Predictive Maintenance Using Internet of Things (IoT), ML, and Digital Twin

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Sr Solution Manager

SAP
Key Outcomes and Objectives

1. Understand SAP’s point of view of predictive maintenance
2. Get an overview of the SAP solution capabilities
3. Learn more about how customers are applying these solutions and technologies
Digital Transformation of Maintenance Programs

Today

Use of Maintenance Strategy*

- Run to Failure
- Preventative
- Condition-based and predictive

Although still relevant, **preventative** maintenance typically results in over-maintaining assets and high cost

Future

Use of Maintenance Strategy*

Reduced Costs and Risk; Increased Asset Availability

The goal is to enable more data-driven & **predictive** approaches to maintenance with machine learning and IoT-enabled engineering simulations to reduce unplanned failures and the number of maintenance actions

The Internet of Things is leading to an increased use of condition-based and **predictive** maintenance

*Proportion of maintenance strategies are for illustration purposes only and will vary based on many factors
Multiple Approaches to Predictive Maintenance

The use of engineering simulations and machine learning models are on the rise

- More time to respond enables greater flexibility to dynamically plan maintenance events

Why more IT driven approaches?
- IIoT/device connectivity
- Big data for ML and simulations
- Massive computing power in the cloud

Potential Failure = First Indication of Failure
SAP Intelligent Asset Management Portfolio

Capabilities & solutions

- **Asset Networks and Collaboration**
  - SAP Asset Intelligence Network

- **Asset Strategy and Performance**
  - SAP Asset Strategy and Performance Management

- **Asset Health Prediction and Optimization**
  - SAP Predictive Asset Insights

- **Mobile Asset Management**
  - SAP Asset Manager
  - SAP Field Service Management

- **Planning & Scheduling**
  - SAP S/4HANA Asset Management for resource scheduling
  - SAP Field Service Management

- **Execution & Reporting**
  - SAP S/4HANA Asset Management (Functional users)
  - SAP S/4HANA Service (Functional users)
  - SAP Geographical Enablement Framework
  - SAP Linear Asset Management

**EH&S**
- SAP Work Clearance Management
- SAP Management of Change

**Industry Solutions**
- S/4HANA Meter Data Management for Energy and Water
SAP Predictive Asset Insights

Convergence of Machine Learning and Engineering Simulations

- Anomaly detection
- Failure probabilities
- Failure mode analysis
- Remaining useful life
- Root cause analysis
- ...

Machine Learning and AI

Engineering Simulations using Digital Twin

IOT Sensor Data

Maintenance records

S/4 and ECC
SAP Predictive Asset Insights

Core capabilities

A 360 Degree View of Assets

Advanced Analytics for Decision Support

Intuitive and Scalable Machine Learning

Simulation-based Digital Twins

Business Process Integration

A comprehensive view across asset model, master, transactional and performance data in a single solution

Advanced analytics to support maintenance execution and strategy decisions

Machine learning for maintenance professionals... “machine learning for the masses”

Feed IoT data into system level engineering models to simulate and predict operational performance

Part of a comprehensive asset management portfolio
360 Degree View of Assets

Next-generation master data layer

A 360 degree view across asset model, master, transactional and performance data in a single solution

Information
Highlight Cards, Data Sheets, Equipment/Model Information, Installation Location, Business Partners

Structure and Parts
Structure, Spare Parts, Visual Parts

Documentation
Documents, Instructions, Failure Modes, Alert Types, Announcements, Improvement Requests, Fingerprint

Monitoring
Alerts, Indicators, Component Indicators, 2D Chart

Maintenance and Service
Notifications, Work Orders, Tickets, Contracts

Equipment Timeline
History and timeline of major equipment events
Advanced Analytics for Decision Support
Driven by machine learning in the background

Advanced analytics to support maintenance execution and strategy decisions

**Failure Mode Analytics**
Utilizes machine learning to generate KPIs around documented failure modes

**Failure Curve Analytics**
Determine remaining useful life and visualize failure curves using Weibull and EAM records

**Fingerprint Management**
A visual approach to capturing asset reference states. Used for visual comparison to current operating performance. (i.e., trend analysis)

