SAP Predictive Maintenance and Service

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Purpose of today’s session

- Establish an overview of SAP's solution and vision on Predictive Maintenance & Services (PdMS)
- Understand the journey – Running a predictive maintenance project requires huge efforts but yields equally big potentials
- Case of Trenitalia
SAP Predictive Maintenance and Service solution
From sensor to outcome

**Sensor**
Connected assets
- Onboarding
- Connectivity
- Device management
- Security

**Data**
IT/OT* Convergence
- Big Data ingestion
- Big Data infrastructure
- Merging sensor data with business information

**Insight**
Data analysis
- Root cause analysis
- Asset health monitoring
- Machine learning
- Anomaly detection
- Triggering of corrective actions

**Action**
Maintenance activities
- Prioritized maintenance and service activities
- Optimized warranty and spare parts management
- Prescriptive Maintenance
- Quality improvements

**Outcome**
Business Value
- Customer experience
- Increased quality
- Lower costs
- Operational efficiency
- R&D effectiveness
- Material procurement

*) OT = operational technology
SAP Predictive Maintenance and Service Conceptual Architecture

Connected assets

Devices, machines, and sensors

OT (device) integration

OT connectivity

IoT base services

IT connectivity

Big Data platform: SAP HANA Platform

Application

Extensions

Operational analytics

Process automation

Business systems (SAP S/4HANA, SAP CRM, and so on)

IT integration

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SAP Products and Capabilities
How SAP Approaches Predictive Maintenance and Service

Operational System, e.g. PM, CRM, MRS, etc.

Take specific actions utilizing existing business systems

Capture operations technology (OT) data through scalable and cost-effective process

Translate the OT data into consumable signals

Deliver insights to the domain expert from interpreted signals

Derived Signals

Custom signals

Insight Providers
(micro-services, operationalized analytics)

Data Management
Data Fusion
Data Processing

Raw Data

Actions

Business User / Operational User

Domain Expert

Data Scientist / Data Analyst

Data Manager
Predictive Maintenance and Service On-Premise Edition (PdMS OPE)
Business Applications built on Modular Analytics

Predictive Maintenance and Service

- Asset Health Control Center (AHCC)
- Asset Health Fact Sheet (AHFS)

Insight Provider
- Geo-Spatial Insight Provider
- Key Figure Insight Provider
- 3D Visualization Insight Provider
- Asset Explorer Insight Provider
- Work Activities Insight Provider
- Derived Signal Insight Provider
- Additional Custom Insight Provider

Data Science Services
- Remaining Useful Life Prediction
- Distance-Based Failure Analysis
- Anomaly Detection with Principal Component Analysis

Insight Provider Lifecycle Management

Product Integration

IoT Applications
- Connected Assets
  - Devices, machines, sensors
  - Integration possible with Telit DeviceWise, SAP PCo

Operationalized Analytics and Data Science Services

Big Data Platform

IoT Base Services

SAP HANA Enterprise Edition
SAP IQ
SAP ESP*
SAP Predictive Analysis*
SAP Lumira*

*Optional components

Process Automation
Closed-loop business process integration into PM and MRS

Geo-Spatial Insight Provider
Key Figure Insight Provider
3D Visualization Insight Provider
Asset Explorer Insight Provider
Work Activities Insight Provider
Derived Signal Insight Provider
Additional Custom Insight Provider
Remaining Useful Life Prediction
Distance-Based Failure Analysis
Anomaly Detection with Principal Component Analysis

Asset Health Control Center (AHCC)
Asset Health Fact Sheet (AHFS)

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Health status at a glance
• Health status of the complete fleet
• Aggregated from component health scores
• Based on out-of-the-box machine learning
• Derived Signals Management

Personal and extensible
• Flexibly composed by insight providers
• Drill-down into 1 machine

Integrated into operational processes
• E.g. close-loop integration for services
• via Multi-Resource Scheduling (MRS)
Maintenance Innovation in Context
Railway Case
Trenitalia at a Glance

- Fully owned by the FS Group, 100% controlled by the Ministry of Treasury
- Staff: 31,082 employees
- Fleet:
  - 1,580 locos
  - 112 EMUs (electro-trains)
  - 1,547 MUs (light trains)
  - 25,896 coaches and freight cars
  - 498 shunting locos
- Passengers: 38.6 Bn of passenger / km per year
- Tons: 14.7 Bn of tons / km per year
- Trains: 7,263 / day
- Revenue: 5.577 M€
The Business Value of Maintenance Innovation

Perform ALL the required interventions, and ONLY the required interventions, at the RIGHT TIME, ensuring availability of the RIGHT RESOURCES.

