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Development of an end state vision to implement digital monitoring in nuclear plants

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Changing the World's Energy Future

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Development of an End State Vision to Implement Digital Monitoring in Nuclear Plants

Agenda

- Overview – Implementation of Digital Monitoring
- Wireless Sensor Techno-Economic Framework
- Online Monitoring
- Data Visualization
- Cloud Computing Services
- Summary and Challenges

Implementation of digital monitoring in nuclear will require utilization of wireless sensors, online monitoring, and data visualization.

Overview:

- A general methodology for techno-economic analysis of wireless sensor modalities.
- Application of data-based techniques for diagnostics and prognostics estimations.
- Identification of tools and visualization schema for getting the right information to the right person.
- Evaluation of cloud-based resources to enable additional cost savings.

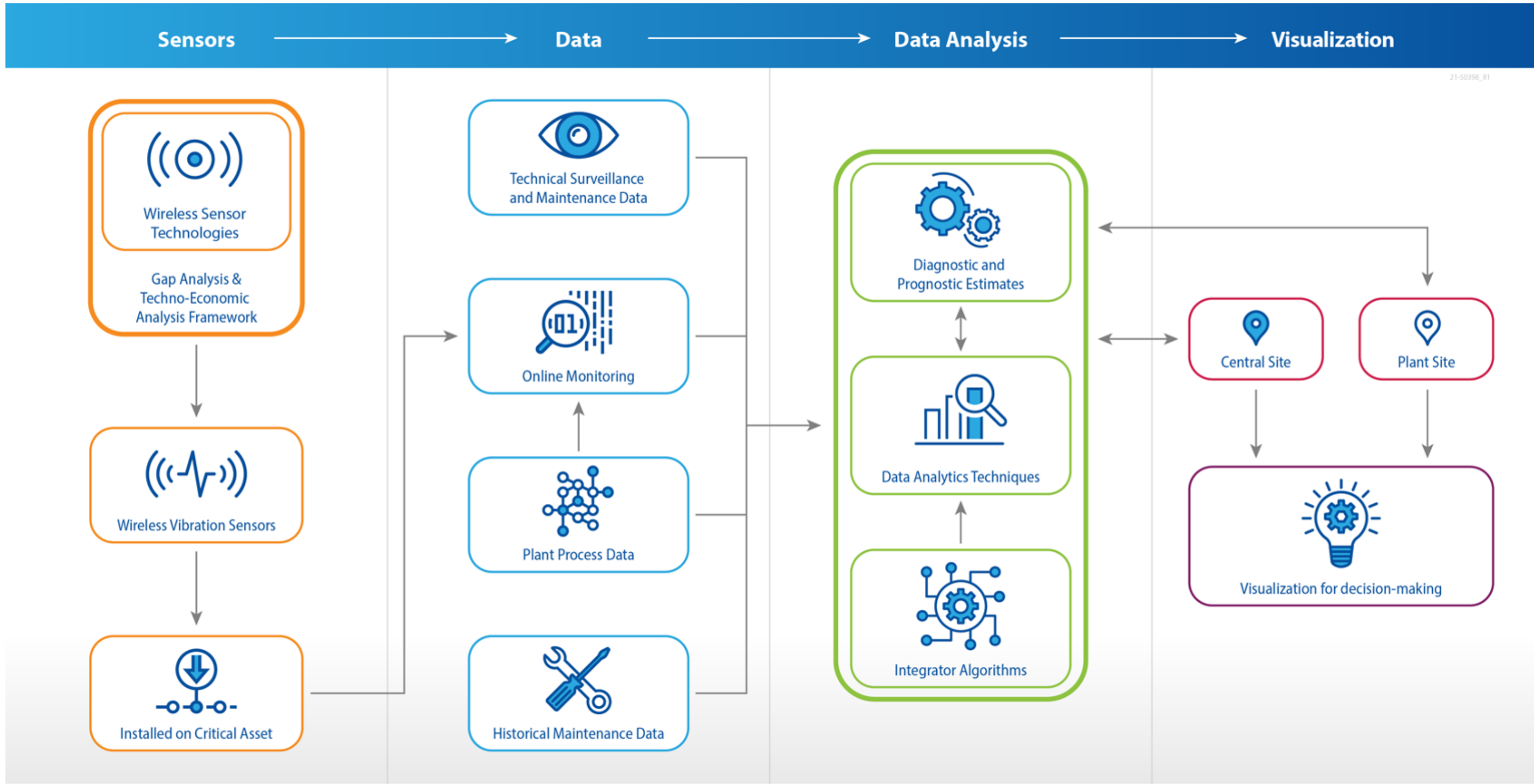

Figure 1. Steps for leveraging digital monitoring to enable cost-effective predictive maintenance for NPPs.

