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Managing Plant Operations: From Data to Decisions

(Data Analytics + Smart Models = Robust Decisions)

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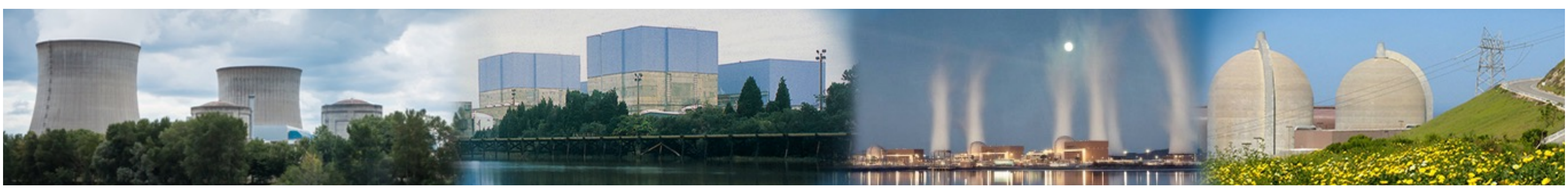
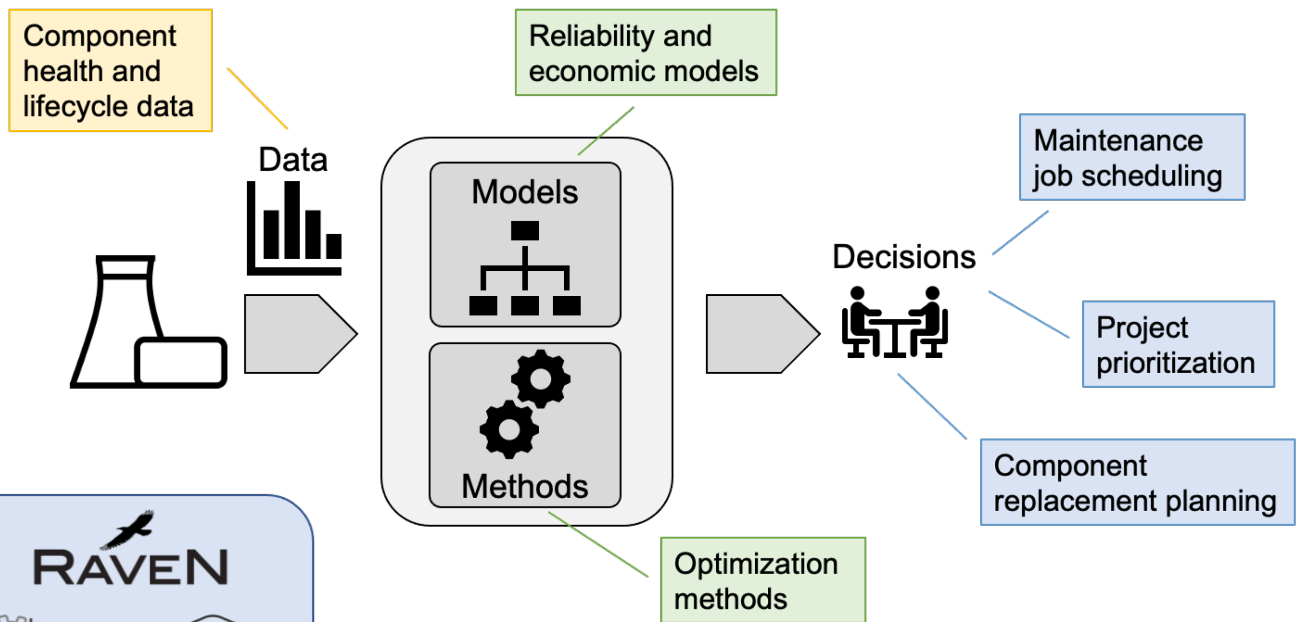


