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Continuous Online Monitoring for Process Anomaly Detection and Predictive Maintenance

Plant Modernization Pathway Stakeholder Engagement Meeting

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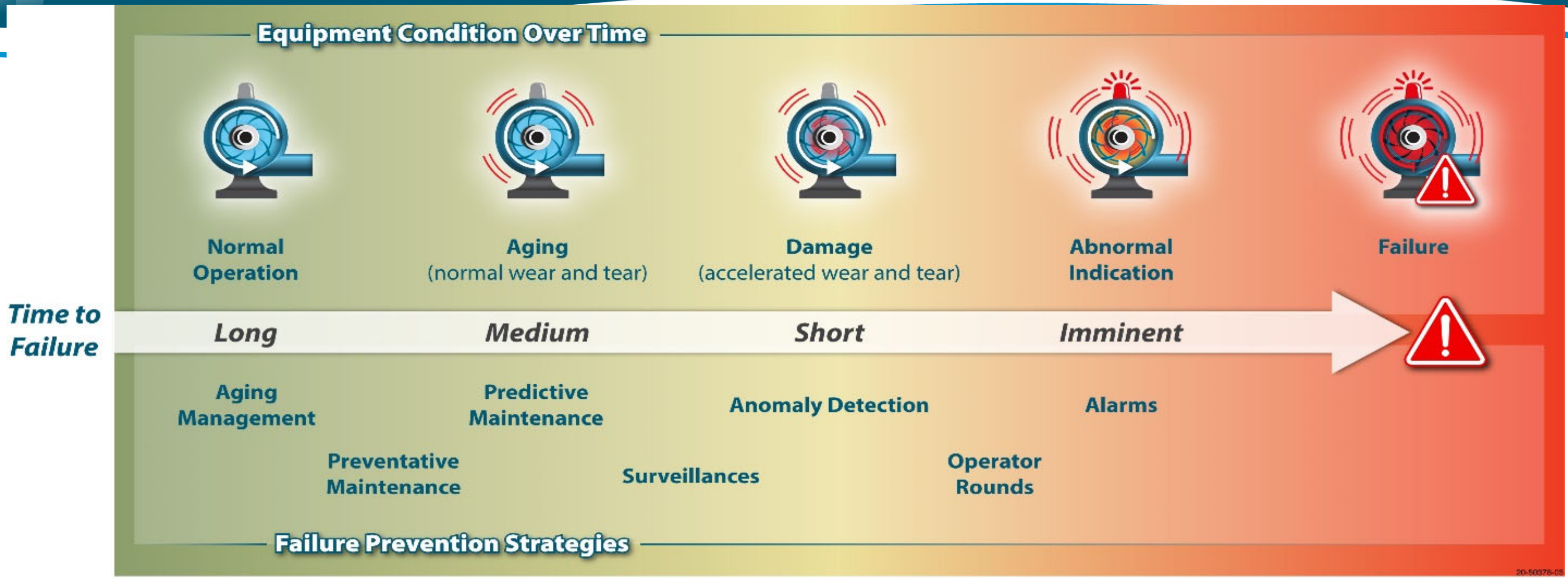


Process Anomaly Detection

- Operates with unlabeled data, making it ideal for systems and components with limited failure history
- Effective in detecting general equipment failures by recognizing changes in plant physics and correlations
- Highly adaptable, can be deployed across diverse systems due to its reliance on data patterns rather than predefined labels

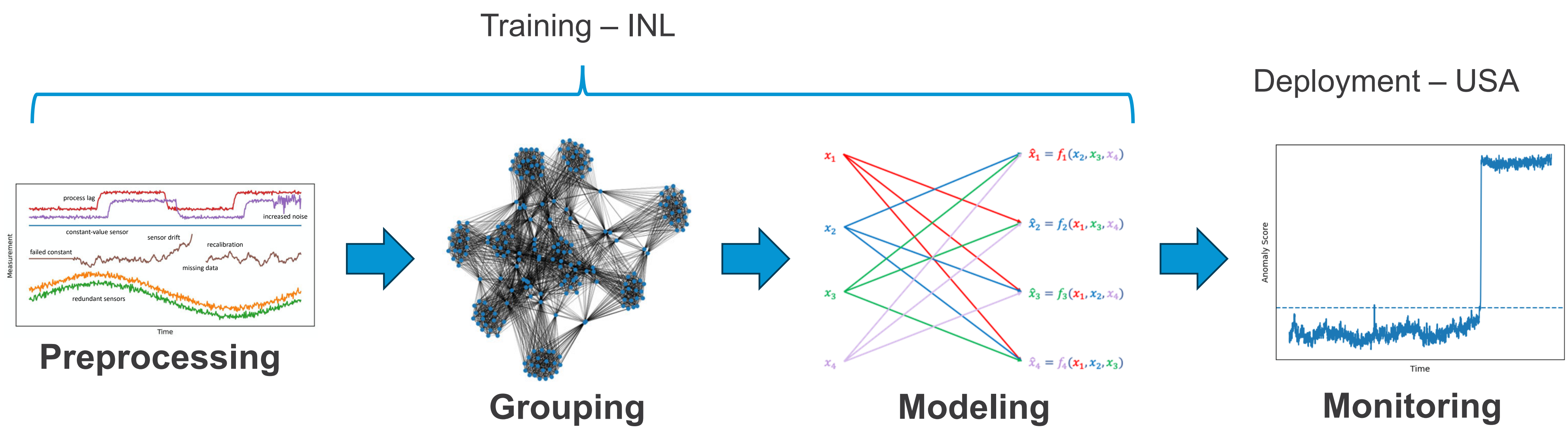
Predictive Maintenance

- Operates with labeled data and work order information, providing increased sensitivity and diagnosability for known failure modes
- Targets specific equipment that undergoes routine preventative maintenance, enabling the transition to predictive maintenance reducing maintenance costs
- Enhances reliability by anticipating failures before they occur, allowing for condition-based intervention

