Observations and Suggestions on Alternative Risk Informed Decision Making Frameworks

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Risk-based / risk-informed decision frameworks

- Risk-informed decision-making (RIDM) involves analyzing potential outcomes, benefits, and risks associated with various options, then deciding which choice is most prudent.
- As commonly understood, risk associated with a situation, event, or choice is defined based on two essential components:
  - {Undesirability and Uncertainty }
  - Or, more specifically { Level of Adverse Consequence, and Likelihood of the Consequence }
- The description of the event can be considered a third element. The resulting three-part description is known as "risk triplet."
- Various metrics have been defined and used to measure and communicate risk, including qualitative and quantitative scales for likelihood and consequences.
- There are also alternative ways of risk representation, for example:

$$R = P*C \quad \text{vs} \quad R=\{P, C\}$$

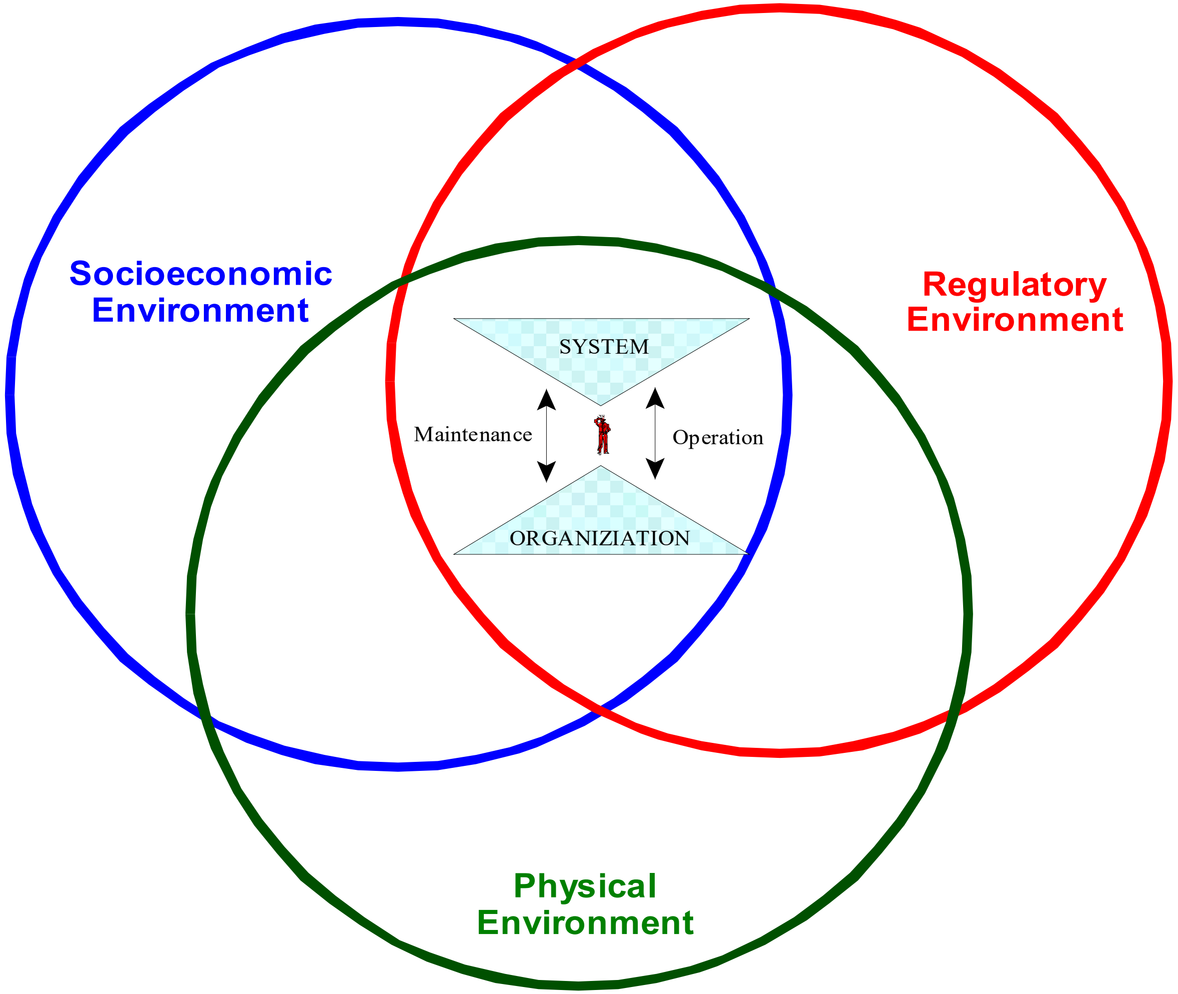
Risk-based / risk-informed decision frameworks

- Essentially, in decision-making under uncertainty there are two main questions that need to be addressed:
  1) what are the future consequences and associated uncertainties of an action (mainly epistemic, or questions of knowledge)
  2) what is a prudent (or right) decision or action (often directly tied to ethical questions, i.e., questions of moral and norms).
- Different risk management approaches have been discussed from the ethical perspective to establish good decisions, using different ethical theories as a basis.
- The corresponding risk management approaches include cost–benefit analysis (CBA), minimum safety criterion (MSC), the ALARP principle, and the precautionary principle.

