Predictive Maintenance & Service and Predictive Quality–Overview and Customer Experiences (incl. Mohawk)

Oliver Mainka, Internet of Things & Customer Innovation
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Agenda

PdMS Motivation
PdMS Fundamentals
PdMS Customer Experiences
Predictive Quality Project
Technology
Related SAP Products
How to engage with SAP
Agenda

**PdMS Motivation**
PdMS Fundamentals
PdMS Customer Experiences
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Failing Assets are a Huge Issue to Owners/Operators and OEMs of Equipment

While the world's GDP is around $46.6 trillion, the value of all assets is assumed to be much higher. Maintenance spend alone comes up to $447 billion.

Source: Global Framework on Maintenance and Asset Management

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**US Maintenance Costs 2011**
- Annual maintenance costs: 200 in billion USD
- Loss due to ineffective maintenance: 60

**Europe Maintenance Costs 2010**
- Annual maintenance costs: 450 in billion EUR
- Maintenance costs addressable by maintenance improvements: 300
- Loss due to ineffective maintenance: 70

Sources: ¹ConMoto, Wertorientierte Instandhaltung (2011) ²ARC Advisory Group, Predictive Maintenance Survey
What is leading performance? Maximize asset productivity

“Top 25% organizations have 35% higher operating equipment effectiveness than bottom 25% peers.”

“Top 25% organizations experience 3.5-fold increase in return on assets as compared to bottom 25% peers.”

“Top 25% organizations witness 7-fold decrease in unplanned downtime/outages as compared to bottom 25% peers.”

<table>
<thead>
<tr>
<th>Operating Equipment Effectiveness (%)</th>
<th>Return On Assets (%)</th>
<th>Unplanned Downtime/Outages (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>88.0% Top Quartile</strong></td>
<td><strong>20.4% Top Quartile</strong></td>
<td><strong>1.0% Top Quartile</strong></td>
</tr>
<tr>
<td>76.0% Average</td>
<td>13.6% Average</td>
<td>3.4% Average</td>
</tr>
<tr>
<td>65.0% Bottom Quartile</td>
<td>5.9% Bottom Quartile</td>
<td>7.0% Bottom Quartile</td>
</tr>
</tbody>
</table>

Source: SAP EAM Benchmarking 2011, based on data from over 60 participants (including SAP customers)
Agenda

PdMS Motivation

**PdMS Fundamentals**

PdMS Customer Experiences

Predictive Quality Project

Technology

Related SAP Products

How to engage with SAP
Predictive Maintenance is an Important Building Block for Improving Failing Assets

- Create notification
- Alter maintenance schedule
- Preposition spare parts
- Improve product quality
- Change product specs
- Service scheduling
- Recommend services
- Lower cost for PowerByHour

50 billion devices connected by 2020*

40-50% CAGR for M2M market until 2020*

1/5 price of sensors, microprocessors & wireless technologies today vs. 4 years ago**

*Source: Gartner – "Top 10 Tech Trends for 2013" – 2012
**Source: Economist Intelligence Unit – "The Rise of the Machines" – 2012

Source: Gartner
Predictive Maintenance and Service Illustrated: The P-F Interval Curve

Machine Capability / Resistance to Failure

Preventive Maintenance & Monitor Condition

Potential Failure

Repair or Replace

Equipment Unusable

"Can"

Early Signal 1 – Ultrasonic Energy Detected
Early Signal 2 – Vibration Analysis Fault
Early Signal 3 - Oil Contamination Detected
Audible Noise
Hot to Touch
Mechanically Loose

Effect of PdMS

"Want"

Functional Failure

Total Failure

Time

Cost to Repair

Initial Break-in Period
Pattern C = 4%

Wear Out
Pattern B = 2%

Fatigue
Pattern E = 14%

Infant Mortality
Pattern F = 68%

Can

Want

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Adoption Rate of Predictive Maintenance

