U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Improving Nuclear Power Plant Efficiency Through Data Analytics

Advanced Sensors and Instrumentation Annual Webinar

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Improving Nuclear Power Plant Efficiency Through Data Analytics

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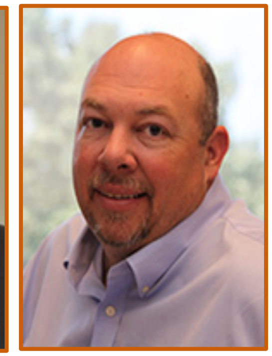

Chris Comfort, SNC

Purpose: Develop and provide data analytics solutions to improve nuclear power plant economic efficiency. These solutions will utilize empirical models to integrate disparate data sources while providing uncertainty estimates to quantify risk and support robust decision making.

Objectives/Tasks:

Task 1: Identify and develop risk-based inferential sensor solutions to support uninterrupted operations during periods of sensor degradation.

Task 2: Integrate disparate data sources for component and process condition assessment to drive optimal maintenance and capital replacement decisions.

Task 3: Develop and drive the use of data analytics solutions through the business to improve organizational effectiveness of nuclear utilities.

Outcomes:

The desired outcomes of this innovative research project are to

- develop data analytic based methods to enhance the technical and economic competitiveness of the U.S. nuclear industry by enabling advanced monitoring of critical assets,
- improving the operating capability of the existing fleet by enabling predictive maintenance in lieu of labor intense and expensive periodic maintenance,
- achieve enhancements in organizational effectiveness.

Project Overview

Task 1 : Data Analytics Models for Inferential Sensing

Objective

- Identify and develop risk-based inferential sensor solutions to support uninterrupted operations during periods of sensor degradation.

Goals

- Perform operational and economic analysis to identify and quantify key opportunities for the installation of low uncertainty inferential sensing technologies in both PWR and BWR plants.
- Collect data related to the parameters proven to have the largest opportunity for economic benefit.
- Develop low uncertainty, reliable empirical models to predict the parameter values in near real time.
- Develop operational solutions and procedures for the temporary use of inferential sensors.
- Develop a safety case for the intermittent and temporary use of inferential sensors.
- Develop a commercial product using nuclear QA processes.

Accomplishments

Milestone: Identify inferential sensor application area with significant potential economic impact and collect modeling data. **Completed 2/28/2019**

Identified opportunities for inferential sensing

a) The steam flow transmitter calibration issue (M3NU-18-TN-UTK_-030401-05) at each of two units at a single SNC site was identified as one of the opportunities. The discrepancies in steam flow calibration was leading to unplanned outages and associated maintenance burdens .

b) At another SNC the feed flow sensors were identified as an opportunity for improved measurement accuracy. Feedwater flowrate is a key parameter for determining and controlling the thermal output of an NPP. Noisy or potentially inaccurate measurements of feedwater flowrate introduce conservativism in the operating limits and setpoints.

c) LEFM has been implemented in most operating facilities to facilitate megawatt recapture. When a LEFM system goes offline, flow measurement relies on traditional flowmeters resulting in power margins reduced to pre-uprate levels.

Collect data for identified variables

a) Steam flow calibration : Steam flow transmitter and related data from three steam generators at each of two units at a single site were provided by SNC. This includes steam flow, feed flow, feed inlet temperature, flow pressures and turbine pressure for all channels. Supporting condition reports and PIDs were also supplied.

b) Feed Flow accuracy : Data from four steam generators from each of the two units. Captured variables and supporting documents were similar to the previous system.

c) LEFM: Data collection in progress.

Accomplishments

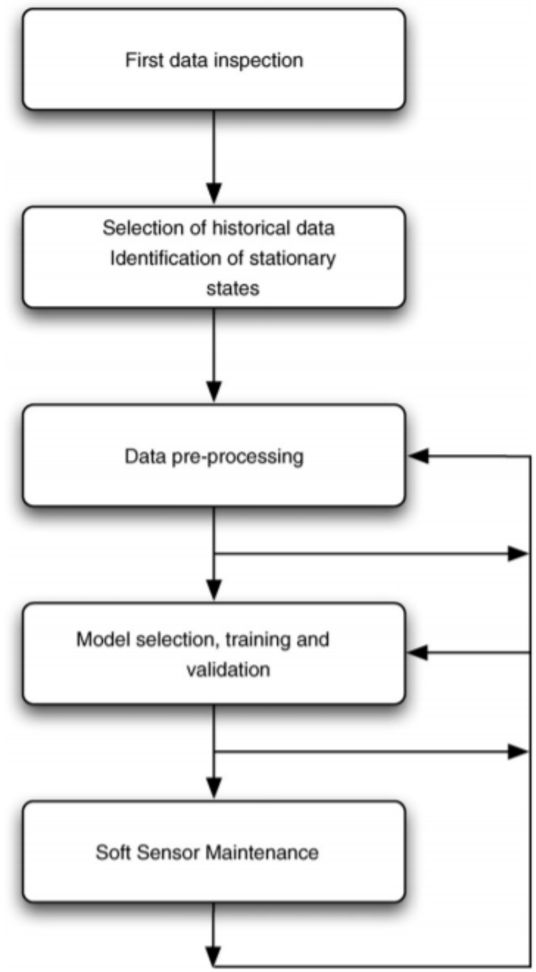
Develop low uncertainty, reliable empirical models

Soft sensor design

- Soft sensor architecture with emphasis on simplicity , flexibility and generalizability.
- Automation of preprocessing phase: Process data characteristic issues were identified. Data cleaning was carried out followed by variable selection and fault detection.

Model Selection and Implementation

- Gaussian process models are used to better capture process knowledge and to take advantage of the uncertainty that is innately characterized in the predictive distribution
- Model selection is carried out with model maintenance in mind, hence four model configurations are being inspected.



Accomplishments

Model Configurations

A gaussian process is specified by its covariance structure and hyper parameters. The data collected from SNC calls for differentiability of operation modes and modeling highly non stationary regions such as outage transients to steady state operations. To achieve this covariance structure within a base model is modified to compare performance.

The model implementation phase is ongoing.

Gaussian process model

Model 1: The base model is a simplified form of a multi output separable Gaussian process model based on [1].This model has a exponential covariance structure with an additive stability term

Model 2: This model implements the base model with a Matérn class covariance function with Automatic Relevance Determination (MARD) to represent the nonstationary formulation of the model.

Model 3: For a simplified treatment of non stationary covariance, the base model is implemented with a moving window based Matérn class covariance.

[1] Tipireddy, Ramakrishna, Megan Lerchen, and Pradeep Ramuhalli. "Virtual Sensors for Robust On-Line Monitoring (OLM) and Diagnostics." *ANS 10th International Topical Meeting on NPIC-HMIT, San Francisco, CA (Report PNNL-SA-124503)*. 2017.

Project Overview

Task 2: Combining Reliability, Performance, and Maintenance Data for Asset Management Decision Making

Objective

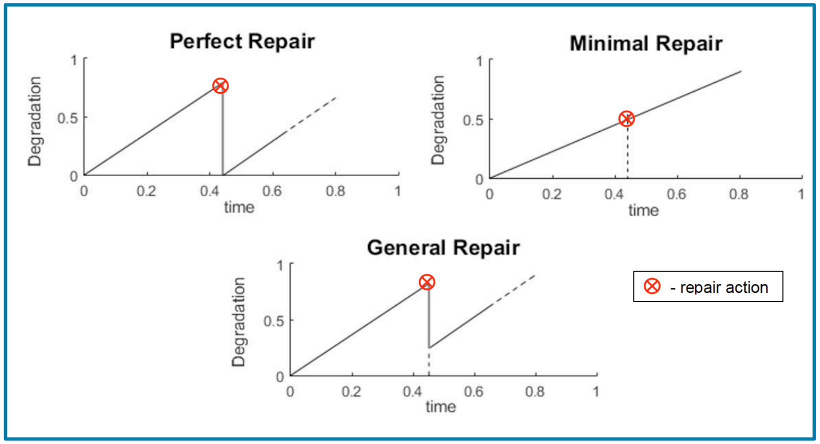
- Integrate disparate data sources for component and process condition assessment to drive optimal maintenance and capital replacement decisions.