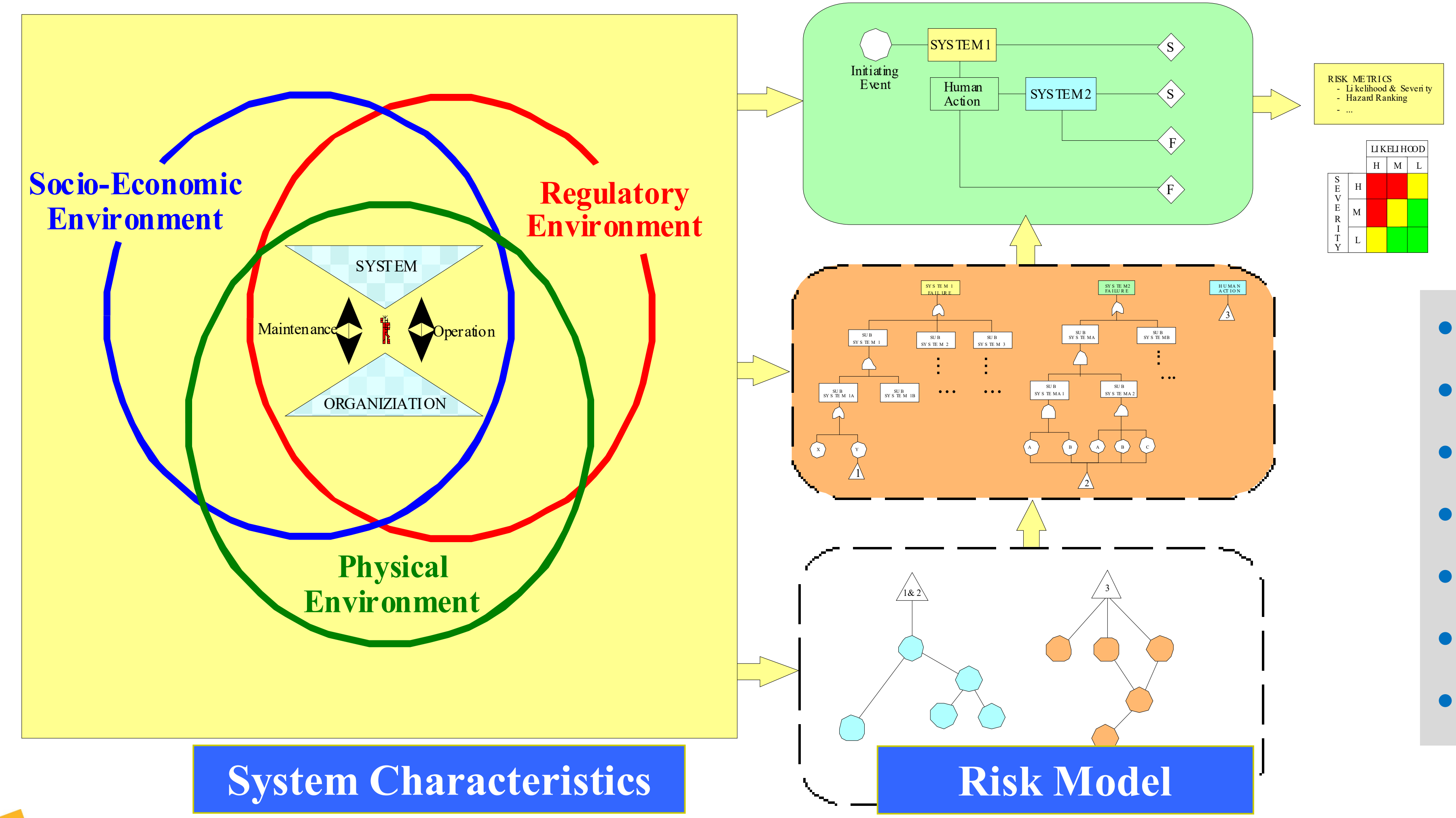
Steps and Objectives of Risk Analysis

- Determine potential ***undesirable consequences*** associated with natural events or use of systems and processes
- Identify ***scenarios*** by which such consequences could materialize
- Estimate the ***likelihood*** (e.g., probability) of such events
- Provide ***input to decision-****makers* on optimal strategies to reduce levels of risk

Typical Context and Scope of RIDM



Model-Based Risk Analysis



- NRC
- FAA
- FERC
- NASA
- BSEE
- EPA
- Chemical Process

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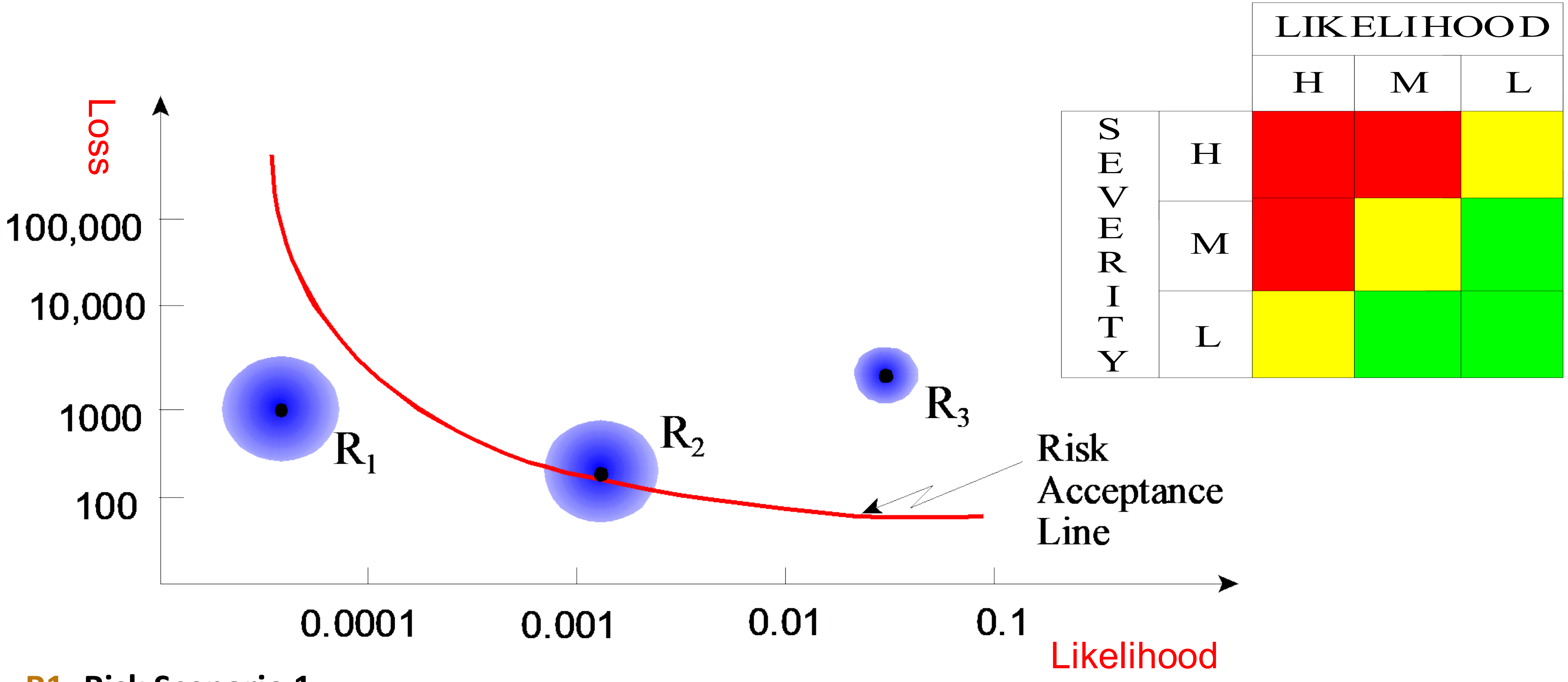
Input to Decision-Making



