IOT ANALYTICS

MARKET INSIGHTS FOR THE INTERNET OF THINGS

REPORT SAMPLE

Predictive Maintenance – Market Report 2017-2022

Moving from Condition-based Maintenance to IoT- & Analytics-Enabled Predictive Maintenance

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For information regarding permission, write to:
IoT Analytics GmbH
Max-Brauer-Allee 271
22769 Hamburg, Germany
insights@iot-analytics.com

IoT Analytics Research Team
Zana Diaz Williams, Senior Analyst – zana@iot-analytics.com
Padraig Scully, VP Market Research – padraig@iot-analytics.com
Knud Lasse Lueth, Managing Director – knud@iot-analytics.com

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1. Navigation is here. Chapter and subchapter names are called out

How to read this report?

Page Summary

In short: Predictive Maintenance (PdM) a condition-based mainte e technique that involves differen f (real-time) analytics to achie ings

Po bu Po m co so and thousands of logged events.

→ **(See next 4 slides for more details)**

2. Important insights are here. Most pages have a grey "Page summary" block on the left – read only this block on every page for a synopsis of each page

Details

Predictive maintenance describes a set of techniques to…

… accurately or the **current condition** of machines or any type of industrial equipment,
… using **solutions**
… with ailure by using automated **real-time analytics, statisti** *Note: Today's PdM implementations often use "near real-tin delay)*

>> This outine or time-based preventive maintenance, because tasks are performed only when warranted

3. Details are here. The details and charts are on the right hand side.

4. Sources and explanations here. Sources and detailed explanations can be found in small print

Source: IoT Analytics Research

Agenda

Executive Summary (1/4)

OVERALL HIGHLIGHTS

- Predictive Maintenance market to become a $10.96B revenue opportunity by 2022. PdM is the #1 use case in Connected Industry settings.
- Fast growing market with a compound annual growth rate of 39%.
- Companies employing PdM solutions report real value. Maintenance efficiency gains of 20%-25% are achieved today.

TECHNOLOGY

- **Storage:** xxx
- **Analytics**: xxx
- **Sensing**: xxx

Source: IoT Analytics Research

Executive Summary (2/4)

MARKET

- **Overall drivers:** xxx
- **Market shift from CBM to PdM:** xxx
- **Internal PdM vs. PdM as-a-service:** xxx
- **Technology stack:** xxx
  - **Shift from Type A PdM (static rule-based) to Type B PdM (dynamic models).** xxx
  - **Shift from On-premise solutions to cloud.** Xxx
- **Industries**: xxx

Source: IoT Analytics Research

Executive Summary (3/4)

COMPETITIVE LANDSCAPE

- **Overall**: xxx
- **Startups**: xxx
- **M&A activity:** xxx

BUSINESS MODELS & USE CASES

- **Overall**: xxx
- **PdM Services:** xxx
- **Customer access:** xxx
- **Use cases:** xxx

Source: IoT Analytics Research

Executive Summary (4/4)

TRENDS & CHALLENGES

- **Main trends:** The following 6 main trends are emerging:
  Xxx

- **Role of PdM in service:** xxx

- **Main challenges:** The following 7 main challenges are emerging (more called-out in Chapter 5):

Xxx

- **Main research areas:** The following 5 main academic research areas are emerging:

xxx

Source: IoT Analytics Research

PREFACE: Moving from Preventive to Predictive Maintenance

Key theme: Moving from preventive to predictive maintenance

Maintenance today often preventive. At present, maintenance is often preventive, time-based rather than based on actual equipment conditions and predictive methods. Maintenance on each asset is performed at more frequent, regular intervals to lessen the likelihood of costly failures. This results in unnecessary maintenance costs and causes unanticipated downtime.

Headed towards predictive maintenance. Connected, real-time IoT solutions allow companies to reliably predict failures, and detect and respond to unanticipated equipment or process degradation. This insight enables companies to perform maintenance based on the actual operating conditions of the equipment and process and also to predict failure ahead of time.

