



Smart Manufacturing Machine Learning for Predictive Maintenance

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Analytical Platform Evolution

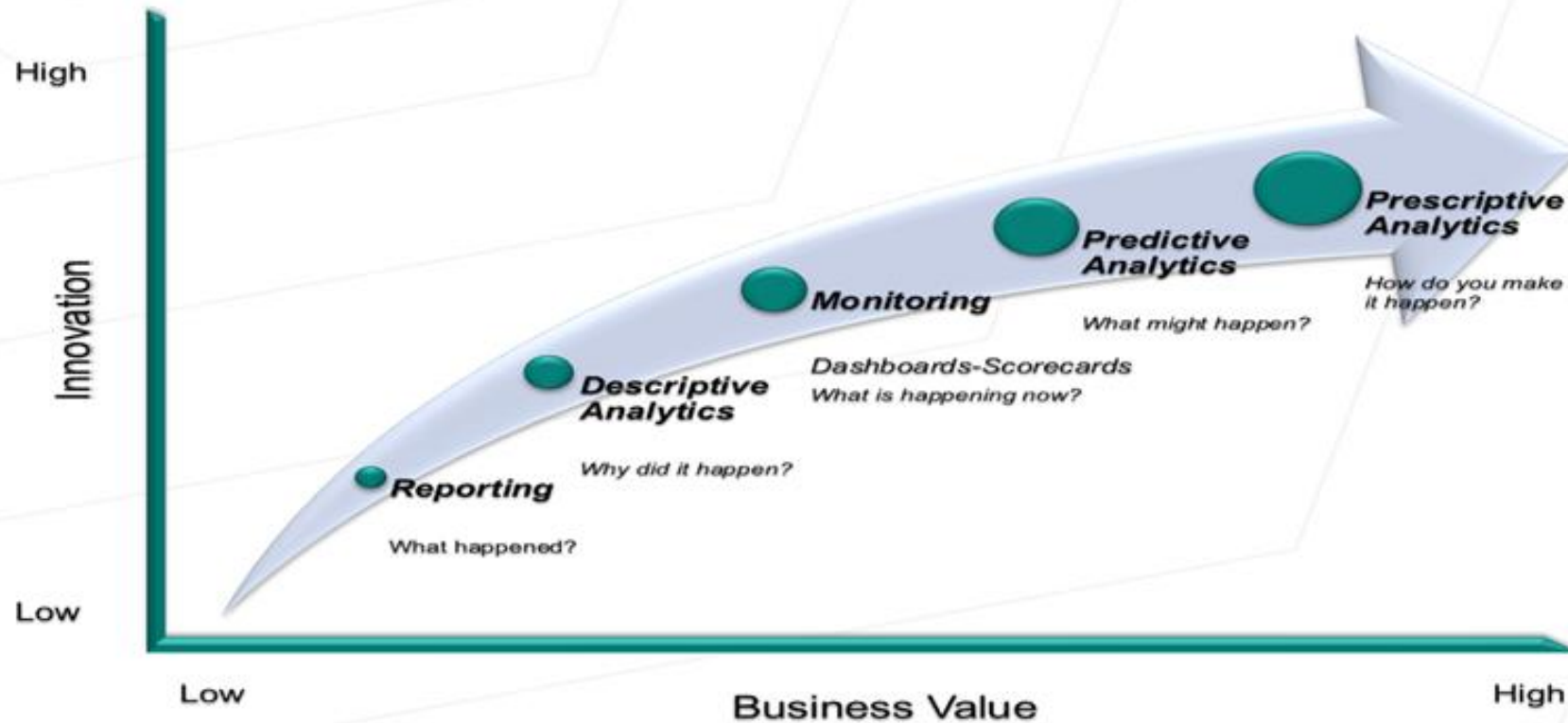
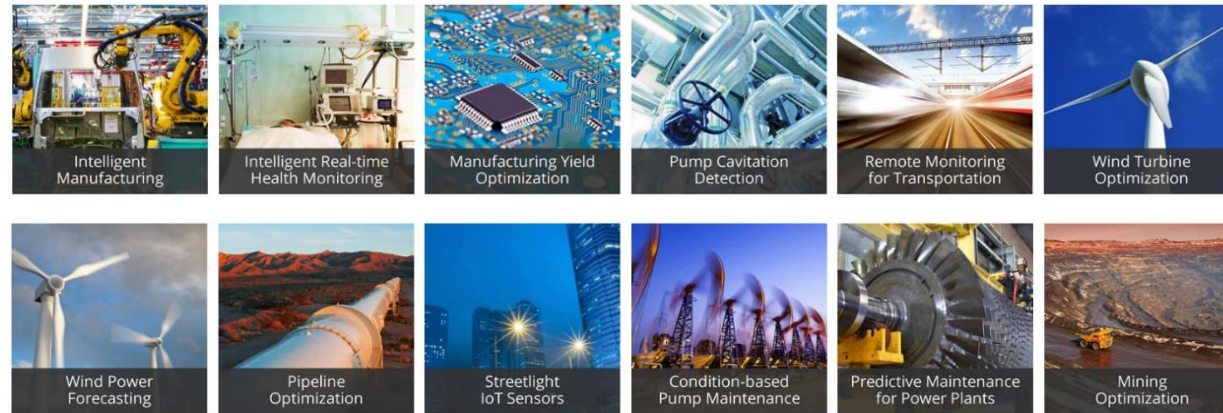
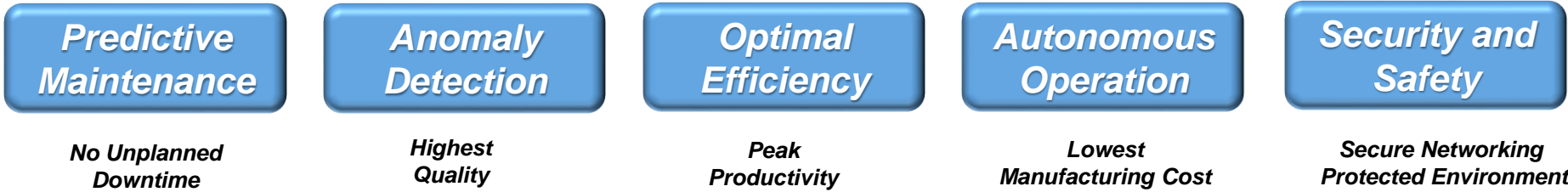