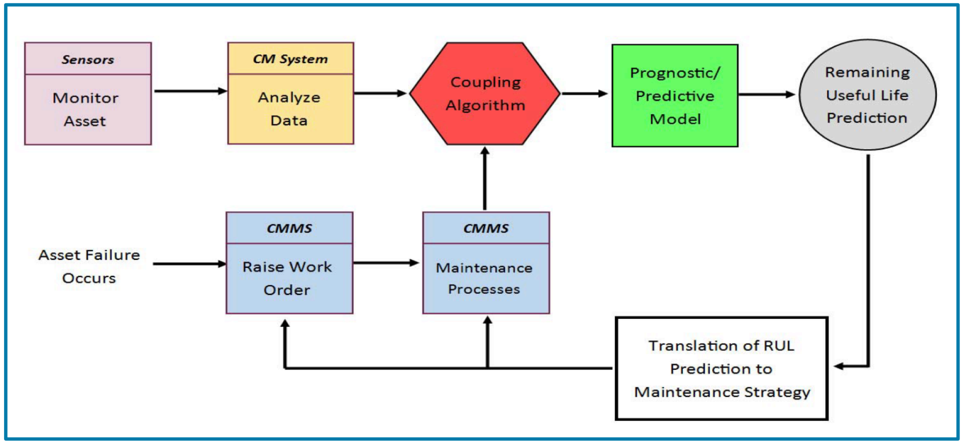
Goals

- Work with MNU to get access to data sources for data mining.
- Develop data mining programs to query the MAXIMO CMMS for maintenance action information.
- Develop coupling algorithm to integrate maintenance action information with maintenance, process, and condition monitoring data.
- Develop maintenance dependent prognostic models and select model type dependent on performance.
- Develop user interface using data compression and visualization methods to present outputs to engineers, operators, and maintenance members for optimal operational and maintenance decisions.

Project Overview

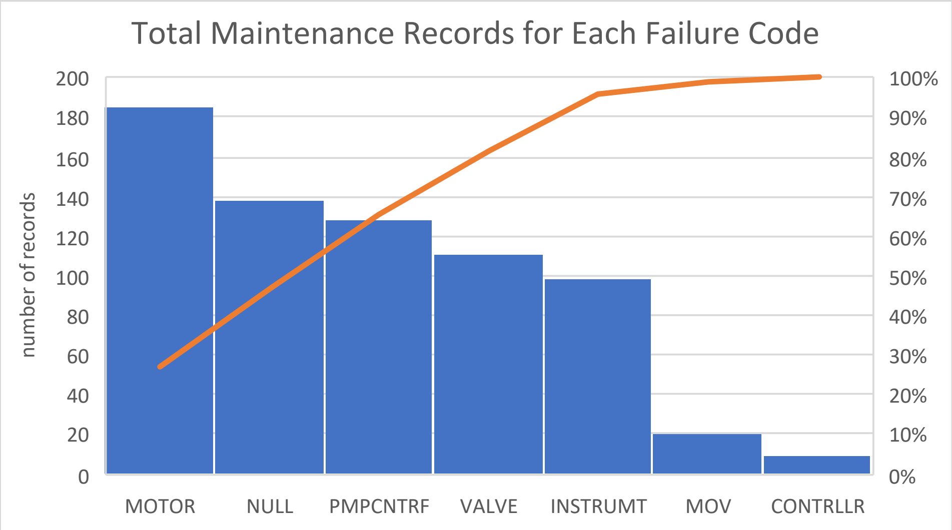
- Quantify and utilize the influence of maintenance activities on equipment degradation to improve prognostic performance.
  - Maintenance changed degradation state
  - Maintenance changes degradation rate
- Using data analytics, the integration of this maintenance information with process information when developing prognostic models results in the development of improved failure distribution estimates.
- Prognose more complex degradation models for different types and quality of maintenance actions.





Accomplishments

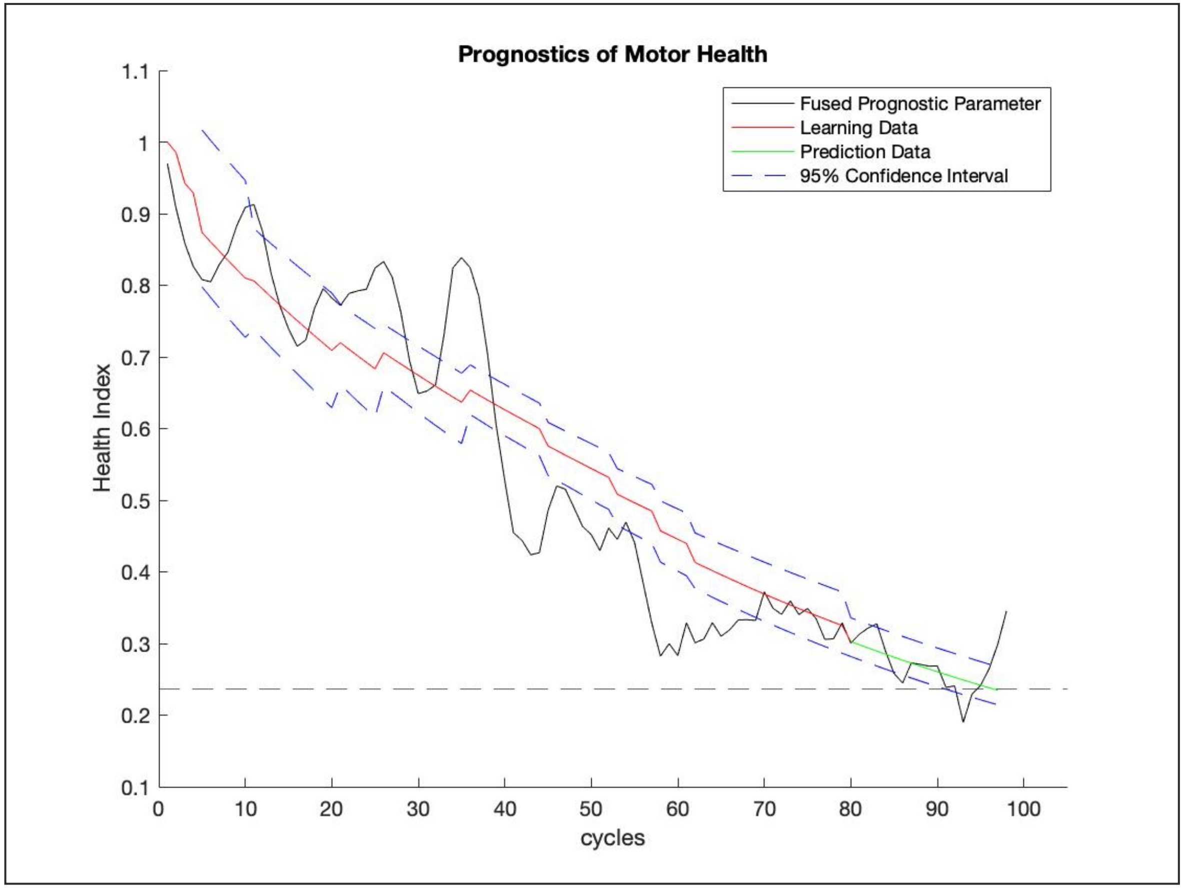
- **Milestone:** Identify component to develop maintenance dependent prognostic model and collect both process and maintenance data **(Completed 7/31/2019)**
- Initially SNC identified the feedwater and condensate system, but it proved to be unusable for this task.
- Subsequently, acquired process data and maintenance record on Circulating Water System (CWS) from Vogtle and Farley, 2 units from each site, in total 4 units.