R1: **Risk Scenario 1**
R2: **Risk Scenario 2**
R3: **Risk Scenario 3**

Key challenges

- Making risk management decisions with muti-dimensional risk consequences
- Defining acceptable levels of risk (risk tolerance) considering technical feasibility and a rational balance between cost and benefits
- Assessment of risk of rare events, mainly low probability / high consequence cases

  -- including risk quantification with little or no data

Perspective on MAVF and CBF Alternatives

- MAVF is primarily an attempt to address the first challenge
- Strengths and shortcomings have been discussed, and also experienced in practice
  - A main criticism has to do with inevitable value judgement as part of risk calculation: attribute ranges and weights
  - Another set of issues relate to quality and rigor of implementation
    - Likelihood and consequence assessment
    - Choice of reference points
    - Level and/or sequence of risk aggregation
    - Accounting for effectiveness of risk mitigations
    - Treatment of dependencies
    - Uncertainly characterization and quantification
- Also, MAVF is mainly a method for “packaging” the results of risk assessment; it does not prescribe how the assessment is done
- As a result, the possibility exists that contributing risk drivers are calculated with inconsistent or incompatible methods
- The MAVF framework does not explicitly address the second and third challenges

Perspective on MAVF and CBF Alternatives

- CBF is also primarily an attempt to address the first challenge
- Conceptual strengths and shortcomings have also been discussed
  - Straightforward interpretation, procedural simplicity compared with MAVF
  - Requires difficult social and ethical value judgments (essentially not very different than the case of MAVF)

- May face some of the the same implementation quality and rigor issues listed for MAVF
  - Likelihood and consequence assessment
  - Level and/or sequence of risk aggregation
  - Accounting for effectiveness of risk mitigations
  - Treatment of dependencies
  - Uncertainly characterization and quantification

- CBF is mainly a method for "packaging" the results of risk assessment, it does not prescribe how the assessment is done, and consequently the possibility exists that contributing risk drivers are calculated with inconsistent or incompatible methods
- Also, the CBF framework does not explicitly address the second and third challenges

Possible Enhancements and other Alternatives

- Both frameworks need improvements to address all three challenges

- Moving from MAVF to CBF trades inherently difficult issues without fully addressing them; as both rely on some form of value judgement
    - Monetized Value of Life vs Normalized Utility (attribute weights and ranges)