Image source: <http://asi-solutions.com/2016/12/evolution-of-analytics-where-does-your-company-stand/>





Machine Learning In Industrial IoT



Machine Learning provides increased intelligence to the Industrial Internet of Things

Image source: <https://www.foghorn.io>

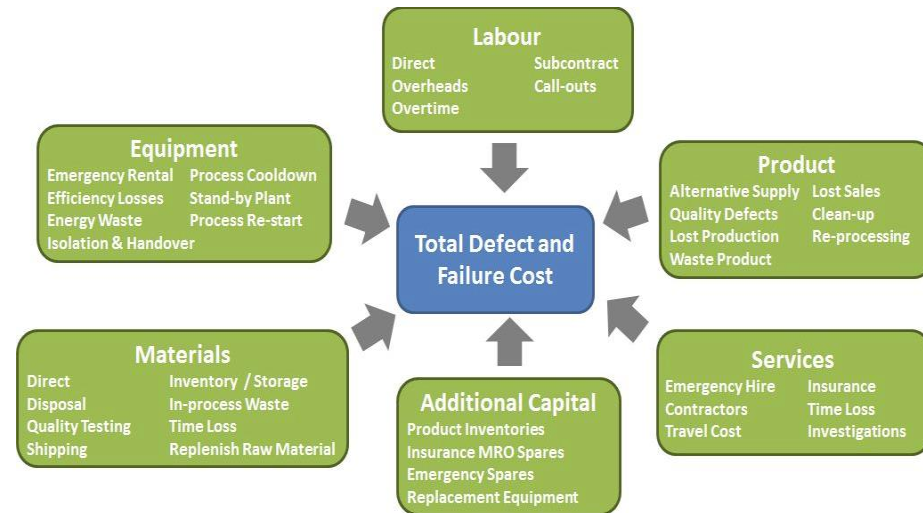
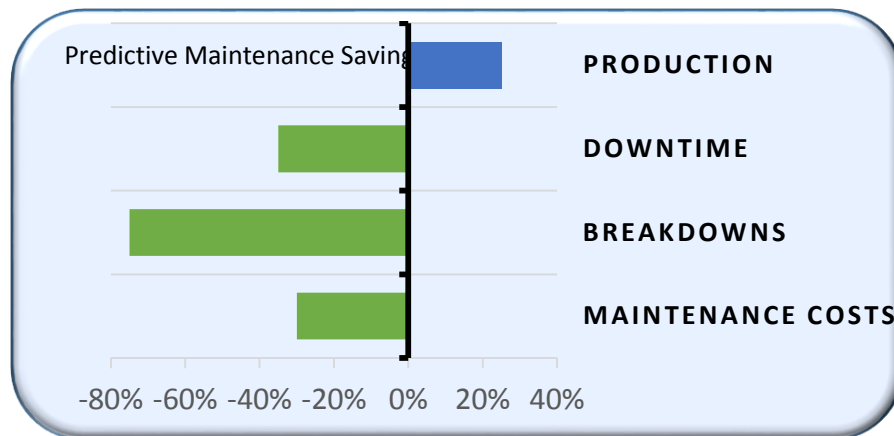




Savings Potential → Total Cost of Failure

Predictive Maintenance can provide significant savings

- 30 - 40 % over reactive maintenance and,
- 8 - 12 % over preventive maintenance programs.