Risk Informed Asset Management Project

- **Context:** Industry Equipment Reliability (ER) and Asset Management programs can be labor intensive and expensive
- **Vision:** Advanced modeling and monitoring technologies have the potential to reduce operating and maintenance (O&M) costs
- **Our Work:** Risk analytics platform
  - Data analytics tools coupled with risk-informed methods to manage plant assets
  - Leverage INL-developed tools and open-source libraries



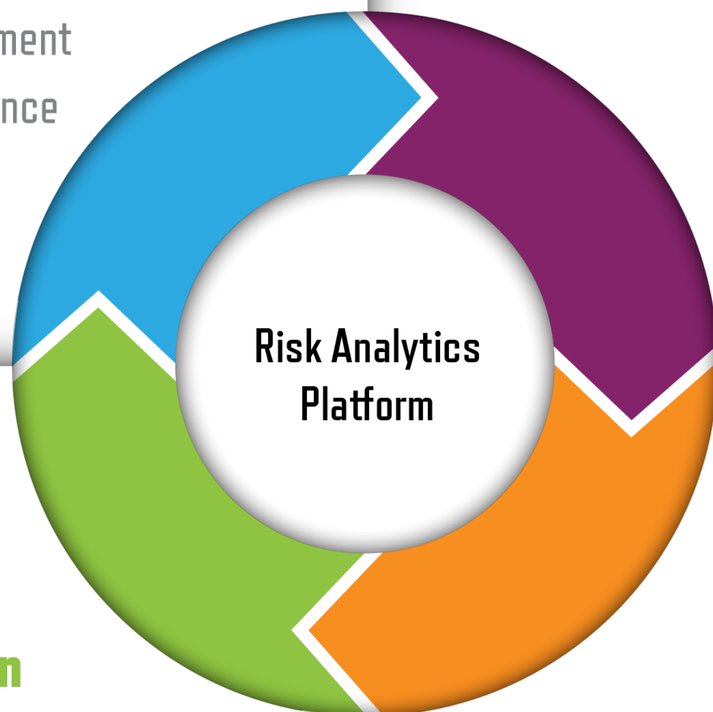
Outline

Goals: O&M reduction costs

- Reliability/ageing management
- Enhance system performance
- Optimize plant resources

ER Data Analytics

- Anomaly detection
- Diagnostics
- Prognostics



Resource Optimization

- Project prioritization
- Project actuation planning
- Job scheduling

Digital Modeling

- Integration of reliability and economic models
- Margin reliability solver

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ER Data Analytics

"Machine learning bounded solely by data is doomed to fail"

- **State of practice:** Focusing on finding patterns from data
  - Data can be misleading!

- **Data elements:** Heterogenous plant ER data format
  - Text (events, logs): Defined over time point or time interval
  - Numeric (e.g., pump oil temperature)

Are both these elements adequately analyzed simultaneously?