- Experience in other industries offer pathways to enhancements and alternatives

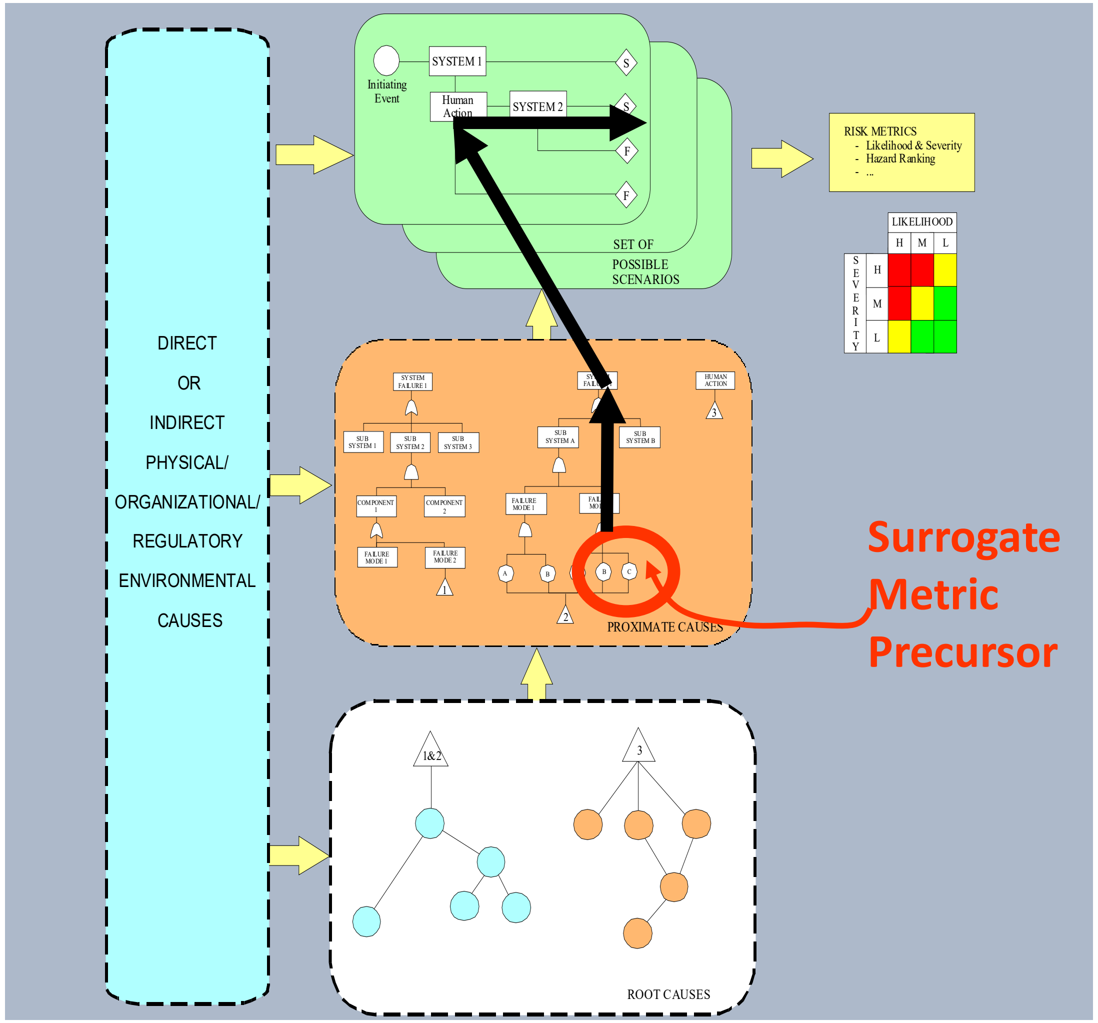
Possible Enhancements and Alternatives

- Several industries rely heavily on subsidiary (surrogate) metrics of risk in their respective regulatory and oversight functions.
- Examples include:
  - Core Damage Frequency (Nuclear Regulatory Commission);
  - Dam Failure Probability (Federal Energy Regulatory Commission); and
  - Critical System Failure Probability (Federal Aviation Administration).
- The idea is to measure controllable outcomes (*e.g.*, ignitions for wildfire or wire-downs rather than injuries/fatalities).

- In these and a few other domains, subsidiary measures are:
  - Defined in a way that does not require difficult value judgments (e.g., value of life);
  - Linked to ultimate risk metric of interest (e.g., number of injuries/death) through risk models; and
  - Often based on "precursors" to actual "risk events."

- Some sectors use "near-miss databases" and/or model-based "precursor studies" to track risk as well as risk mitigation effectiveness. These include NRC, NASA, FAA, and BESSE.

Surrogate Risk Metrics



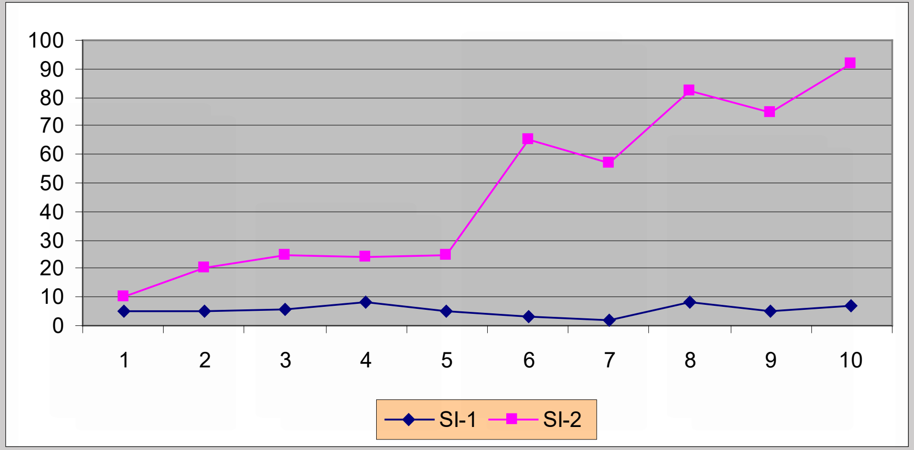
- The risk level is calculated as

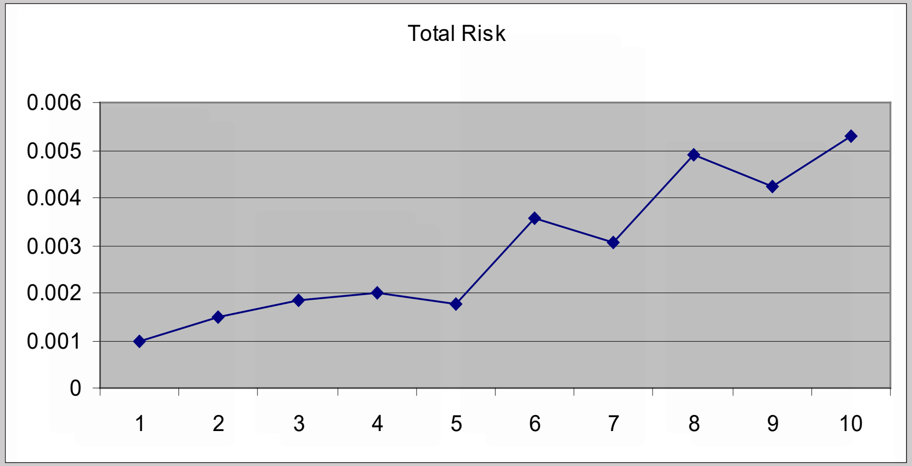
$$R = \Phi * P\,(Accident \mid Precursor\,)$$

- Φ is the frequency of the precursor event of a certain type
- If there are other precursors, the total risk is calculated by summing over individual precursor risks

Risk Monitoring with Surrogate Measures (Civil Aviation)

	Indicator	Frequency	"Risk Weight"
1	Engine Failure	3	0.02
2	Hydraulic System Failure	0.1	0.70
3	Missed Approach	1	0.01
4	…..	0	0.5
	…..		
	…..		
N	SI-N	φ_N	P_N