Cost-savings and new business models. The accurate prediction of upcoming maintenance not only enables reduced downtime, it also allows operators and service providers to optimize maintenance activities. By improving maintenance scheduling, they can both maximize the use of maintenance resources and optimize maintenance inventory and supply chains. The achieved cost savings, along with the production and operational benefits, of IoT-enabled predictive maintenance are significant, often >20% of addressable costs. Equipment OEMs are starting to introduce various PdM-based services that help them differentiate their product in the market and further tap into the lucrative aftermarket.

PdM is enabled by a set of new technologies. Sensors intelligently and continually capture data from equipment in the field, optionally processing it at the edge before transmitting critical data to a centrally hosted system for both near real-time and historical analysis. Here new technologies, such as machine learning, advanced analytics and applied data science, play a vital role; as does the ability to process large amounts of data across a significant number of devices and geographically dispersed assets. These critical technology-enablers work together to detect the equipment and process condition patterns that predict equipment failures, performance degradation, and process upsets.

PdM technology is evolving further. Innovations are continuing in the technological arenas that enable condition monitoring, including advanced sensing, advanced analytics, asset condition visualization, simulation, and user experience.

This report provides an overview of the ongoing shift in technology, the state of current PdM implementation projects in various industries, provides a landscape of companies enabling this shift and discusses the trends accompanying IoT and PdM specifically.

Source: IoT Analytics Research

Definition in Detail

Page Summary

In short: Predictive Maintenance (PdM) is a maintenance technique, based on the monitoring of equipment conditions combined with different sets of (real-time) analytics to achieve cost savings.

Like CBM, PdM builds on condition monitoring but has a unique set of advantages. PdM is different from other maintenance approaches. It combines various sensor readings, sometimes external data sources and performs powerful analytics on thousands of logged events.

→ (See next 4 slides for details)

Definition

Predictive maintenance describes a set of techniques to…

… accurately monitor the **current condition** of machines or any type of industrial equipment,
… using either **on-premise** or **cloud analytics solutions**
… with the goal to predict upcoming machine failure by using automated (near) **real-time analytics** and **supervised or unsupervised machine learning.** *(Note: Today's PdM implementations often use "near real-time" analytics i.e. with several minutes of delay)*

>> This approach promises **cost savings** over routine or time-based preventive maintenance, because tasks are performed only when warranted

What it is NOT

Reactive Maintenance: Run-to-failure – i.e., only performing maintenance when problems occur
Preventive Maintenance: Regularly scheduled maintenance – using either time intervals or usage as a trigger
Proactive Maintenance: Root cause analysis – Measures are taken to prevent equipment failure altogether
Condition-based Maintenance (CBM)[1]: Machine status monitoring – Use of sensors to monitor current asset condition, without performing further analytics (i.e., predicting remaining useful life or overall machine health)
Prescriptive Maintenance [2]: Machines "self-diagnose" and schedule maintenance *(Note: This concept builds on predictive maintenance but is not widely adopted today)*

1. CBM and PdM base on the concept of condition monitoring, but differ in sophistication levels. 2. Prescriptive Maintenance builds on PdM
Source: IoT Analytics Research

Comparison to Other Maintenance Approaches

Functional view

A. Maintenance Approaches w/o Sensing Technologies

1 Reactive Maintenance

- Run-to-failure-strategy

Result: Low routine maintenance costs but high costs in case of equipment failure and risk of long downtimes

2 Preventive Maintenance

- Maintenance is planned and performed in regular intervals
- Time or a usage triggers are used to schedule maintenance

Result: Reduced likelihood of failure, but an ongoing-effort is necessary

3 Proactive Maintenance

- Determining the root causes for machine failure
- Taking measures / corrective actions to avoid equipment failure altogether e.g., Give workers training on best-practice machine operation

Result: Reasons for equipment failure are avoided

B. Maintenance Approaches Using Sensing Technologies

4 Condition-based Maintenance[1]

- Condition Monitoring via sensors
- Maintenance is performed, only when equipment problems have been registered

Result: Anomalies are identified and resolved prior to functional failure
Implementation variations: Hand-held devices or retrofitted/previously integrated sensors

Focus of this report

5 Predictive Maintenance[2]

- Condition Monitoring is enhanced by advanced statistics, stochastics, real-time analytics or even machine learning algorithms, which allow to make predictions on when equipment will fail
- On-Premise and/or Cloud analytics

