FY'22 – FECM Spring R&D Project Review

Award FE0032035 –

Predictive Analytics for Thermal Power Plants – Using ML with ORAP® Data

Points of Discussion

- Who is on the Team?
  - ✓ **Advisors**
  - ✓ **Project team**
- Brief overview
  - ✓ **Project review – background of the project**
  - ✓ **Strategic value**
  - ✓ **Advisor input & feedback**
- What's been done so far?
  - ✓ **Do the math**
  - ✓ **It starts with "form and function" – a design process**
    - ❖ **What does it do?**
    - ❖ **What does it look like?**
  - ✓ **Don't forget the data**
  - ✓ **Stick to the plan**
- Questions???

Advisors

- Rick Tomlinson, Chevron Pipeline & Power
- Don Haines, PPOMC
- Steve Worthington, Arizona Public Service
- Ed Fuselier, Kindle Energy

The Project Team

- ✓ Omer R. Bakshi - Project Manager
- ✓ Ashley Reichl - Contract Specialist

Project Leadership, Data analytics & Support, IT

- ✓ Sal DellaVilla – CEO & Principal Investigator
- ✓ Bob Steele – Vice President IT
- ✓ Tripp DellaVilla – Project Manager & Business Analyst

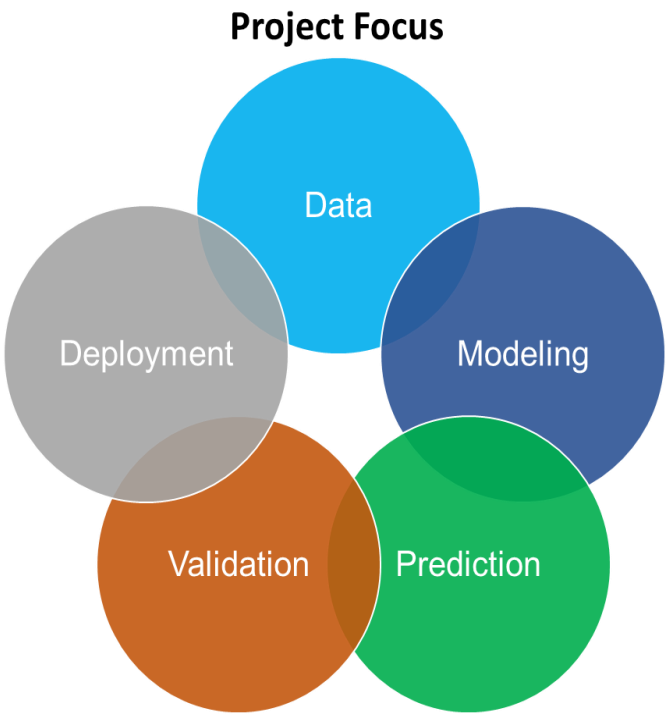
Project Management, Support, and Engineering

- ✓ Chris Perullo – Directing & Supporting technical input & providing SME for modeling & Weibull Analysis
- ✓ Scott Sheppard – Data Analysis
- ✓ Steven Koskey – Data Analysis

Data Analysis and AI/ML Model Building Capability

- ✓ Edgar Lara-Curzio– Leadership
- ✓ Matt (Sangkeun) Lee – RAM Data & Machine Learning
- ✓ Olivera Kotevska – RAM Data & Machine Learning

Roles & Responsibilities



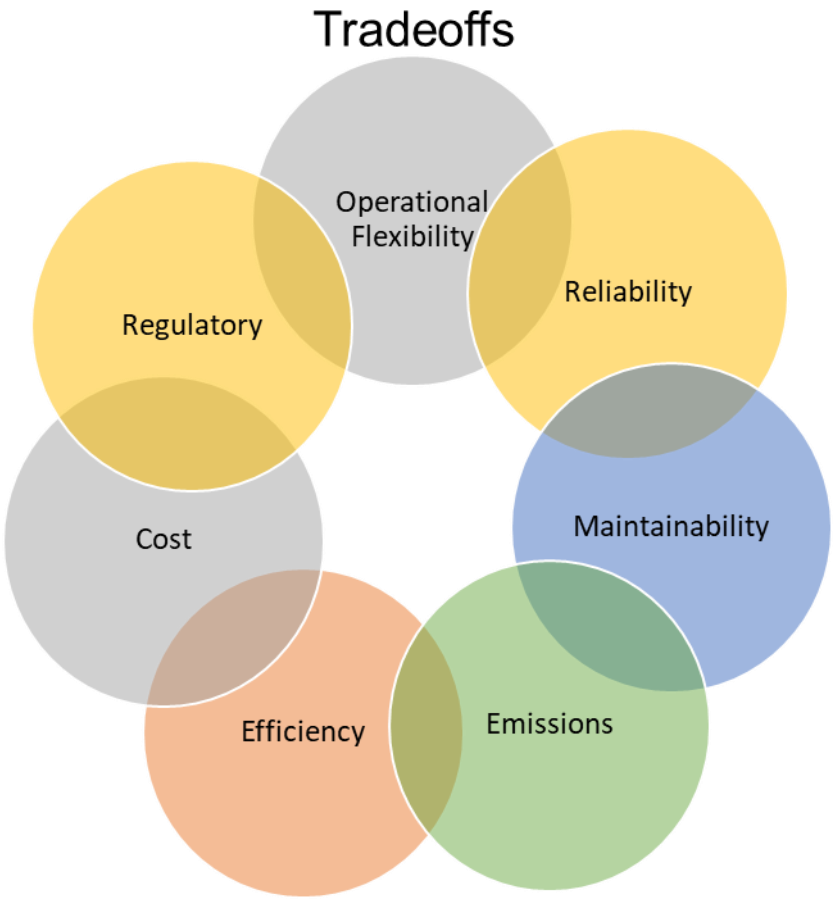
- SPS
  - ✓ Provide project direction & leadership
  - ✓ Provide ORAP data expertise & expectations
  - ✓ Engage Owner/Operators – Participation
  - ✓ Sensitivity analysis, validation and verification
  - ✓ Deployment strategy
- Turbine Logic
  - ✓ Lead ORNL effort
  - ✓ Develop strategy for processing synthetic events
  - ✓ Develop Weibull & simulation model - Python
  - ✓ Prepare for deployment
- ORNL
  - ✓ Refine ML model
  - ✓ Create synthetic events (Unit & technology focused)
  - ✓ Support Weibull modelling
  - ✓ Recommend deployment options – Migrate from HPC