Source: SAP EAM Benchmarking Study
Predominantly Reactive – where Reactive Strategy accounts for 50% or more
Predominantly Preventive/ Predictive – Higher of the two
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How to engage with SAP
### PdMS Co-Innovation Projects (1/2) (All OEMs)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Country</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finished 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automotive</td>
<td>Germany</td>
<td>Manufacturing Quality Assurance by automatic failure identification and anticipation based on machine data.</td>
</tr>
<tr>
<td>Automotive</td>
<td>Germany, US</td>
<td>Vehicle health prediction to improve manufacturing quality, service planning and customer satisfaction based on business and telemetry data. Very big data: Hana / Hadoop</td>
</tr>
<tr>
<td>Automotive AMG</td>
<td>Germany</td>
<td>Product improvement in R&amp;D based on vehicle test data.</td>
</tr>
<tr>
<td>Agricultural Equipment John Deere</td>
<td>US</td>
<td>Early identification of emerging issues for product improvement and failure prediction to reduce downtime based on business and telemetry data.</td>
</tr>
<tr>
<td>Agricultural Equipment</td>
<td>Germany</td>
<td>Identification and prioritization of machine failure pattern for product improvement based on business and machine data.</td>
</tr>
<tr>
<td>Compressed Air Equipment</td>
<td>Germany</td>
<td>Machine health prediction to lower service costs and increase machine up-time. Enable service, sales and R&amp;D to transform the company to an industrial service provider.</td>
</tr>
<tr>
<td>Food Industry Equipment</td>
<td>Germany</td>
<td>Identification of health finger print based on vibration analysis. Integration of and monitoring of machine health using failure pattern for product improvement from business and machine data.</td>
</tr>
<tr>
<td>Aerospace OEM</td>
<td>US</td>
<td>Systems trending and alert management framework which allows customer support to propose alternative maintenance schedules which may avoid unplanned downtime, increase aircraft availability and increase service and maintenance revenues.</td>
</tr>
</tbody>
</table>
## PdMS Co-Innovation Projects (2/2)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Country</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Finished 2014</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerospace MRO</td>
<td>Switzerland</td>
<td>Root cause analysis / new customer services</td>
</tr>
<tr>
<td>Chemical BASF</td>
<td>Germany</td>
<td>Data mining of all manufacturing data from assets and production</td>
</tr>
<tr>
<td>Rail Trenitalia</td>
<td>Italy</td>
<td>Optimized maintenance schedules based on telematics</td>
</tr>
<tr>
<td><strong>Finished 2015</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil &amp; Gas Valero</td>
<td>USA</td>
<td>Asset analytics, bad actor analytics, sensor data investigation</td>
</tr>
<tr>
<td>Mining</td>
<td>Canada</td>
<td>Yield prognosis for wells based on asset measurements</td>
</tr>
<tr>
<td>IM&amp;C Pumps</td>
<td>Germany</td>
<td>Root cause analyses</td>
</tr>
<tr>
<td>Flooring Mohawk</td>
<td>USA</td>
<td>Correlations between customer warranty cases, production issues, and faulty machines</td>
</tr>
<tr>
<td>IM&amp;C Elevators</td>
<td>Germany</td>
<td>Root cause analyses</td>
</tr>
<tr>
<td><strong>In Progress</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IM&amp;C Trucks</td>
<td>USA</td>
<td>Root cause analyses, customer services</td>
</tr>
<tr>
<td>IM&amp;C Heavy Eq.</td>
<td>China</td>
<td>Root cause analyses</td>
</tr>
<tr>
<td><strong>Discussing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>~10 companies</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Value with little data science: Leading U.S. O&G Downstream Enterprise

**Phase I:** focus on CMMS (SAP PM) analytics for rotating equipment

**Data**
- 14 refineries, 17 years
- 1.2 M equipment, 33 K pumps
- 4 M work orders, 3 M notifications

**Use Cases**
- Fill data gaps with HANA rules engine and SQL rules
- Text analysis of breakdowns
- Bad actor reports
- Pump ranking lists
- KPI and cost trends
- Weibull analysis

**Phase II:** pump sensor data failure analysis
Value with little data science: Key figures for 2773 sensors across 3 years calculated and presented in 9 seconds

Aggregations based on 6 · 10⁹ sensor readings in less than 9 seconds
Options for Failure Prediction

1. **Incident**
   - Extract rules
   - Find the reason
     - Root cause analysis
   - Permanently remove reason if possible

2. **Anomaly Detection**
   - Automatically find early deviations from normal
   - Analyze and repair if necessary

3. **Classification**
   - Learn a prediction model from sensor data and failures
   - Repair if probability of failure high
Association Rules and Decision Trees

