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

Advanced Sensors and Instrumentation

Advanced Online Monitoring and Diagnostic Technologies for Nuclear Plant Management, Operation, and Maintenance

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

October 30 – November 2, 2023

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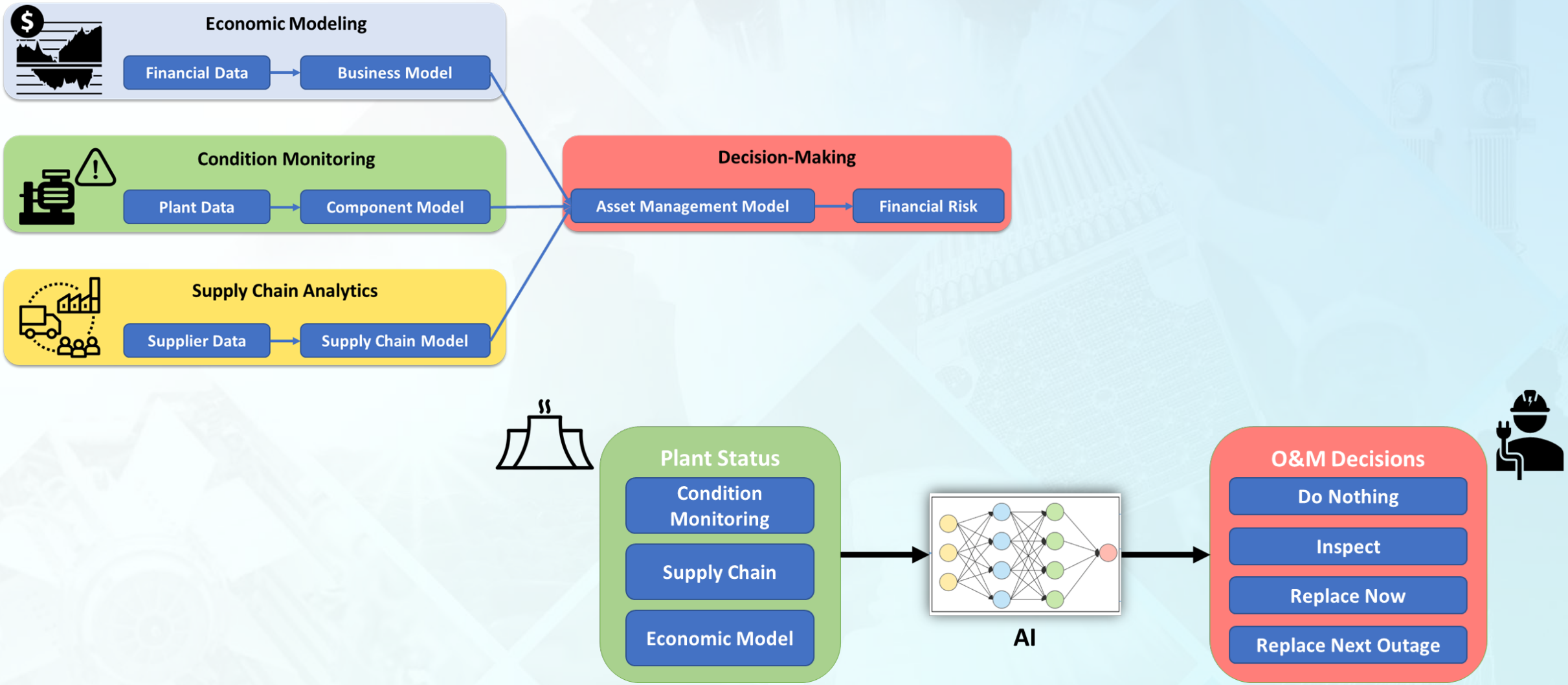
Integrating condition monitoring, supply chain analytics, and decision making, we can improve asset-management for nuclear O&M



Technology Impact
The goal is an integrated approach for long-term decision-making for plant operation

Utilities would be better able to manage plant O&M

Minimize staffing levels with real financial impact.

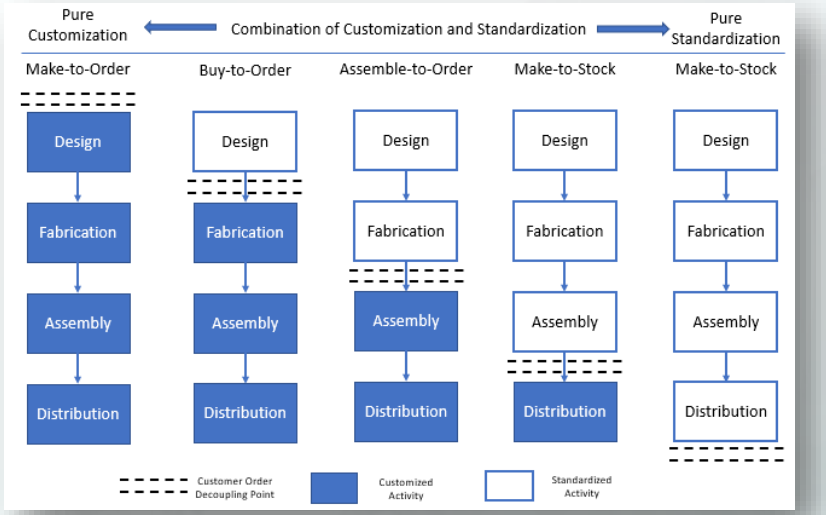
The asset management analysis will support decision-making for

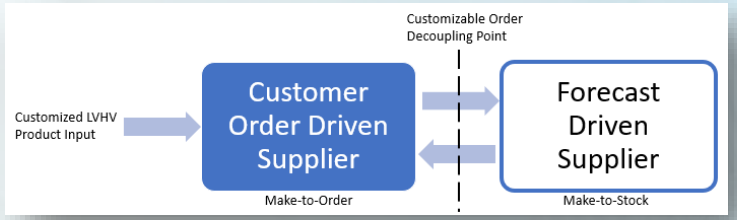
- **SSC replacement and asset management**
- **supply chain, resource availability, and outage planning**
- **license extension for long-term operation**