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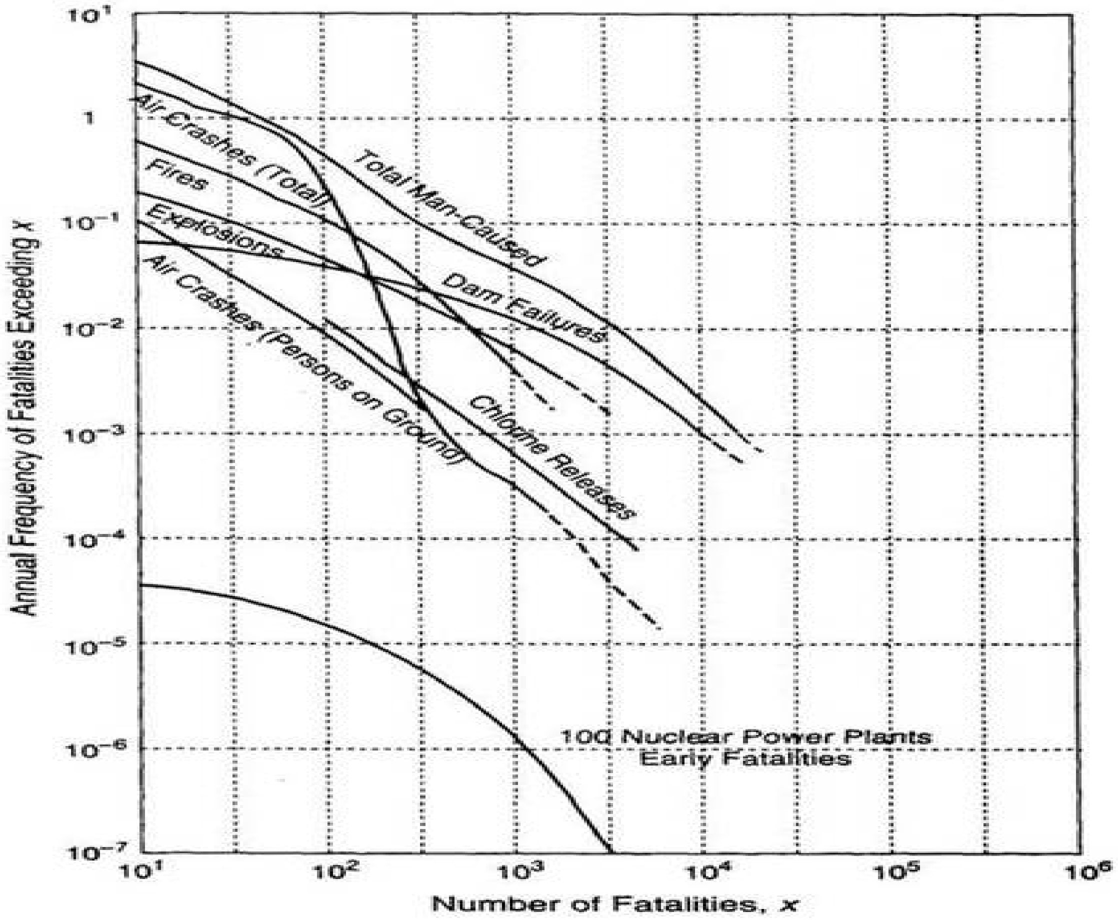
Risk Curve Representation

R= [Probability , Magnitude of Consequences]
AKA
- **Farmers Curve**
- **FN Curve**

Preserves critical distinction between LP/HC and HP/LC risk



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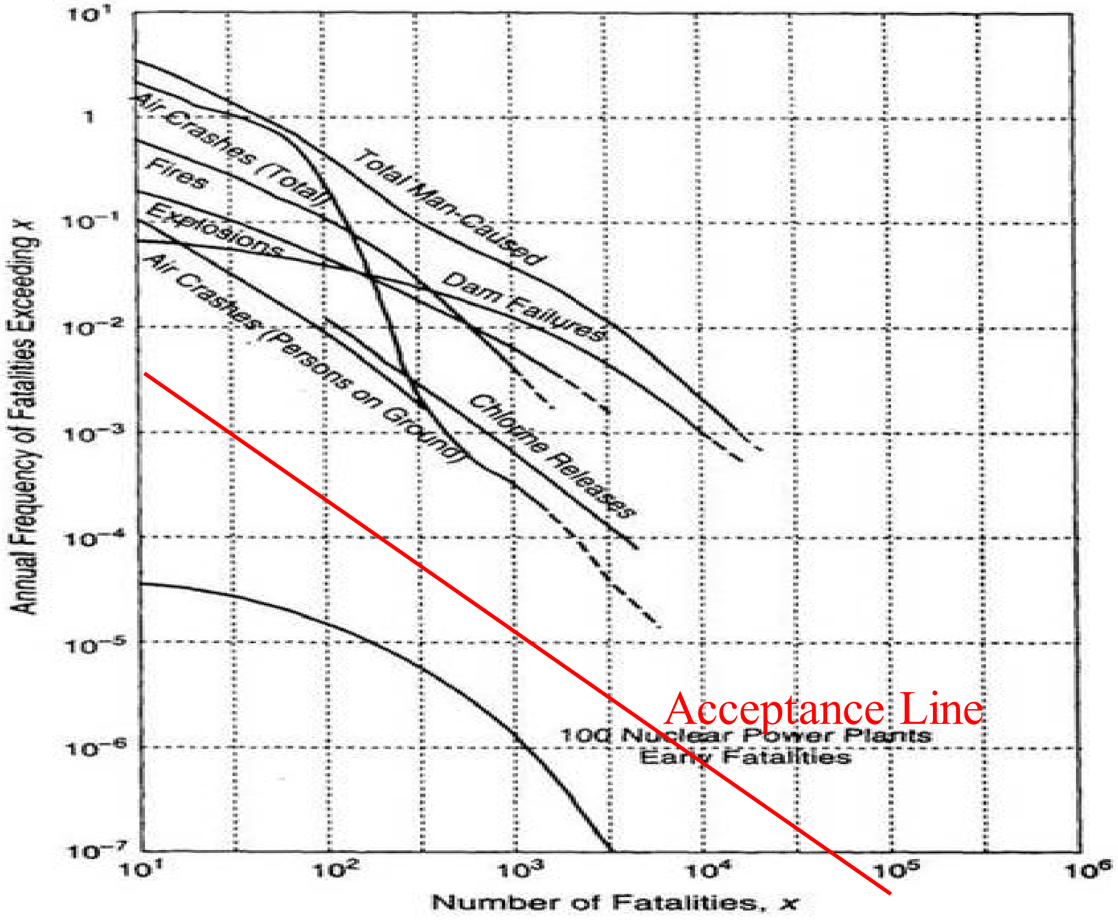
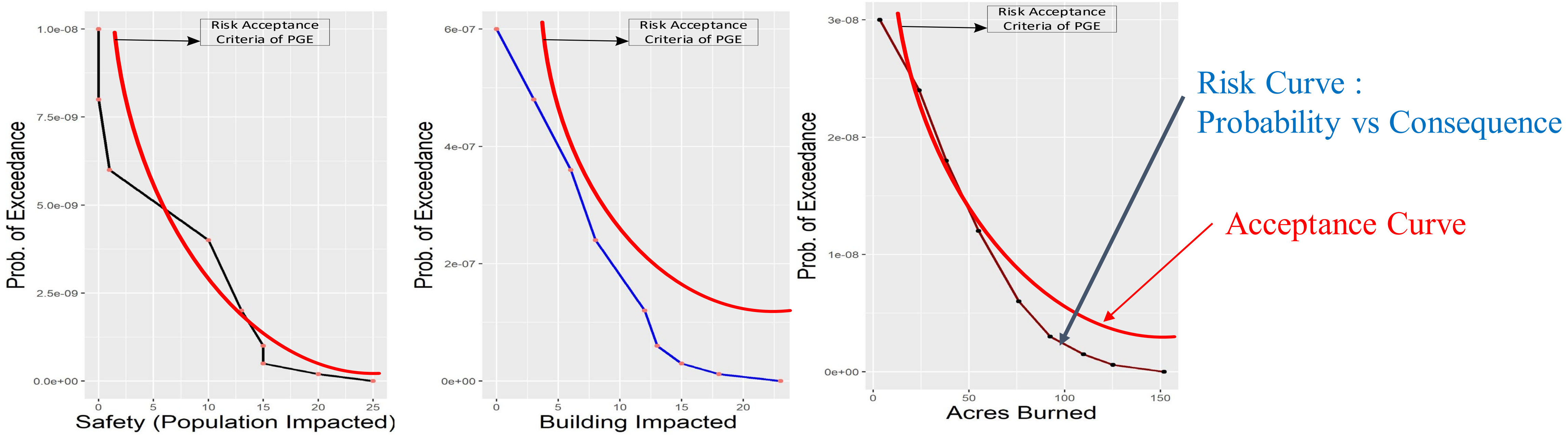
Risk Tolerance Line