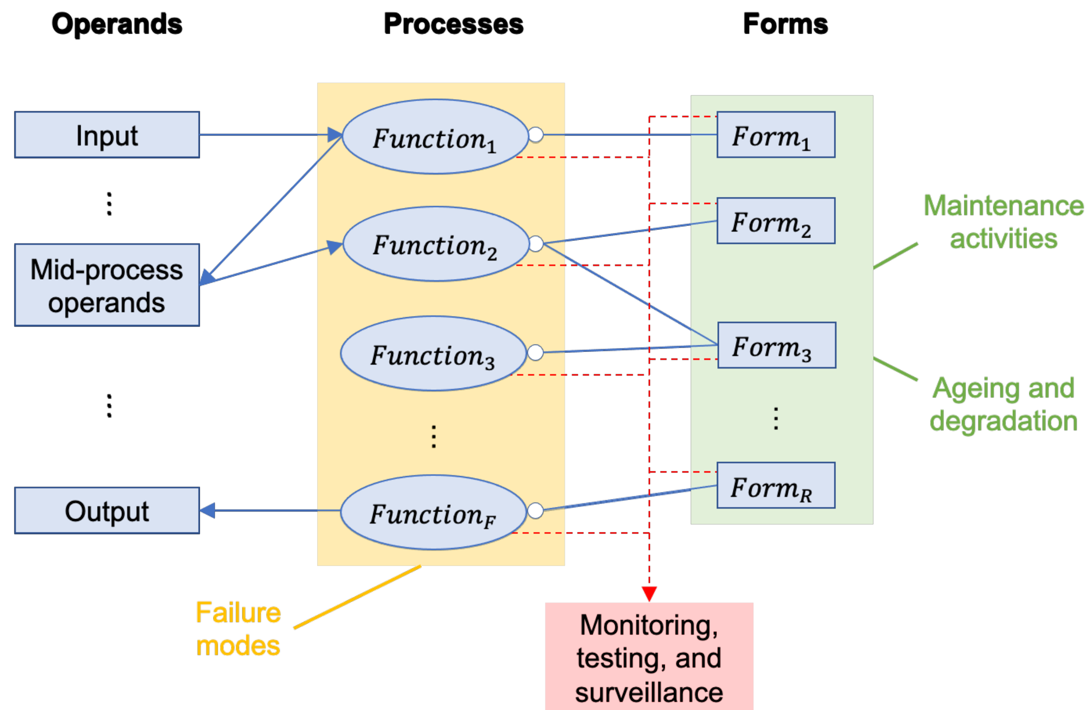
- **Our work:** Find <u>causal</u> patterns from data
  - We need to use data along with models

Not all patterns tell us something about the system

- **Applications**
  - Anomaly detection: Find abnormal behavior from normal conditions
  - Diagnostic: What caused the abnormal behavior?
  - Prognostic: What are the consequences?
  - <u>Integration of ER data into plant digital models</u>

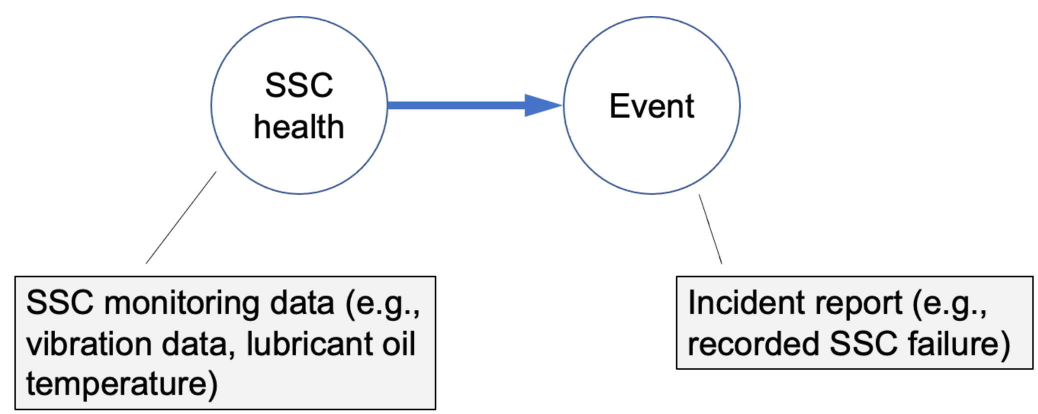
ER Data Analytics

- **System engineer view:**
  - MBSE representation of a component (e.g., OPM or SysML diagrams)
  - Understand "what a text is talking about"
  - Emulate system engineer knowledge about SSC/system architecture



~~Machine learning~~ reasoning

- **Data scientist view:** causal inference (data+models) coupled with natural language processing (NLP) methods
  - Discover causal relationship between data elements
  - Integrate numeric and text data