Result: Equipment failure is predicted and preventative actions can be taken
Implementation variations: Using static-rule-based analytics or using dynamic-model-based analytics (Type B)

6 Prescriptive Maintenance

- Machines "self-diagnose" and schedule maintenance

Result: Completely automated maintenance workflow

Sophistication of Analytics

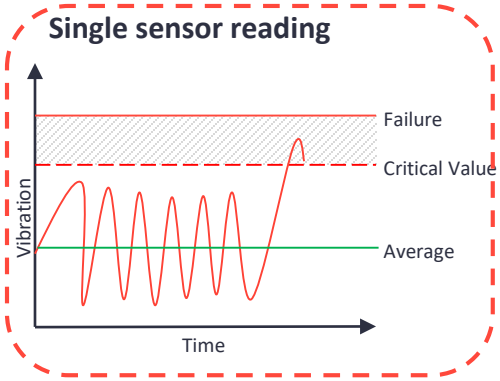
1. Sometimes also referred to as "diagnostics"
2. Sometimes also referred to as "prognostics"

Source: IoT Analytics Research

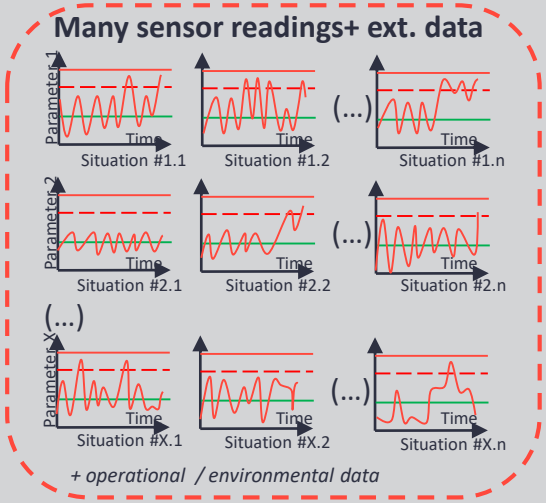
Comparison to Other Maintenance Approaches (...)

Analytics View

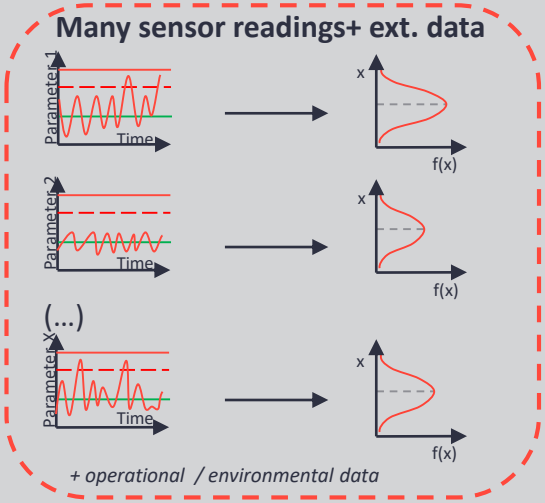
4 Condition-based Maintenance



5a Type A PdM[1]



5b Type B PdM[2]



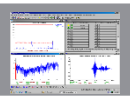
"[In contrast to condition monitoring] ***Predictive maintenance applies analytical models and rules against the data to proactively predict an impending issue****; it then delivers recommendations to operations, maintenance and IT departments to address the issue."* Source: IIC

Functionality	Critical values are defined based on experience or specifications set by the machine supplier. Each sensor is monitored individually. Warnings occur only if critical values are reached or experts identify unusual sensor readings.	Condition monitoring is used as the basis for predictive maintenance, combining multiple timelines and all measurable parameters. **Static rules** enable **failure identification**.	**Dynamic models** enable the **prediction of failure likelihood**.
Calculated Value	**Warning signal** (provides information that unusual machine activity has been registered)	Combined **health** or **risk score** (indicates how critical equipment status is)	Calculated **Remaining Useful Life (RUL)** (gives exact information on a timeframe in which maintenance needs to be scheduled)
Improvement measures	Possibility to manually alter critical value threshold over time, based on experience	Automatic improvement of prediction capabilities by constantly feeding maintenance logs into the model, thus further advancing machine learning algorithms.	