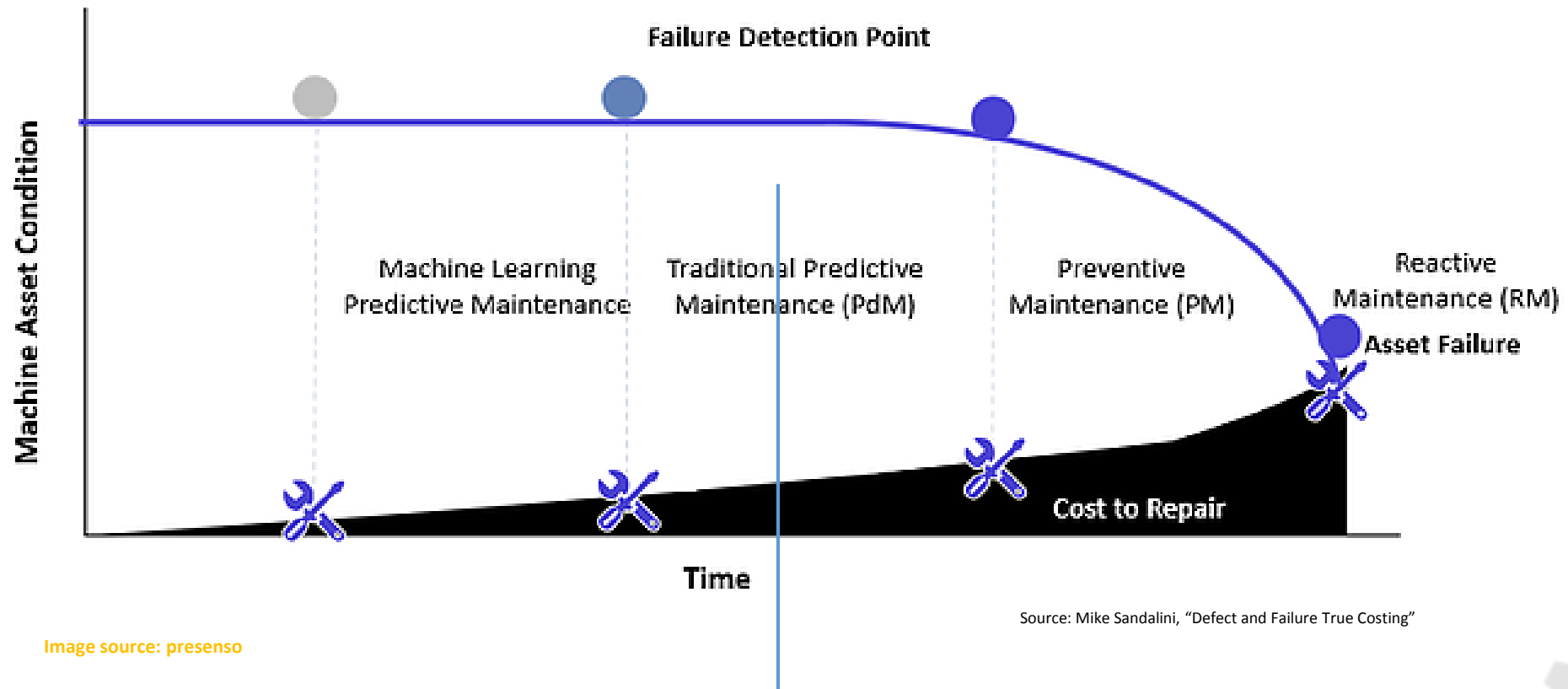


Source: Mike Sandalini, "Defect and Failure True Costing"