A Review – Background of the Project

- Project work initiated under 2 HPC4Mtls Projects: Performed by NETL & ORNL teams
- Extend the research results beyond the proof-of-concept phase
  - Including verification and validation testing
  - With direct support and collaboration from operating power plants
- Rely on the field data that is available for use in the ORAP® (Operational Reliability Analysis Program®) database
  - Historical Time Series Data to a component level
  - Near Real-Time Process Data (sensor quality process data points)
- Data Fusion: **To benefit operating plants**
  - Not remote monitoring & Not the Digital Twin
  - Reduced plant disruptions – impact of changing service demand (operating flexibility)
  - Understand the impact of more challenging duty cycles (cyclic), readiness for green fuels (H2)

Challenges Facing Plant Operators

- Responding to Faults During Plant Lifecycle
- Anticipating and Reducing the Impact of Impending Failures
  - ✓ Complex technology & total plant
- **Predicting** Plant Events & Outage Durations (Cost)
  - ✓ How quickly can we look back at data for analysis, use and decision-making?
  - ✓ M&D (Monitoring & Diagnostics) Evolved to mitigate OEM (Original Equipment Manufacturer) risks… not to be predictive



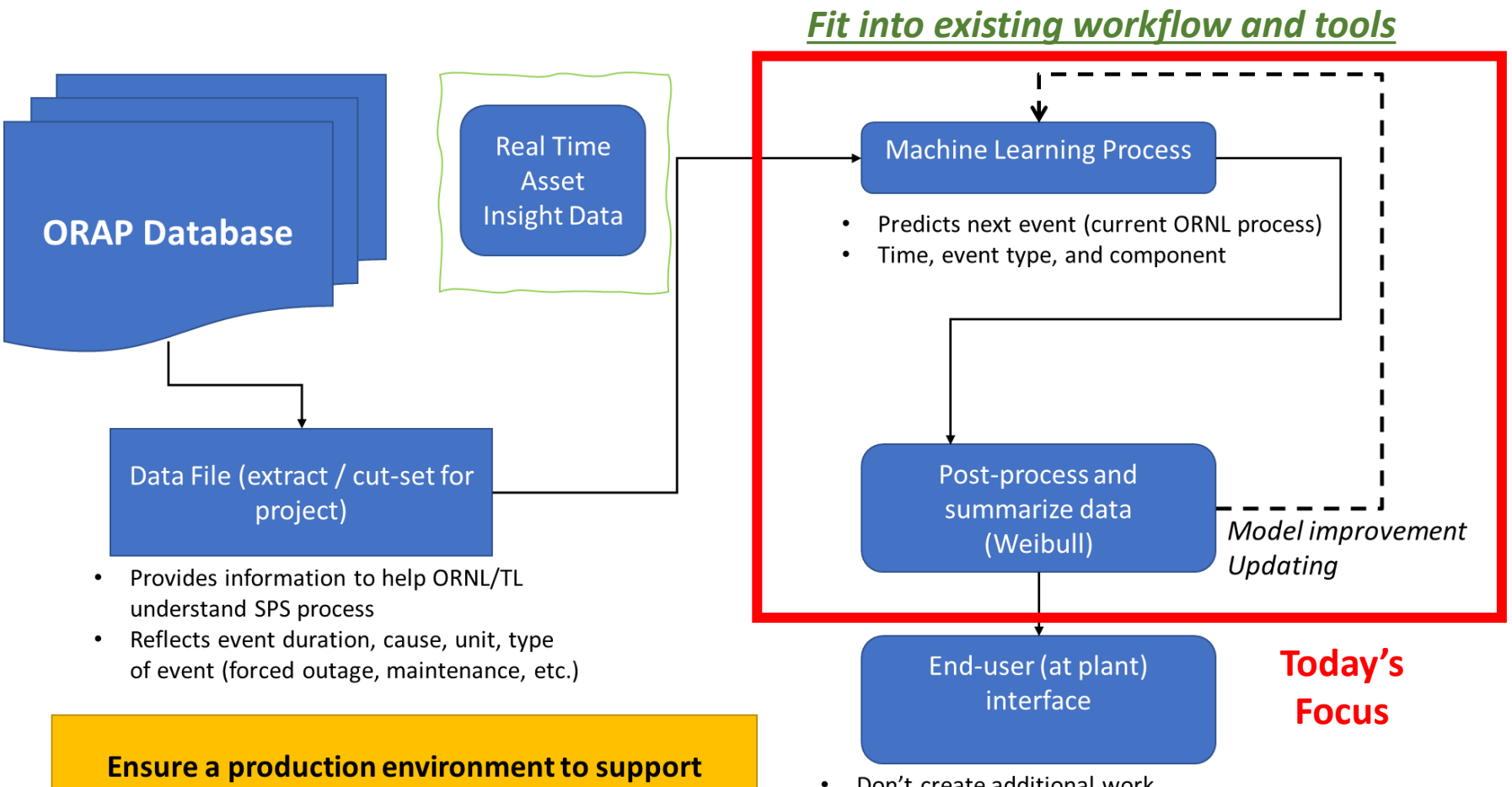
Strategic Value

- It is important to recognize that the owner/operator (Asset Manager) **already have an abundance of technical and operating knowledge, with lots of data at their fingertips**; experience and expertise that, for many, results in “best in class” performance
- The intent of FE0032035 is not to replicate or replace what already works in the Asset Manager’s best interests, rather, its purpose is **to fill a large gap** providing something that **they don’t currently have and that they absolutely need**
- Asset Managers are concerned with **what is going to prevent their operating plant from fulfilling its operating “mission” now**
- They are concerned about issues/events that **they are not expecting to happen**, and when they do happen, **how long it will take to recover and at what total cost**
- The value is to predict the adverse behavior of physical systems, components, materials, and designs with **sufficient time and guidance for cost effective corrective action at the plant**
    - **What, and when, is the next significant event?**

Advisor input and feedback

- **Safety** – not putting people in harm's way is critical to operations.
- Consider the **operating envelope** – can we safely extend outside of the operating envelope