Create a story out of data

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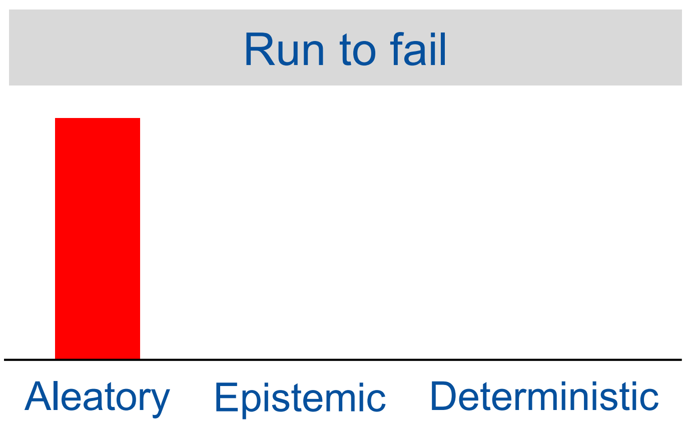
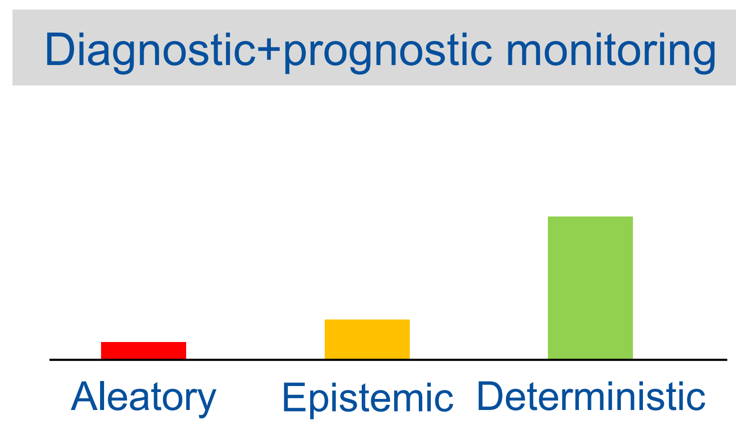
Issues with Current Reliability Approaches

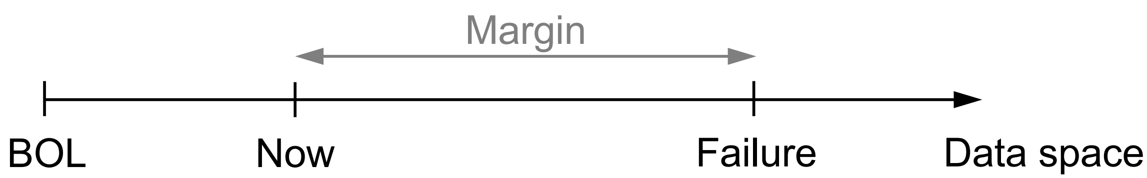
- **Is ER data effectively integrated into plant reliability models?**
  - Easy for components designed to run to fail (i.e., MTTF)
  - What about condition, diagnostic, and prognostic data?
- **State-of-the-art reliability modeling**
  - Bounded by language based on failure rate or failure probability concepts
    - E.g., linear ageing model
  - Does use of “system failure probability” support ongoing decision-making?
- **Thoughts on the concept of failure rate**
  - Rate of occurrence of an aleatory variable
  - Assume testing, surveillance, diagnostic/prognostic monitoring are performed
    - Am I still dealing with an aleatory variable?





Reliability Modeling: A New Language

- **System engineers** are familiar with a different reliability concept: **margin**
- Definition: The "**distance**" between present/actual status and an (estimated) undesired status for a specific component