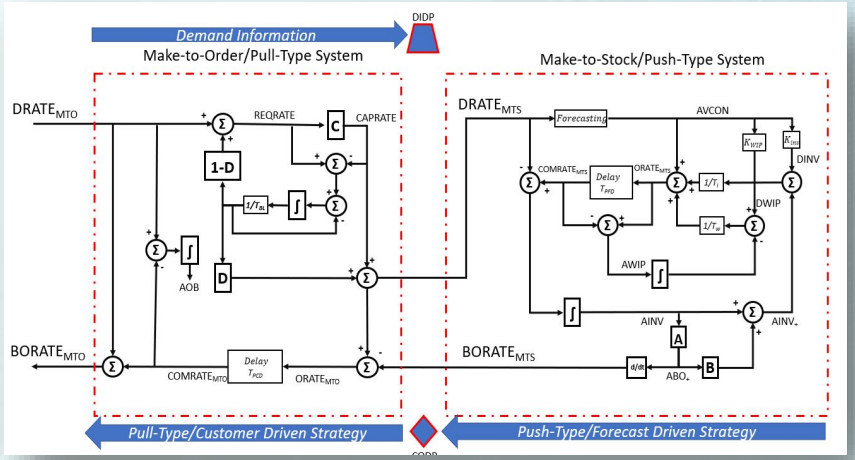
By better accounting for obsolescence and replacement in financial decision-making, utilities can optimize costs.

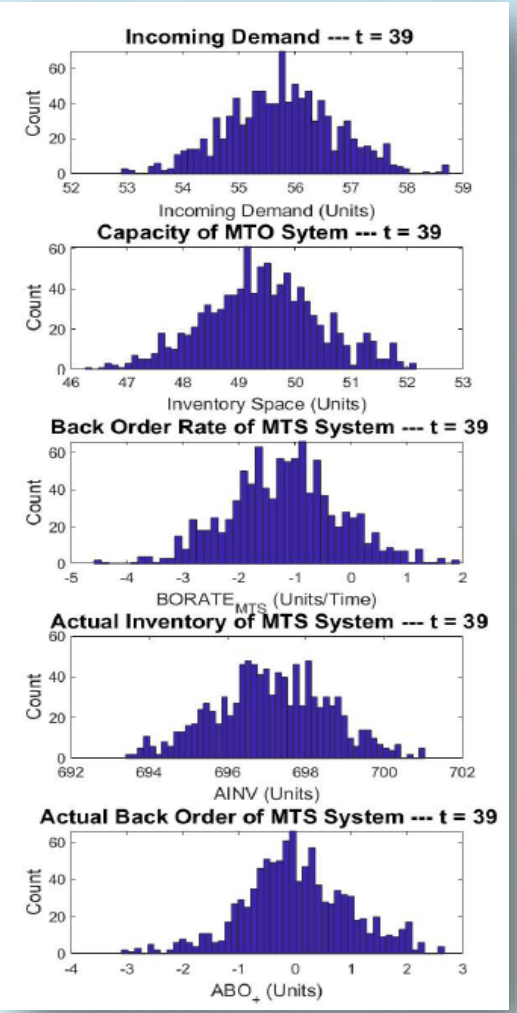
The proposed technology can be applied to different reactor designs or fuel cycle applications.

The inventory of upstream suppliers can be estimated to reduce the uncertainty in available resources