Process Anomaly Detection

- Current approaches to anomaly detection:
  - Perform some preprocessing
  - Use groups generated manually from subject matter experts (SMEs)
    - Focus on high-value systems
  - Require selection of normal and anomalous periods during training
- INL's Automated Latent Anomaly Recognition Method (ALARM) suite of tools can:
  - With minimal effort, model a large percentage of a given plant, including numerous systems that are typically overlooked for modeling
  - Be adapted to new NPPs with minimal involvement from subject matter experts

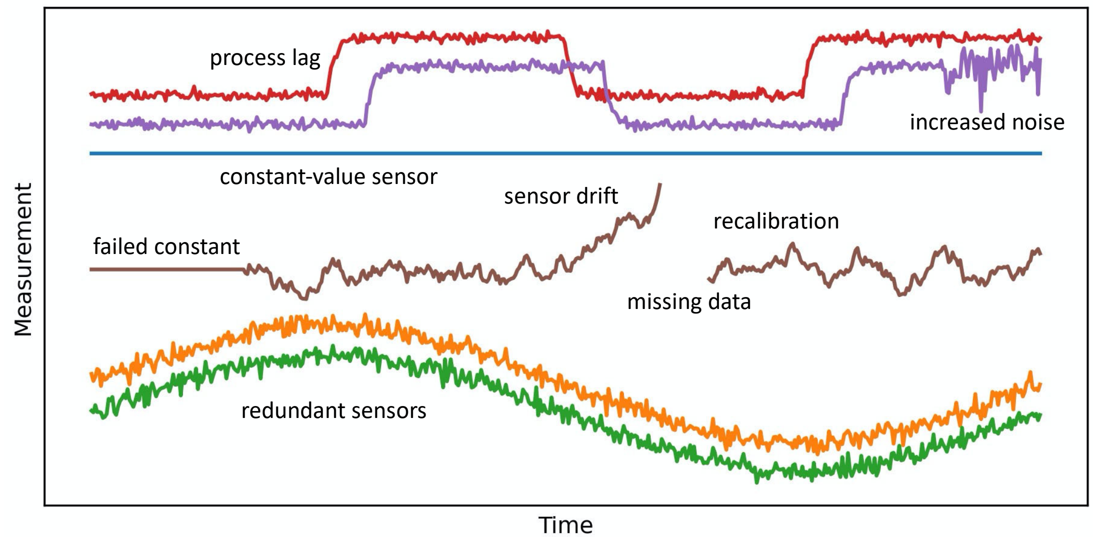
The ALARM toolbox contains a suite of algorithms and tools for automated and equipment-agnostic anomaly detection



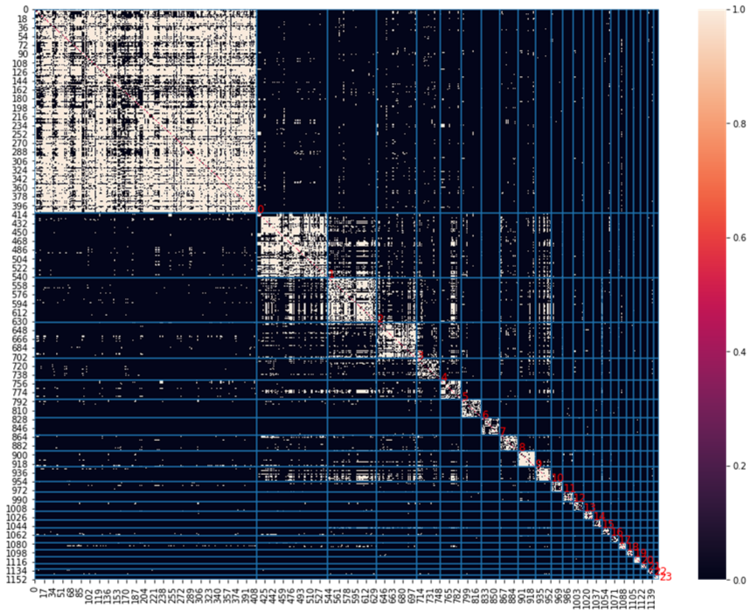
To minimize performance issues caused by inconsistent data, automated preprocessing was used to address a range of issues seen in the provided data