- This change implies a **redefinition of risk**

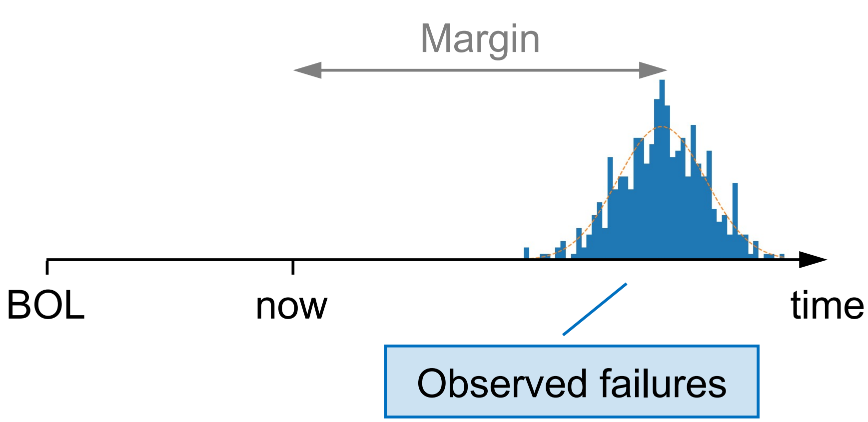
Regulatory definition	System engineer definition
What can go wrong	What can go wrong
What are its consequences	What are its consequences
How likely it is	**How distant it is**

- Change of viewpoints basically amounts to a change of variable
  - From "system/component failure probability"
  - To "system/component margin to failure"

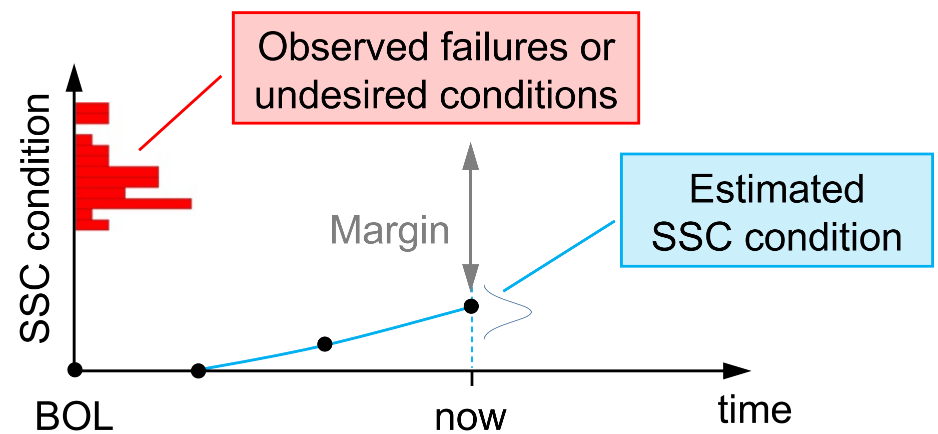
Reliability Modeling: A New Language

- Margin is defined over actual and past ER data
  - Direct integration of ER data
- **Margin values change with time**
  - New SSC condition data are observed — Degradation: Margin ↓
  - ER operations (e.g., maintenance) are performed — Margin ↑
- SSC are characterized by several failure modes
  - Each failure mode is modeled through its own margin