Multi-Attribute Risk Curve Formulation



Expected Risk Score
Probability times Consequence

$$R_S = \Phi \sum_{i=1}^{N} P_{Si} S_i \qquad R_R = \Phi \sum_{i=1}^{N} P_{Ri} R_i$$

$$R_F = \Phi \sum_{i=1}^{N} P_{Fi} F_i \qquad R_E = \Phi \sum_{i=1}^{N} P_{Ei} E_i$$

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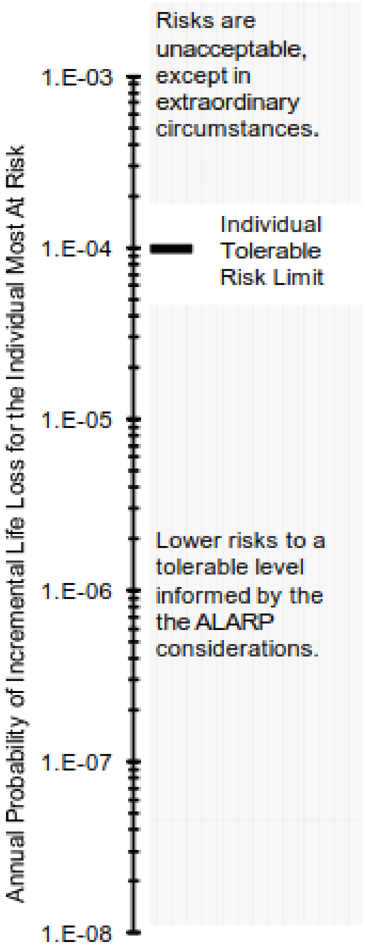
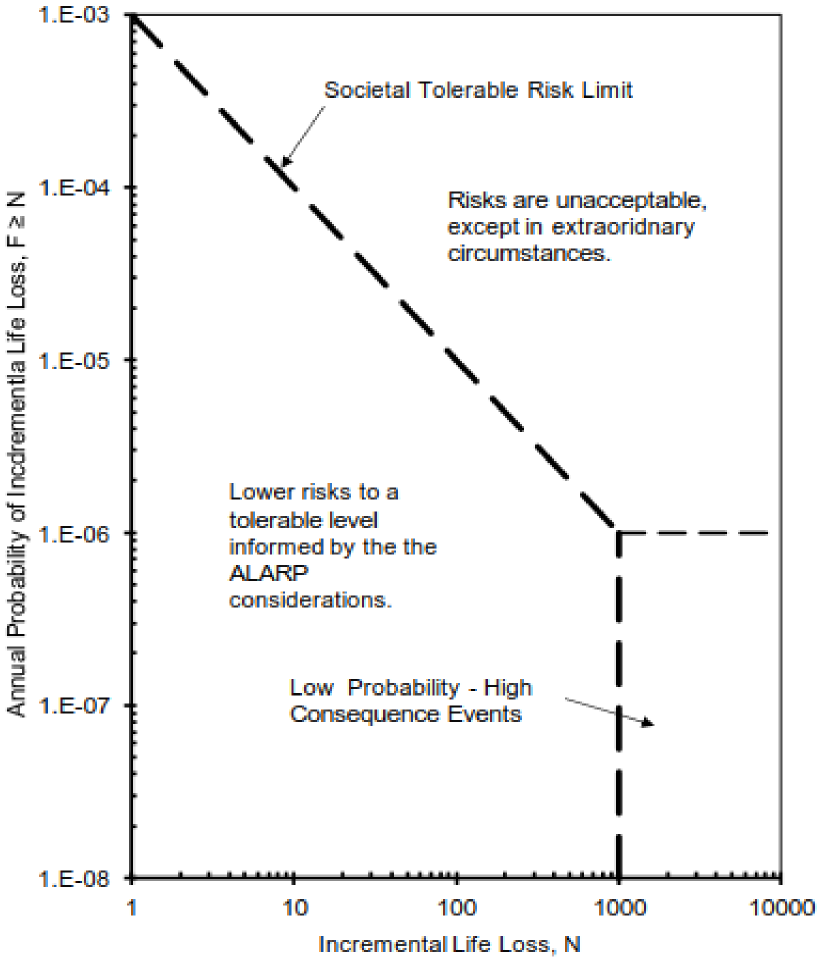
Example Application of Risk Curve and Tolerable Risk Concepts (USACE 2014 Guideline)



(a)



(b)