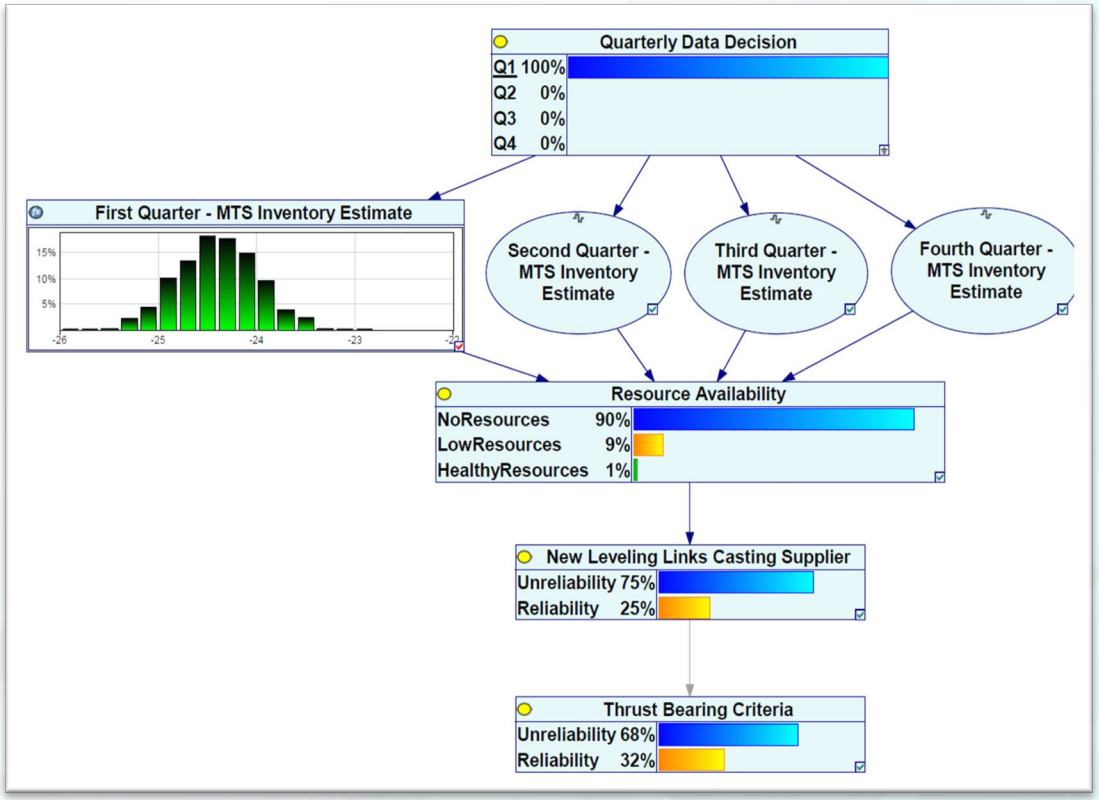


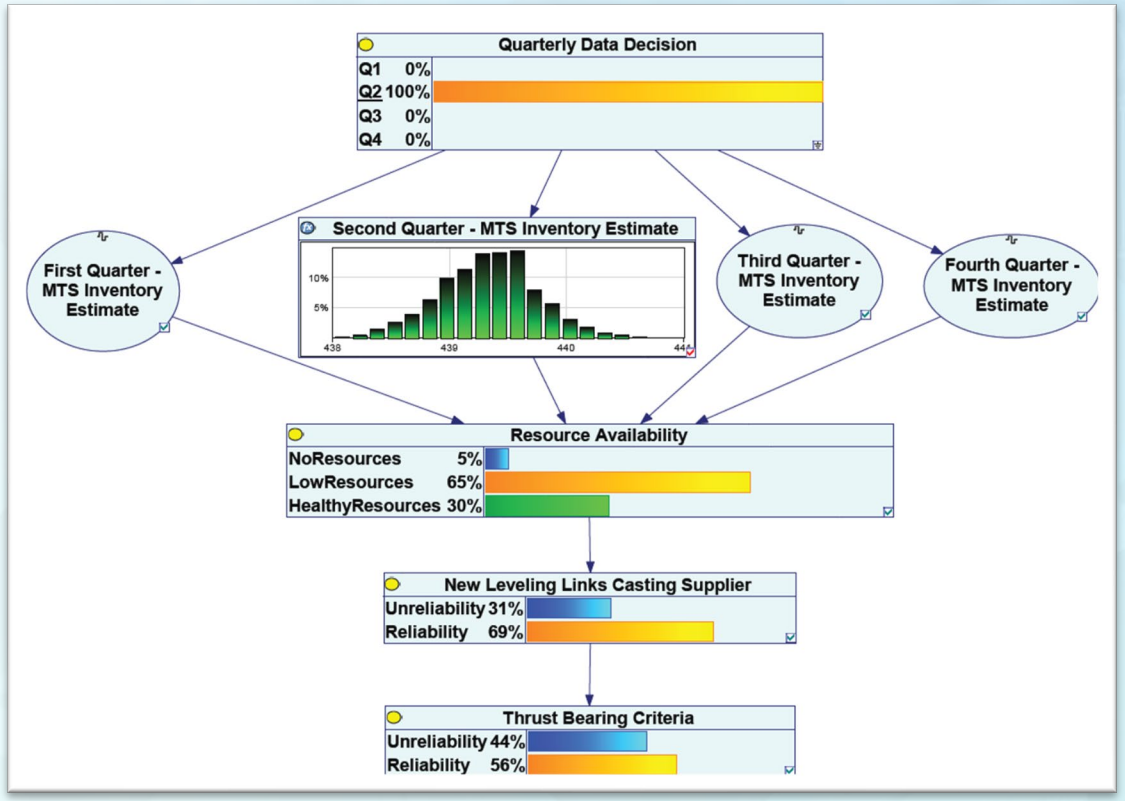




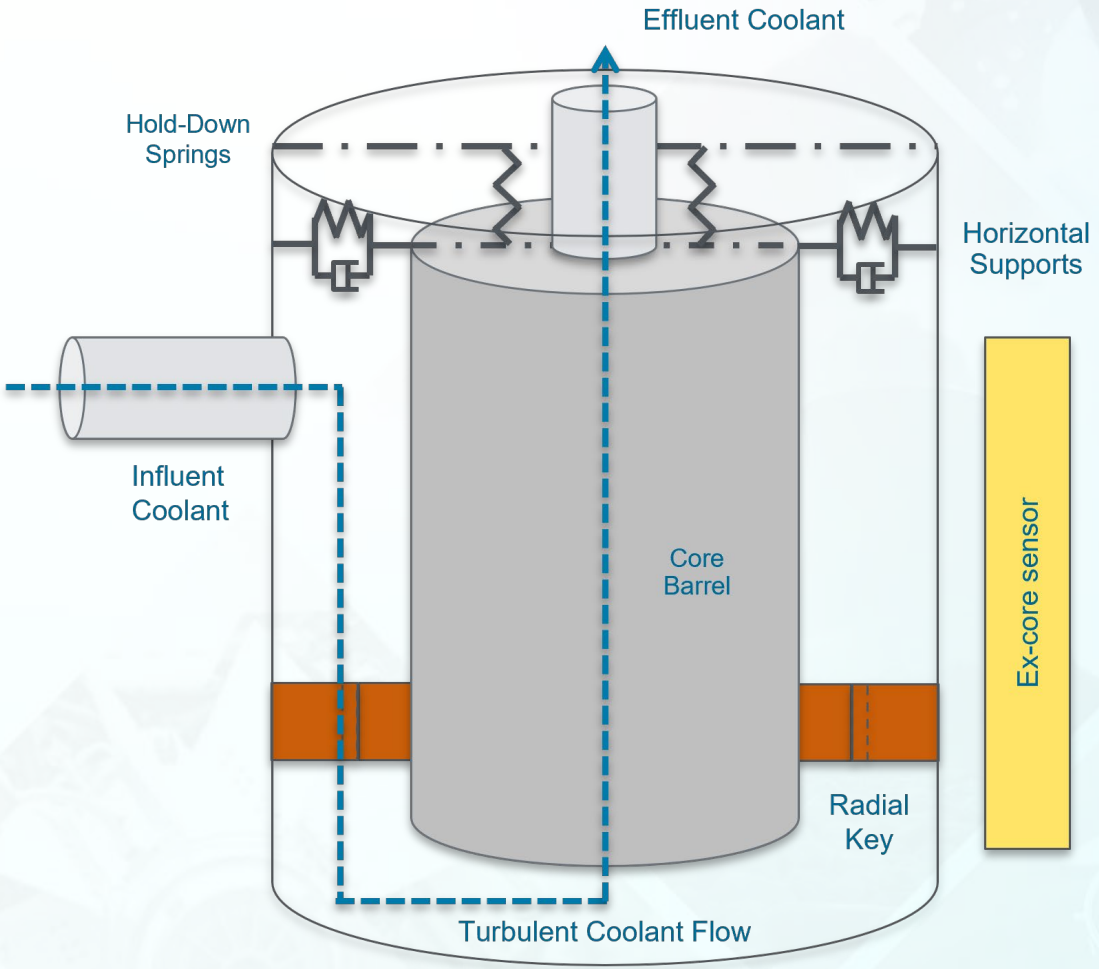


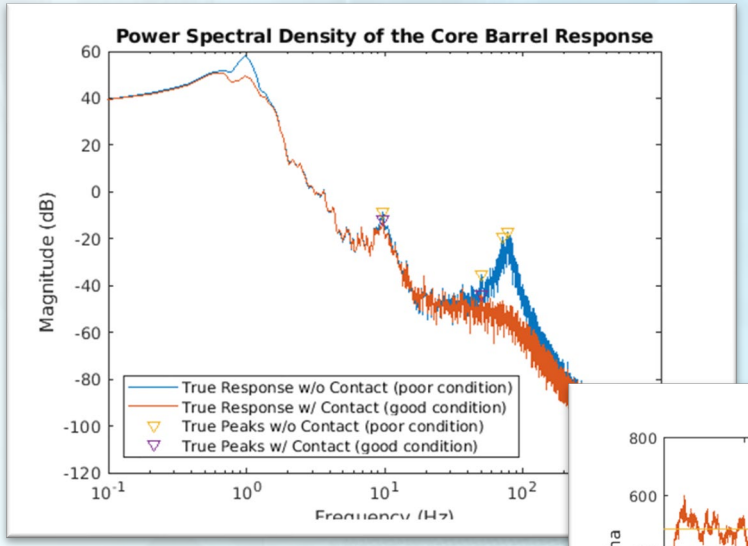
Bayesian networks can be trained to determine the likelihood of resource availability

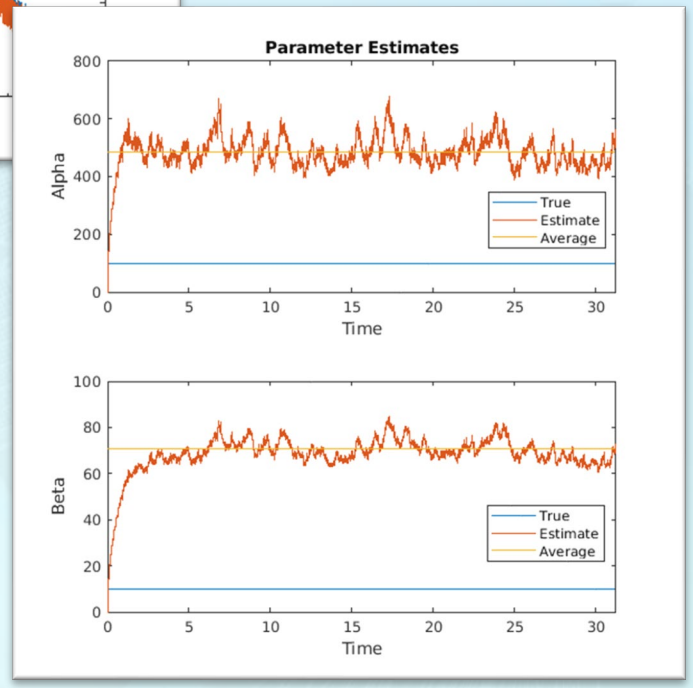