Incident Discovery

Country A + Air Con ➔ Frequent Failures

- country
  - A
  - Not A
- engine
  - 50kW
  - 150kW
- air conditioning
  - yes
  - no
Practical Example for Association Rules and Decision Trees

### Tabular View

<table>
<thead>
<tr>
<th>Rule</th>
<th>Subset</th>
<th>Defect Rate</th>
<th>Lift</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.<strong>1</strong></td>
<td>1</td>
<td>78.94%</td>
<td>2.9262</td>
</tr>
<tr>
<td>2.<strong>820</strong></td>
<td>13</td>
<td>72.22%</td>
<td>2.6769</td>
</tr>
<tr>
<td>3.<strong>820</strong></td>
<td>13</td>
<td>72.22%</td>
<td>2.6769</td>
</tr>
<tr>
<td>4.<strong>820</strong></td>
<td>13</td>
<td>71.42%</td>
<td>2.6475</td>
</tr>
<tr>
<td>5.<strong>MD_D10_0040</strong></td>
<td>13</td>
<td>70.58%</td>
<td>2.6163</td>
</tr>
<tr>
<td>6.<strong>MD_D10_0040</strong></td>
<td>13</td>
<td>70.58%</td>
<td>2.6163</td>
</tr>
</tbody>
</table>

Showing 253 out of 253 rules, inclusive defect rate: **27.0%**

### Graphical View

#### All Machines

<table>
<thead>
<tr>
<th>Rule</th>
<th>Subset</th>
<th>Defect Rate</th>
</tr>
</thead>
</table>
| All Machines | 341 | 27.0%
| YYUTP = 820 | 108 | 9.2%
| YYUTP = 120, 300, 800 | 90 | 23.3%
| XXL | 18 | 55.5%
| C13 | 87 | 34.5%

Inclusive defect rate: **27.0%**
P12 Decision tree
Leading indicators occurring 1 day before a repair

Results generated by regression to compute the contribution of sensor range / buckets to the target (Repair event)

Interpretation of the specific path: When in a day (time window chosen to monitor the sensor pattern around a repair event) all pumps that have had readings that followed the combinatorial rule below, there has been a definitive repair observed on the unit (100% correlation to repair event occurring) after a day:

- High feed % range is: HF%(L) – HF%(H) and
- High feed rate (BPD) range : HF(L) -HFb and
- Low temperature range : LT(L) – LT(H) and
- High temperature range : HT(L) – HT(H) and
- Avg feed % : AF(L) – AF(H)
Demo Predictive Maintenance & Services Application

SAP Predictive Maintenance and Service

Plane 456-1024
- 53 Downtime
- 2 P3 Notifications
- 99.89% Operational Availability

Alert Severity
- All OK
- P1 Alerts
- F1 Alerts

Filter by
- Model
- Status
- Plane

Map Markers
- Service Centers

Notifications
- Total Mean Time To Repair: 16 hours
- Total Estimated Cost: $10,000
Integrating data from unstructured text

2012 Toyota Highlander, 1G1JF27W8GJ178227. Policy #456-788-99. $500 deductible. Insured are William Thomas Snow and Christine W. Snow. On 1/09/13, received via text message "In accident! Need tow truck." and "Corner of Winter & Cross Rd". Dr. Snow slid through a stop on the snowy road and hit the stop sign. Significant damage to front of the car. He was unhappy at tow truck response time. Contact wtsnow@medicalcenter.com or 651.772.1234. Advance Appraisals Inc. to come out at 8:30am Monday to make further assessment.

Who, What, Where, When, How much, as well as Feelings
Tag Clouds
Text Cluster Analysis
Agenda

PdMS Motivation
PdMS Fundamentals
PdMS Customer Experiences

**Predictive Quality Project**

Technology
Related SAP Products
How to engage with SAP
Project focus area

- Mohawk Products
  - Hardwood
  - Laminate
  - Carpet
  - Rugs
  - Vinyl
  - Tile
  - Extrusion
  - Yarn
  - Tufting
  - Dyeing
  - Coating
  - Plant
  - Other plants
  - Sidematch Claim
  - Other Claim Types
Problem Statement (from customer executives)

Help reduce warranty cases by finding contributors to quality issue root causes – focus on “side-match” claims (Cost ↓)

