Risk-Informed Plant Health and Asset Management Project

LWRS
LIGHT WATER REACTOR SUSTAINABILITY

Diego Mandelli (INL)
diego.mandelli@inl.gov

Idaho State University
JENSEN HUGHES
Northwestern University
TEXAS STATE UNIVERSITY

Problem Statement and Vision

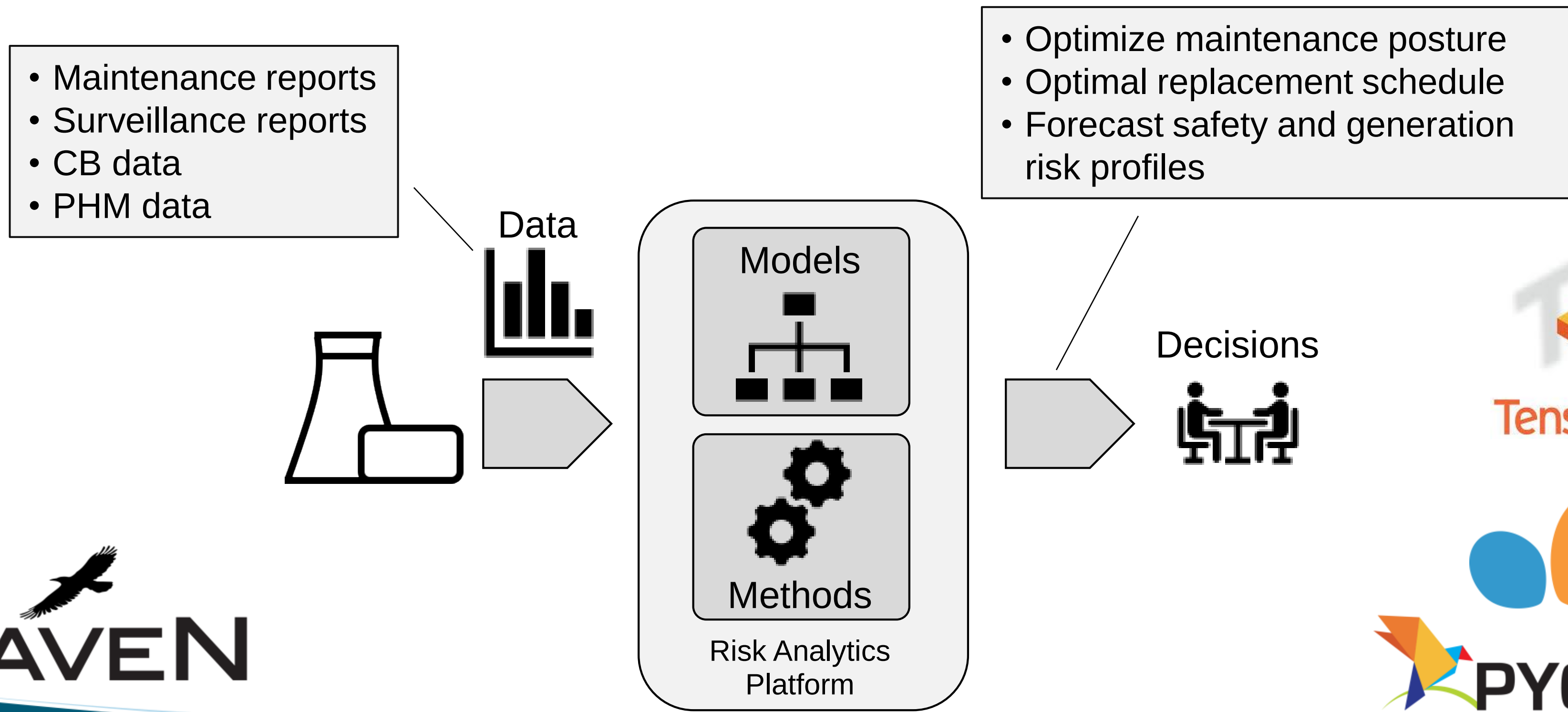
- Context
  - Industry Equipment Reliability (ER) and Asset Management (AM) programs can be labor intensive and expensive
  - Opportunity to significantly enhance the collection, analysis, and use of this information to provide more cost-effective plant operation