- More automation **less human input** – "Self Sufficient"
- Application needs to be **pragmatic** – it needs to integrate into current practices and be easily useable, not be a totally new workflow
- M&D good at telling you things that are degrading, but **real challenge is one-off events**
- Since we are providing probabilities of failure, will want to **watch out for "false positive-type"** situations for the one-offs
- Need to be sure to **consider downstream components** – especially equipment that may be shared across units at the plant, such as boiler feed pumps that may be shared among two HRSGs

What's the big picture?

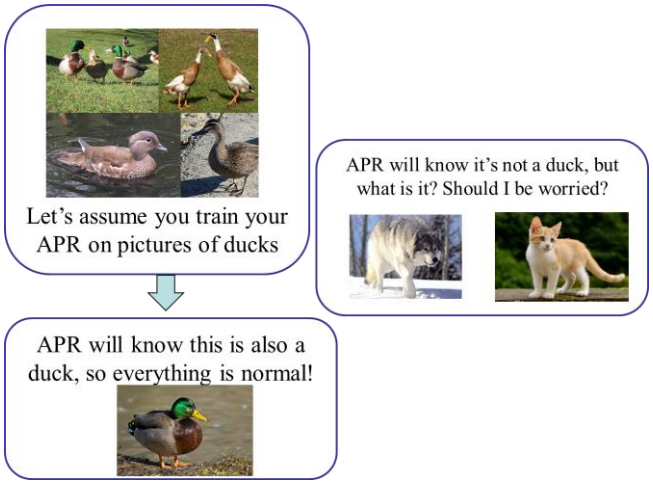


What's Been Done Since We Last Met?

- Defined how to process ORAP data to answer:
  - **What will prevent operating mission now?**
  - **What issues should I be aware of that I am not expecting to happen?**
- How have we done this?
  - Fundamental information to answer these questions already exists in ORAP
  - Defined processes, methods, and algorithms to transform the data to provide additional insight
  - Defined output metrics that will **automatically** be generated from ORAP data
    - What are the *current* probabilities of an adverse event for each of my components?
    - What is the expected duration to recover from an event? (-> Cost)
    - Based on my operations, what are…
      - My likely future events?
      - Which components?
      - When?

Form and Function – What is Needed?

- Current AI Software (Most of you Use Today)
  - Generic – designed to work for any asset
  - Generally based on pattern recognition
- Pros
  - Adaptable – easy to setup and make models
- Cons
  - Lacks any domain knowledge
  - Data is local to your operations
    - Ok for data rich sources, **reliability problems are generally rare events**
  - Many false alarms



Purpose Built AI/ML for ORAP. Not another generic tool

Form and Function – What Does it Do?

Issues with Current Commercial AI/ML Approaches	*Solution – The Data*	*Solution – The Models*
Lack of Domain Knowledge	ORAP data contains domain expertise implicitly	AI/ML designed specifically for ORAP dataset and user needs
Lack of sufficient quantity of data	ORAP provides large dataset of events	Anonymized data provides opportunity for models to learn from fleet experience
False Alarms	ORAP data carefully vetted and validated	Provides probability of event – allows you to set your own risk threshold

Purpose Built AI/ML for ORAP. Not another generic tool

Do the math… Where am I and Where am I going

Where am I?