Treatment of Uncertainty

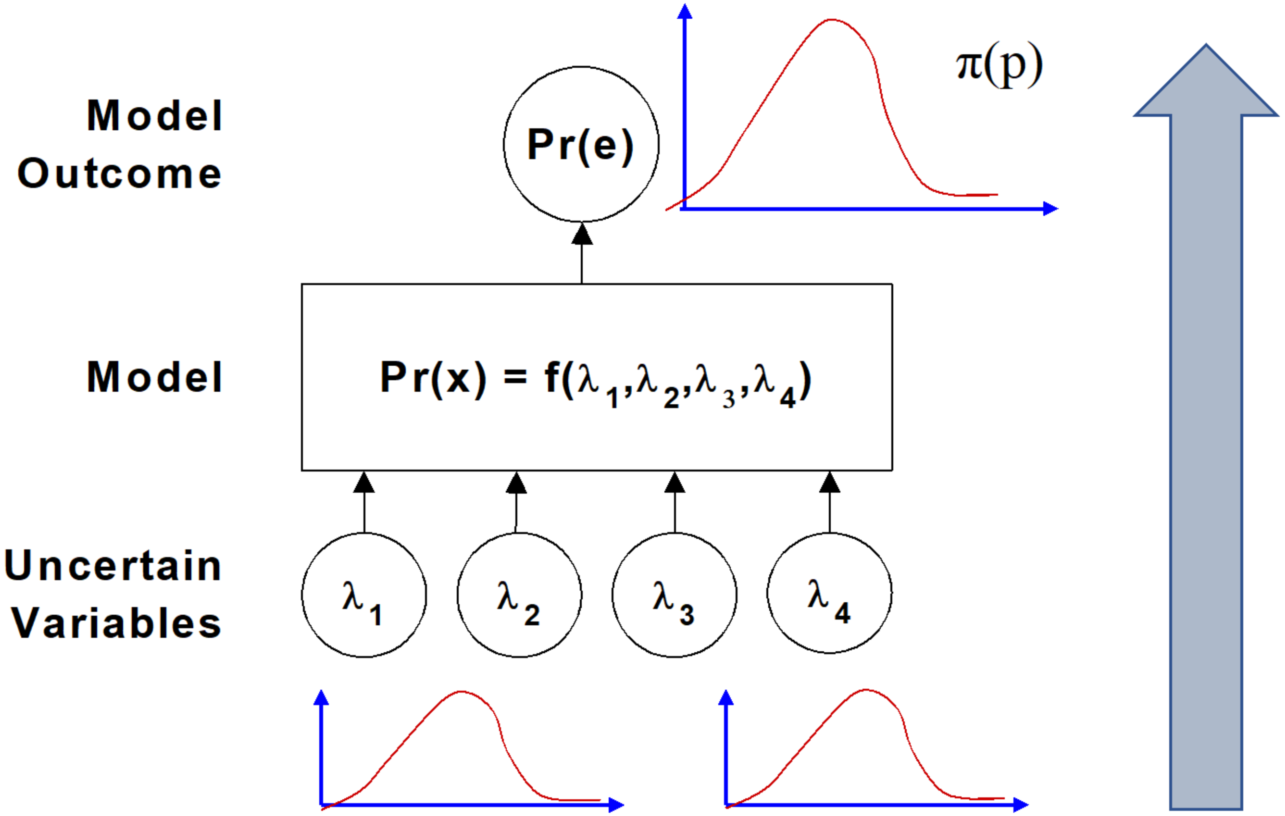
<u>Types of Uncertainty</u>

1. Parametric Unc.
- Epistemic
- Aleatory

2. Modeling Unc.

<u>Types of Analysis</u>

- Unc. Assessment
- Unc. Propagation



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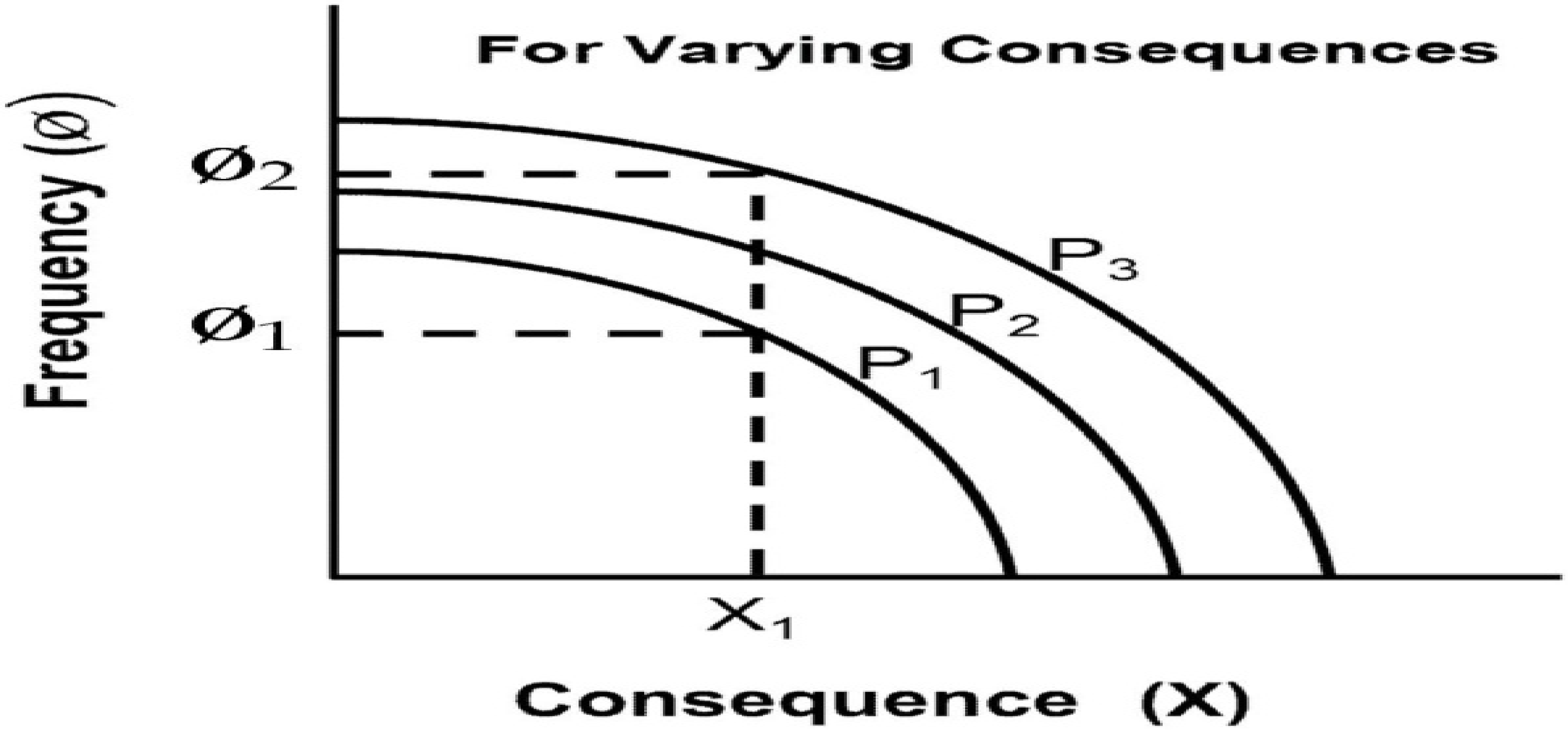
Accounting for Uncertainties