- Vision
  - Advanced monitoring technologies have been successfully implemented to assess equipment performance in many industries
  - Increased deployment of these technologies has the potential to reduce costs associated with monitoring and regulatory compliance at operating nuclear plants

- Our Work
  - Develop and apply data analytics tools coupled with risk-informed methods to manage plant assets over the remaining years of plant operation

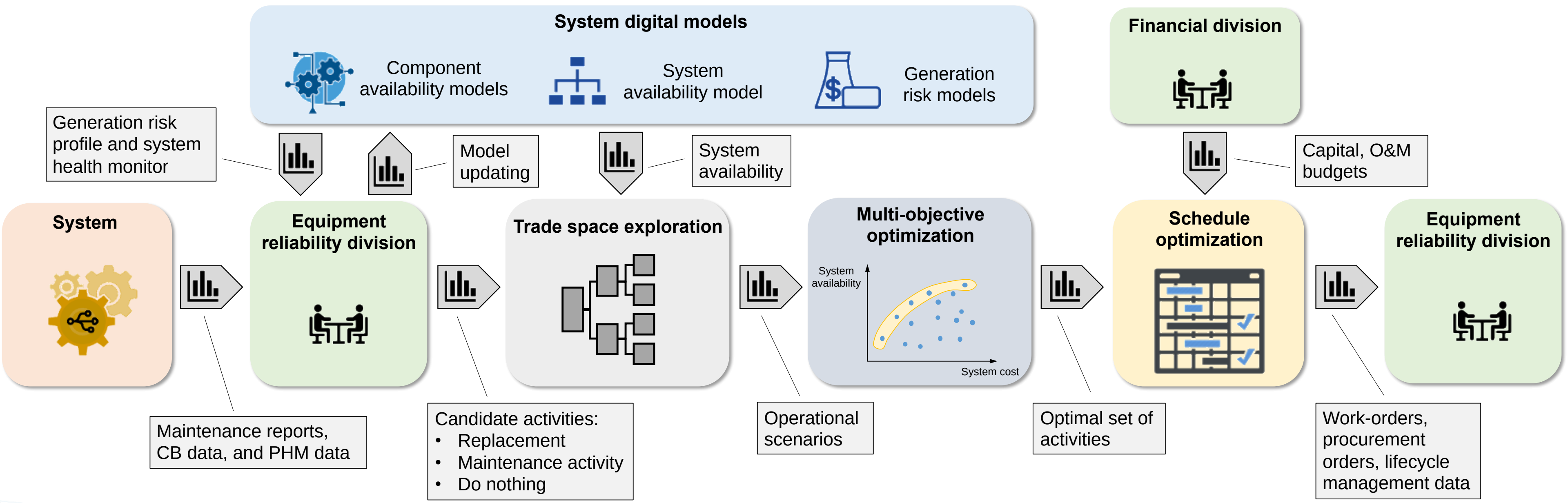
Project Overview

- Develop Risk Informed Plant System Health (RI-PSH) methods and tools to provide relevant information to decision-makers to enhance plant economics while maintaining safety
  - Risk analytics platform
  - Data analytics tools coupled with risk-informed methods to manage plant assets
  - Leverage INL developed tools and open-source libraries



RI-PSH Platform: From Data to Decisions

- Objectives
  - Leverage advanced technology to enhance plant operations
  - Enhance system performance and equipment reliability
  - Reduce operational costs
  - Inform plant equipment maintenance and investment decisions
  - Integrate and balance safety and economic risk