Help Mohawk quality and production managers to more easily and iteratively get integrated views of related data (Productivity ↑)

Help to find issues which are not obvious to humans with deep manufacturing expertise (Productivity ↑)
Extrusion impressions
Yarn production impressions
Tufting impressions
WIP rolls
Dyeing impressions
Coating impressions
Finished rolls
Production process combo of discrete and continuous steps

- Plastic pellets
  - Extrusion
    - Yarn production
      - Tufting (sewing)
        - Yarn spindles
          - Dyeing
            - Dye
              - Chemicals
                - Primary backing
                  - Secondary backing
                    - Latex
                      - Fiber
                        - Coating (backing)
                          - Greige roll
                            - Dyed Groll
                              - Finished roll
                                - (cut of Groll)
                                  - (full Groll)
                                    - (cut of finished roll)
                                      - (full finished roll)
                                        - (cut of)
                                          - (cut of)
                                            - (full)
Data objects and volume

- ERP Warranty Claim: ~20K
- ERP Finished Roll (sold product): ~600K
- Optical Quality Inspection: ~200K (2 ½ years)
- Maintenance record: ~20K PMs (4 years)
- Alarms: ~400K (2 ½ years)
- MES WIP Roll: ~350K
- Machines / Sensors: ~1.8B (356 sensors, 2 lines, 2 years)
Workstreams

Claims

Manufacturing Execution

Machine sensors

Machine alarms

Quality inspections

Machine maintenance

Analytics single source (e.g. sensor issues, inspections ranges, …)

Analytics multiple sources (e.g. preventive maintenance vs. alarms)

Product Tracker

Predictive Analytics

(Improved) Statistical Process Control and Alarming

1. Integrate disparate data sources
2. Extend breadth/depth and speed of analytics
3. Understand what product was exposed to and whether that led to issues
4. Prevent past quality issues from repeating
1 – Product Tracker
Rolling, unrolling, cutting carpet
Roll entry + speed + sensor location = carpet affect
Stacked Sensor Charts for One Finished Roll

Different sensor readings of the same finished roll at various locations stacked onto each other

Stretched to same full length

Alarm overlay
Visual Inspection

Inspect large amounts of sensor data visually.

Seamlessly transition aggregation levels and slide through dimensions.

Overlay relevant business data such as machine alerts, recorded malfunctions, etc.

Define constraints to make data more comparable.
2 – Predictive Analytics
Initial Data Exploration, Little Differentiation

796 rolls: \( \text{abs}(x) < 1 \)

- WC
- No WC
Final Predictive Model Results (using certain combo of sensor data)

Data: 937 rolls

Training Set: 236 rolls with claim; 236 rolls without claim

Test Set: 237 rolls with claim; 228 rolls without claim

<table>
<thead>
<tr>
<th>Predicted</th>
<th>Claim</th>
<th>No Claim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Claim</td>
<td>195</td>
<td>42</td>
</tr>
<tr>
<td>No Claim</td>
<td>25</td>
<td>203</td>
</tr>
</tbody>
</table>

Model: Random Forests

True Positive (TP) rate: % of claim rolls correctly predicted: $\frac{195}{195+42}$: 82%

True Negative (TN) rate: % of non-claim rolls correctly predicted: $\frac{203}{203+25}$: 89%
Calculating Decision Trees
3 – Statistical Process Control
SPC – Statistical Process Control

- Sensor behavior varies between usage runs of an asset, but within certain limit
- Sensors show an anomaly in a usage run of the asset if their behavior is very different to their behavior in other usage runs
- Use average sensor value in „regular“ asset use as descriptor
- Automatically fit control limits which show normal operation using SPC (XBar Chart):
  - Centerline: $\bar{x}$ (Mean of means over asset uses)
Control Charting in HANA and R

- Wider date range
- More granular time interval
- Easier filtering → better focus
- Better speed → more iterations
- Determine spec limits from control limits
Sample generated charts

Steamflow vs. Dryer Face Temp

Alarm Pareto

Optical Inspection Trends

Control Chart in MiniTab

Dryer ambient temp vs. carpet face temp, interpolated seconds

Sensor values and set points

Style tag clouds
Agenda

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Predictive Quality Project

Technology
Related SAP Products
How to engage with SAP
Using HANA for PdMS

E.g. O&G: 4 M work orders, 3 M notifications, 1.2 M equipment – Chem: 6 B sensor data readings – Auto: Hadoop integration
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Current PdMS Product Offerings