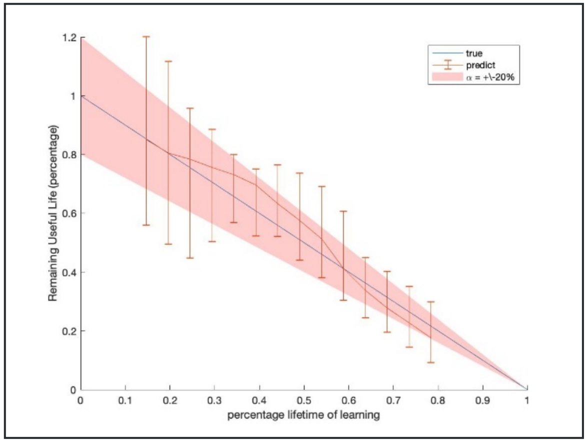


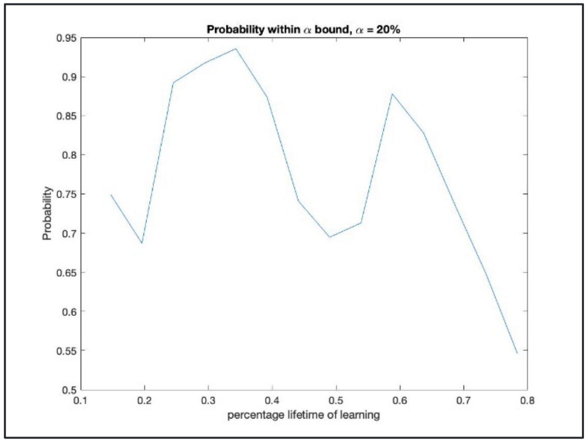
Process Data Type	Number of features
Water Level	2
Condenser Water Pressure	6
Circulating Water Pressure	1
Generator Ouput Power	1
Condenser Water Inlet Temperature	2
Condenser Water Outlet Temperature	4
Condenser Hotwell Generator Temperature	3
Circulating Water Pump Temperature	8
Ambient Temperature	2

Accomplishments

- Developed a Bayesian-based particle filter model with state estimation and parameter estimation coupling algorithm to integrate process and maintenance information.







Accomplishments

- Improved Particle Filter method as prognostic model:
  - Integrated capability to handle non-linear and non-Gaussian state models.
  - When maintenance occurs, the **degradation state** is reinitialized uniformly from a distribution and the **degradation rate** is adjusted by updating model parameters with parameter estimation.
  - Sequential Importance Resampling is the most time-consuming step in Particle Filter calculation. Applied systematic resampling method is at least 500 times faster (for 100k particles) than traditional multinomial resampling method.
  - Proposed dynamic particle numbers and adaptive parameter shrinkage rate allows fast response to maintenance.

Technology Impact

- Ability to quantify the influence of maintenance activities on equipment degradation and utilize it for prognostics.
- Improve failure distribution estimation by developing prognostic models integrating maintenance records and process information.
- Analyze the impact of maintenance quality on condition and prognostics.
- Assist nuclear utilities to move from periodic maintenance to condition-based maintenance.
- If commercialized, this has great potential for utilities to save money and become more economically competitive.

Task 2: Conclusion

- Utilized Bayesian-based algorithm to integrate process and maintenance information for prognostics.
- Analyzed data provided by Southern Nuclear Company to being incorporated into developed algorithms.
- Prognosis is based on the actual component condition to drive optimal maintenance and capital replacement decisions.
- Successful development of this model will help utilities transition from periodic maintenance to condition-based maintenance to improve safety and reduce operational costs.

Project Overview

Task 3: Development of data analytics technologies to improve Organizational Effectiveness

Objective

- Analyze and identify improvement strategies for organizational effectiveness from the perspective of metrics.

Goals

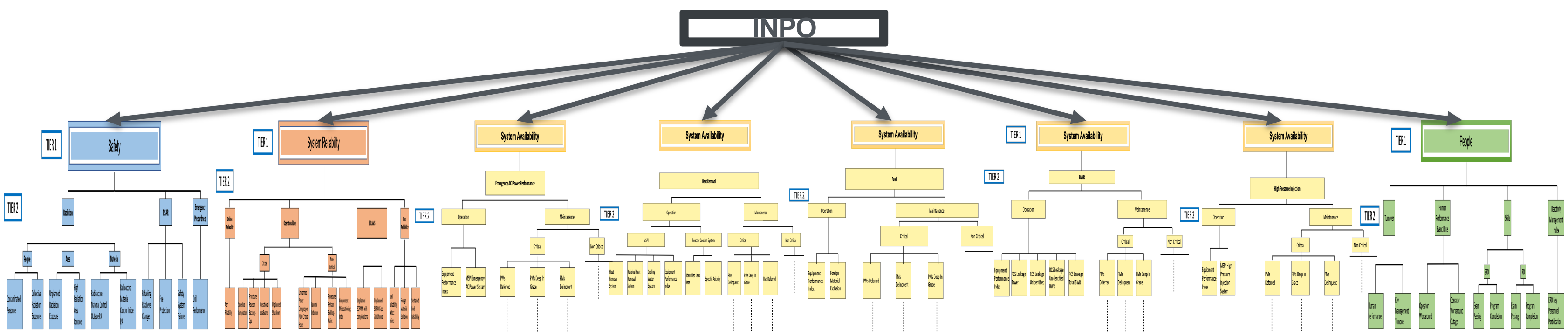
- Work with MNU to identify the metrics and KPIs currently in use.
- Assess the data to develop a categorization of the KPIs.
- Develop a hierarchical model which relates KPI categories.
- Validate the KPI hierarchical model using MNU inputs.
- Use scenario-based studies to simulate the utility of the hierarchical model in improving KPI values.

Milestone: Work with major nuclear utility (MNU) to identify and gain access to operational effectiveness data sources from each of the multiple units at the multiple sites.

Completed 8/1/2019

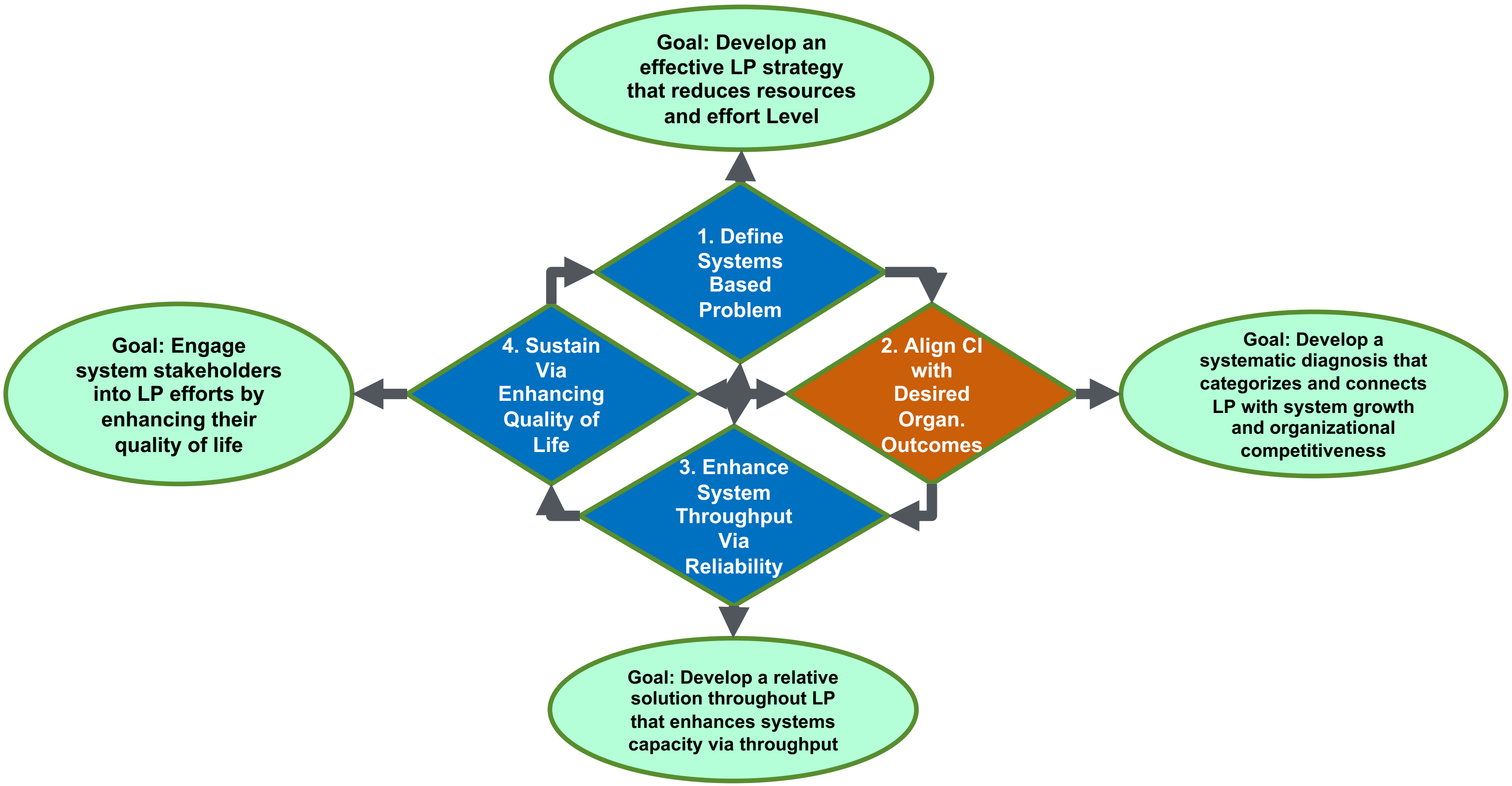
Project Overview

- Assess operational effectiveness from the perspective of organizational KPIs
- Develop a hierarchical model for organizing KPIs.
- Represent the interrelationships between KPIs.
- Demonstrate the methods to utilize the hierarchical model to improve KPIs
- Participants: Task 3: Rupy Sawhney