Project Execution Plan

- Focus is improved / more economical equipment performance and reliability over the remaining life of the plant
- Technologies address different aspects of issue that relate to two distinct timeframes
  - Equipment Reliability
    - Short to intermediate term (1 – 5 years)
    - Impact on operations and maintenance (O&M) costs
    - Focus on engineering / technical elements
  - Long-Term Operations / Asset Management
    - Intermediate to long term (> 5 years)
    - Impact on both O&M and capital planning costs
    - Focus on business / financial elements
- Development and deployment of methods / tools intended to be accelerated via collaboration with host utility partners
  - Utility provides access to data and Subject Matter Experts (SMEs)
  - Provides host utility early access to technology development / deployment and allows them to leverage lab expertise to address issues important to the plant

LWRS LIGHT WATER REACTOR SUSTAINABILITY

RI-PSH Platform: Under the Hood

Philosophy:
- Develop computational tools
  - Satisfy industry needs
  - Designed for general purpose applications
- Near future direction: open-source release

RI-PSH Platform

- **RAVEN** Analysis framework
- **LOGOS** Asset management
- **SR^{2}ML** Reliability models
- **TEAL** Economic models
- **VERT** Plant generation models
- **SRAW** Pre-defined workflows

RAVEN:
- Main computational driver
- Uncertainty quantification and optimization capabilities

Plugins:
- Libraries of models designed for specific use-cases
- Easy interface to RAVEN

Plugins repositories:
- Source code
- Documentation (e.g., user manual)
- Regression tests

Computational Models

Models

- A Models Based System Engineer (MBSE) approach to system reliability
- Models-of-models philosophy
  - Integration of reliability and economic models

System Health Models

Architecture models

Data workflow management

- Logical model
- Ensemble model

System models

Propagation of ER data to the system level

- Plant PRA models
- Plant GRA models
- MCS solver
- System economic models

Component models

Integration of ER data

- Component ageing models
- Component maintenance and testing models
- Component economic models

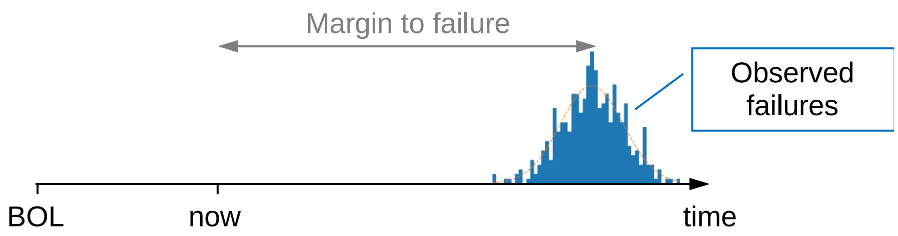
A New Language to Reliability Modeling

- Observations from literature on state-of-the-art maintenance optimization methods
  1. Often rely on assumptions that are far from reality
  2. Does “system failure probability” provide information that is usable by a system engineer?
- System engineers are familiar with a different reliability concept: margin to failure

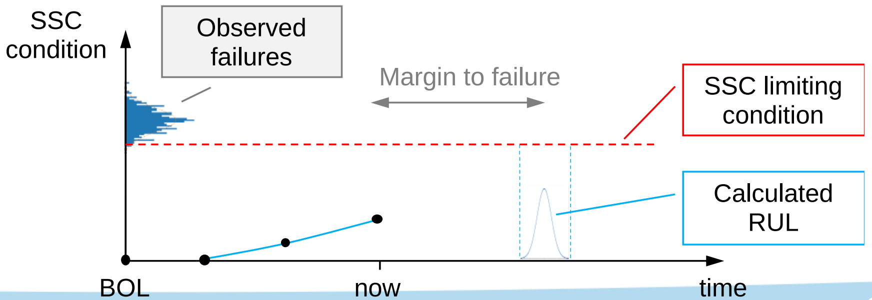
Regulatory definition		System engineer definition
what can go wrong what are its consequences **how likely it is**	→	what can go wrong what are its consequences **how distant it is**

- Goals for reliability modeling in RI-SHM
  - Data centric construction of reliability models
  - Provide information of system health in terms of margin to failure