**Leading Indicator Analytics**
A machine learning capability used to identify the most impactful indicators leading to failure events or specific failure modes

**Advanced Rule-based Alert Creation**
Generate value added alerts for maintenance professionals through an intuitive and flexible rules engine
Failure Mode Analytics

1. System uses unsupervised machine learning to extract topics from notification texts.

2. System matches topics to standard failure modes (e.g. ISO 14224).

3. Expert user double-checks matching results.

4. System uses supervised machine learning based on user reinforcement to assign all notifications to failure mode.

5. Failure mode to notification mappings are stored in the system for machine learning and analytics.

Failure Curve Analytics

Estimate RUL and failure probability without IOT data
Calculate a Weibull model for a set of equipment and their breakdown notifications, by failure modes

Visualize a failure curve for an equipment, by failure curve model and failure mode
View probability of failure and confidence intervals, conditional probability of failure, failure date, and days until failure

\[ f(t) = \left( \frac{t}{\eta} \right)^{\beta - 1} e^{-\left( \frac{t}{\eta} \right)^\beta} \]
Fingerprint Management

Visual capture across one or more indicators
Easy capture of sensor data signatures using 2D chart functionality across multiple indicators

Capture fingerprints for multiple operational states
Capture multiple operational (e.g., start-up, high load, shut down) states as “snapshots” for comparison to operating assets
Leading Indicator Analytics

**Leading indicators** are the indicators from sensors readings such as temperature or pressure whose specific conditions (e.g. temperature > 90 degrees F and pressure < 50 PSI) are correlated to breakdowns (optionally by failure mode) of an equipment or equipment model. Identifying these specific leading indicators and conditions based on ML systematically can help PdMS customers determine **Condition-Based Maintenance (CBM) rules** quickly without pre-built models or data science resources.

- **Failure Events** (i.e. labels in Data Set Configurator)
- **Notifications**
- **Sensor Time Series data**

**PAI Leading Indicator Analytics**

Leading Indicators Models are Machine Learning Models designed for non-data scientist users

In a few clicks, the leading indicators and conditions are turned in to alert rules that are ready to be activated for CBM monitoring!
Advanced Rules-Based Alerting

Rule-based alert suppression
Specify when to suppress alerts (ex, machine start-up) to avoid false positives

Alert de-duplication
Specify minimum time periods to generate duplicate alerts

Alert lifecycle management
Track status of alerts to ensure issues are addressed in a timely manner and a record of completion is maintained

Alert details
Comprehensive alert details which include sensor data visualization and likely failure modes
Out-of-Box Machine Learning

Intuitive and scalable

Machine learning for maintenance professionals... “machine learning for the masses”

Dataset configuration and model management
Intuitive dataset preparation capabilities to prepare data for machine learning. Tools to configure, train, and score models.

Anomaly detection and failure prediction algorithms with automated machine learning
9 out-of-the-box machine learning algorithms tailor made for predictive maintenance use cases; 2 are automated

Flexible extension concept
Deploy custom algorithms into solution or perform machine learning outside of solution in tool/language of choice

### Anomaly Detection Algorithms

<table>
<thead>
<tr>
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<th>Technique</th>
<th>Input Data Type</th>
<th>Output</th>
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### Prediction Algorithms

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Dataset Configuration and Model Management

**Dataset configurator**
Intuitive dataset preparation capabilities to prepare data for machine learning (i.e., aggregation periods, new features, null values). Enables creation of new data sets or the copying of existing data sets.