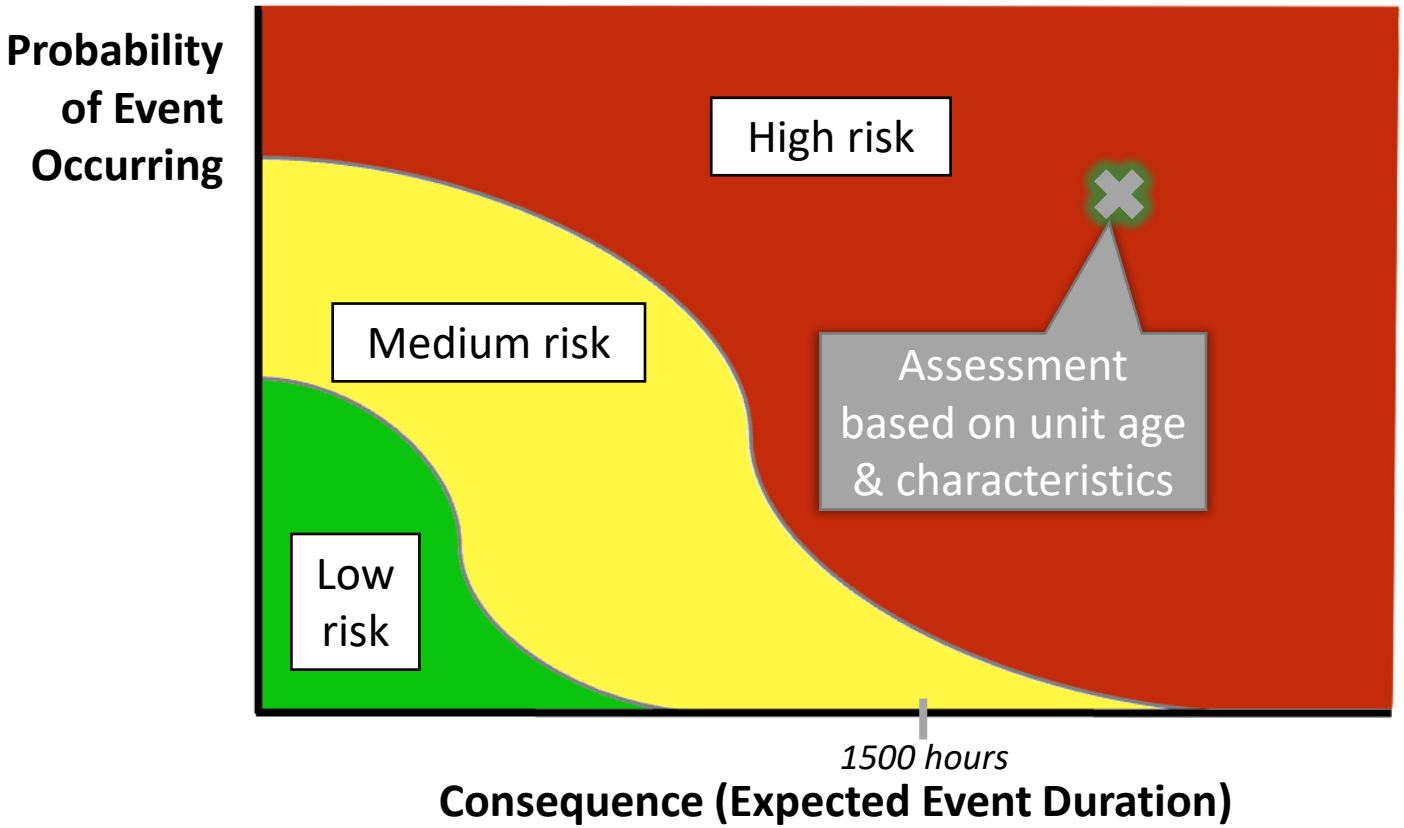
Fleet Risk Identification Scoring

Goal: **Provide automated risk scorecard**

- Example using four components
  - Flame Detector
  - Combustion Thermocouple
  - Fuel Nozzle
  - Inlet Journal Vibration Sensor
- Looking at risk of forced event based on current operations and unit characteristics
  - Could filter on other event types (e.g., maintenance)

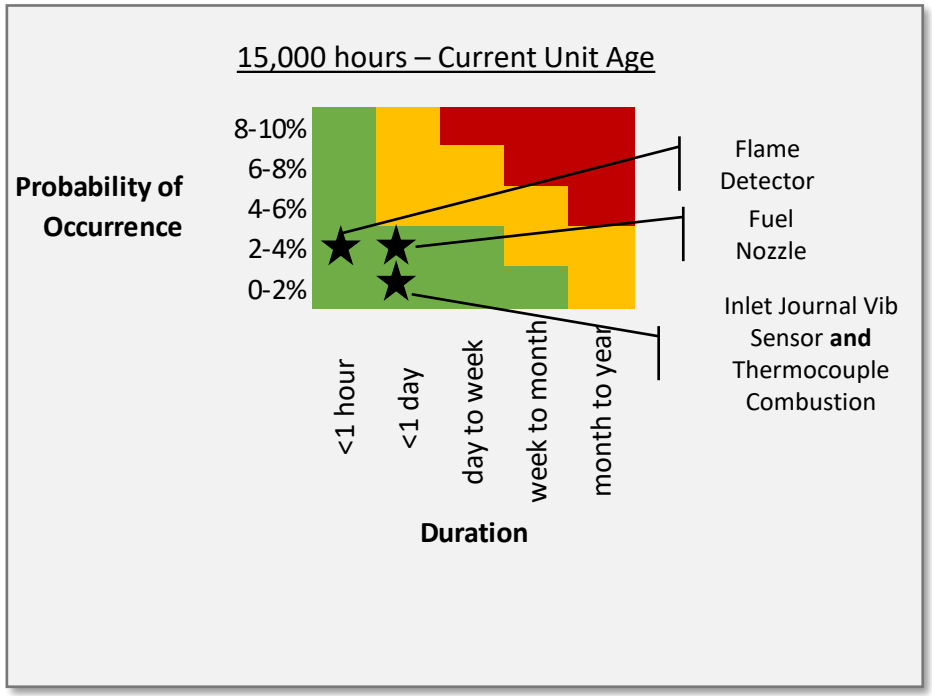
- Numbers based on ORAP data – but exact calculation methods being finalized – use for example only