Significant Savings Potential

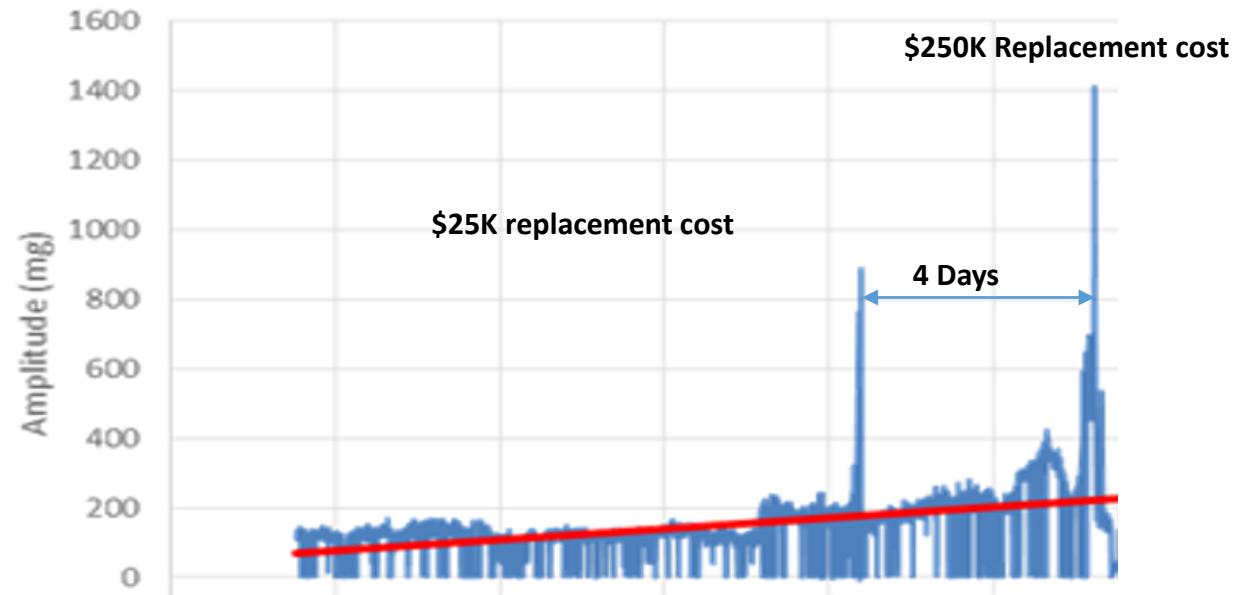


Predictive Maintenance market expected growth: \$1,404.3 Million in 2016 to \$4,904.0 Million by 2021, Compound Annual Growth Rate (CAGR) of 28.4%*

*Source: <https://www.linkedin.com/pulse/20140814090436-13439787-the-business-case-for-predictive-plant-maintenance>



- **Early failure prediction can help reduce unplanned downtime reduction**
Costs \$50K+ per hour in high-productivity markets like automotive
- **Component failures signals can be measured and detected at early stage**
Helps to avoid damage of other related/connected components



- **Machine learning-based monitoring systems can identify system inefficiencies**
A single line in production CN codes with slightly different parameters 2% loss in cycle time
Detection using machine learning techniques identified process anomalies.



Predictive Maintenance – Machine Learning for Early Prediction



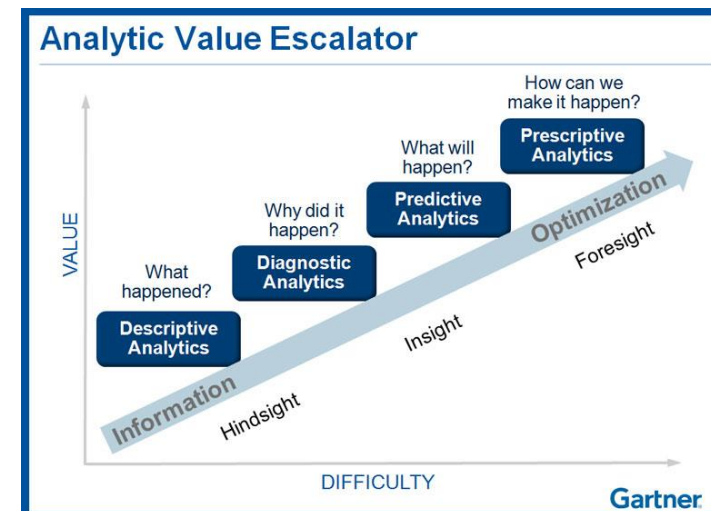
- **New machine learning-based solutions for efficient manufacturing:**

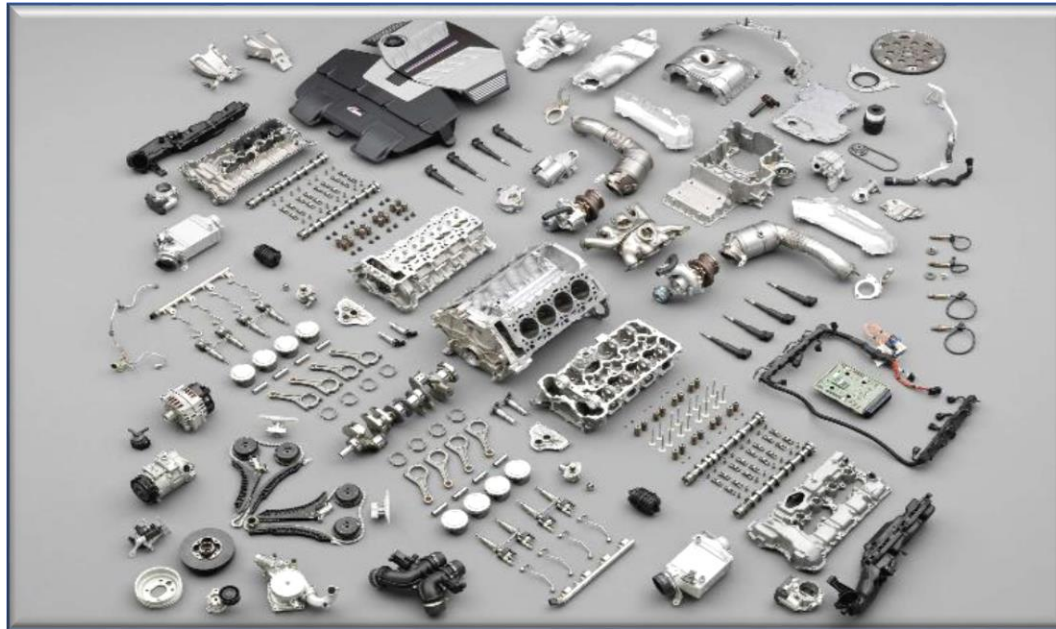
Machine learning-based tools used to increase detection rate and reduce occurrence value of High Risk Priority Numbers (RPN) for critical parts identified by machine tool's FMEA. This helps to reduce RPN increasing machine availability

