-A	Refined (mogas, diesel)	LSFO
Corrosion Monitoring	Yes	Yes	No
Inhibitors/Process Measures	No	Yes	No
Severity of anomalies	<50%	none	<15%
TPD	4	4	5
Depth of Cover	Over 3 feet	Over 3 feet	Under concrete, near RR, all developed
Signage	Adequate, line of sight	Adequate, line of sight	Adequate, line of sight
Row/Land Use	Utility coridoor, residential	Utility coridoor, residential	Agriculture, resorts
One-calls	1/week	1/week	1/quarter
Dents >2%	No new dents	No new dents	1 dent in 2005
PA Program	Effective	Effective	Effective
Incidents (damage, no one-call)	No	No	No

Fault Tree / HAZOP

- Very widely used in PSM world
- Good for identifying complex interactions
- Leverages human experience & intuition
- Crosses-disciplines and experience levels
- Can involve modeled parameters
- Limited to small domains
- Very time consuming



Subject Matter Expert (SME)

- Similar strengths to PSM approaches
- Less time consuming but with similar upside
- Good for evaluating complex interactions
- Capitalize on ancestral knowledge
- Focuses on prevention and mitigation
- Time-consuming and subjective
- SME's tend to underestimate risk
- Limited repeatability

Statistics and Models

- Capitalizes on historical failure rates
- Good for high frequency data sets
- Adds rigor and accuracy to data analysis
- Critical to engineering/impact analysis
- Significantly more objective
- Not applicable for rare-event data
- Poor at interactive threats
- Not applicable for complex systems

Bayesian Modeling

- Failure analysis and hypothesis testing
- Probability estimates include uncertainty
- Good for estimating what's difficult to test
- Good when data is scarce
- Improves as more data is made available
- Subjective prior development
- Somewhat limited real-world applicability
- Need skill to defend and react

Integrated-Approach

- Statistics to understand past failures
- Models to predict impact thresholds
- Indexes to bracket low quality data
- What-if to evaluate worst case scenarios
- Complex models to test assumptions
- GIS to visualize the spatial component
- SMEs for final integration and evaluation
- SMEs to develop preventive measures

What about the Black Swan?

LP-HC Pipeline Failures

- 1999 Bellingham, WA
- 2000 Carlsbad, NM
- 2010 San Bruno, CA
- 2015 Santa Barbara, CA

Example LPHC Failure

1. Contractor didn’t notify operator of excavation,
2. Operator did not review drawing changes,
3. Contractor severely damage the pipeline,
4. Contractor backfilled without notifying the operator,
5. ILI analyst ran invalid dent calculations,
6. Operator reviewing the data had minimal training,
7. Operator incorrectly aligned separate ILI reports,
8. Scheduled repairs never executed due to weather,
9. Proposed repairs were forgotten,

Example LPHC Failure

10. Relief valves didn’t meet system pressure rating.
11. Improper testing resulting in defeated actuators.
12. Control Room training inadequate.
13. Development work being performed on live SCADA.
14. Development errors resulted in SCADA errors.
15. SCADA errors resulted in loss of view/overpressure.
16. Controller restarted pumps twice after rupture.
17. Pressure-recording chart paper had run out.
18. Pressure control SCADA screens not yet developed.

Example LPHC Failure

- Human Error
- Procedure Error
- Training Error
- Third Party Damage
- Common Mode Failures
- Bad Luck

So what's the <u>Best</u> Approach?

- Risk Matrix?
- Index-Based?
- Fault-Tree?
- Subject-Matter Expert?
- Classical Statistics and Models?
- Bayesian/Monte Carlo Simulation?

Risk of Probabilistic Risk

Fukushima Japan - Nuclear Safety Commission

- Daiichi Nuclear Power Plant
- Detailed Probabilistic Risk Assessment (PRA)
- Melt-down scenarios per year = 1×10^{-6}
- The meltdown occurred 40 years later
- They were off by 10^{-5} (999,960 years)

Probabilistic Models

Probabilistic models significantly underestimate the likelihood of catastrophic failure, if not deliberately exclude it.

Items of Concern

1. Naive optimism (“it’ll be fine”)
2. Bell-curve data (the average, the predictable)
3. Past performance (“it never happened in the past”)
4. Over reliance on math (1×10^{-6})
5. Bad data (garbage in = garbage out)
6. Data vs. Knowledge
7. Compounding Error (if’s and assumptions)
8. Assessment (vs. prevention and mitigation)
9. After the fact confidence (only hind sight is 20/20)

Items for Consideration

1. Determine up front what questions you want answered.
2. Establish your approach(s) with top-down support.
3. Don’t model in a box. Involve SMEs. Own the model.
4. Evaluate critical data and collect what’s missing.
5. Understand your data and model uncertainty.
6. Evaluate interactive and common mode threats
7. Require “actionable” outputs to your assessment.
8. Drive toward location/attribute-specific outputs
9. Calibrate your SMEs

Items for Consideration

10. Keep your eye on the ball (... risk management).
11. Focus on prevention and mitigation (resilience).
12. Plan – Do – Check – Adjust
13. Process, Process, Process.
14. Management of Change (MOC).
15. Robust incident investigation/RCA process.
16. Knowledge management and knowledge transfer
17. Real training and real qualification (human factors).
18. Measure model performance moving forward.

Items for Consideration

- “A weak risk management approach is effectively the biggest risk in the organization”

–Douglas Hubbard

Andrew Kendrick

Kendrick Consulting LLC *KendrickLLC.com*