By measuring turbulence-induced vibrations using the ex-core sensors, we can infer the condition of reactor vessel internals

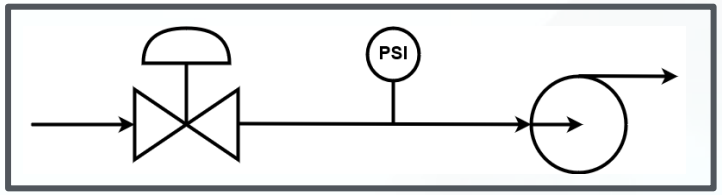






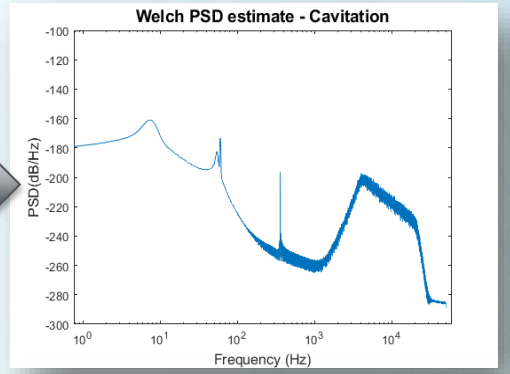
We combined physical laws and Bayesian network models to provide a health estimate of structures, systems and components