**Reduce Costs of Operations**
- Avoid any unnecessary activity
- Plan in advance and in detail for any intervention, ensuring availability of spare parts, facilities, tools and trained resources

**Reduce Unplanned Downtime**
- Prevent breakdowns while trains are in operations
- Prevent extended maintenance downtime due to unforeseen activities

- >8-10% of direct savings on impacted maintenance costs
- >5-8% increase in asset availability
- >x% of reduction of breakdowns of trains in operations

Ground diagnostic
On board diagnostic
Dynamic Maintenance Management System
The Problem with Preventative Maintenance Planning

• Work done by simple assets can be described by a simple indicator such as time of operations or units of throughput, but if we consider a complex machine like a train, the specific operational conditions have a huge impact on how its various components wear out.
• These operational conditions are not known a priori by the manufacturer of the machine, and can change dramatically in the day-by-day work – this creates the need of operating under extremely conservative assumptions.
• The only real value of these plans is that they are logistically very simple to execute and don’t require much information.

Depth of Maintenance Activity

Example
Increase Planning Efficiency and Relevance With Life and Health Indicators

**Life**

Measure as precisely as possible the expected wear of the part by counting and projecting a set of relevant parameters (e.g. cycles, hours of operation, kilometers, energy etc.)

Maintenance is performed when predefined thresholds are reached

**Health**

Takes into account the actual status of operation by measuring physical parameters (e.g. closing time for a door, temperatures of cooling systems) or relevant combinations of indicators.

Maintenance is performed when the parameter goes out of the normal range, indicating a probable deterioration of condition.
Planning Engine
Improving the Relevance of Maintenance Activities

Planning based on Km / Time of operations

- Current model, standard in the industry
- Easy to operate because all the components in the material share the same driver
- Sub-optimal for the same reason

Planning based on Life Indicators

- Based on more relevant drivers and indicators that better represent the effective current and expected usage of every single component
- Increased precision is directly connected with the quality and precision of the planning for the materials
- Requires optimization methods in order to produce a plan, due to the fact that every component in a material can have different life situation

Planning based on Life and Health Indicators

- Further increase the relevance of the plan, considering the future effects that the evolution of life indicators will have on the ability of every component to perform, and on its risk of failure
- Requires sophisticated mathematical methods to predict the behavioral patterns of health indicator based on the expected usage of the materials
- Health indicators can in any case used to trigger short term maintenance activities
Life and Health Indicators in Action

<table>
<thead>
<tr>
<th>Life Ind.</th>
<th>Health Ind.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearings</td>
<td>Vibration pattern</td>
</tr>
<tr>
<td>Wheels</td>
<td>Edge shape</td>
</tr>
<tr>
<td>Engine</td>
<td>f(power gen, power absrbd)</td>
</tr>
<tr>
<td>Doors</td>
<td>Open / close time</td>
</tr>
<tr>
<td>Pantograph</td>
<td>Up / down time</td>
</tr>
<tr>
<td>A/C</td>
<td>f(Delta int temp)</td>
</tr>
</tbody>
</table>

- “Real” Big Data in action: hundreds of TB, huge number of sources and entities involved
- Complex algorithms to predict indicators and optimize the outcome across multiple dimensions
- Huge transformational value and financial impact

Operational plans for Rolling Stock

- Telemetric readings
- Detailed Information on Infrastructure

Predicted Life and Health Indicators

- Check against safety thresholds

Consolidated picture for the planning unit

Maintenance calendar

Check availability of resources

Optimization for costs vs. risk granular decisions
Life and Health Indicators for Trains Doors

1. Past values are monitored by sensors on board of trains

2. Projection of life indicator considering the plans for the material, prediction of the consequence on the health indicator using mathematical methods

3. Health safety threshold – function of life

4. Trigger of maintenance request due to the life indicator reaching risk threshold
Life and Health Indicators for Trains Doors

1. Past values are monitored by sensors on board of trains
2. Projection of life indicator considering the plans for the material, prediction of the consequence on the health indicator using mathematical methods
3. Health safety threshold – function of life
4. Trigger of maintenance request due to predicted health issues
Life Indicator / Time Relationship – Example L1

1. Line describing the expected aging of the component based on a linear relationship with time (and KM), which is the basis of current maintenance scheduling.

2. Curve describing the effective evolution and projection of the synthetic function of life indicators.

3. Time for which the maintenance can be postponed based on life indicators, compared to time / km based planning.
Life Indicator / Time Relationship – Example L2

1. Line describing the expected aging of the component based on a linear relationship with time (and KM), which is the basis of current maintenance scheduling.