Walker C., Agarwal V., Lybeck N., Ramuhalli P., Taylor M. (2022) “Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Platns.” INL/RPT-22-66878

Techno-Economic Analysis (TEA) allows the comparison of different network architectures to achieve desired capacity and coverage.

- Wireless technologies differ in quality of service, latency, and bandwidth requirements.
- A one-size-fits-all solution may not be an option.
- A heterogenous network with diverse range of wireless technologies may be highly desired.
- TEA covers the operational and capital expenditures (OPEX and CAPEX) as well as the economic performance measures, total cost of ownership (TCO) and net present value (NPV).

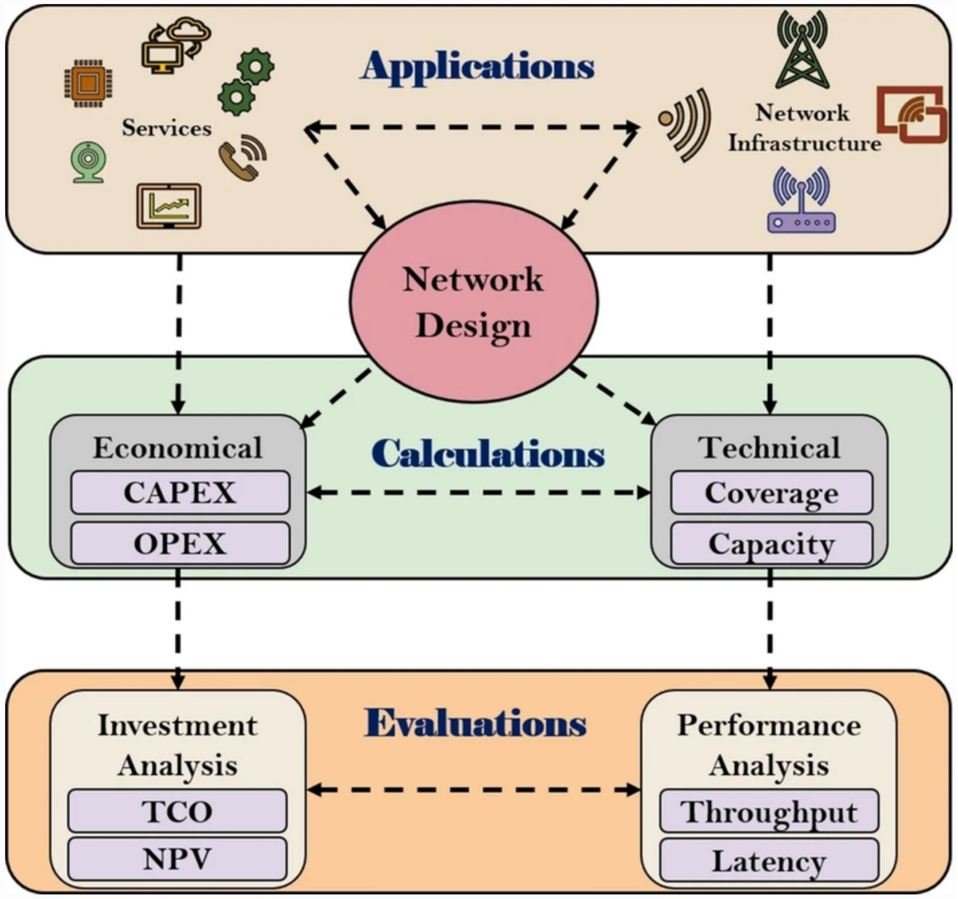

Figure 2. Flow diagram of TEA

Manjunatha, K. A., & Agarwal, V. (2022). Multi-band heterogeneous wireless network architecture for industrial automation: A techno-economic analysis. Wireless Personal Communications, 1–19.