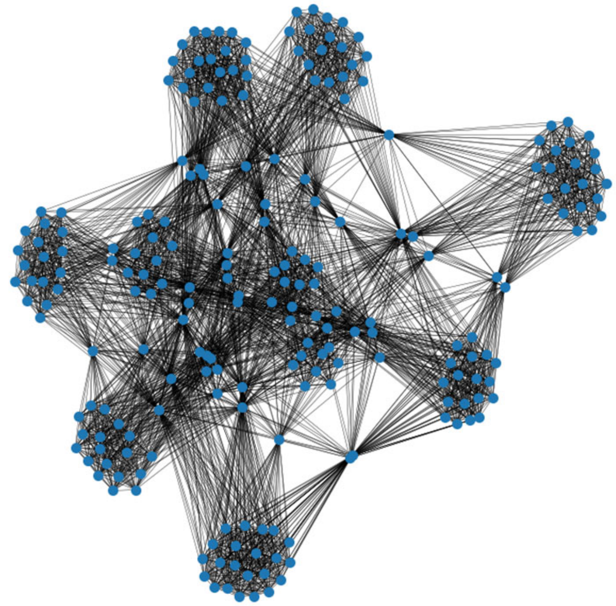
The preprocessing steps included:

- Unifying sampling intervals
- Separating numeric/categoric data
- Handling unusual sensor patterns
- Identifying redundant sensors
- Accounting for process lag
- Normalizing sensor scales
- Removing outlier data
- Detecting failed-constant data
- Accounting for missing data



Due to strong correlations across different subsystems, the grouping process used a multivariate correlation approach that allowed for overlapping groups

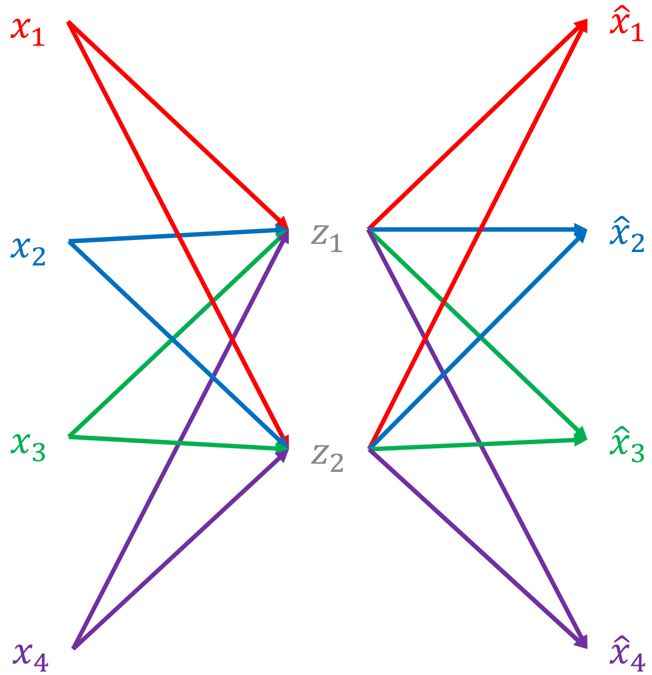




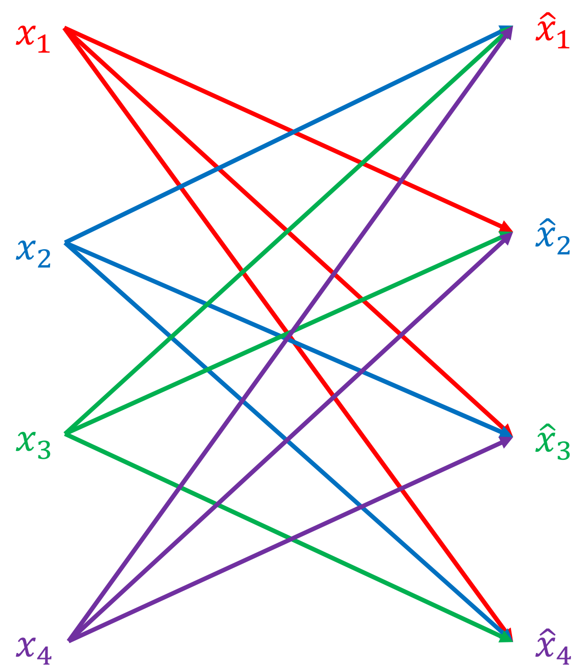
The grouping methods implemented on NPP data generated over 1,000 groups and monitored more than 1,500 unique sensors

For detection, the PCA and INL-developed LOVO models were used, which calculate anomaly scores as a function of prediction error

Principal Component Analysis (PCA)



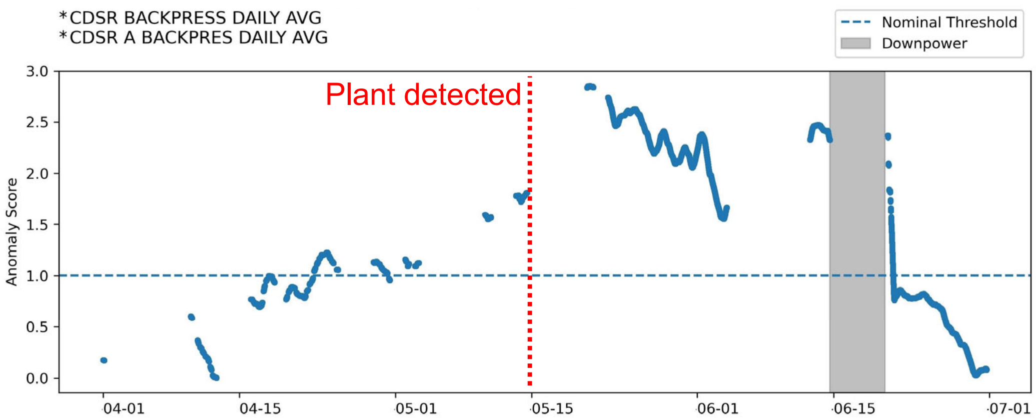
Leave-One-Variable-Out (LOVO)