Corrective maintenance

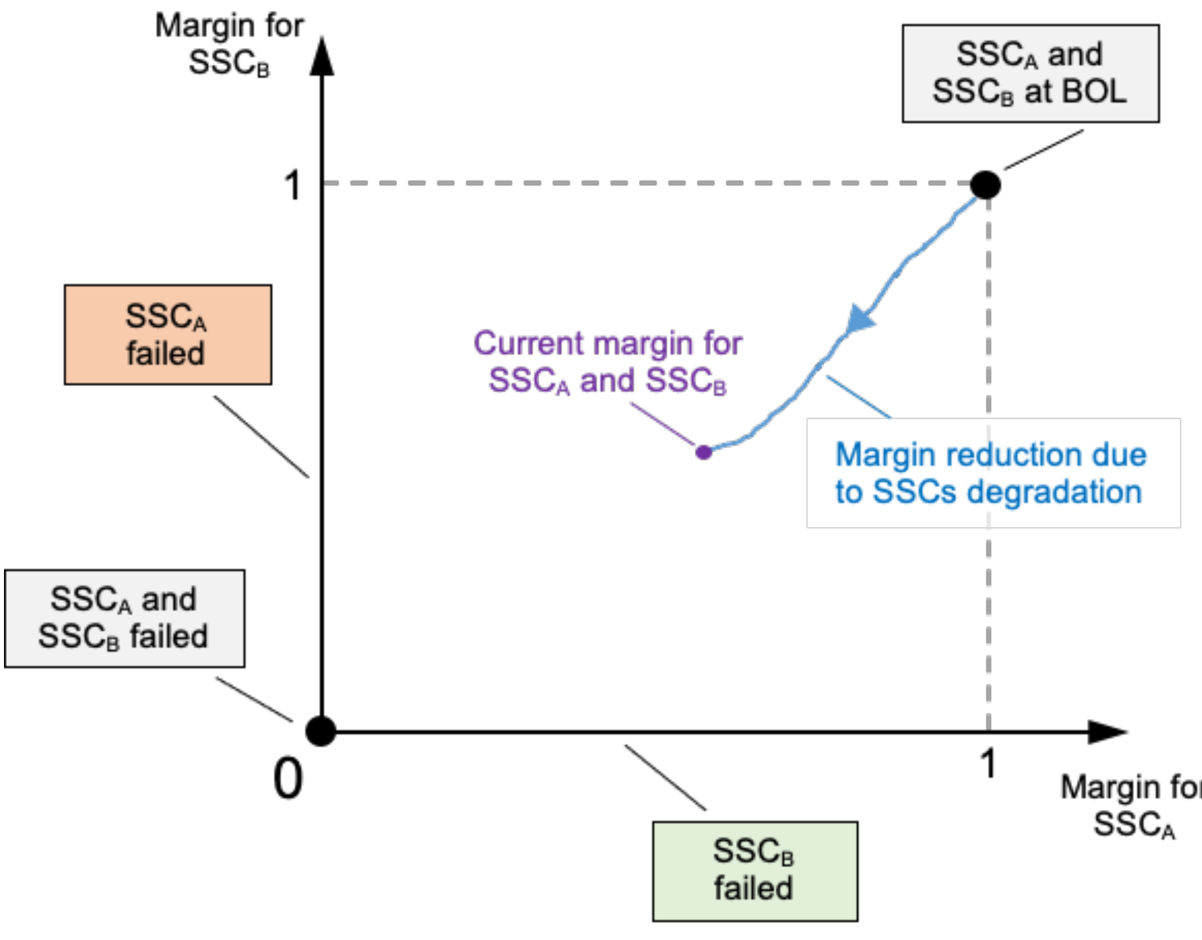


Condition-based maintenance



Reliability Modeling: A New Language

- System reliability models are typically based on **fault trees**
  - Deterministic models that depict system architecture from a **functional perspective**
- Fault trees can be used to propagate basic event margins
- Margin calculations can be **carried out directly from the minimal cut (or path) sets** generated by any PRA code
- Operation through metric spaces are much **faster** compared to Boolean logic operations
- **Applications**
  - Monitor system/plant health
  - Prioritize failure modes that impact system/plant reliability



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Plant Resources Optimization