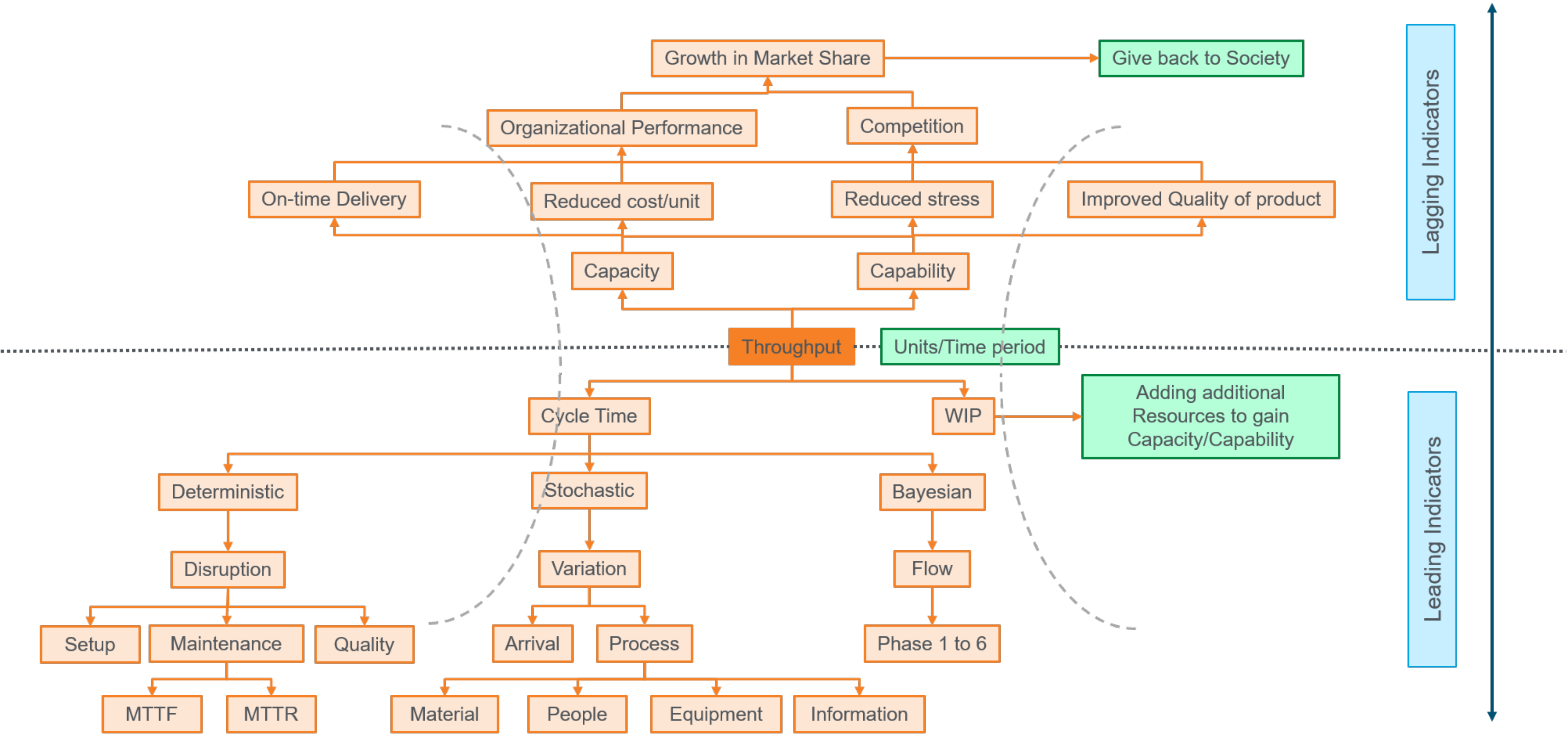
Accomplishments

- Identified the Sawhney Model as the basis for KPI hierarchy identification



Accomplishments

- Establish the leading-lagging indicator framework as the foundation of the method.



Accomplishments

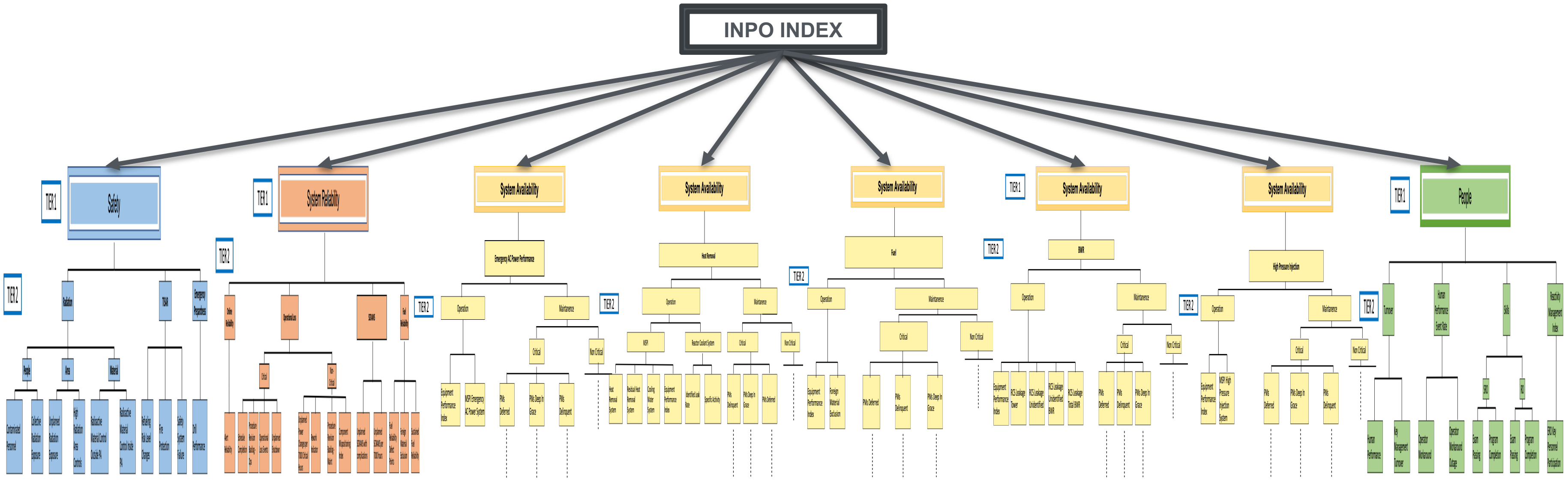
- Comparative basis: the current organization of KPIs at SNC.