Using NPP data, the algorithms generated four groups (two shown) that detected a condenser anomaly without prior knowledge of its type or location

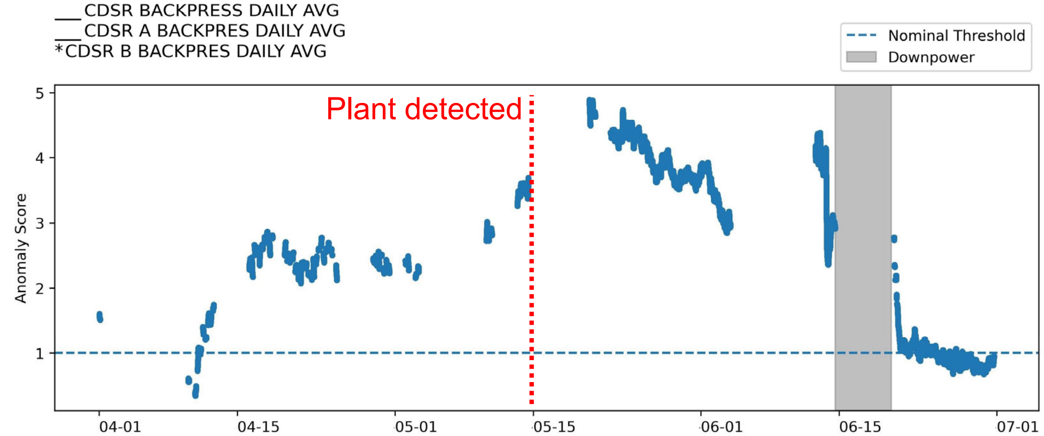
Expected behavior: scores rise in response to a developing problem and decrease once the issue is resolved through maintenance

*CDSR BACKPRESS DAILY AVG
*CDSR A BACKPRES DAILY AVG



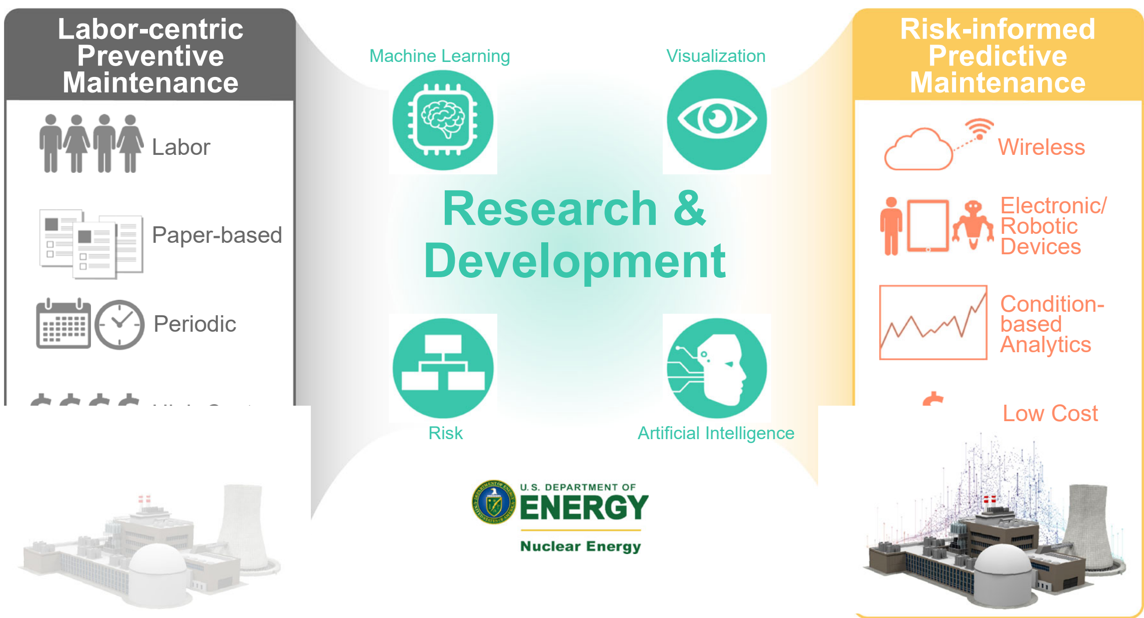
Group 1

* PRZR PRT T
* CNTMT AIR TEMP ELEV-697
* CNTMT AIR TEMP ELEV-738
* CNTMT AIR TEMP ELEV-755
* FCU 12 MTR STR T
* FCU 14 MTR STR T
*Redundant Group:
___ SAS CNTMT TEMP HI ALM LIM
___ SAS CNTMT TEMP AVG 15MAVG
*Redundant Group:
___CDSR BACKPRESS DAILY AVG
___CDSR A BACKPRES DAILY AVG
*CDSR B BACKPRES DAILY AVG