**Manage models to calculate health indicators**
The Health Indicator Model Management application brings scale to the machine learning processes. Intuitive tools to support model configuration, training, and scoring.
## Out-of-Box Algorithms

### Anomaly Detection (Unsupervised ML)

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### Failure Prediction (Supervised ML)

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Machine Learning Engine Extensibility

- Extensibility mechanism which can be used by any PAI customer and partner, as well as SAP internal stakeholders
- Design focus on the execution of algorithms outside of the PAI architecture (IP safe, include external services, full control for the customer)
- Underlying idea is to enable data scientists and analysts to seamlessly access asset data (e.g., time series) leveraging inbuild preprocessing capabilities and write back results to be consumed by PAI/IAM dashboards
- Mechanism supports potentially unlimited programming languages and environments, where an SDK is provided within python and R
Simulation-based Digital Twins
IoT driven engineering simulation

Leverage IoT enabled engineering simulations to carry out virtual inspections and condition monitoring of critical assets

ANSYS Integration
Existing ANSYS digital twin models can be readily deployed or built from scratch using ANSYS Twin Builder

Multiphysics Simulation
Analyze asset health based on engineering simulation models enabled by a multiphysics engine from ANSYS

Virtual Sensors
Leverage engineering simulation models to use virtual sensors for condition monitoring and predictive maintenance

*CFD - Computational Fluid Dynamics
**FEA - Finite Element Analysis
ANSYS Integration

SAP Predictive Asset Insights

Digital Twin Runtime (ANSYS OEM)

Application Logic

Physical Asset

SAP Cloud Platform

Simulation-Based Digital Twins

Export

Deploy

Digital Twin

3rd Party Tools, Measurement Data

Validated 3D ANSYS Physics

Twin Builder System Libraries

Software Control Models

Data Analytics Extensions

System Model

A 360 Degree View of Assets

Advanced Analytics for Decision Support

Intuitive and Scalable Machine Learning

Simulation-based Digital Twins

E2E Process Integration

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Digital Twin technology from ANSYS

- Model with standard languages and exchange formats including VHDL-AMS and Modelica.
- Combine conserved (acausal), signal-flow (causal), and discrete event system behaviors.
- Compose your system by including multiple physical domains including Electrical, Mechanical, Hydraulic and other domains.
Virtual Sensors based on Simulations

Virtual Sensors

A virtual sensor is a device we can place at a specific location on the product that provides a continuous reading of physical state at this location.

Virtual sensors are required because of:

- Physical restrictions
- Quantity itself cannot be measured
- Lifecycle costs of sensors
- Sensor calibration
Business Process Integration

Seamless integration with EAM and IAM

- Share asset health indicators with operators/customer

- Assess asset health indicators and real-time performance to determine maintenance strategy effectiveness

- Monitor asset condition and health indicators to prioritize work and plan resources (tools, parts, tech pubs)

Decision Support for Asset Management & Reliability Professionals

SAP Asset Intelligence Network

SAP Asset Strategy and Performance Management

SAP S4HANA/Asset Manager Maintenance Execution

3rd Party Maintenance Service Provider

Reliability Engineer

Maintenance & Service Technicians
## Integrating Planning and Execution with SAP Intelligent Asset Management

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<th>Step</th>
<th>Key Enabler</th>
<th>Outcome</th>
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<td>Collect Asset Information</td>
<td>An central repository of information to have complete knowledge about each of your assets across the lifecycle</td>
</tr>
<tr>
<td></td>
<td>Collaborate for better information</td>
<td>Connect with business partners to have the best live asset data, and innovate new business processes</td>
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<tr>
<td>2</td>
<td>Perform Risk and Strategy Assessments</td>
<td>Know the importance of every asset, measure its performance and have a recommendation for its life</td>
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<td>3</td>
<td>Generate Dynamic Demands</td>
<td>Generate dynamic maintenance demands based on Industry 4.0, time and predicted indicators</td>
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<tr>
<td>4</td>
<td>Plan, Approve &amp; Orchestrate</td>
<td>Single backlog for all work types, orchestrated with supply chain, procurement and finance</td>
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<tr>
<td>5</td>
<td>Schedule &amp; Dispatch</td>
<td>Intelligent optimization &amp; prioritization of work with capacity management and resource assignment</td>
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<tr>
<td>6</td>
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### Key Enablers