Standard Cloud Solution

- PdMS Cloud Edition
  - HANA Cloud

Custom On-Premise Solution

- PdMS Foundation
  - HANA On-Premise

- Custom Application
  - One or more of the options of SAP predictive analytics

- One or more data transfer / streaming options

Sensor and business data
# PdMS Foundation - Accelerator for final on-premise PdMS solution

Requires custom development project project for final solution

**Preconfigured**
- IT data model

**Configuration UIs**
- OT data tables
- OT data aggregations
- IT data table changes

**Improved OT data compression**

**Application UI building blocks**
- Map
- Filter
- KPIs
- Tag cloud
- 3D Sensor Data
- Lumira
- R Container

**Sample application**

![Image of application UI](image-url)
Planned new standard software functions for PdMS On-Premise

Initial standard business applications

“Machine Health Control Center”
- See machines and predicted health scores
- See related alerts and maintenance activities
- Geographic maps, charts, lists, health score explanations, and KPIs
- Trigger a follow-up maintenance activity for at-risk machines

“Emerging Issue Detection”
- Investigate machine issues
- Iteratively apply investigation tools from a catalog
- Create a case
- Collaborate a case
- Track a case

Architecture

On-premise (and later on-cloud)
Support of very large data sets
Any data model
Modular services
Included data science services for machine health scoring
SAP Predictive Maintenance and Service, Cloud Edition
Condition Monitoring

Analysis of Sensor Data
Flexible visualization and analysis of sensor data
Comfortable time series drill down to the second level

Condition Monitoring
Threshold based monitoring of sensor data and alert triggers
with graphical visualization of warning and error zones
Configuration of thresholds
Health monitor with measuring point overview
SAP Predictive Maintenance and Service, Cloud Edition
Alert Analysis

Visualize machine KPIs and drill-downs
Role based visualization of machine alerts and KPIs
Powerful drill-down scenarios for near real-time insights

Map device locations
Add positioning data to devices for placement on maps
Graphical highlights of alert situations and drill down into the device
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How to engage with SAP
# Options to Engage with SAP on PdMS

<table>
<thead>
<tr>
<th>SAP Offer</th>
<th>Customer Profile</th>
<th>Your Next Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>PdMS Cloud Edition</td>
<td>Use standard functionality in cloud now</td>
<td>Contact your AE</td>
</tr>
<tr>
<td>Lighthouse Council</td>
<td>Influence and Learn</td>
<td>Contact <a href="mailto:adrian.Langlouis@sap.com">adrian.Langlouis@sap.com</a></td>
</tr>
<tr>
<td>PdMS Foundation &amp; Custom Development Project</td>
<td>Use “any” functionality on-premise now</td>
<td>Contact your AE</td>
</tr>
<tr>
<td>“Sprint Zero” PoC</td>
<td>Try before you buy</td>
<td>Contact your AE (and AE will involve Custom Development AE)</td>
</tr>
<tr>
<td>New Planned Standard On-Premise Functions (EID/MHCC) Feedback Council Onsite Workshops Co-Innovation Project</td>
<td>Influence and learn, optionally prepare for productive phase</td>
<td>Contact <a href="mailto:oliver.Mainka@sap.com">oliver.Mainka@sap.com</a></td>
</tr>
<tr>
<td>Related SAP Engines (HANA, PA, IP, ESP, …)</td>
<td>DIY mentality, create your own solution from scratch</td>
<td>Contact your AE (plus probably some solution expert)</td>
</tr>
</tbody>
</table>
Opportunities to collaborate with SAP on new standard on-premise functions

Feedback Council
Review functions and designs
3-4 90 minute remote feedback sessions over three months
1:1 or in group (up to customer)

Workshops
More in-depth review of customer processes and artefacts against SAP functionality
1-2 half- to full-day workshops at customer over three months
1:1 with SAP

Co-innovation Project
In-depth PoC against customer processes, data
1-3 month project involving several customer business and IT people
Preparation for an eventual go-live
1:1 with SAP

Our focus for today

Effort
Influence
Depth
Our focus for today
Thank you

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