Group 2

Predictive Maintenance



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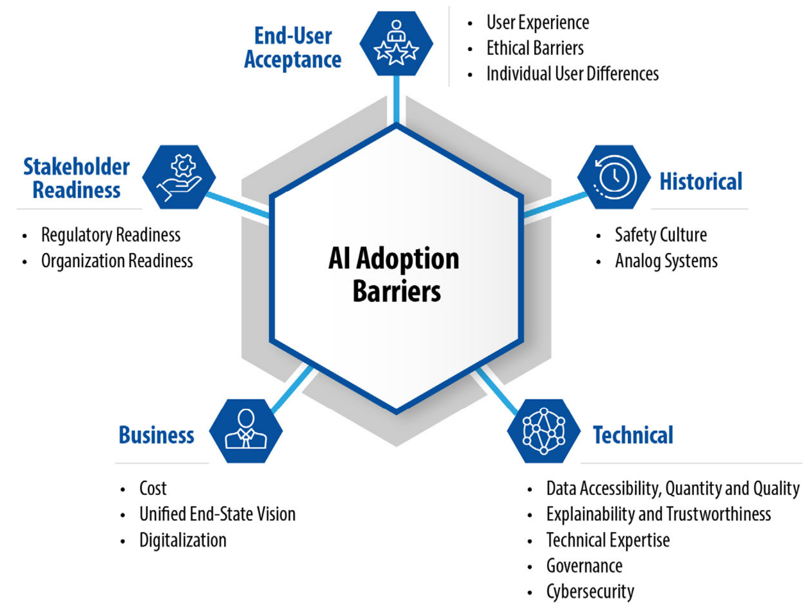
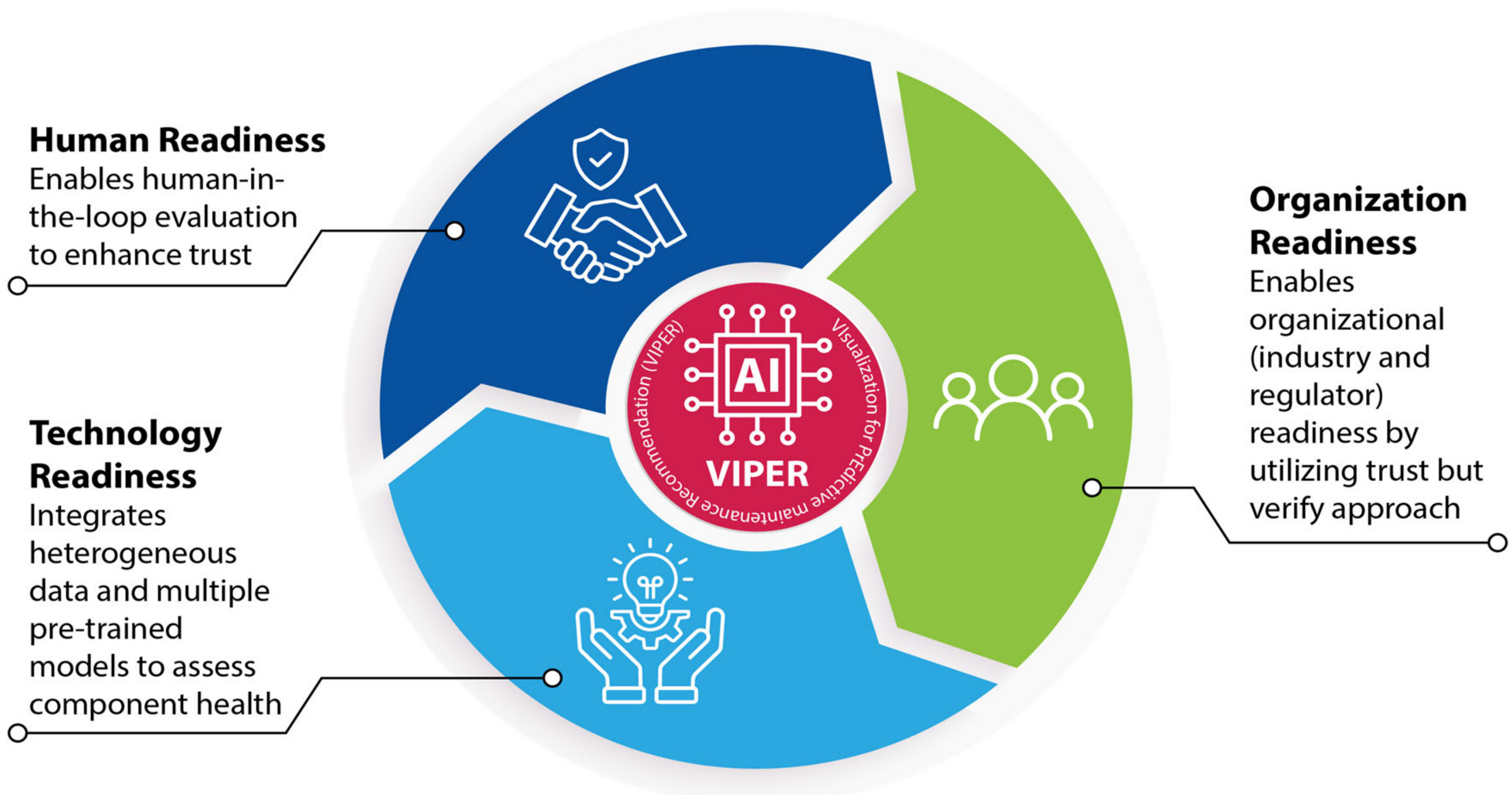
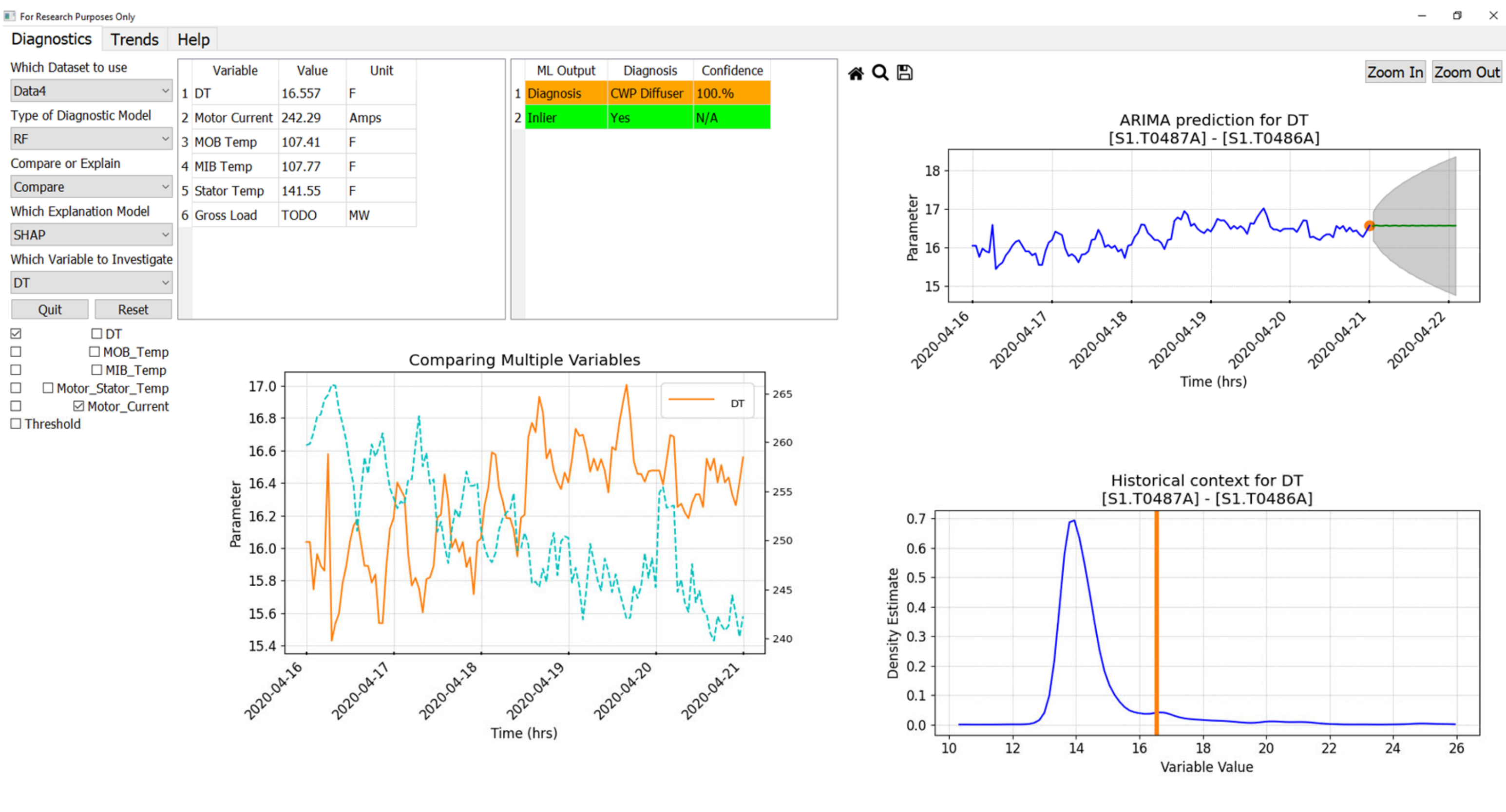