Group	Metric	St	U1	U2
INPO Index	INPO Index			
	Capability Factor			A
	Online Reliability Factor			
	Operational Loss Events			
	Unplanned Weighted Auto and Manual Scrams			
	High Pressure Injection Performance		A	A
	Heat Removal Performance			A
	Emergency AC Power Performance	A		
	Sustained Fuel Reliability			
	Fuel Reliability Defects Points			
	Chemistry Effectiveness Indicator BWR			
	Collective Radiation Exposure BWR Unit 1			
	Collective Radiation Exposure BWR Unit 2			
	Total Industrial Safety Accident Rate	A		
	Equipment Performance Index Unit 1 *			
	Equipment Performance Index Unit 2 *			
	Reactivity Management Index *			
	Contaminated Personnel *			
	High Radiation Area Controls *			
	Radioactive Material Control Inside RA *			

Group	Metric	St	U1	U2
Org	Crit PMs Deferred			
	Crit PMs Delinquent			
	Crit PMs Deep In Grace			
	Emergent Work			
	Online DC			
	Outage CC			
	Online CC			
	Outage DC			
	Rework Indicator			
	Foreign Material Exclusion Indicator			
	Open Positions Indicator			
	Key Management Turnover			
	Human Performance Event Rate			
	Procedure Revision Backlog-Maint			
	Procedure Revision Backlog-Ops			
	RO Exam Pass Rate			
	RO Program Completion			
	SRO Exam Pass Rate			
	SRO Program Completion			
	Unplanned Scrams Per 7000 Critical Hours			

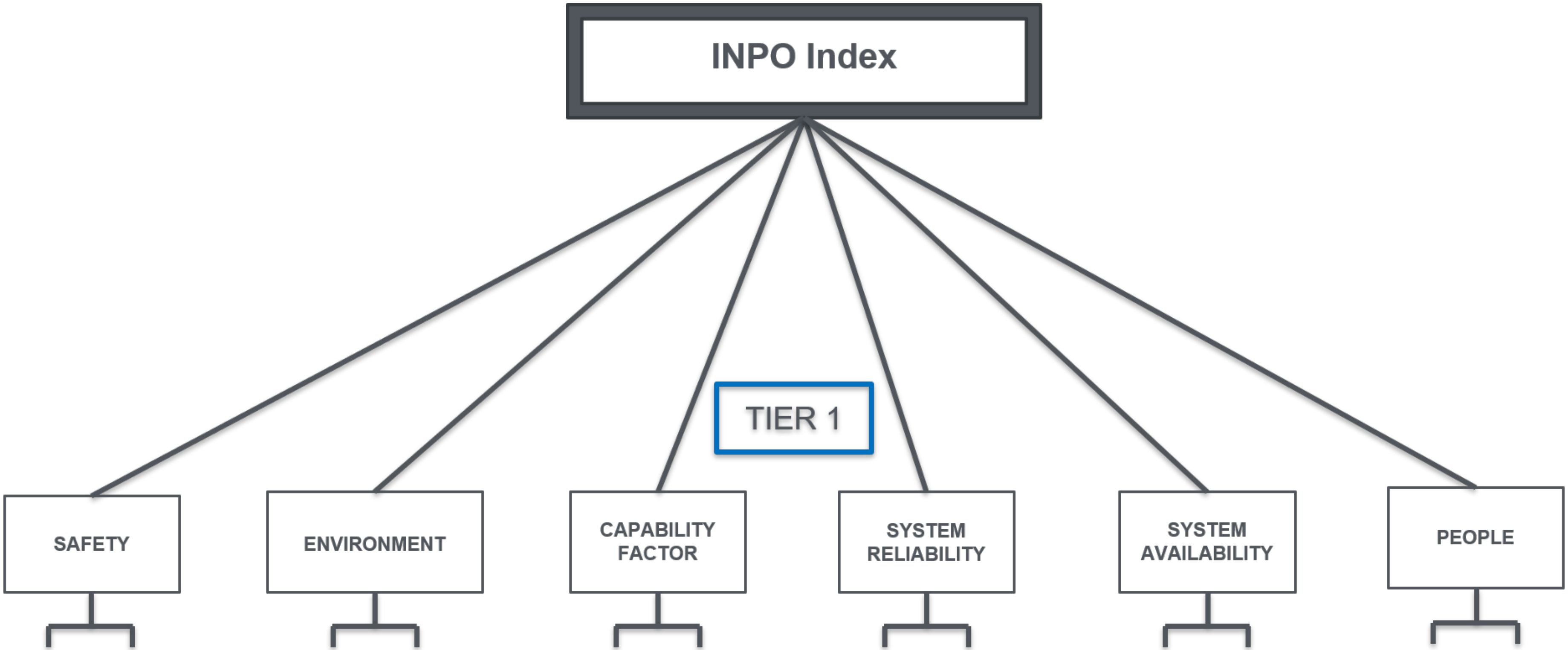
Accomplishments

- Proposed method: hierarchical organization of KPIs.