- **Support early failure prediction**

Cross-multivariable/multicomponent degradation monitoring supported through real-time machine learning solutions. These solutions can run diagnostics tasks that can evolve to prognostic detection to reduce random failure

Note: 85% of failures are considered random lack of understanding the failure mechanism(s).





Predictive Maintenance Potential

- Increase system availability through 8% reduction in unexpected downtimes.

Automotive:

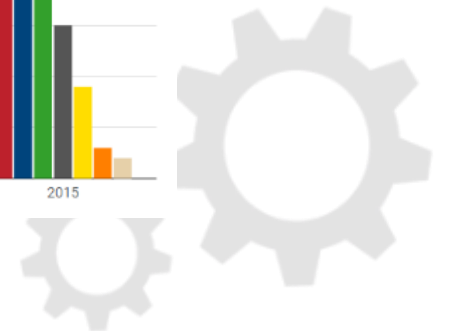
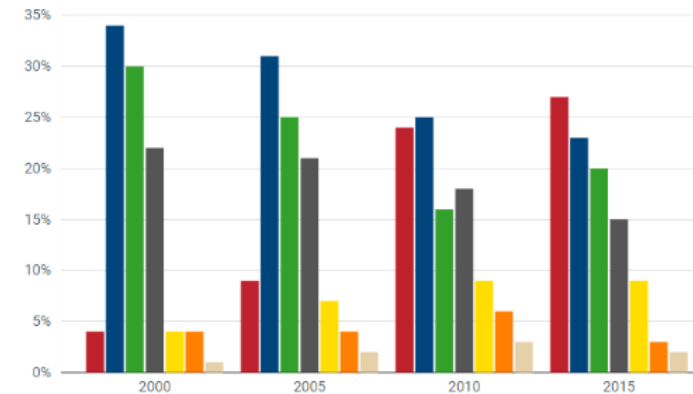
- 91.5 million motor vehicles were produced globally in 2015.
- ~ 250,000 motor vehicles produced per day.
- **High-productivity machining of powertrain: >1,000 systems/day**

World motor vehicle production

% share



■ China ■ Europe ■ North America ■ Japan/Korea ■ South Asia ■ South America
■ Middle East/Africa



 Aingura IIoT Powered by Xilinx





SMART FACTORY MACHINE LEARNING FOR PREDICTIVE MAINTENANCE

SMART FACTORY MACHINE LEARNING FOR PM • TESTBEDS



Testbed in Action

CASE STUDY: VALUE OF PREDICTIVE MAINTENANCE

This case study exemplifies where Predictive Maintenance with Machine Learning would have avoided significant financial and production line delay in a high volume manufacturing system. Shortly after experiencing initial problems, an unknown degradation in system

FAST FACTS

MEMBER PARTICIPANTS:

Aingura IIoT, Xilinx

SUPPORTING COMPANIES INCLUDE:

Aicas, Bosch Software Innovations, System View, Thingswise, T

MARKET SEGMENT:

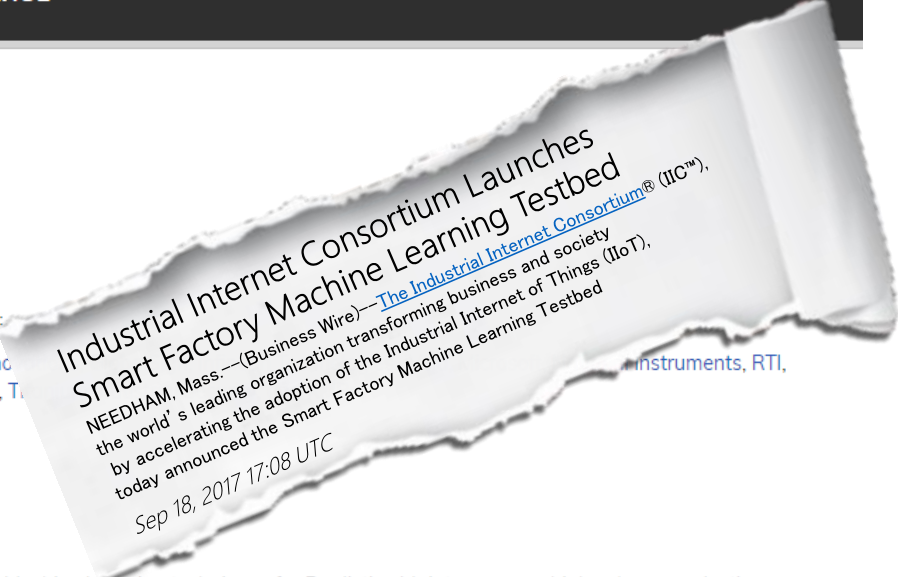
Industrial Manufacturing

GOALS:

- Evaluate & validate Machine Learning techniques for Predictive Maintenance on high volume production machinery to deliver optimized system operation.
- Achieve increased uptime & improved energy efficiency utilizing Machine Learning techniques for advanced detection of system anomalies and fault conditions prior to failure.