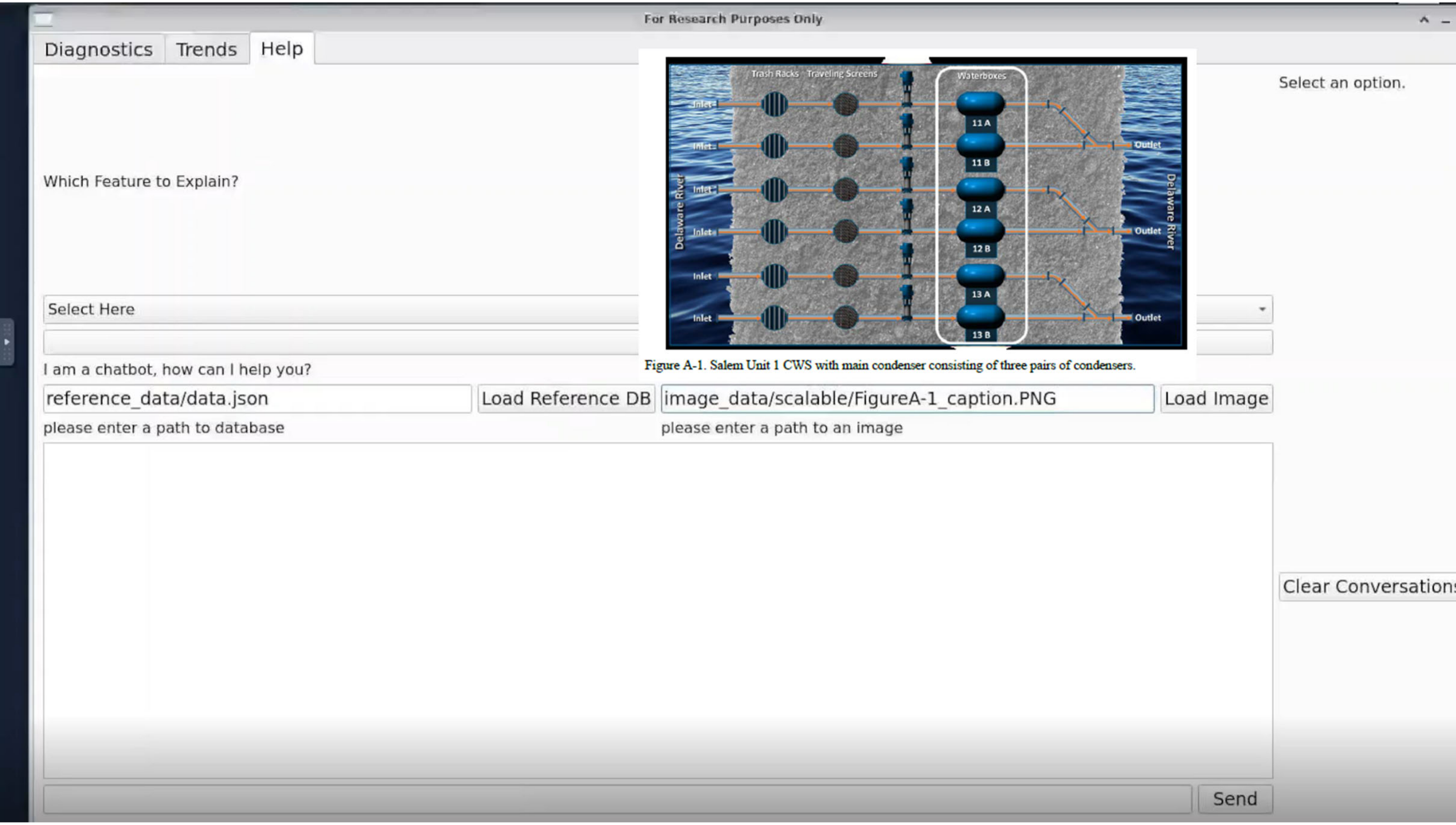
VIsualization for PrEdictive maintenance Recommendation (VIPER)