Margin to failure for corrective maintenance



Margin to failure for predictive maintenance



Quantitative Methods

Methods

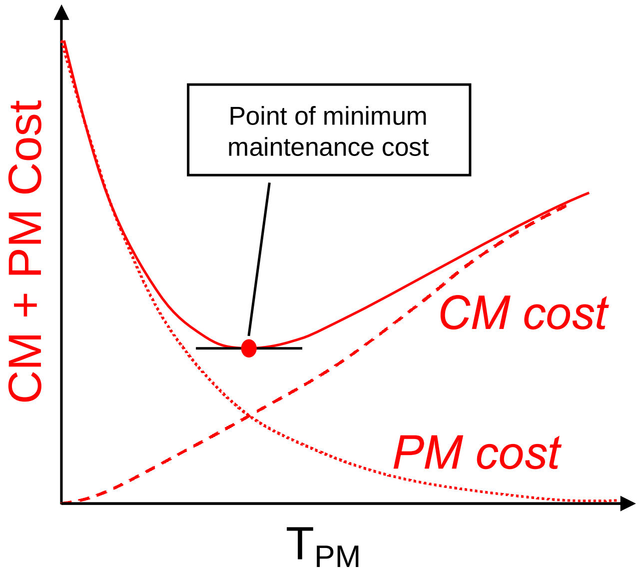
- Main target: Optimization methods (discrete and continuous forms)
- Propagation of uncertainties
- Data analysis

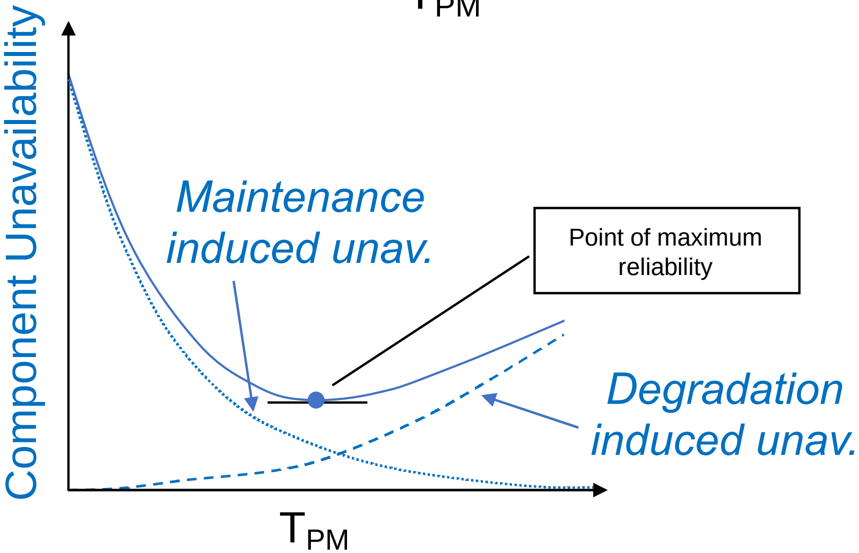
Plant Asset Management Methods

Early	Planning	Late/Execution
Data uncertainties	Prioritization type	Evaluate “what if” analysis
Simulation-based approach	Stochastic optimization	Deterministic capital budgeting
Full stochastic optimization		Job scheduling optimization
	Model based optimization	
Pareto frontier optimization	Risk based optimization	
	Distributionally robust optimization	