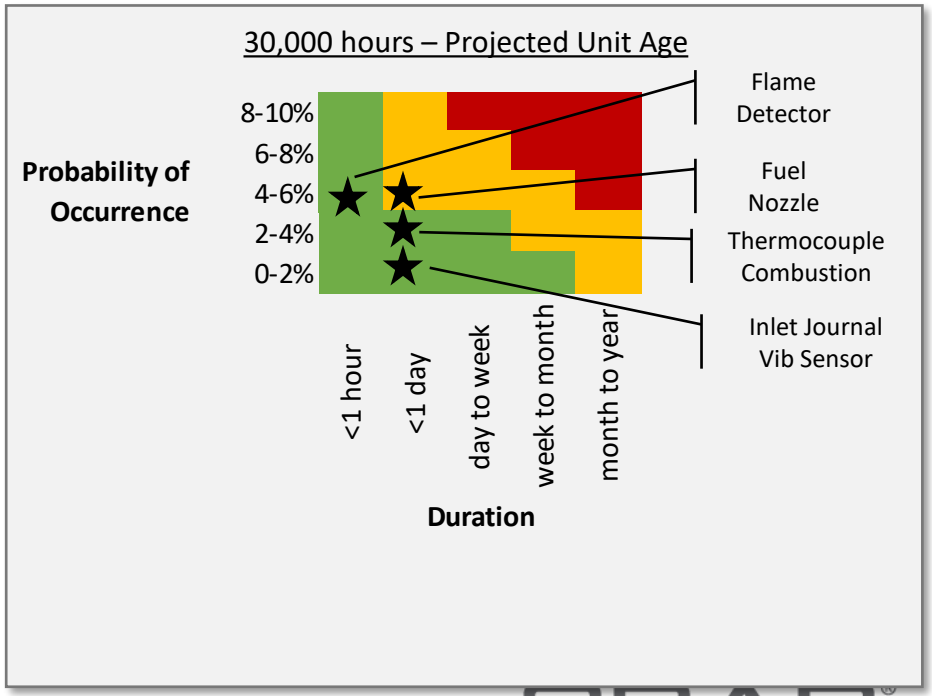
Risk Benchmarking Goal (Example Only)



Predicting Issues You Aren't Expecting

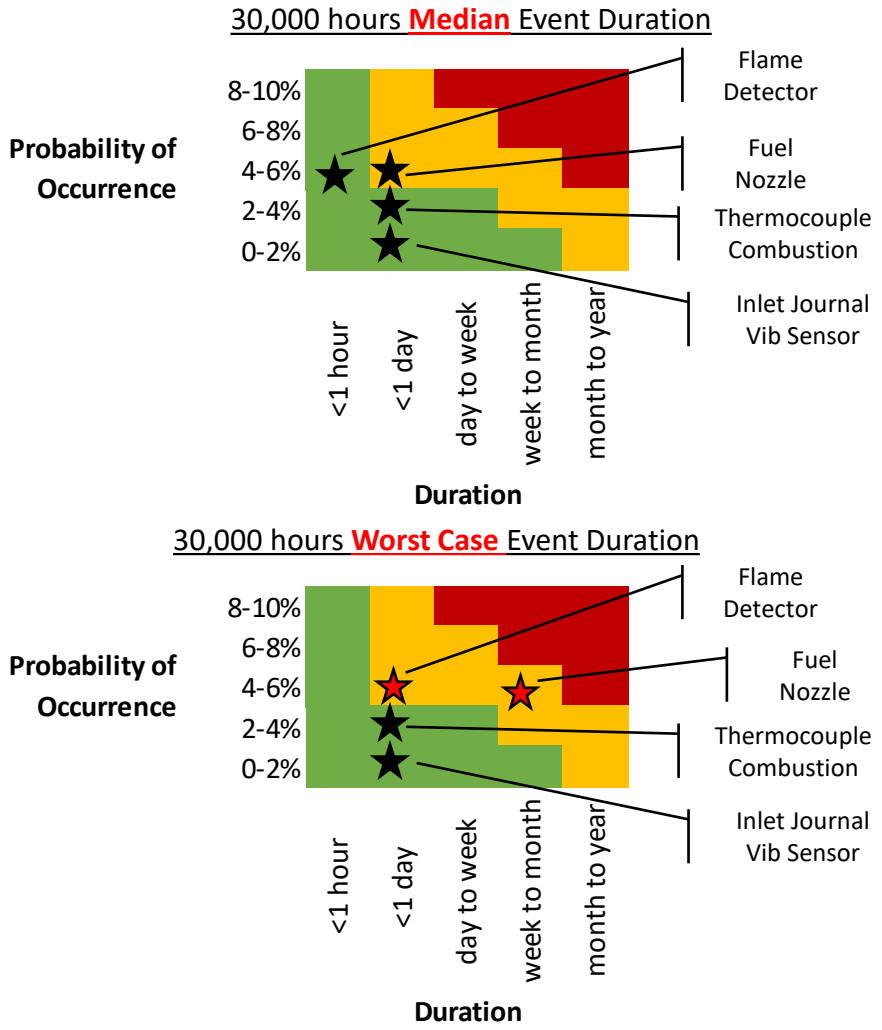
- Leverage ORAP Data to identify events that will prevent you from completing mission now, and in the future
  - Leverages ORAP data and your unit's history
  - Set your individual risk tolerance to provide guidance and time for cost corrective action
- Risk
  - Probability of an adverse event
  - Cost – Using estimate of recovery time as surrogate for cost





Risk Benchmarking

- Automated identification and reporting of:
  - Personalized reporting of high-risk components based on current experience
  - Personalized reporting of high-risk components in next year based on projected operations
  - Fleet emerging issues
  - Automated identification of recurring issues at higher than expected frequency
- Points for discussion:
  - Defining the consequence side of risk – is duration sufficient?
  - How to accommodate risk tolerance?
  - Is event duration benchmarking useful in its own right?