Valve position **Suction pressure**



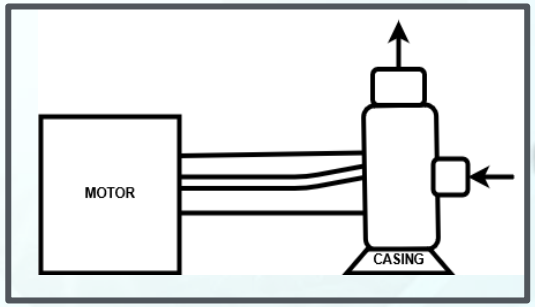
Cavitation

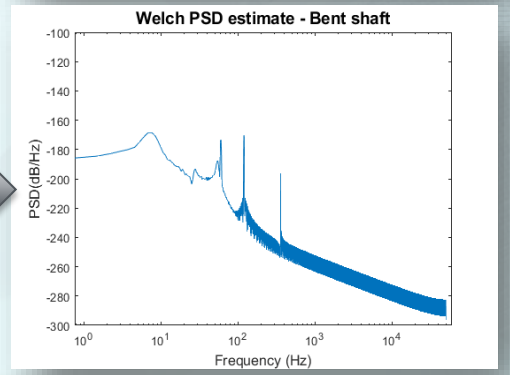
Vibration response

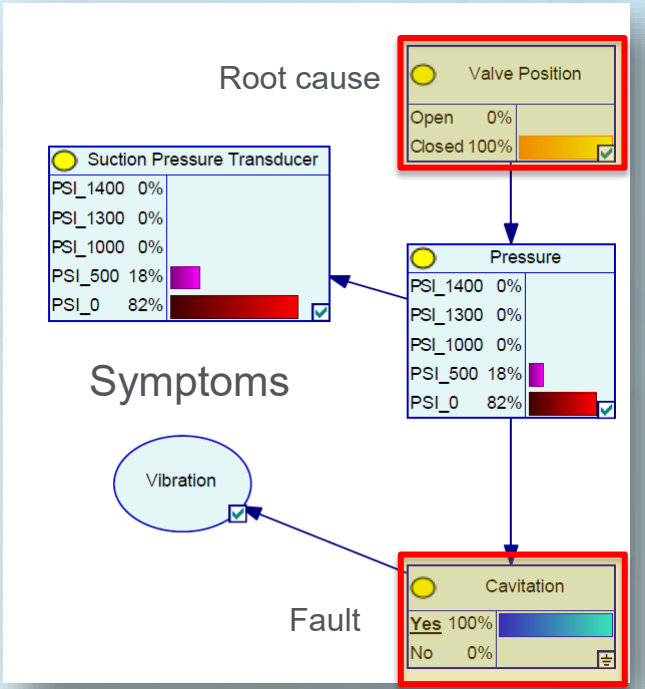


Coupling lubrication

Bent shaft



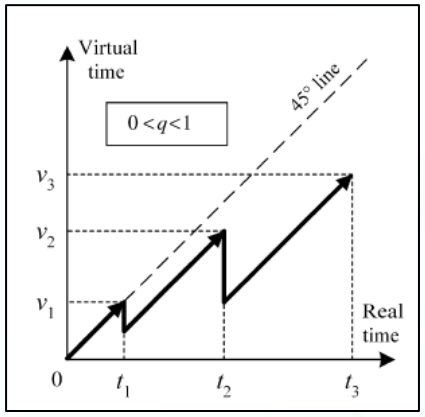


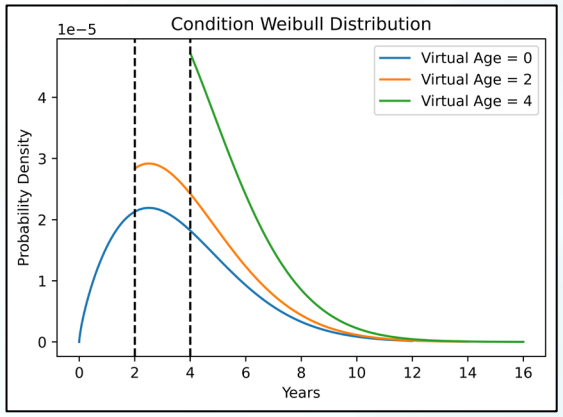


http://blog.pes-solutions.com/pump-impeller-cavitation-major-causes-and-prevention/
https://www.machinerylubrication.com/Read/844/lubrication-rolling-bearings

The generalized renewal process model fits the repairable system data better than MTBF

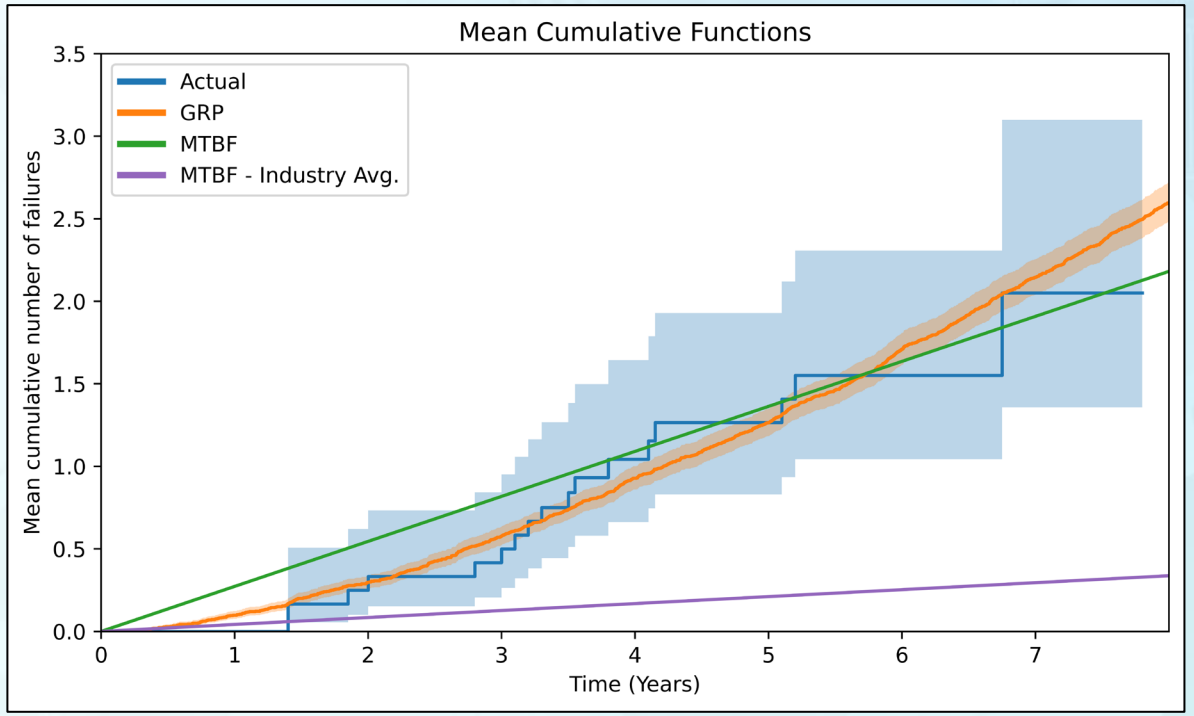
Generalized Repair Process (GRP)