The proposed system is predominantly Distributed Antenna System (DAS) or wireless local area network.

1. High bandwidth and data transmission rates, with low latency
2. Prioritized data transmission
3. Provision for most of the wireless technologies to have either a Wi-Fi or DAS system as their back-end network
4. Act as a bridge between end devices and the internet or an outside network
5. Easy network maintenance by assimilating all the networking technologies into a single network architecture

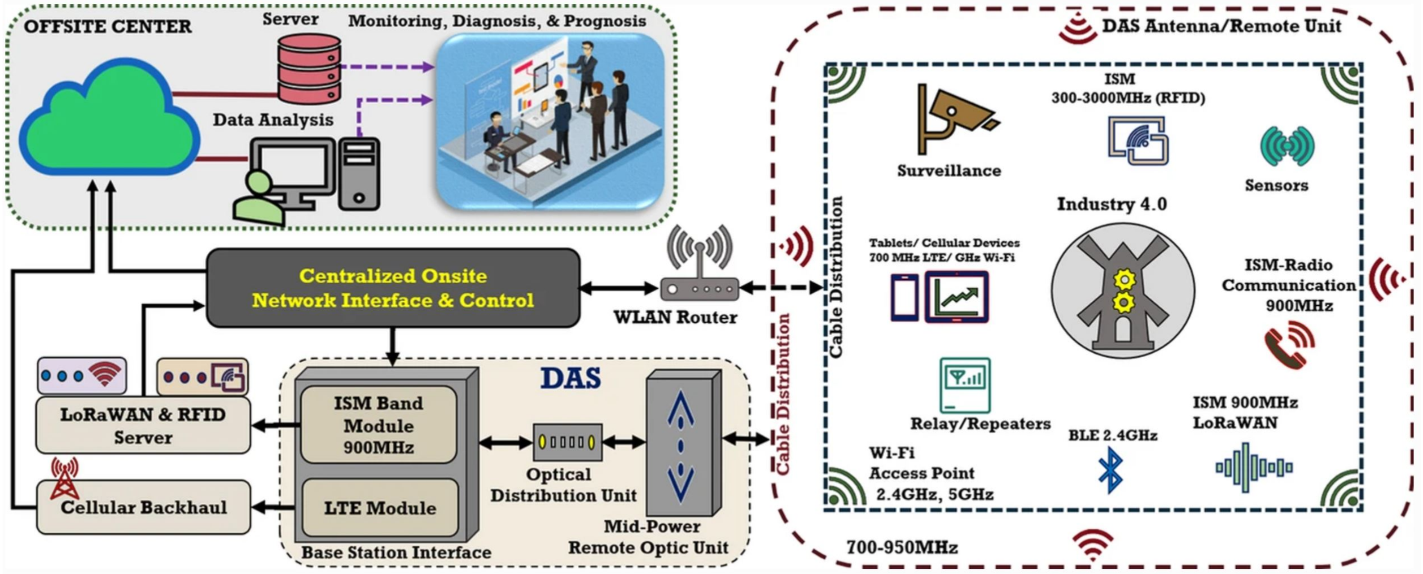

Figure 3. Proposed wireless network architecture.

Manjunatha, K. A., & Agarwal, V. (2022). Multi-band heterogeneous wireless network architecture for industrial automation: A techno-economic analysis. Wireless Personal Communications, 1–19.

Once the data have been collected, they must be analyzed to produce diagnostic and prognostic results.

- This research focused on a boiling water reactor's feedwater and condensate system.
- Feature selection included Shapley additive explanations.
- Three different ML methods (i.e., long short-term memory [LSTM] networks, support vector regression [SVR], and random forest [RF]) were employed to estimate two different forecast horizons (i.e., 1 hour and 1 day) for pump temperature.