2. Curve describing the effective evolution and projection of the synthetic function of life indicators.

3. Area of risk of failure, because of the component likely wearing out faster than foreseen in the standard maintenance plan.
Life Indicators in Action: Braking System

Objective and Approach

- Calculation of the life indicator → energy dissipation by friction braking systems, with separated analysis for locomotives and coaches
- Development and test of calculation algorithms for all the possible cases identified

Results Achieved

- Monitoring of the effective usage and level of wear-out for every single component of the braking system against the risk thresholds identified
Life Indicators in Action: Braking System

- High variability of the energy dissipated per km clearly indicates that distance is not a good indicator of consumption for braking systems.
- Comparison between traditional indicators such as km and more precise life indicators highlights the significant opportunity for optimization of maintenance operations.
Life Indicators in Action: Braking System

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Anomaly Detection Analysis on Turnouts

- 19 turnouts analyzed over a period of around 17 months
- Diagnostic equipment records tension and current of the actions
- Over the period there were only 11 actual failures, corresponding to an MTBF (Mean Time Between Failures) of around 21,000 hours
- Turnouts are inspected on the average once a month

Data seem to indicate a situation of over-maintenance, driven by the strong priority of avoiding failures almost at any cost. This is typical of critical assets where failures come with big penalties.
Analysis on Turnout 1

Thresholds on anomalies defined as a combination of severity and number of instances in a rolling period, and tuned to match violations and prevalence of failures, at least in terms of order of magnitude.

Anomaly score in the 20-day period

Failure
Analysis on Turnout 2

Anomaly score in the 20-day period

Failure
Analysis on Turnout 3

Anomaly score in the 20-day period

Failure
Results of Anomaly Detection Analysis on Turnouts

- 5 out of the 11 failures were predicted by the algorithm a few days in advance
- 6 failures were not predicted, best hypothesis is that around half could be identified with better diagnostic equipment, half is highly intractable from a data science perspective
- 69 false positives were also generated

\[ \text{Accuracy} = \frac{TP + TN}{Total} \]
\[ \text{Misclassification} = \frac{FP + FN}{Total} \]
\[ \text{True Positive Rate} = \frac{TP}{Actual \text{ Yes} - \text{AKA Sensitivity / Recall}} \]
\[ \text{False Positive Rate} = \frac{FP}{Actual \text{ No}} \]
\[ \text{Specificity} = \frac{TN}{Actual \text{ No}} \]
\[ \text{Precision} = \frac{TP}{Predicted \text{ Yes}} \]
\[ \text{Prevalence} = \frac{Actual \text{ Yes}}{Total} \]
\[ \text{Negative Predictive Value} = \frac{TN}{Predicted \text{ No}} \]

→ Very high accuracy and specificity
→ Very low precision
→ Prevalence (number of weeks in which a failure happens / total number of weeks analyzed) is below 1%

In rare event prediction case, achieving high accuracy, precision and sensitivity at the same time is extremely challenging

The real actionable insight often sits in the Negative Predictive Value

Data are analyzed in time series, but presented discretized by week
Anomaly Detection on Electric Engines of Locomotives

Failures
Anomaly Detection on Electric Engines of Locomotives
Anomaly Detection on Electric Engines of Locomotives
Conclusions
Definition of maintenance policies can be seen as the management of the tension and trade-off between costs and risks. Most of the efficiency efforts are aimed at making sure that the right balance is reached.

Internet of Things-based maintenance innovation represents the opportunity of transforming structurally the system and reach a new level of balance between costs and risks.
Remember all the sophisticated models....

Principal Component Analysis of Switches

Anomaly Detection with Principal Component Analysis scores

K-Mediod cluster analysis to partition the population into classes of similar devices

Weibull Remaining Useful Life Estimation

\[
f(x; k, \lambda) = \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k}
\]

where

\[
x = e^{\frac{\lambda x}{k}}
\]

PCA

Battery behavioural groupings

Wasserstein Metric for battery performance analysis

Automatic Rule Extraction with Decision Trees

Expert Rule Validation

Automatic Rule Extraction with Decision Trees

Expert Rule Validation
….need to work under the conditions of the “real world” eventually!
Extending to Meet Business Needs
Optional PoC is an opportunity to increase customer value proposition

START

OPTIONAL PROOF OF CONCEPT

Discovery Workshop

Data Modeling

Validation

Iterations

< 3 months

IMPLEMENTATION
(SAP SERVICES / CD)

Implementation

CDP (optional)

GO-LIVE

PdMS Go-Live

- Understand and reframe the problem(s)
- Ideate possible solutions
- Ensure technical feasibility

- Prepare data
- Model data
- Generate derived signal models
- Determine standard out-of-the-box fit
- Evaluate technical feasibility
- Weekly iterations to collect feedback
- Pass acceptance tests and/or success criteria
- Standard Implementation
- Based on SAP standard PdMS product
- Custom development of new functionality
- Go-Live Support
- Standard Support
- SAP CD Support (optional)
- Application Management Service (AMS) (optional)
Thank you

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