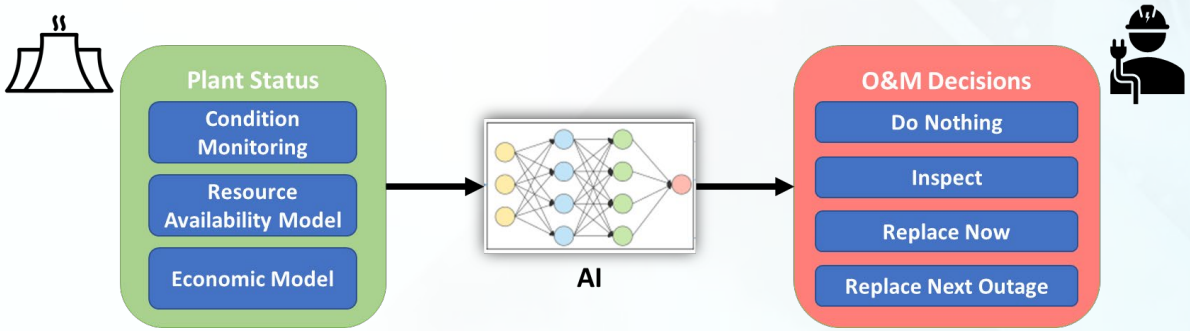


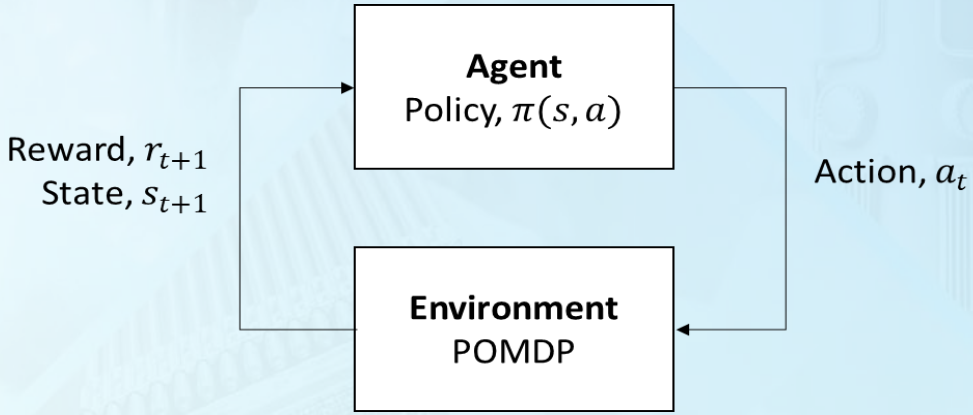
Parameter	RP	NHPP	GRP (Type II)
λ	0.1724	0.0800	0.0780
β	1.38	1.71	1.80
q	0	1	0.642
Log-likelihood	-38.22	-37.08	-36.90

Mean Cumulative Number of Events



Using deep reinforcement learning, we can train a decision-maker to reduce overall costs

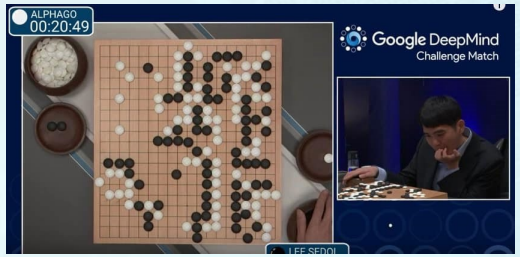




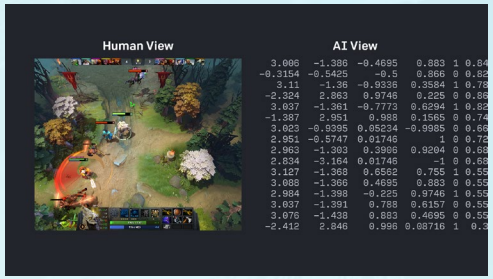
Deep Reinforcement Learning (DRL):

- **Two major components:**
  - **Environment**
  - **Agent (decision-maker)**
- **Learns through trial-and-error**
- **Maximizes expected long-term reward**

Go (Google DeepMind)

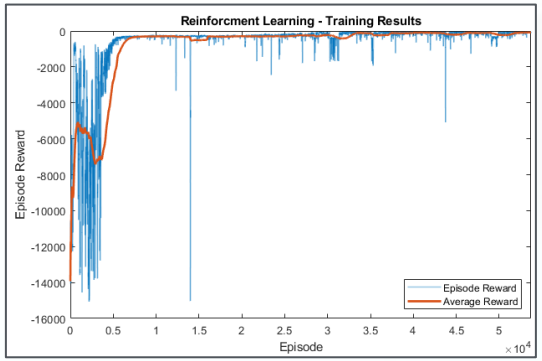


Dota 2 (OpenAI)

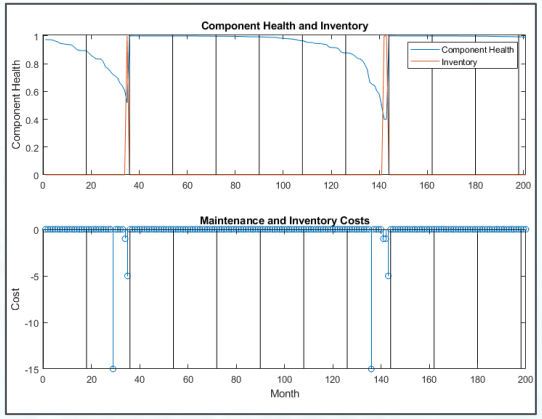


An agent was successfully trained to make maintenance and inventory decisions, minimizing overall lifecycle costs