- **Resources: personnel, budget, assets, time**

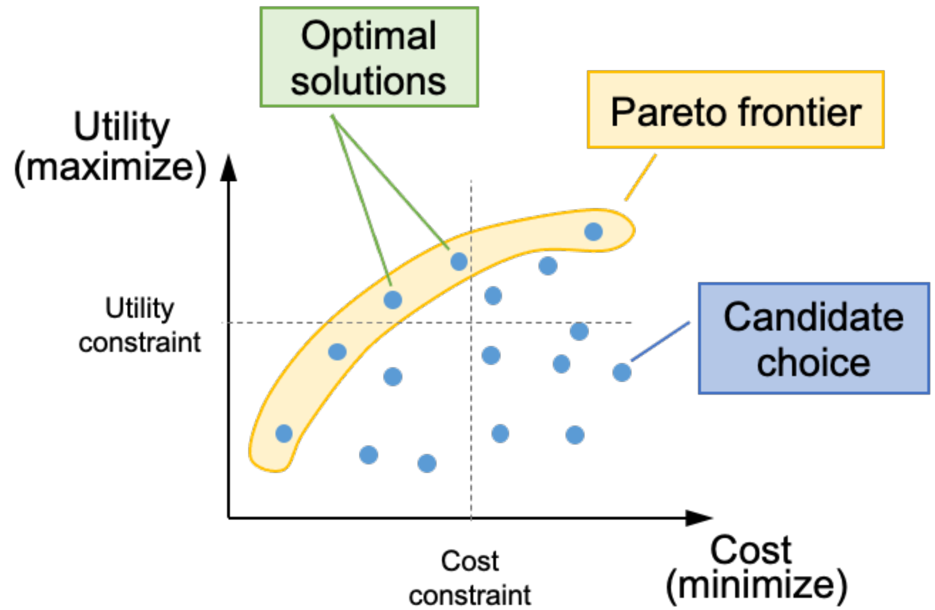
- **What does optimization mean?**
  - Maximize value of spent $
  - Minimize maintenance crew activities
  - Maximize ER workforce productivity
  - Maximize SSC lifecycle performance (availability/reliability)
  - Minimize SSC lifecycle cost

- **Applications**
  - Task scheduling (short-term horizon decisions)
  - Project planning and scheduling (long- and mid-term horizon decisions)

- **A simulation-based approach**
  - Optimization methods
    - Data based: linear integer (deterministic, stochastic, distributionally robust)
    - Model based: single- and multi-objective
      - E.g., gradient-based, genetic algorithms, Pareto frontier
  - Integrate reliability and economic models

Multi-Objective Optimization

- **Objective:** balance multiple factors in the decision process
  - E.g., costs and reliability
- **Applications**
  - Determine optimal set of maintenance activities
  - Evaluate optimal alternatives for maintenance posture
  - Determine system optimal monitoring configuration



- **Method:** Multi-objective optimization
  1. Trade-off exploration: evaluate system costs and utility for several options
  2. Identify Pareto frontier
  3. Propagate uncertainties
  4. Impose utility/cost constraints

Project Prioritization/Scheduling

- **Goal:** Select optimal set of projects and actuation schedule that maximizes overall NPV
- **Input data:** Candidate projects
  - Options for each project (timing, duration, and costs)
  - Budget constraints per year and per resource (e.g., capital funds, O&M funds)
  - Consequences of stochastic events (e.g., SSC failure)

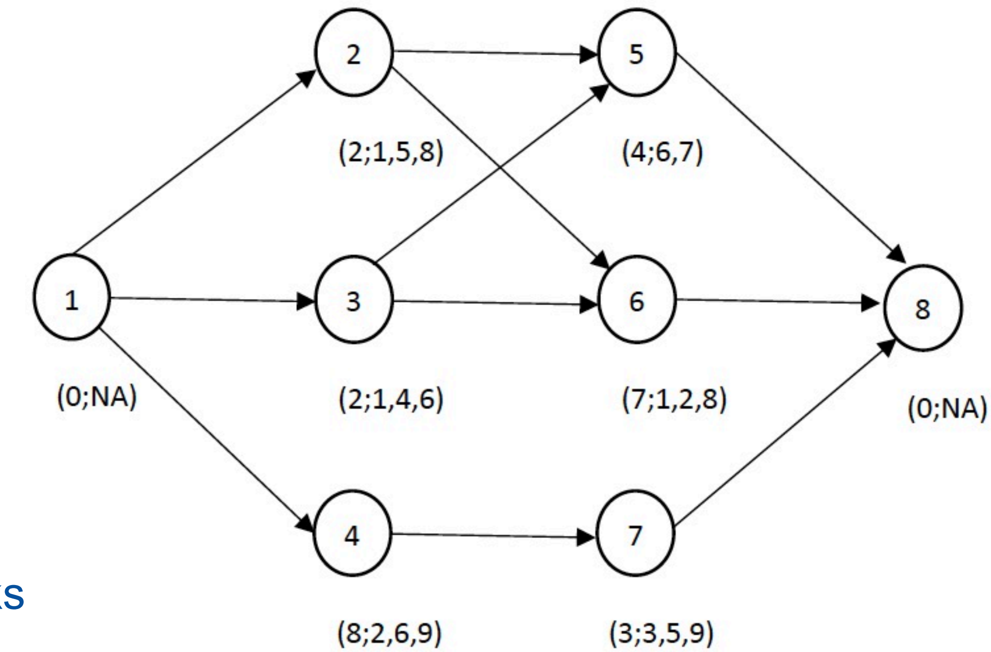
Component-scenario	T1 $ 50K	T2 $ 90K	T3 $ 90K	T4 $ 90K	T5 $ 70K	T6 $ 40K	MTTR [h]	Power Loss	Failure Probability	Risk
M1-A	$ 40K						10	10%	0.2	0.2
M1-B		$ 40K					10	10%	0.25	0.25
M1-C			$ 40K				10	10%	0.3	0.3
M1-DontDo							10	10%	1	1