1. Type A = Static-rule based analytics 2. Type B = Dynamic-model-based analytics Source: IoT Analytics Research

Comparison to Other Maintenance Approaches

Maintenance Technician View

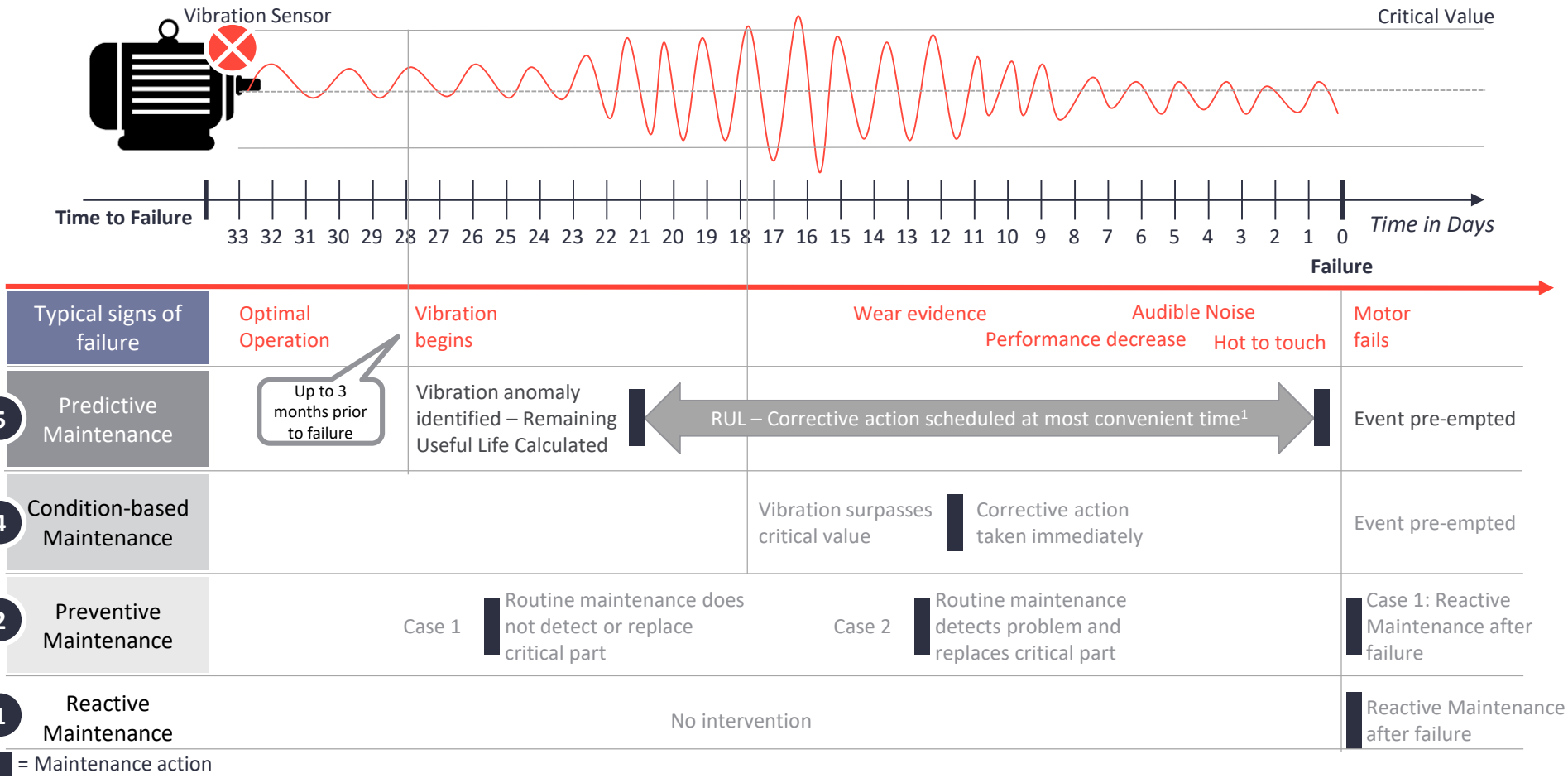
	4. Condition-based Maintenance		5. Predictive Maintenance	
	a. Mobile Condition Monitoring 	b. Online Condition Monitoring 	a. Type A PdM 	b. Type B PdM[1] 
Sensing Technology	Handheld Device	Integrated Sensors	Integrated Sensors	Integrated Sensors
Monitoring Frequency	In regular intervals / on demand	Constantly	Constantly	Constantly
Visualization	On specific device	Online / Mobile	Online / Mobile	Online / Mobile
IT-Architecture	On-Premise	On-Premise or Cloud	On-Premise or Cloud	On-Premise or Cloud
Real-time monitoring	✗	✓	✓	✓
Combination of data sources	✗	✗	✓	✓
Analytics	✗	✗	✓ Static Rules[2]	✓ Dynamic Models[3]
Maintenance Trigger	If monitoring shows critical values	If monitoring shows critical values	When calculated health-score reaches critical value	When failure risk and outage costs surpass maint. costs