CHALLENGE:

Today's methodology of Preventative Maintenance, taking machines offline on a regularly scheduled timeline is not cost efficient and does not necessarily ensure addressing the actual problems leading to system failure. Gaining accurate, actionable insight from the tremendous amount of data acquired in real-time, to understand key component anomalies during operation before system failure, for Predictive Maintenance is a daunting challenge. Furthermore, the root cause of over 80% of failures is not understood.





Goals

- Evaluate & validate Machine Learning (ML) techniques for Predictive Maintenance (PM) on high volume production machinery to deliver optimized system operation
- Achieve increased uptime & improved energy efficiency utilizing ML techniques for advanced detection of system anomalies and fault conditions prior to failure

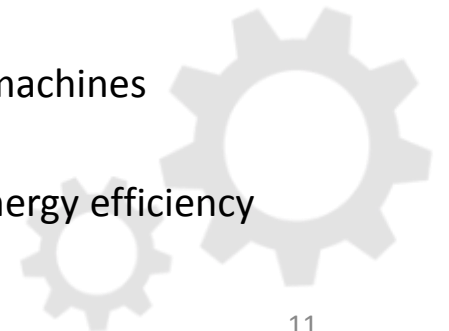
Participants

- Sponsors: Plethora IIoT: R&D of ML IP, Oberon system & applications with visualization
Xilinx: All Programmable Technology, Connectivity IP, Security, Machine Learning framework and related IP



Phases

- 1) *Lab Development and Test: Utilizes simulated data and degradation/fault conditions for ML exploration - Spain*
 - Development / Exploratory phase: understand, implement & validate requirements for CNC Manufacturing system and preparation for pilot factory deployment
- 2) *Pilot Factory: Initial Deployment in limited production facility - Spain - Etx-Tar CNC Manufacturing Facility*
 - Field test in controlled facility – emphasis on PM and ML deployment on production manufacturing machines
- 3) *Production Facility: Deployment of ML and real-time analytics in Automotive OEM facility – Confirmed -TBA*
 - Deployment, validation of ML techniques on production CNC systems for optimized operation and energy efficiency





Smart Factory Machine Learning Testbed





Solution Overview

Deployment Scenarios (OT)



Factory



Production Line



Manufacturing Cell



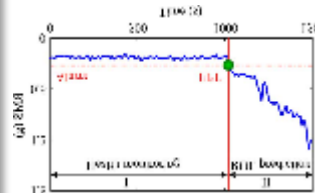
Machine

100011100
010110111
111000010
Data

Convergence (OT-IT)



- Time critical sensor fusion to synchronize data from different domains
- Feature (variables) subset selection to:
 - optimize data transmission and
 - improve algorithms performance.
- Machine Learning algorithms to:
 - leverage knowledge discovery and
 - failure prediction