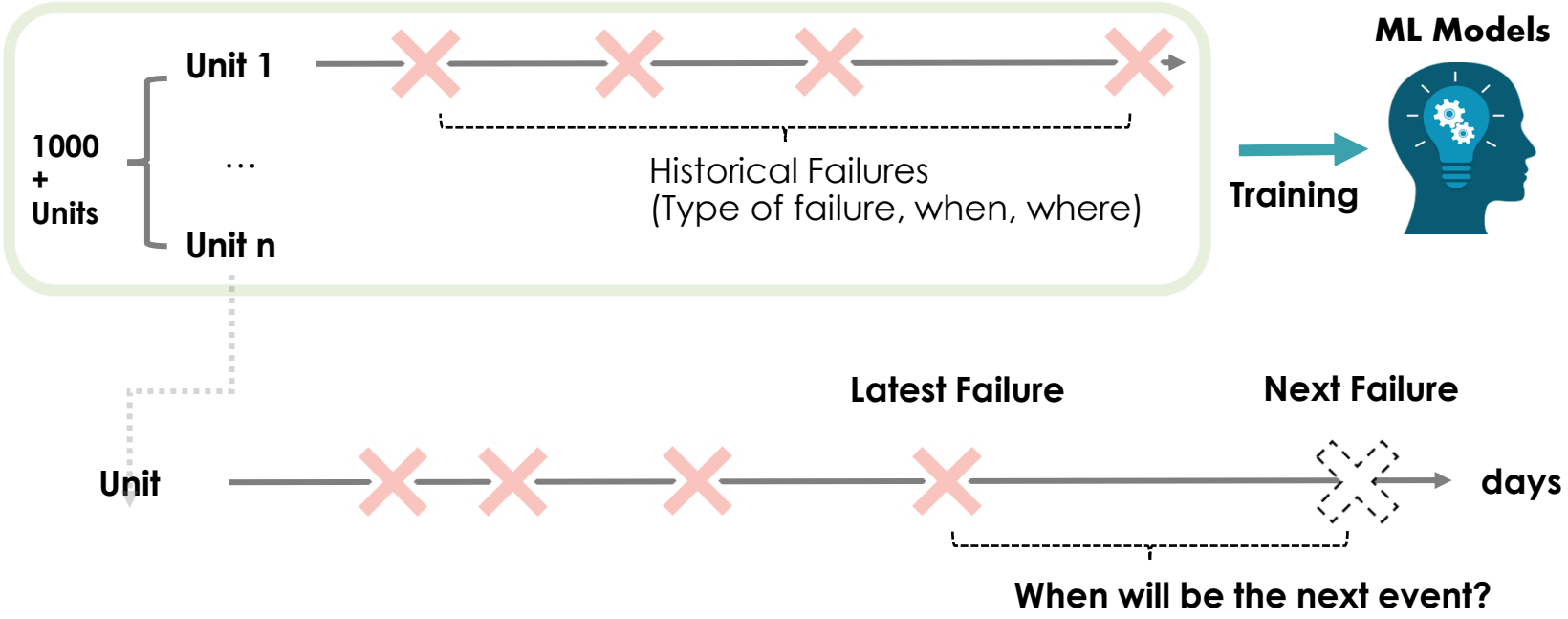


Projected Failures (Where am I going?)

- Advanced AI can also help predict
  - When will the next event be?
  - What type of event and what component is likely to be affected?