- **Key Enabler** S/4HANA + Asset Central Foundation (with Utopia Extensions)
- **Key Enabler** Asset Intelligence Network
- **Key Enabler** Asset Strategy & Performance
- **Key Enabler** Predictive Asset Insights
- **Key Enabler** S/4HANA Maintenance & Service Management
- **Key Enabler** S/4HANA Resource Scheduling SAP Field Service Management
- **Key Enabler** Mobile Asset Manager

### Outcomes

- **Structured and complete information provides the foundation for automated decisions**
- **Leverage knowledge beyond your companies four walls to always be up to date**
- **Know which assets to focus on and ensure complete coverage with the best recommendations**
- **Reduction in unnecessary and un-planned work, automating what ‘needs to be done’ for “zero unplanned downtime”**
- **Optimal balance of proactive and reactive maintenance, with reduced inventory and costs**
- **Reduction in manual planning, improved resource utilization and better asset up-time**
- **Less trips back to the office and better real time visibility of work being executed**

### Asset Performance Management + Maintenance and Service Operations
Intelligent Asset Management Architecture

OEM & Component Manufacturers
- PLM & Manufacturing Systems
- CFIHOS/ @eClass / ISO 14224
- Installation guides
- O & M Manuals Specifications

Obsolescence Details

ERP Systems
- ECC 6 EhP6+
- S/4HANA Cloud
- S/4HANA OP & S/4HANA Cloud
- Non SAP ERP

SAP IOT & Edge Services
- Sensors

PAI
- Predictive Asset Insights

AIN
- Asset Intelligence Network

ASPM
- Asset Strategy and Performance Management

DMC
- Digital Manufacturing Cloud

Asset Central Foundation
- Common data foundation for master and transactional data (e.g. equipment, work order)

PAI
- Streaming Rules

Plant Connectivity (PCo)

Integration and SDK

3D Envelope
- 3D Parts

Visual Conversion Services

ETO
- Plant Design

Approved Equipment Lists

EPC & Contractors
- P&IDs, Construction Drawings, Progress Reports

Engineering Authoring Systems
- System 1

System 1
-...

SAP Analytics Cloud

Datahub & Vora

Big Data Stack

Plant Maintenance
- Customer 1
-...

End Customers
- P&IDs, Construction Drawings, Digital Services

Asset Manager
- Online / Offline Native Mobile App

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The Role of IoT and SAP Intelligent Asset Management

IoT Data Ingestion and Big Data Storage:
Validation of incoming data, automatic harmonization of different sensor types, and automatic data tiering considering hot, warm and cold storage.

Onboarding & Device Management:
Manufacturers can easily connect and manage devices using industry-proven, highly scalable services from SAP as well as from other major cloud providers.

Extensibility via Multitenant IoT Applications:
Allows manufacturer and service providers to enter new digital business models while protecting their IP and keeping asset data under customers’ control.

Edge Computing:
Extend business applications close to the source of data to support immediate response and actions by bringing together local compute, persistency and business transactions.
Ansaldo Energia S.p.A. - An International Utilities Company
SAP PAI and SAP IoT support comprehensive Industry 4.0 strategy

• First implemented in their lighthouse plant for European Industry 4.0, Ansaldo gathers and analyzes equipment data and use Predictive Asset Insights, and facilitate faster, more efficient processes

1. Devices / Edge Locations
   • Interfacing and acquiring data from plant equipment such as milling machines, e.g. component rotation, axis rotation

2. Business Logic
   • Analytical pre-processing for local alerts and throttling, e.g. sending only measurements out of predefined range
   • Storage, normalization and validation of IOT data not processed directly at the edge for machine learning

3. Resolved Challenges
   • Create situational awareness on health and performance of plant equipment and field assets
   • Apply machine learning for asset health monitoring
   • Enable root cause analysis on operating processes at the edge

4. Business Outcomes
   • Reduce downtimes of productive machines and systems
   • Improved quality and customer service
   • New revenue stream through predictive asset service

Company Profile:
Industry: Utilities
Headquarter: Italy
Size: Large Enterprise

Solutions:
SAP Predictive Asset Insights
SAP IoT
SAP Edge Services
SAP S/4HANA

+1.3M Expected in service revenue over the next years
5-8% Cost reduction in equipment maintenance processes