Application 1: Maintenance Optimization

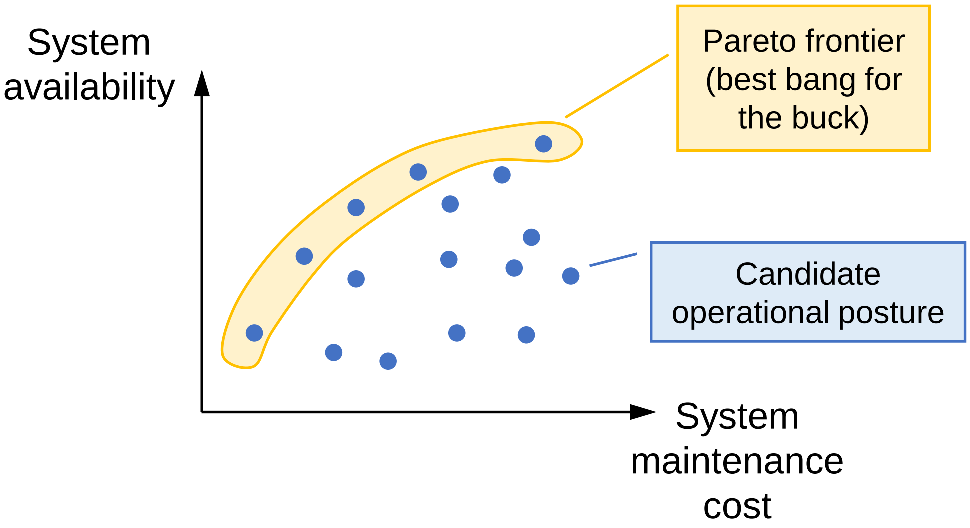
- Goal: balance unavailability and cost of Preventive Maintenance (PM) activities (system level)
- Objective: determine optimal time between PM activities
  - Minimize PM cost
  - Maintain system unavailability under fixed limits (constraints)
- Method: constrained optimization
- Integration of
  - Component unavailability model
  - Component cost model
  - System unavailability model
  - System cost model

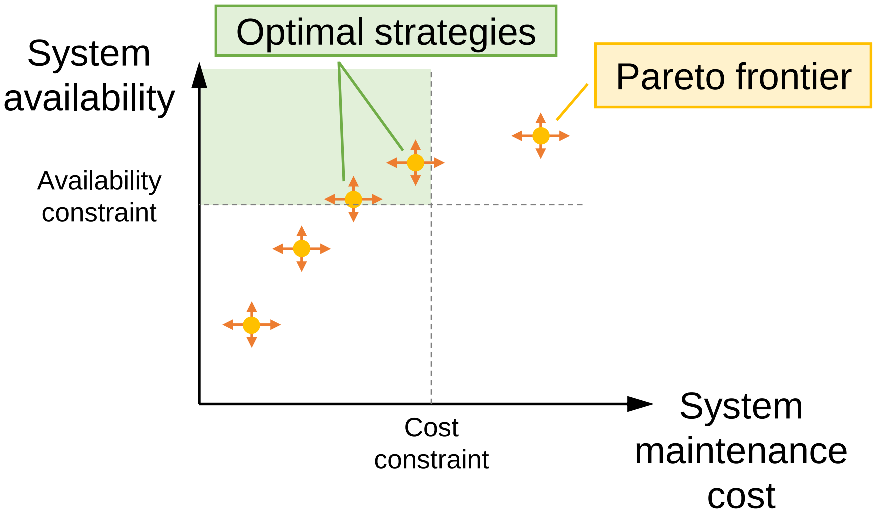




Application 2: Multi-Objective Optimization

- Goal: determine optimal maintenance posture, i.e., maintenance strategy for each component
- Objective: balance system costs and performance (availability)
- Method
  1. Trade space exploration: evaluate system costs and availability for several candidate maintenance postures
  2. Identify Pareto frontier
  3. Impose availability/cost constraints
- Integration of
  - Component unavailability model
  - Component cost model
  - System unavailability model
  - System cost model





Application 3: Schedule Optimization

- Goal: identify optimal schedule for projects (e.g., ones selected in Application 2)
- Input data
  - Candidate projects
  - Options for each project (timing, duration, and costs
  - Budget constraints per year per resource (e.g., capital funds, O&M funds)
  - Allow data uncertainties
- Method
  - Linear integer optimization
- Output data
  - Selection/prioritization of projects
  - Optimal project schedule optimization

Capital budget
O&M budget

Project-option	Year 1	Year 2	Year 3	…
FeedwaterHeater - Option A	0.219 0.075	0.257 0.080	0.234 0.085	
FeedwaterHeater - Option B		0.225 0.075	0.267 0.080	… …
FeedwaterHeater - Don't Do	0.08	0.09	0.1	

Capital cost
O&M cost