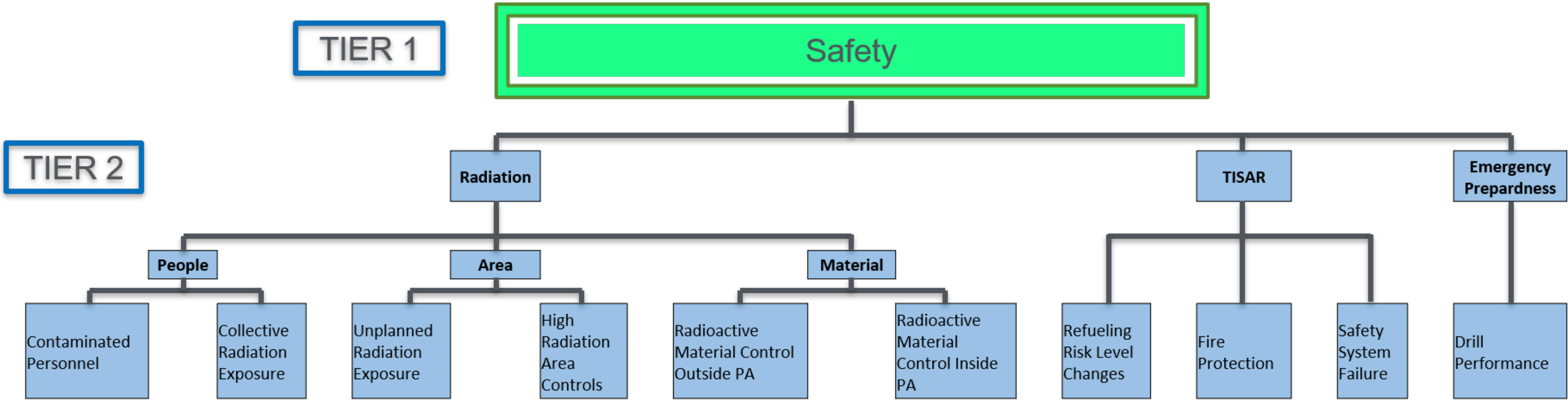
Accomplishments

- Identify the highest tier of KPI hierarchy: the INPO index



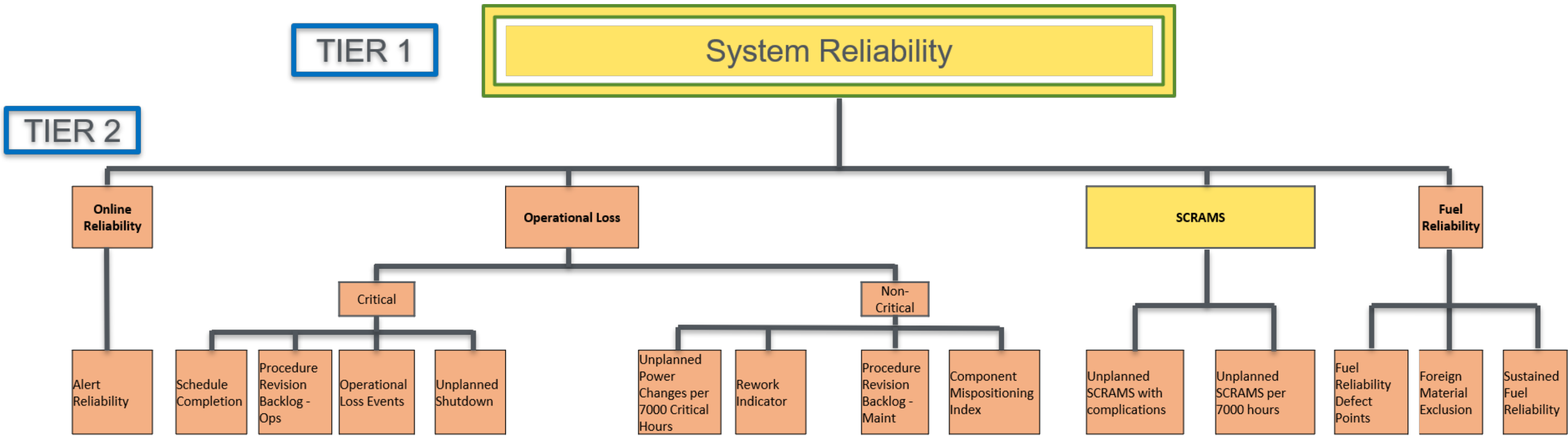
Accomplishments

- Breakdown for the Safety subsystem



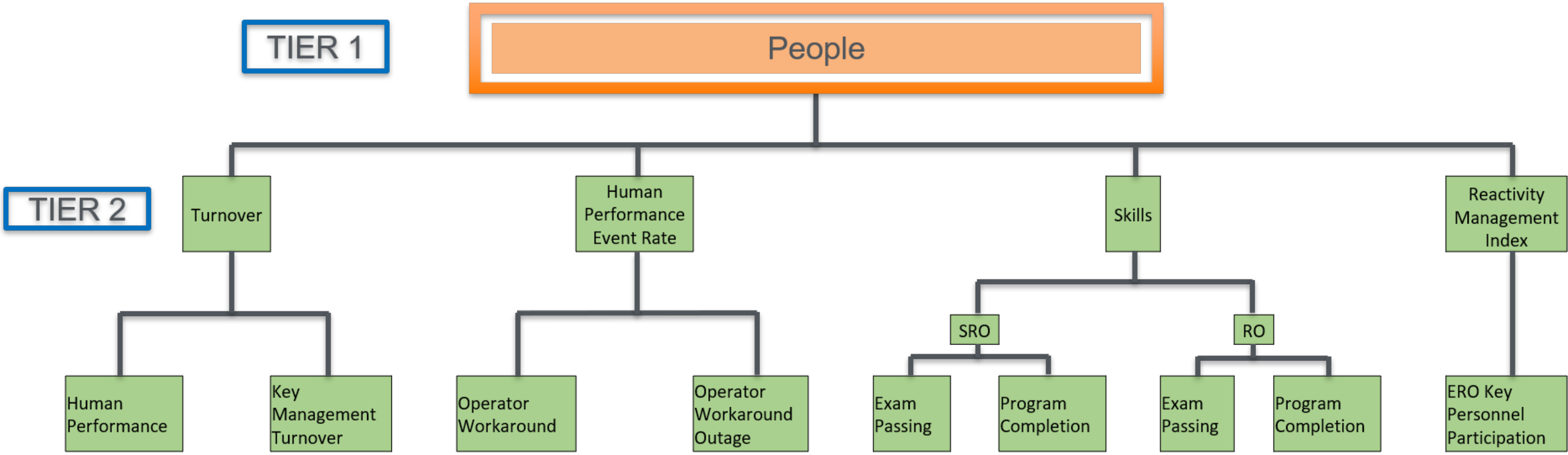
Accomplishments

- Breakdown for the System Reliability subsystem



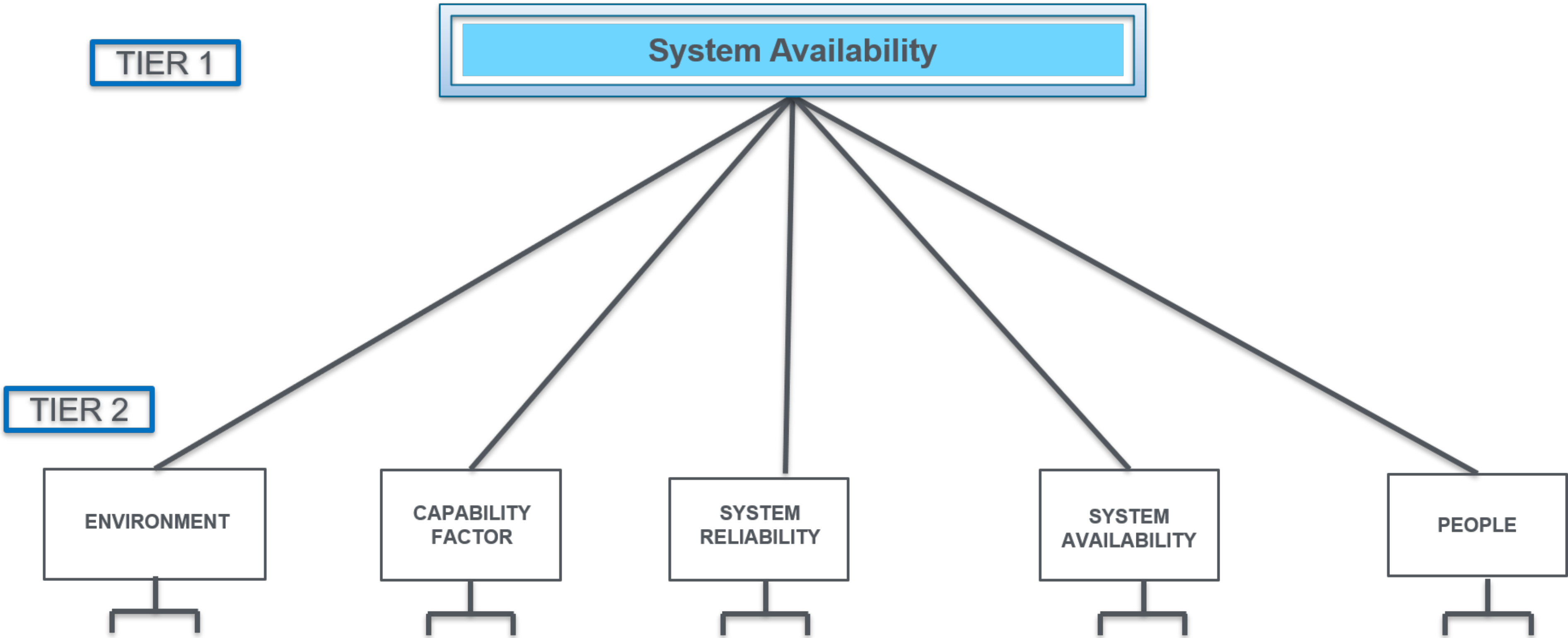