1. Sometimes also referred to as "prognostics" 2. Static Rules = Using static methods such as SPSS, regression 3. Dynamic Models = Using dynamic models such as Bayesian Networks, etc.
Source: IoT Analytics Research

Comparison to Other Maintenance Approaches

Equipment View

Example of a Typical Motor or Generator



1. The later maintenance is performed, the more accurate predictions get.

Source: Adapted from DELL, IoT Analytics Research

Total PdM Market

Predictive Maintenance a $1,498M Market in 2016, Expected to Grow to $10,962M by 2022

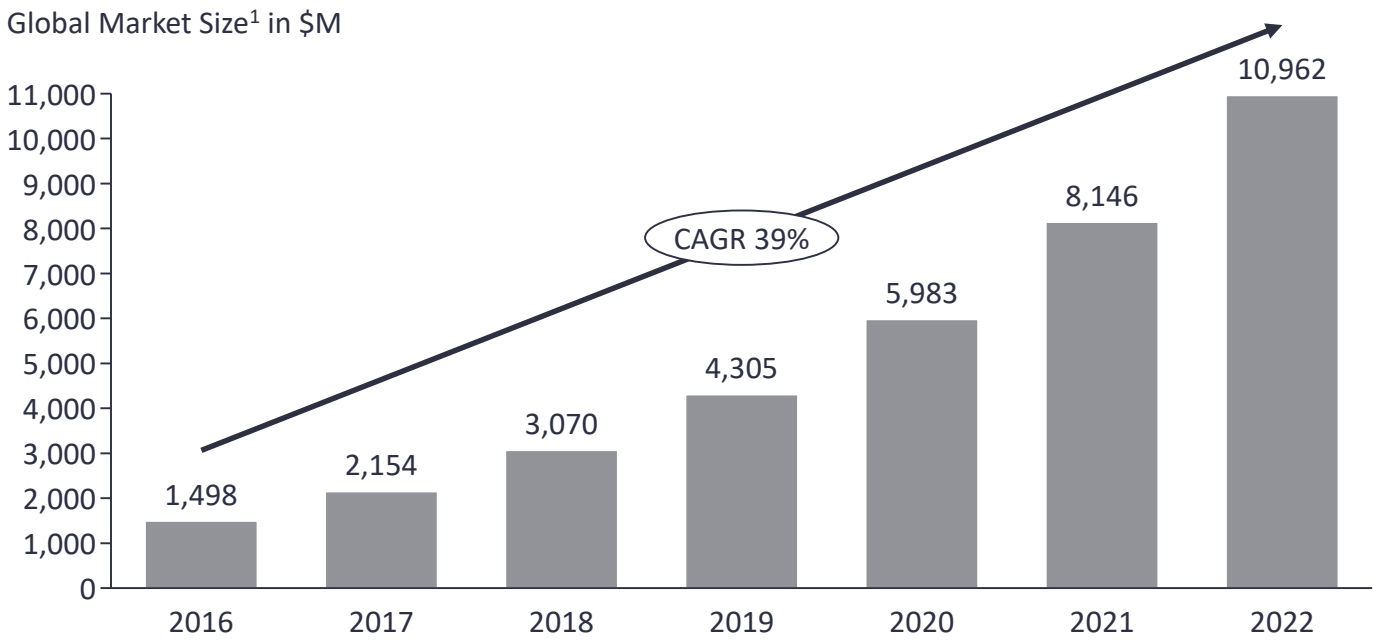
Page Summary

PdM was a $1.5B global market in 2016. It is expected to grow by 39% annually to $10.96B by 2022.