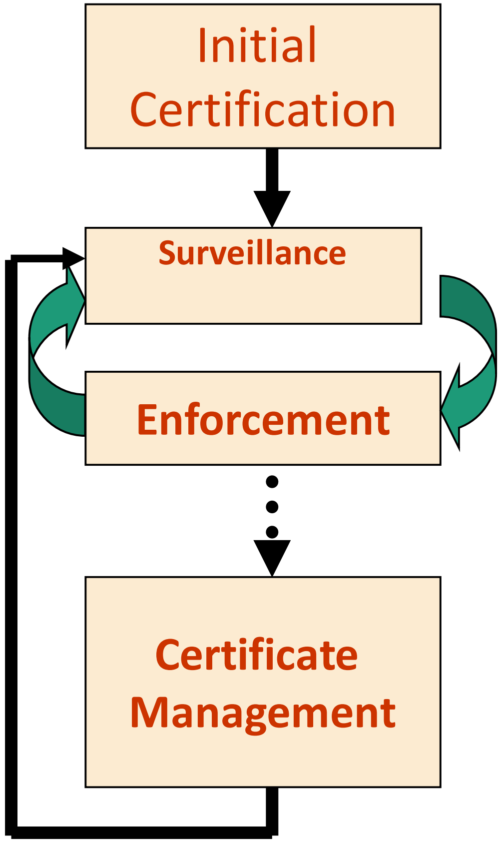


Additional Considerations

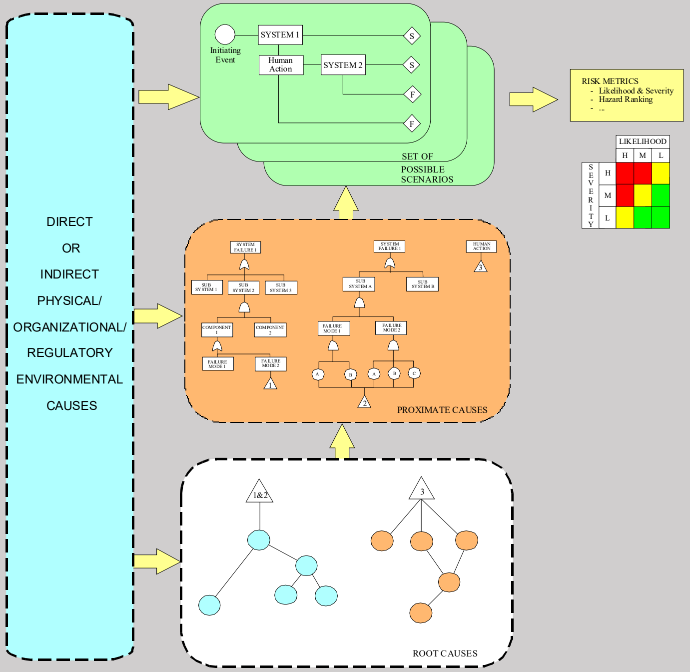
- Compatibility of risk metrics used for regulatory and oversight functions with the risk modeling and assessment methods is essential for:
  - reducing “translation error” and additional subjectivity;
  - improving traceability of risk drivers;
  - improving transparency and efficiency of communication between the regulatory body and industry; and
  - improving the impact of risk-informed regulatory objectives and requirements on operational and investment decisions by the industry.

Reference Model for FAA-Air Carriers Communication on Safety Matters

FAA Oversight Functions

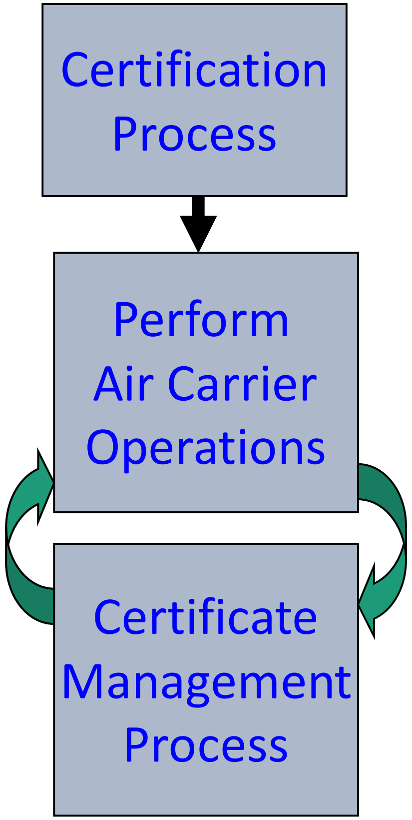


Integrated Risk/Safety Model



Air Carriers Functions

Safety Quality Management System



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Additional Considerations

- Harmonization of methods and tools used by all stakeholder is very important, if not essential, for robust and consistent risk-informed regulatory and operational decision making.
- A first step is to agree on the basic principles, core formwork, and minimum requirements for a credible risk assessment/ management. This has been discussed in recent TWG meetings.
- This should be accompanied by development of
  - Guidelines /Good Practices for conducting risk assessment (NRC, NASA, FAA, FERC, etc.)
  - Possible standardization (similar to ASME/ANS PRA Standards for nuclear industry)
  - Peer review (process and guidelines)

In summary …

- Both MAVF and CBE frameworks need improvements to be responsive to key challenges in RIDM

- Moving from MAVF to CBF trades inherently difficult issues without fully addressing them; as both rely on some form of value judgement

- Vast body of knowledge and experience in other sectors offers pathways to enhancements and alternatives for defining risk metrics, establishing risk tolerance, and applying compatible risk assessment methods