Accomplishments

- Breakdown for the People subsystem



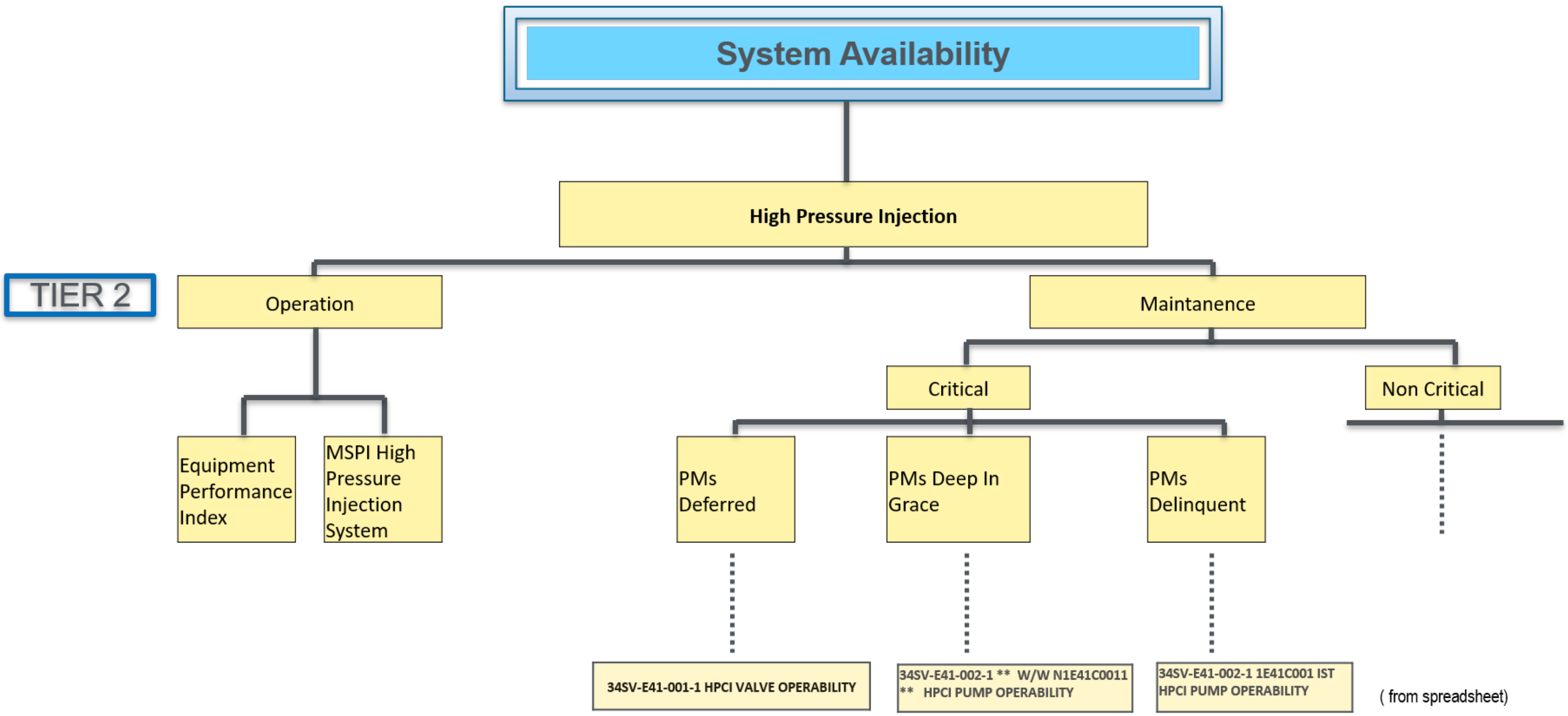
Accomplishments

- Breakdown for the System Availability subsystem



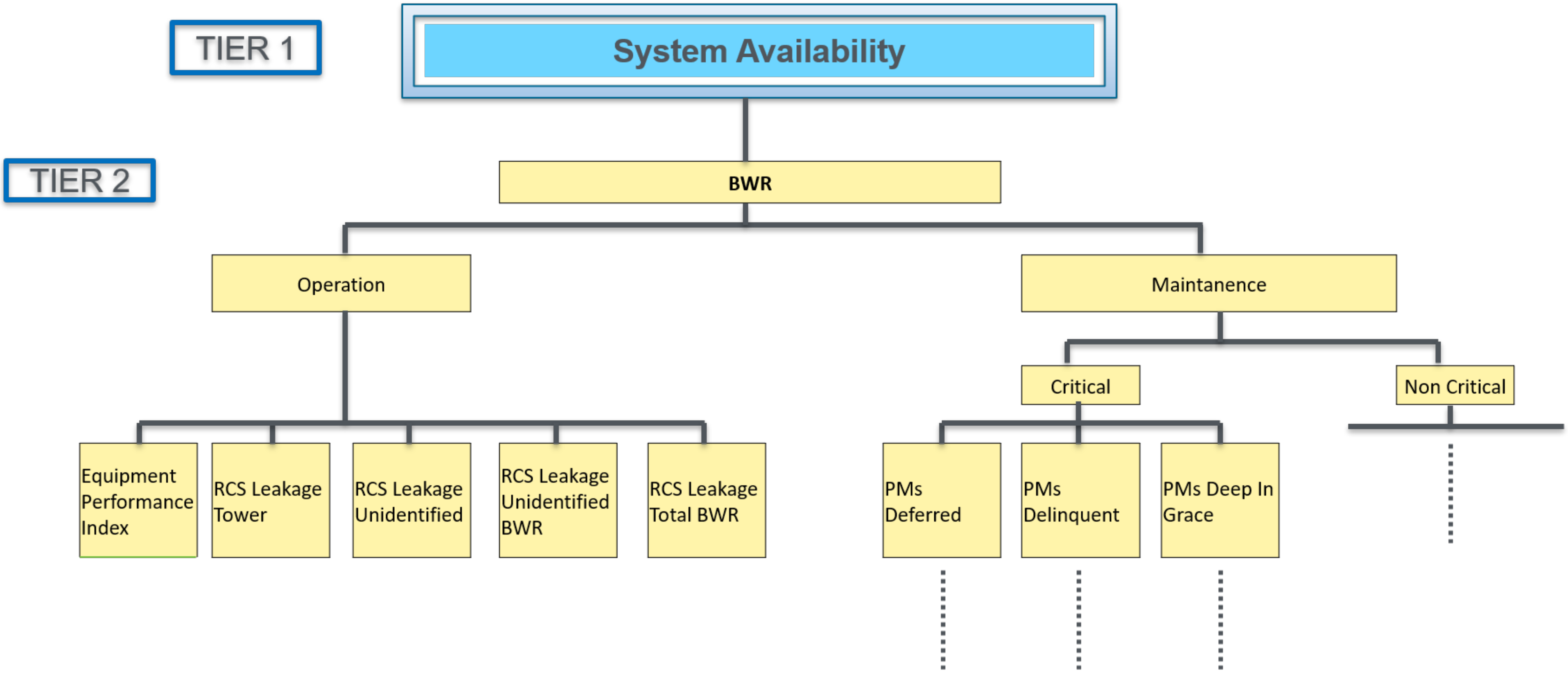
Accomplishments

- System Availability is comprised of several subsystems
- Breakdown of the subsystems is covered in the next few slides
- High pressure injection subsystem