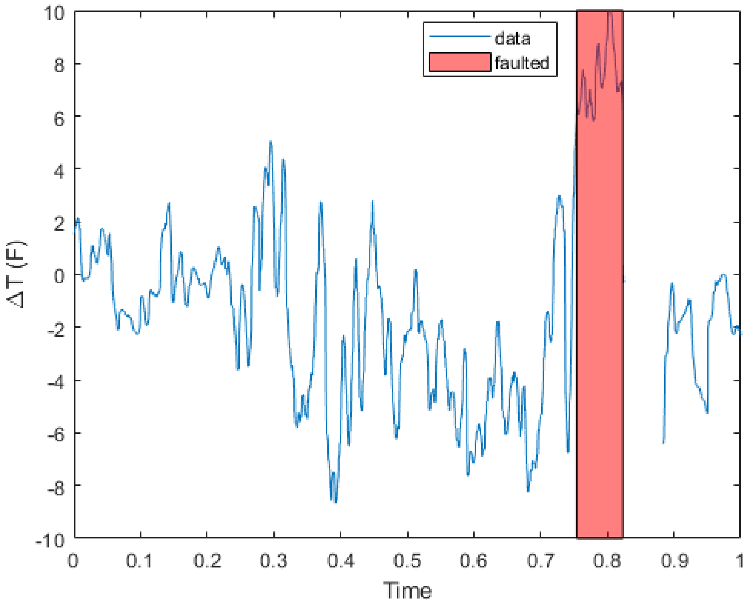

Figure 4. The average seasonal component temperature subtracted from the current component temperature.

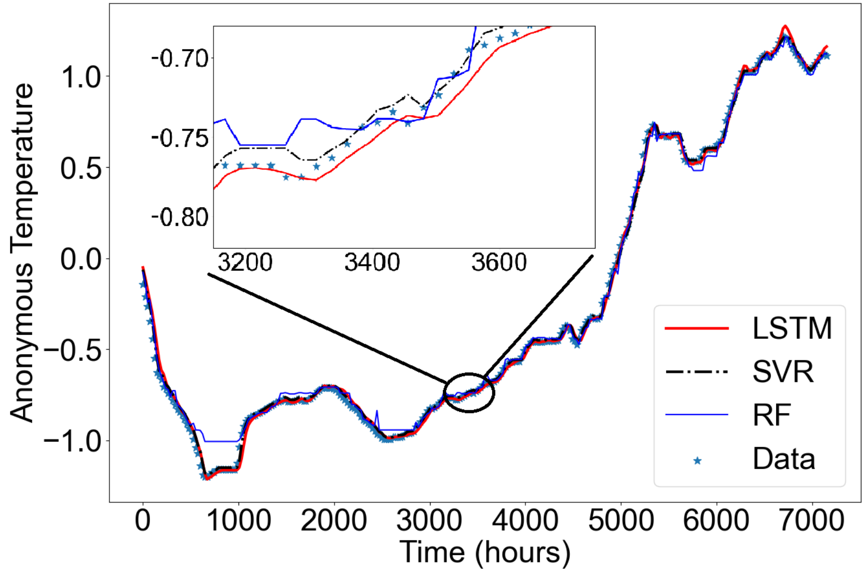

Figure 5. Predictions of pump temperature 1 day ahead, using the SHAP-determined input to LSTM, SVR, and RF models.

Walker C., Agarwal V., Lybeck N., Ramuhalli P., Taylor M. (2021) Nuclear Power Fault Diagnostics and Preventative Maintenance Optimization. INL/EXT-21-61427.

Data visualization should provide meaningful, actionable information to the human in the loop.

1. Consequential information should clearly indicate if there is a significant deviation from an expected pattern.
2. Interdependent information should be grouped meaning-fully.
3. Dashboards displaying high-level information for monitoring plant conditions should also allow the ability to delve into additional lower-level information to provide context or specific historical data.
4. There should be a clear distinction between measured and predicted information, since all predictive information entails some level of uncertainty.