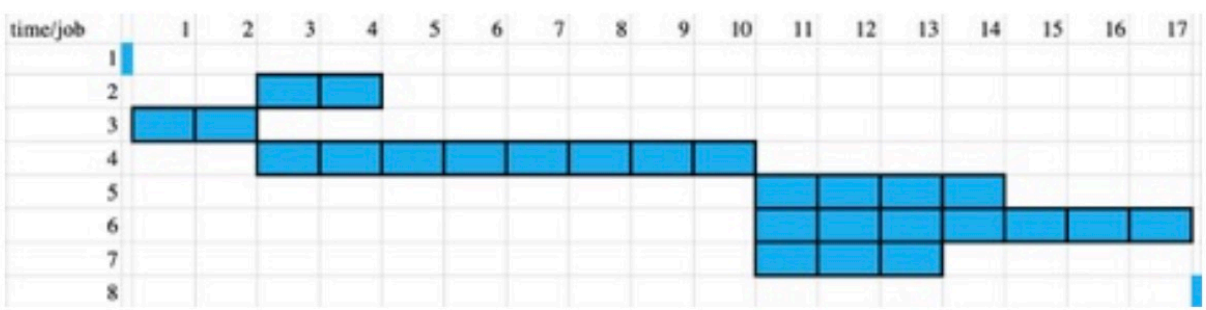
- **Output data:** Selected projects and prioritization and optimal project schedule

	T1 $ 50K	T2 $ 90K	T3 $ 90K	T4 $ 90K	T5 $ 70K	T6 $ 40K	Risk
M1-B		$ 40K					0.25
M2-B			$ 50K				0.36
M3-B				$ 35K			0.18
M4-A				$ 40K			0.18
M5-A		$ 45K					0.2
M6-A	$ 25K						0.168
M7-A			$ 30K				0.72
Total	$ 25K	$ 85K	$ 80K	$ 75K	0	0	2.058

Task Scheduling

- **Applications**
  - Scheduling of maintenance and surveillance activities
  - Scheduling of outage activities
- **Input data**
  - Crews (skill set, availability)
  - Tasks (duration, dependencies, skills)
- **Objective:** minimize time to perform all tasks
- **Methods**
  - Mixed integer linear optimization
  - Genetic algorithms
- **Output data**
  - Task schedule assigned to each crew





Conclusions

- Project overview: **Linking ER data to decisions**

- **ER data analytics**
  - Causal inference of numeric data and events
  - System and data perspective: moving away from a data-driven mindset

- **Reliability modeling using margin-based solvers**
  - Easy integration of data analysis methods
  - Compatible with employed system reliability models (fault trees)
  - Complete and explainable representation of system plant health
    - Target both system engineers and plant managers/decision-makers
  - Support plant health/asset management decisions through explainable models/data

- **Plant resource optimization**
  - Long-term: Prioritization projects that provide higher value
  - Medium-term: Project execution planning
  - Short term: Job scheduling

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