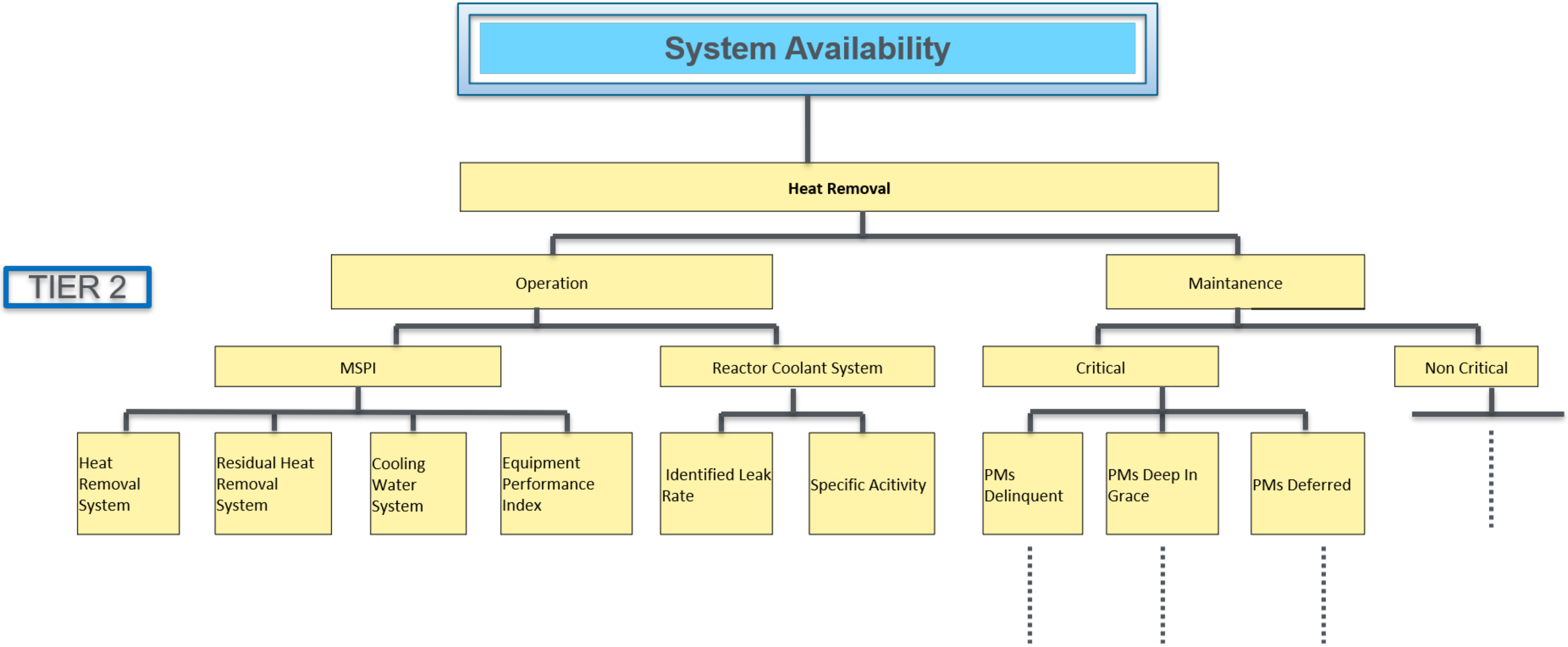
Accomplishments

- BWR subsystem



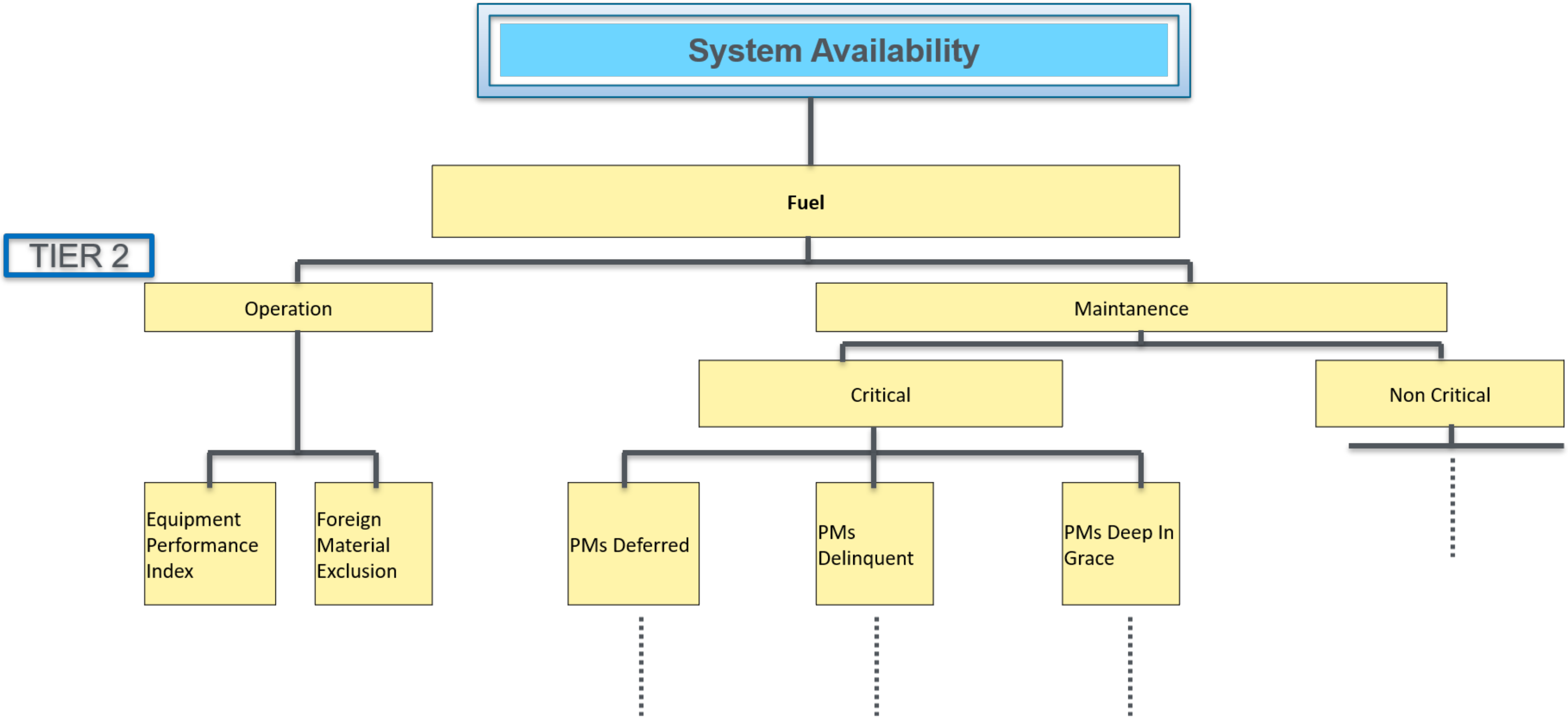
Accomplishments

- Heat Removal subsystem



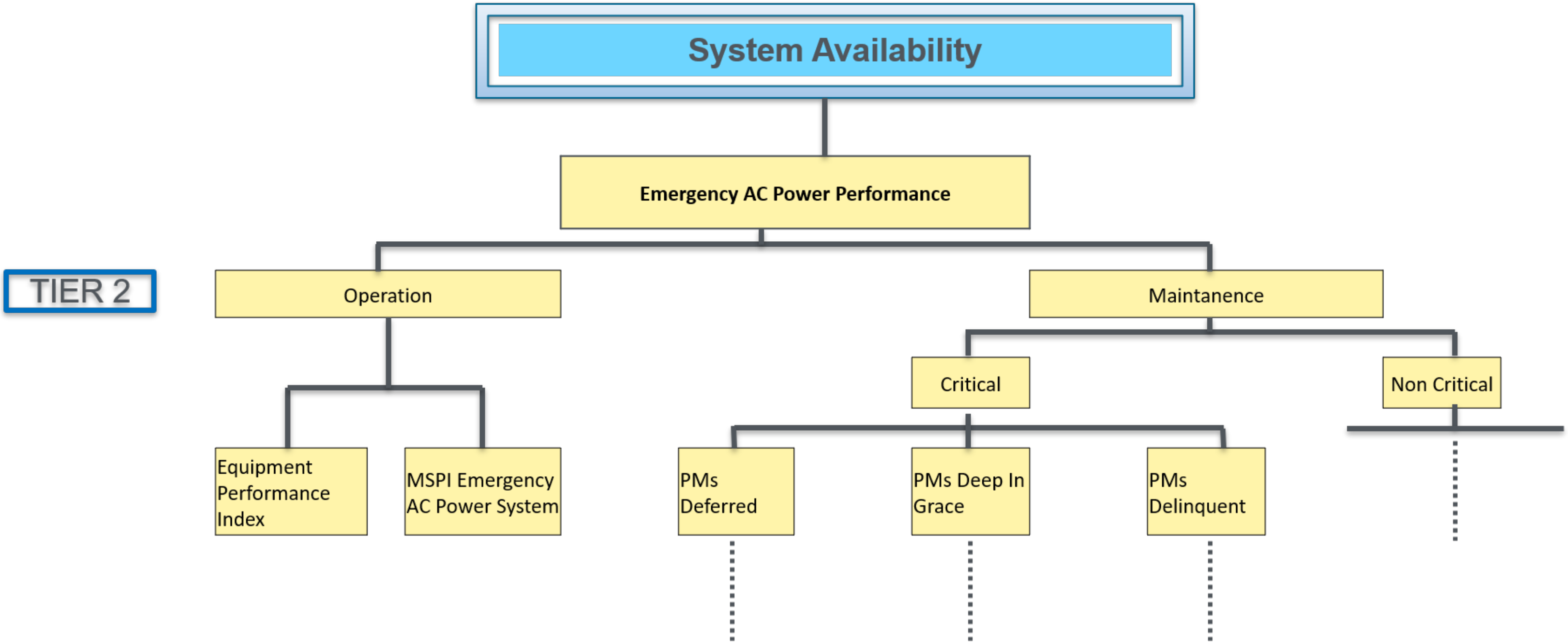
Accomplishments

- Fuel subsystem



Accomplishments

- Emergency AC Power subsystem



Task 3: Conclusions

- Developed a hierarchical KPI representation based on the Sawhney Model for operational excellence.
  - The KPI hierarchy will be validated based on data and discussions with SNC.
- Developed a roadmap for KPI improvement based on the hierarchical representation.
  - The roadmap will be further refined and validated based on SNC inputs
- Successful implementation of this model has the potential to reduce lead times for identification and implementation of KPI improvement efforts.

Summary

- There were several challenges to the project, none of these were unexpected.
  - Getting an NDA agreed to and signed by multiple organizations it always difficult.
  - As with all data analytics projects, communicating your data needs, identifying the systems of interest, and getting access to the correct types of data are all difficult tasks. These are complicated by different data systems at different sites and the proprietary nature of corporate and nuclear process data.
- All three tasks are on schedule and three milestone have been completed with the respective reports submitted.
- Early results will be disseminated in the form of conference and journal publications
- This project contributes by developing data analytics technologies to improve the economical competitiveness of the industry. The inclusion of AMS into the project team allows for commercialization of the products.

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