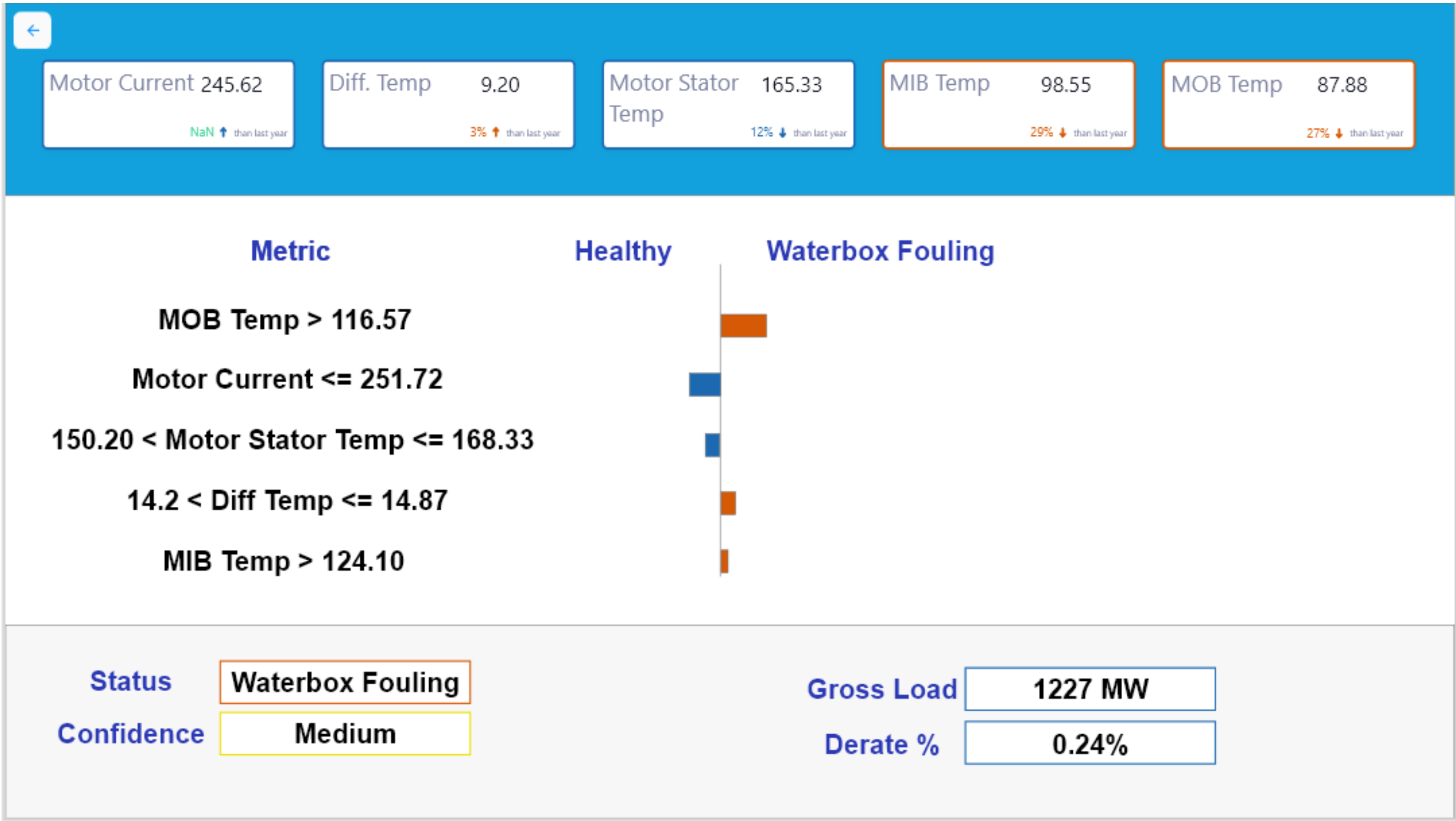

Figure 6. Prototype of machine learning output interface for quickly explaining model outcomes and feature importance.

Agarwal, V., Walker C., Manjunatha K., Mortenson T., Lybeck N., Gribok A., (2022) Technical Basis for Advanced Intelligence and Machine Learning Adoption in Nuclear Power Plants. INL/RPT-22-68942

Cloud computing may provide economic solutions for nuclear power operation through additional computing power and storage.

- Cloud-based services afford many new opportunities for transitioning to an offsite centralized maintenance and diagnostics (M&D) center.
- Cloud-based services offer things such as distributed denial of service protection, data storage, upgrading, patching, backups, monitoring, and monitoring.
- Cloud-based services also provide off-the-shelf AI tools for automated ML, anomaly detection, computer vision, and natural language processing.