The main aspects driving this growth are:

- New PdM-based business models
- Increased senior executive buy-in for IoT/PdM implementations
- General decrease in cost of IoT technology
- Favorable technology replacement from CBM to PdM

Global Market Development (PdM)



Key drivers

1. **New PdM business models.** The growth of PdM is to a large extent driven by new PdM-based business models (e.g., ThyssenKrupp's MAX elevator service – see use case 4).
2. **Senior executive buy-in.** As (industrial) firms double down on their "digitization efforts", CEOs/CDOs increasingly see the benefits of IoT/Digitalization/PdM, subsequently push for PdM projects.
3. **Decrease in cost for IoT technology.** IoT technology is getting cheaper at a fast pace due to standardization and scale effects, thereby making the business case for PdM more attractive. (e.g., declining prices for cloud, connectivity)
4. **Favorable technology replacement.** Some existing condition monitoring solutions are upgraded to more sophisticated PdM solutions. → see next page

1. Market Size defined as entire "Annual PdM technology-spend" by companies implementing PdM solutions in USD
Source: IoT Analytics Research

Company Profile (2/10) : Sanitized company

Company Basics

Headquarters:	Redwood City, CA, USA
Type:	xxx
Revenue:	xxx
Employees:	xxx
Founding date:	xxx
CEO:	xxx

Company Description

Originally established in the energy sector COMPANY (before: xxx) offers a comprehensive platform as a service (PaaS) for the rapid design, development, deployment, and operation of next-generation AI and IoT applications that unlock data-driven insights and transform business processes. The company led by xxx has received more than $100M in funding and a $1.4B valuation. It has invested more than $300M in its technology platform

PdM Technology

- Application
- Analytics
- Platform
- Storage
- Connectivity
- Device

The xxx Predictive Maintenance SaaS application is built on the COMPANY technology Platform. It is a fully integrated application, which ingests, cleans, normalizes, and analyzes data, and then employs multiple machine learning algorithms to identify and predict assets likely to fail. PdM employs both supervised machine learning algorithms as well as anomaly detection in cases when labeled failure data are unavailable. COMPANY claims to be making 8M predictions per day with >95% accuracy.

Differentiators

- Deep experience in the energy industry
- Patent pending graph network representation capability to reconstruct and visualize complex networked systems

Ecosystem Partners

amazon web services, westMONROE, McKinsey&Company

Customers

ENGIE, PG&E, origin, enel, Exelon.

Industry Focus[1]

1. Energy	x
2. Oil & Gas	x
3. Metals & Mining	
4. Chemicals	
5. Pulp & Paper	
6. Water & Wastewater	
7. Machinery	
8. Automotive & Transport	x
9. Discrete other	x
10. Healthcare	
11. Buildings	x
12. Consumer Products	
13. Other	x

Project Experience

#	Title	Industry	Customer	Weblink
1	Failure Predictions for Power Plant	Energy	Large European integrated electric utility	https://COMPANY.com/case-study/predicting-diagnosing-and-reducing-the-economic-impact-of-equipment-failures/
2	Failure Predictions for Oilfield Equipment	Oil & Gas	Large Oil Producer	https://COMPANY.com/case-study/large-independent-oil-producer-leverages-advanced-analytics-platform-to-predict-failure-of-oilfield-equipment/
3	Predictive Maintenance for Chillers	Buildings	Global building equipment manufacturer	https://COMPANY.com/case-study/predictive-maintenance-for-chillers/

1. Industry Focus = Industries with most traction / known implemented projects
Source: COMPANY, IoT Analytics Research

Predictive Maintenance Use Cases (2/11)