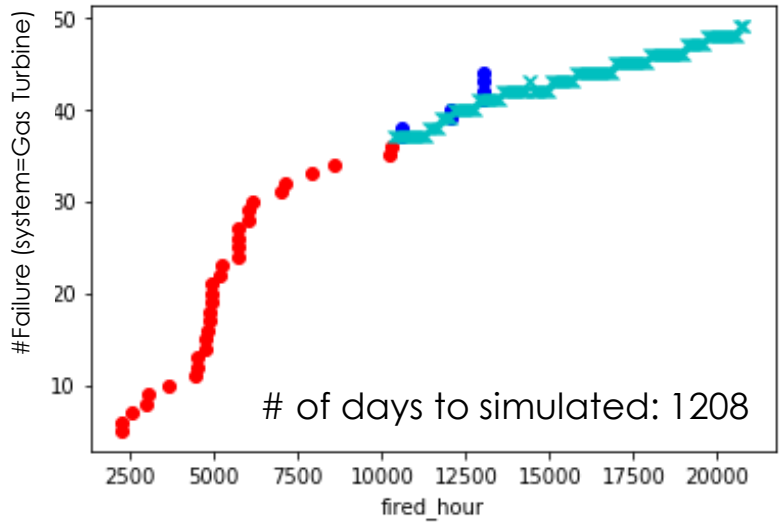
Next Failure Prediction

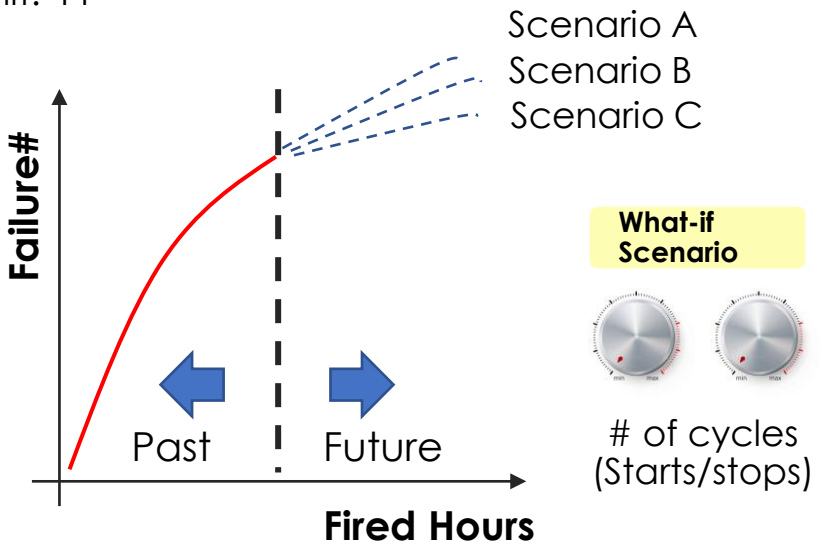
- **Learn from the ORAP Data and Predict**
  - When will the next event be?
  - What type of event and what component is likely to be affected?



Next Failure Prediction

- **Example** Unit ID: 4261 Simulation Date: 2017-03-31 12:00:00
  Total # of actual events for this unit: 44





Different operation profiles can be simulated

Red : Failure Data Included for Training
Blue : Failure Data not included for Training for validation
Cyan: Prediction from the model

What does it do?

- Two major focus areas
  - What is my current risk? What should I be paying attention to?
  - Where am I going? What will my emerging issues be?
- Leverages learning from fleet leaders (ORAP Data) and your unit's experience

What Does it look like?

Past
What failed?
Should it have happened?
Was it costly?

Prior Events and Benchmarking:

- In the last twelve months you had the following events:

Event Type	Component	Duration	Comparison to Rest of Fleet	Should this Have Happened?
Forced Outage Automatic Trip	Flame Detector	1.5 hours	Average	Yes
Forced Outage Automatic Trip	Thermocouple Combustion	85 hours	Significantly Higher (top 5%)	Unlikely

Current Events Expected to Happen Today:

- ORAP Fleet Benchmarked Risk Items:

Low	Medium	High
Flame Detector		
Fuel Nozzle		
Inlet Journal Vibration Sensor		
Thermocouple Combustion		

Present
What might stop you today?
What are fleet emerging issues?

Future
Based on ORAP fleet experience – what might cause problems?

Events at Risk In 12 Months:

- Fleet Benchmarked Risk Items (Italicized text indicates no change from today):

Low	Medium	High
Flame Detector	Fuel Nozzle	
Inlet Journal Vibration Sensor		
Thermocouple Combustion		

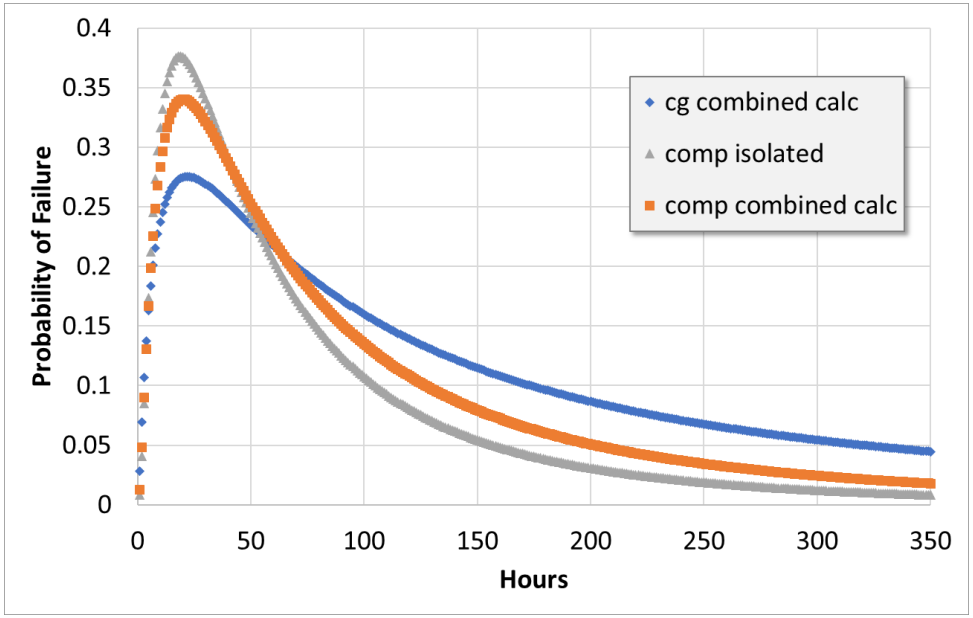
Automated Reporting with Focus On Key Information

Don’t forget the Data

- Event Data to Component Level based upon Hierarchical Equipment Breakdown Structure (EBS):
  - Major System> System> Component Group> Component
  - Similar Components across Different Systems have same component level code:

    Compressor Discharge Temperature Sensor GTCPIC070

    Exhaust Gas Thermocouples: GTTBIC070
- Investigating ways to utilize similar components to inform distributions of Downtime