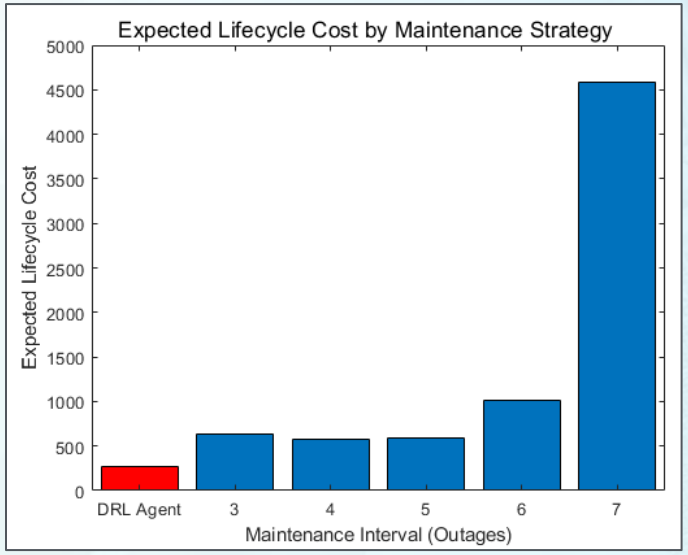
Training

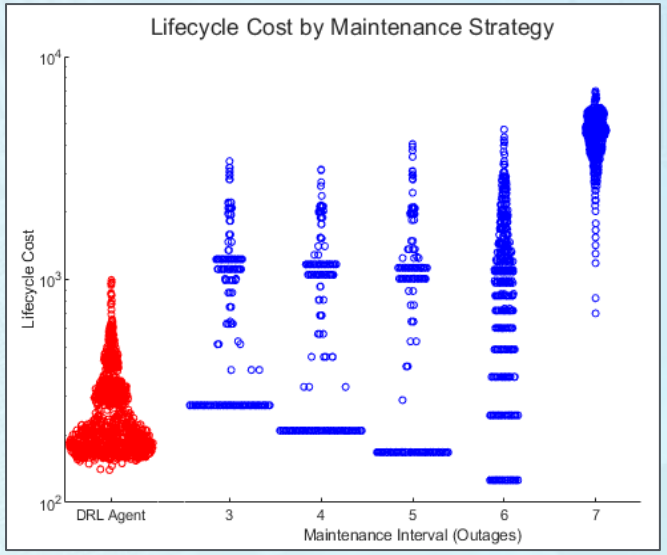


Simulation



Results

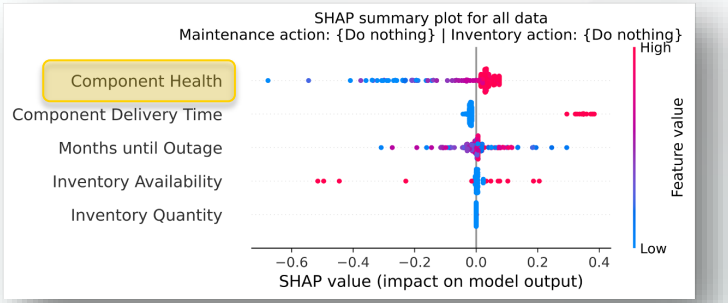




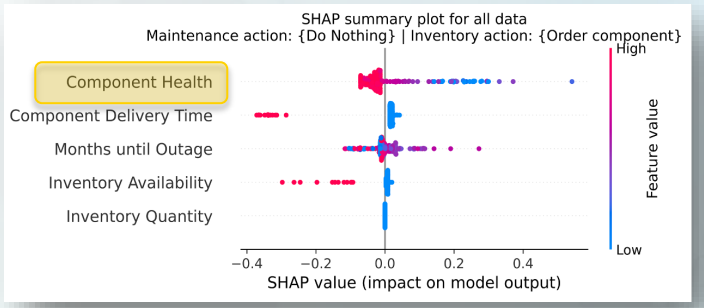
53% cost reduction in expected life-cycle cost

The AI has already decided to replace the component when it ordered a spare. Replacing is based on available inventory.