Machinery

Name

Predictive Analytics as a Service for Flow Control Products

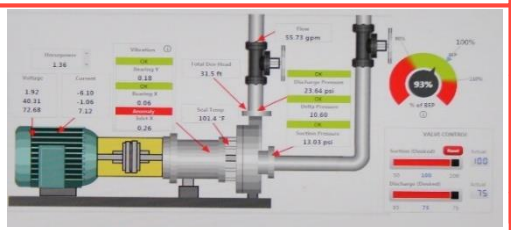
Project description

Company:	**COMPANY Corporation**
Location:	Irving, TX, USA
Company size:	> 10,000 employees
Project Start Date:	2014 (estimated)
Status:	In deployment
No. of connected devices:	> 5,000 Pumps

Description

Pump manufacturer COMPANY offers a Predictive Maintenance as a service solution for its own pumps.

Solution Brief



COMPANY engaged several technology vendors to work together on a comprehensive PdM technology for their pumps. The company now offers a complete PdM-Solution as a Service, with the option to integrate the solution into the customer's existing processes. Pumps can be purchased including sensory hardware and older pumps' retrofit later on. The solution enables predictions ~6 days prior to failure, an improvement of 20x, only 2% of alerts are false positives.

Technology

Analytics modelling approach:

Data Cleansing	Dimension Reduction	Feature Space Navigation	Opti-mization	Prediction
Aggregated data from 3 files based on common time stamps	Analysed data over time to study trends and reduce dimensions	Created new feature abstract spaces using Machine Learning	Applied optimization methods to reduce false positives and maximize time to prediction	Used a prediction algorithm to predict the next failure once higher order features were extracted and optimized

Provided data:
- 3 months historical sensor data in 10 second time resolution
- Component failure logs
- Additional data from artificially generated failures

Analyzed the derivative features to identify trends

Technology partners

National Instruments	OSIsoft.	Hewlett Packard Enterprise	ptc	sparkcognition
Hardware	PI System	Edge-Solution	IoT Platform (Thingworx)	Predictive analytics

Latest information

Oct 2016: COMPANY and Honeywell collaborate on further IIoT Solutions

Further resources

http://www.osisoft.com/enterprise-intelligence/downloads/cb-COMPANY-lt-en.pdf
http://www.osisoft.com/Presentations/COMPANY/SparkCognition--Industrial-Intelligence---Cognitive-Analytics-in-Action/

Source: COMPANY, OSIsoft, HPE; ptc, sparkcognition, IoT Analytics Research

Methodology of this study

Overall Methodology

The report at hand is based on extensive desktop web and literary research, 25 expert interviews with key stakeholders in the predictive maintenance market (technology vendors and technology users), as well as conference materials from various IoT/Maintenance focused events and further web data analysis.

Expert interviews were equally distributed across SMEs and MNCs, and a few startups. The technology companies were selected from the fields of condition monitoring, industrial automation, IoT-storage & platforms and predictive analytics. A few companies offering PdM as a Service with their products were also interviewed.

Market Sizing Criteria

The market for 2016 was sized using a bottom-up approach, summing up the PdM-related revenues of known companies in the field. In cases where the revenue for predictive maintenance related offerings was not known, it was estimated on the relevance of PdM for the company in relation to its latest overall report revenue numbers or (if not reported) based on an employee-based revenue estimate. Technology and industry splits were based on insights gained in expert interviews and through the use of web indicators such as employment status.
The forecast to 2022 is a triangulation of a.) IoT-based market growth forecasts, b.) past growth in Predictive Maintenance as well as other maintenance strategies, such as Condition-based Maintenance and Preventive Maintenance which are about to be replaced by PdM in the upcoming years and c.) Current growth figures (2015 to 2016) in this field that some of the technology vendors are reporting (sometimes only “ballpark figures” d.) Expert opinion.

IoT Analytics GmbH

Market Insights for the Internet of Things

IOT ANALYTICS

Zirkusweg 2 (Astraturm, 6. OG)
20359 Hamburg
Germany

info@iot-analytics.com
+49 40 88950090
http://iot-analytics.com