Don’t forget the Data

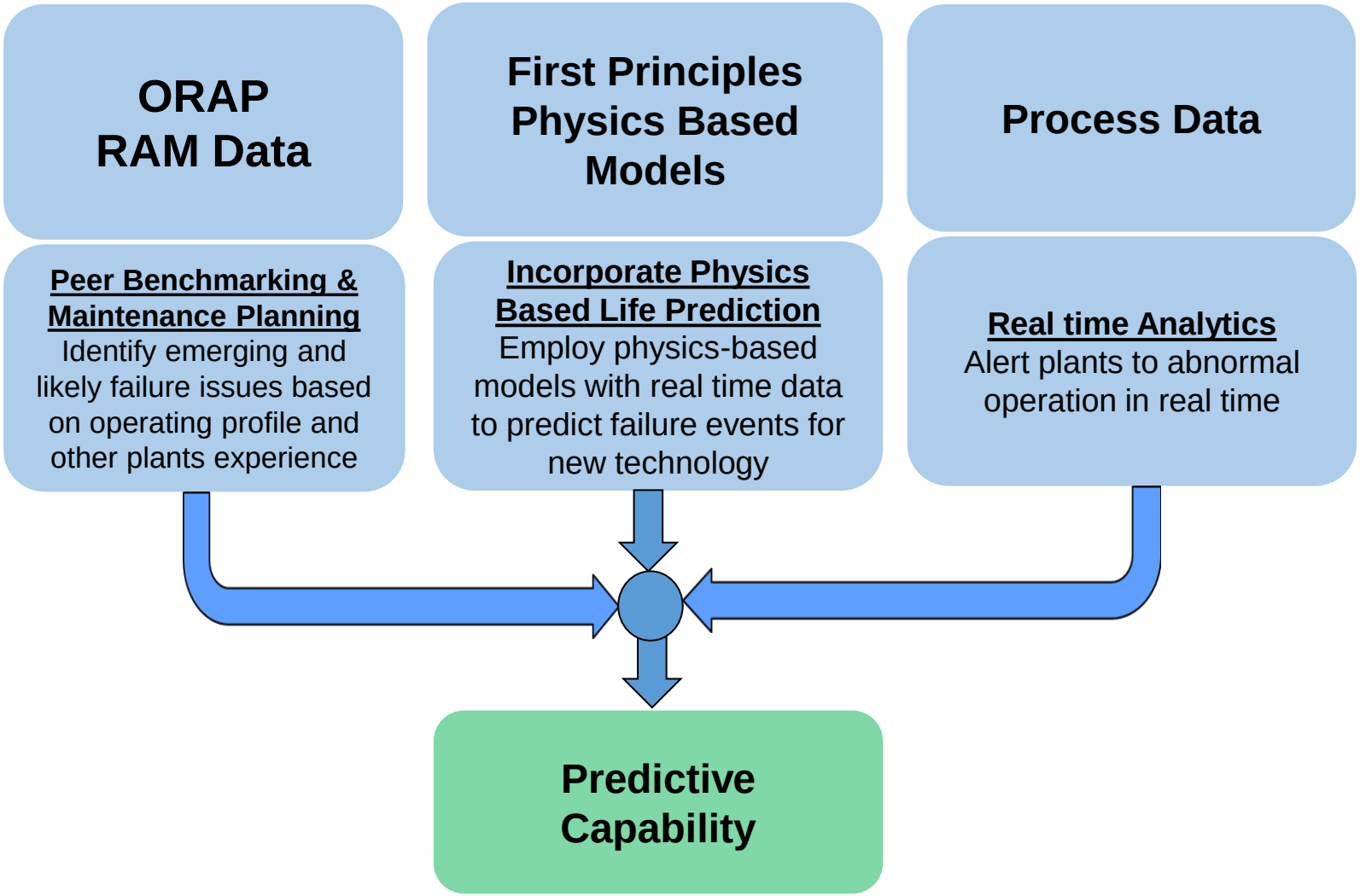
Initial Extracts from ORAP – 4 Designs

- Period from January 2010 to December 2021
- Simple-Cycle & Combined-Cycle Across Various Duty Cycles and Applications
  - Heavy Duty Frame Gas Turbines:
    - GE 7E/EA
    - GE 7F (Including 7F.03, 7F.04 & 7F.05)
    - Siemens SGT6-5000F (Previously Westinghouse 501F)
  - Aeroderivative
    - GE LM6000 (Various Models SAC & DLE)

Sample	Unit-Years	Average Service Factor (%)	Average Service Hours per Start	# Forced Events	# Maintenace Events
7E/EA	3,176	19	25	11,972	15,525
7F	3,853	60	75	21,008	15,912
SGT6-5000F	1,705	64	107	11,155	6,878
LM6000	4,084	37	28	36,961	29,703

Stick to the plan

Data Fusion =



Wrap up/Close out of meeting

Milestones

Data	See Prediction	See Prediction	
Modeling	See Prediction	See Prediction	
Prediction	Augmented Reliability Prediction with Real-Time Data Analysis - 10 months after project start April 8, 2022 In Process: 5% Complete	Incorporate Weibull Analysis into AI/ML Approach - 3 months after Comparison of AI/ML & Conventional Analysis July 15, 2022 In Process: 5% Complete	
Validation	Field Validated Physics Lifing Model - 8 months after project start October 1, 2022 Not Started	Comparison of AI/ML Approach to Conventional Analysis - 10 Months after Project Start April15, 2022 In Process: 20% Complete	ORAP Acceptance Criteria - 11 months after project start April 8, 2022 In Process
Deployment	Identify ORAP Participants for Field Test & Demo - 14 months after project start August 16, 2022 Not Started	Field validated Operator Reviewed Models - 18 months after project start December 30, 2022 Not Started	

Thank You