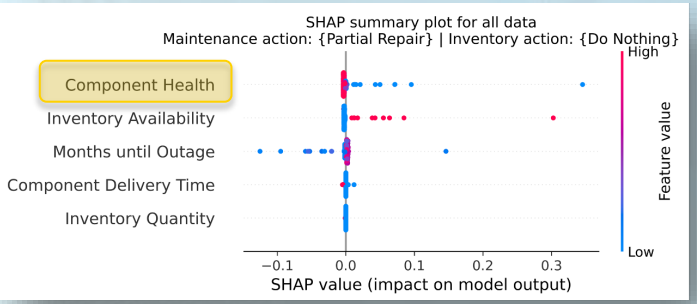
don't repair/don't order



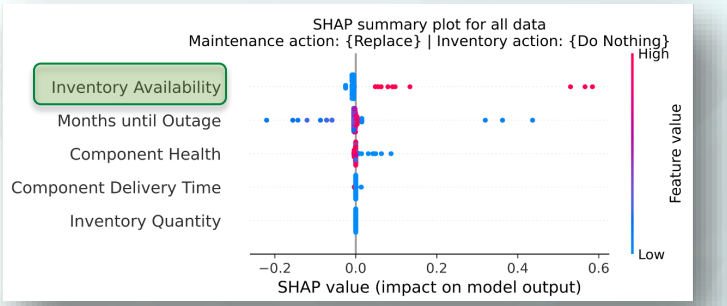
don't repair/order



partial repair/don't order

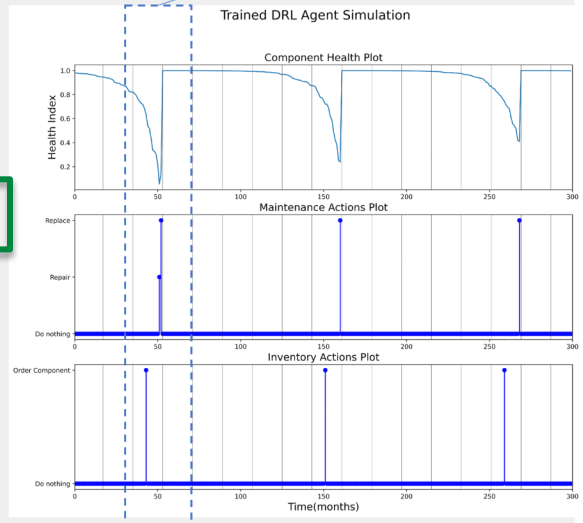


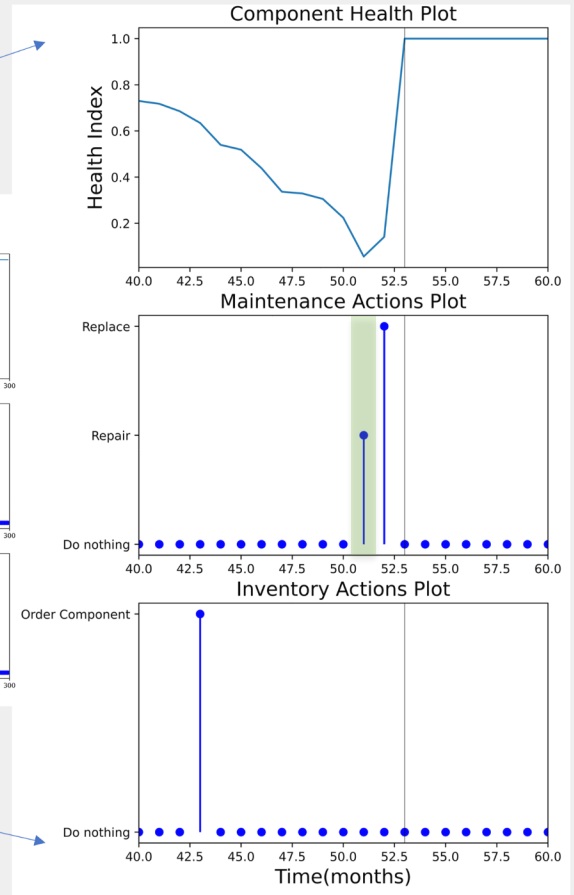
replace/don't order

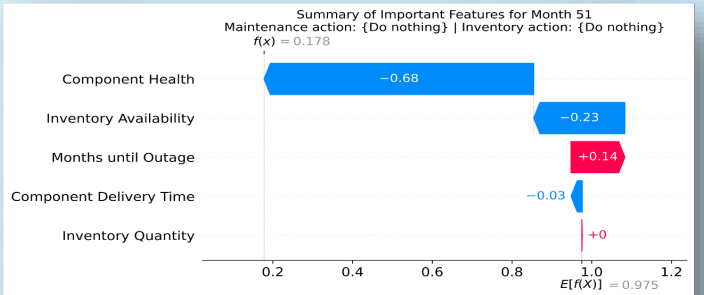


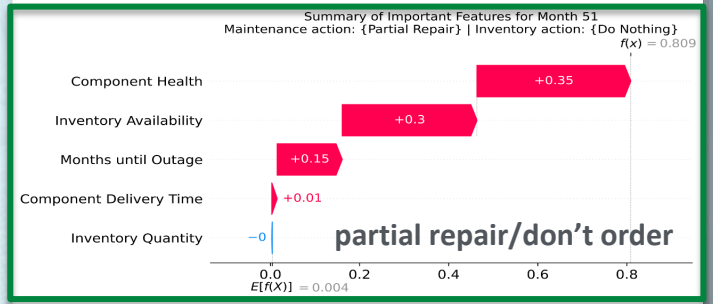
Explainable AI helps us interpret why a certain decision was made at particular point in time

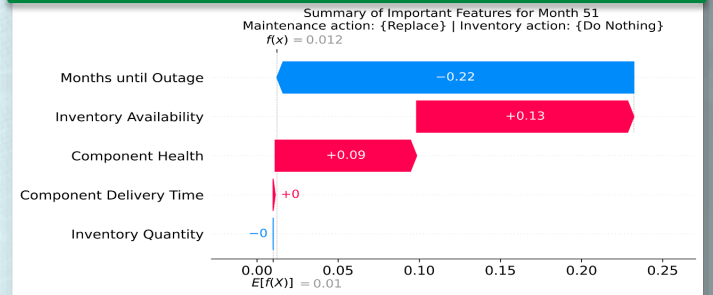
Decision for Month 51	Confidence
Maintenance: Do nothing, Inventory: Do nothing	1.78054884e-01
Maintenance: Partial Repair, Inventory: Do nothing	8.08819950e-01
Maintenance: Replace, Inventory: Do Nothing	1.22569455e-02
Maintenance: Do Nothing, Inventory: Order component	8.72728197e-05
Maintenance: Partial Repair, Inventory: Order Component	1.27083331e-04
Maintenance: Replace, Inventory: Order component	6.53829949e-04

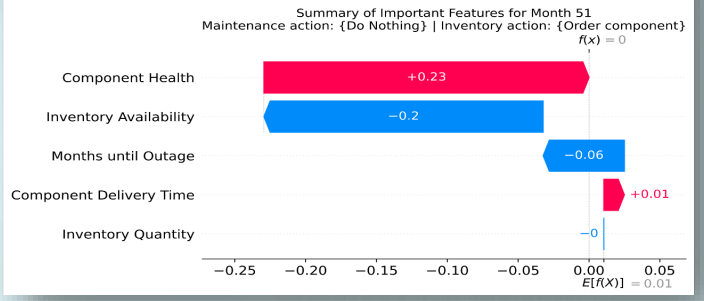












By modeling the environment and training an agent to make decisions, we can lower overall lifecycle costs of the plant

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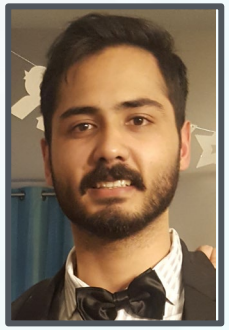
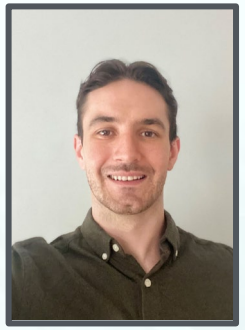
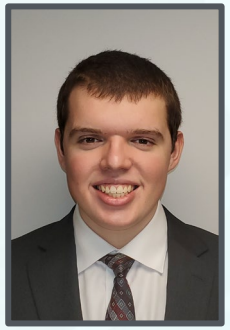


Manyu Kapuria



Robert Lois



Nicholas Harn