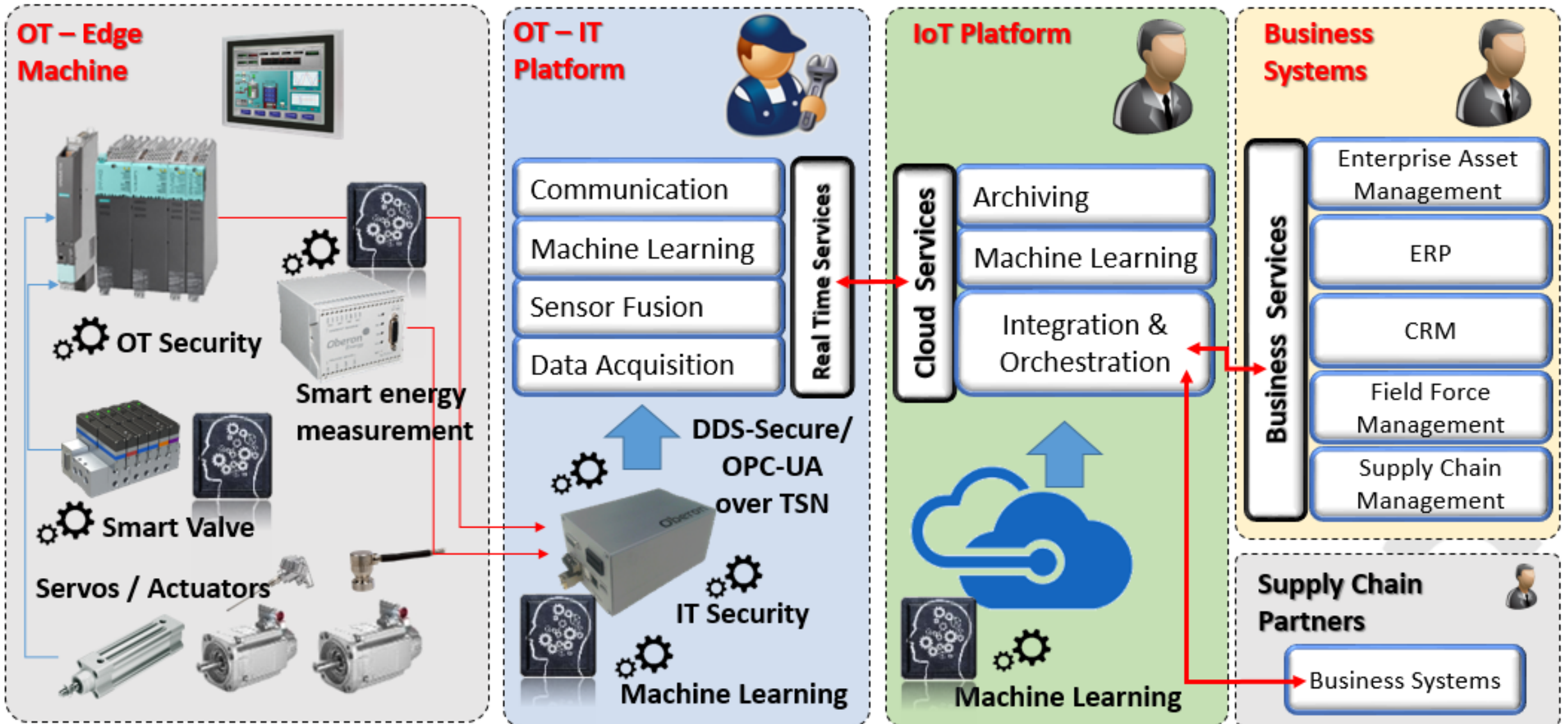
Information

Result (Actionable Insight)

- Machine Tool System
 - Component degradation pattern analysis
 - Machine behavior pattern
- Manufacturing cell
 - M2M interaction
 - Energy consumption patterns
- Production line
 - Energy optimization
 - Production line characterization
- Factory Production plant
 - Overall data aggregation
 - Availability optimization