VIPER Interface




For Research Purposes Only
Diagnostics
Trends
Help
Which Dataset to use
Data1
Type of Diagnostic Model
RF
Compare or Explain
Compare
Which Explanation Model
LIME
Which Variable to Investigate
DT
Quit
Reset
DT
MOB_Temp
MIB_Temp
Motor_Stator_Temp
Motor_Current
Threshold
Variable Value Unit
1 DT 14.648 F
2 Motor Current 260.15 Amps
3 MOB Temp 104.13 F
4 MIB Temp 72.362 F
5 Stator Temp 173.80 F
6 Gross Load 1225.2 MW
ML Output Diagnosis Confidence
1 Diagnosis Healthy 79.9%
2 Inlier Yes N/A
Zoom In
Zoom Ou
ARIMA prediction for DT
[S1.T0487A] - [S1.T0486A]
Parameter
Time (hrs)
Comparing Multiple Variables
Parameter
Time (hrs)
Historical context for DT
[S1.T0487A] - [S1.T0486A]
Density Estimate
Variable Value

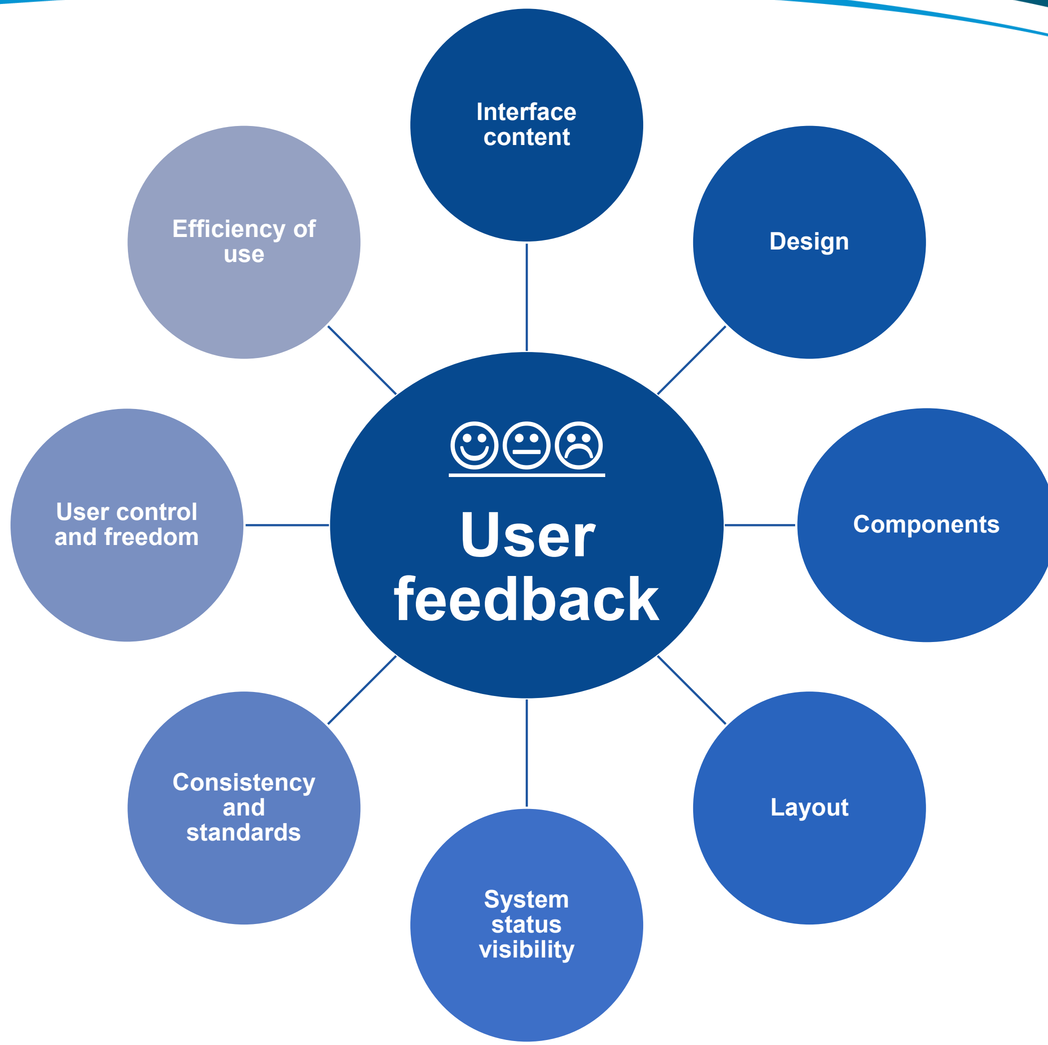

For Research Purposes Only
Diagnostics
Trends
Help
Which Feature to Explain?
Select Here
I am a chatbot, how can I help you?
reference_data/data.json
Load Reference DB
please enter a path to database
Trash Racks
Traveling Screens
Waterboxes
Inlet
Outlet
Delaware River
11 A
11 B
12 A
12 B
13 A
13 B
Figure A-1. Salem Unit 1 CWS with main condenser consisting of three pairs of condensers.
image_data/scalable/FigureA-1_caption.PNG
Load Image
please enter a path to an image
Select an option.
Clear Conversation
Send

Human Factors Evaluation

- Human Factors scientific expertise essential ingredient to AI success in nuclear

- Two complementary studies evaluated usability
- Quantitative and qualitative data collection
- Multi-generational testing
  - plant personnel and new generation engineers

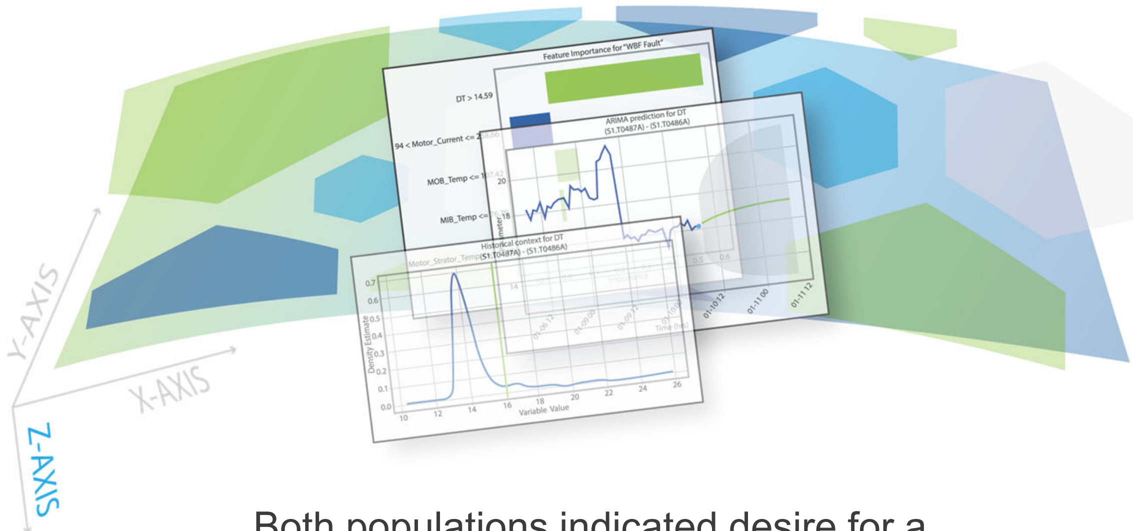
- User feedback essential for AI adoption and HTO readiness



Human Factors Key Findings

VIPER technology favorably received

- Plant personnel:
  - requests to include desired status for comparison
  - no unnecessary info on display
  - “trust” an important research topic
    - important implications for psychology safety
- New generation engineers:
  - indicated diagnosis was clear
  - requests to improve checkboxes
  - described interface as relatively easy to use (low effort required)
  - high information situation awareness



Both populations indicated desire for a layered architecture display with z-axis (i.e., simplified interface)

Conclusions

- INL's ALARM and VIPER toolsets offer two complementary paths to improving plant operations and maintenance
- Using ALARM, models can, with minimal effort, be used to monitor a large percentage of a given plant, including numerous systems that are typically overlooked for modeling
- With VIPER, plants can transition their maintenance strategy for critical equipment from preventative maintenance to predictive maintenance, providing explainable insights to support operations
- Implementation of these methods represents a significant advancement in automating operations and maintenance activities in NPPs, promising enhanced efficiency, reduced costs, and improved safety through early anomaly detection and data-driven maintenance

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