Transform your business with the Internet of Things
SBB – The National Rail Company of Switzerland
SAP Intelligent Asset Management keep Swiss trains running like clockwork

• SBB sought to adopt a reliability-centered maintenance strategy based on IoT sensor data

1. Devices / Edge Locations
   • Monitor vehicle fleet 6000 trains operating daily as well as track lines

2. Business Logic
   • Get operational insights
   • Integrate real-time onboard and trackside monitoring data from multiple tracking systems

3. Resolved Challenges
   • Optimize maintenance process with access to real-time data and insights based on condition monitoring and machine learning
   • Meet rising customer expectations

4. Business Outcomes
   • Operational efficiency through a proactive maintenance approach
   • Enable more efficient maintenance process with access to data to optimize labor planning and material availability

Increase efficiency and reduce costs

Company Profile:
Industry: Transportation
Headquarter: Switzerland
Size: Large Enterprise

Solutions:
SAP Predictive Asset Insights
SAP Asset Strategy and Performance Management
SAP Asset Intelligence Network

1 2 3 4

Monitor vehicle fleet 6000 trains operating daily as well as track lines
Get operational insights
Integrate real-time onboard and trackside monitoring data from multiple tracking systems
Optimize maintenance process with access to real-time data and insights based on condition monitoring and machine learning
Meet rising customer expectations
Operational efficiency through a proactive maintenance approach
Enable more efficient maintenance process with access to data to optimize labor planning and material availability
Kaeser Kompressoren – Manufacturer of Compressed Air Systems
SAP Intelligent Asset Management and SAP IOT helps create a customer centric supply chain

- SAP IoT capabilities as innovation foundation for Kaeser’s new solution that connects compressors smartly in the cloud, allowing it to offer a next-generation service at a lower price

- Monitor operations and health of compressed air systems at customers
- Near real-time analysis of machine data for reliable operation (e.g. oil levels, stand-by status) and predictive maintenance service (failure notice)
- Enable smart control of complex compressed air systems
- Service team unable to access calibration data and other equipment-specific information at customer
- Increase service efficiency with one single source of product, component, spare-part and service information
- Higher customer and dealer satisfaction and improved supplier collaboration
- Greater transparency across the company’s installed base
- Offer air-as-a-service as additional revenue stream to selected customers

Company Profile:
Industry: Manufacturing
Headquarter: Germany
Size: Large Enterprise

Solutions:
- SAP Predictive Asset Insights
- SAP IoT
- SAP Asset Intelligence Network

Define new business models
Volvo Construction Equipment - Automotive Industry
Driving Volvo’s Factory 4 Tomorrow digital transformation initiative

- Reducing assembly line downtime with SAP IoT and SAP PAI through analyzing sound of sand blasting engines and establishing predictive maintenance

1. Devices / Edge Locations
   - Monitor shot blasting as a key step of the production process, e.g. electric current, temperature and vibration

2. Business Logic
   - Gather and filter data for training models to predict motor failure
   - Alert employees to deviations, allowing them to stay ahead of potential malfunctions and line shutdown
   - Remote validation and troubleshooting

3. Resolved Challenges
   - Move from manual inspection to predictive maintenance
   - Prevent equipment breakdown and line stops

4. Business Outcomes
   - Reduced maintenance costs and man hours on shop floor
   - Increased effectiveness of maintenance personnel
   - Increase understanding of data analysis and prove its effectiveness, which justifies expansion to other use cases

240,000 SEK/year
Previously caused by equipment breakdown
→ 0 Line stops since implementation

Company Profile:
Industry: Automotive
Headquarter: EMEA North
Size: Large Enterprise

Solutions:
SAP IoT
SAP Predictive Asset Insights (PAI)
SAP Plant Connectivity
Where to Start? It depends...

- Machine Learning & AI
- IOT Condition Monitoring
- Engineering Simulations

Data Availability vs. Equipment Complexity
Questions?

For questions after this session, contact me at si.lee@sap.com.
Thank you.