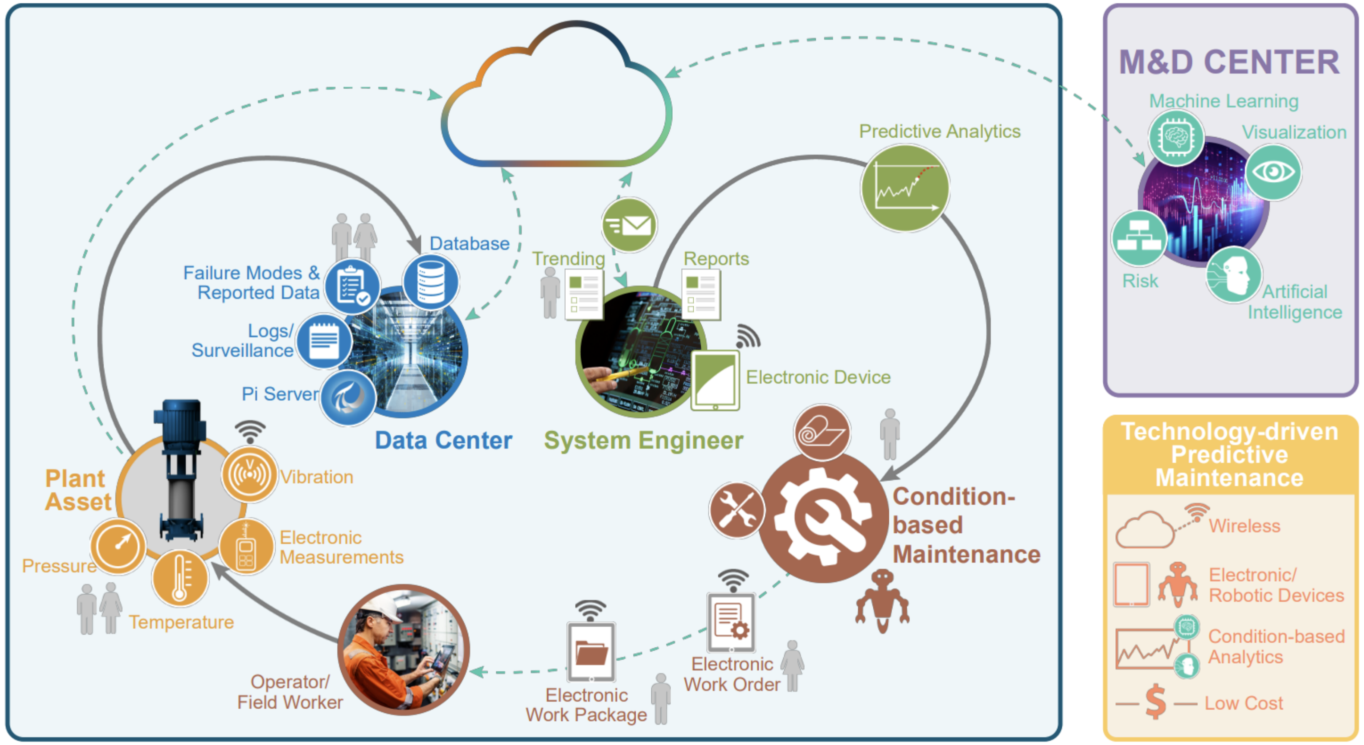

Figure 7. Example of how cloud computing services can be utilized to enable cost-efficient, predictive maintenance.

Agarwal. V., "Transition from Preventative to Predictive Maintenance Strategy." Machine Learning & Artificial Intelligence Symposium. April 17, 2020.

Discussion & Challenges

- Complete end-to-end vision for conducting online monitoring as data are collected wirelessly, stored, preprocessed, modeled, and visualized using cloud computing services.

- Challenges facing nuclear for implementing an online-based prognostic health management system:
  1. Digitalization of infrastructure.
  2. Communication and cybersecurity
  3. Human in the loop.

- Explainability of Artificial Intelligence (AI) is also crucial for widespread industry adoption of emerging technologies.

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