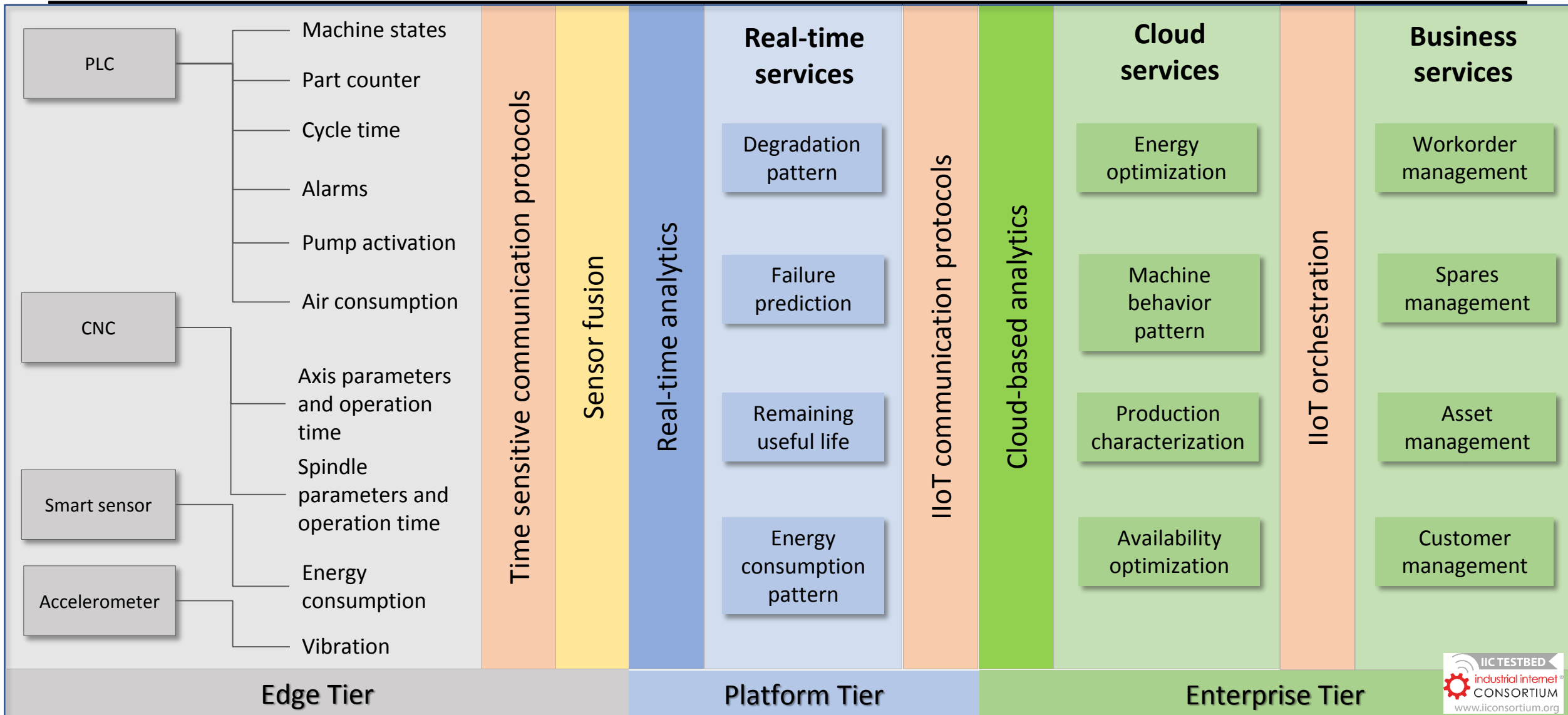


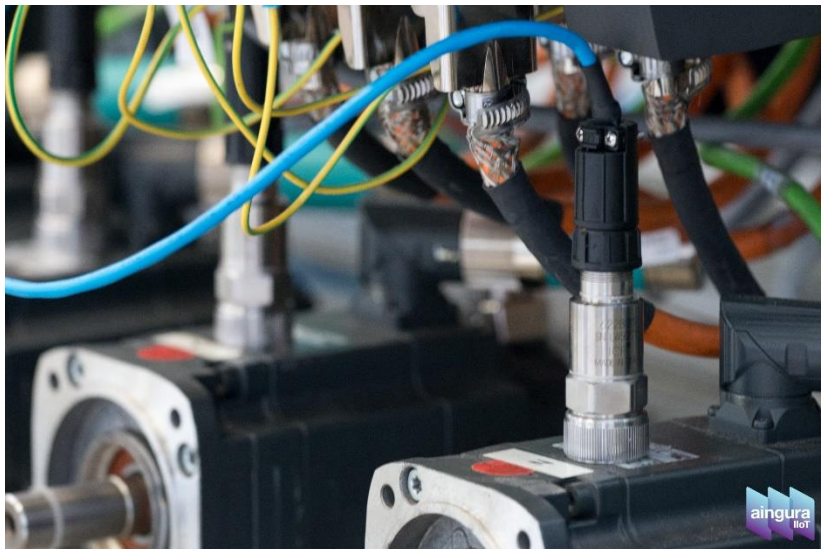
Solution Overview



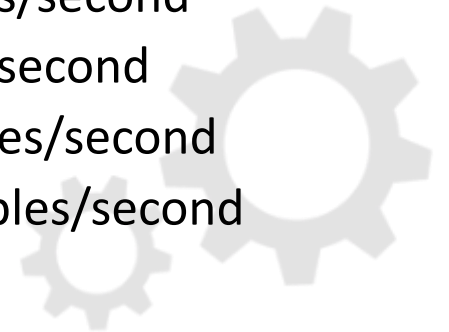


Solution – Service Stack Example



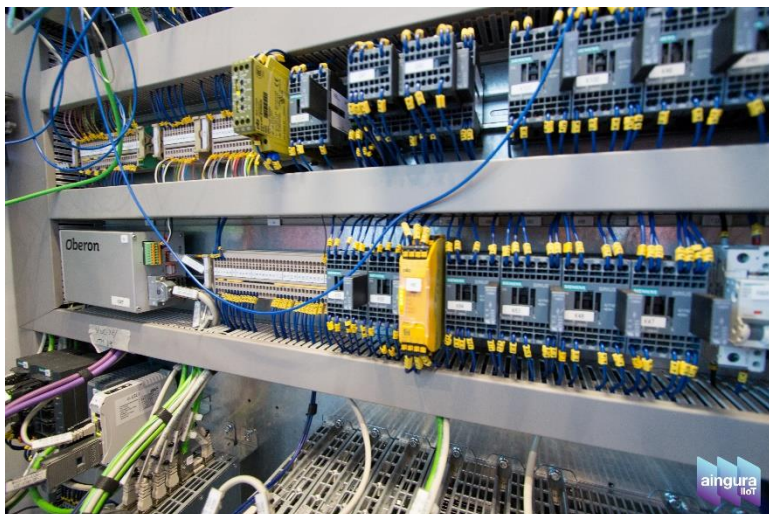


- **Business (ERP, CRM, etc.)**
 - Company name, address, etc
 - 20 variables
- **Machine**
 - PLC, CNC, sensors, actuators
 - 110.000 variables
- **Sensors working on different domains**
 - Different sampling times
 - Temperature: 0,01 samples/second
 - Angular velocity: 10 samples/second
 - Power consumption: 4.000 samples/second
 - Vibration+: 32.000 samples/second





Platform Tier - IIoT Programmable SoC

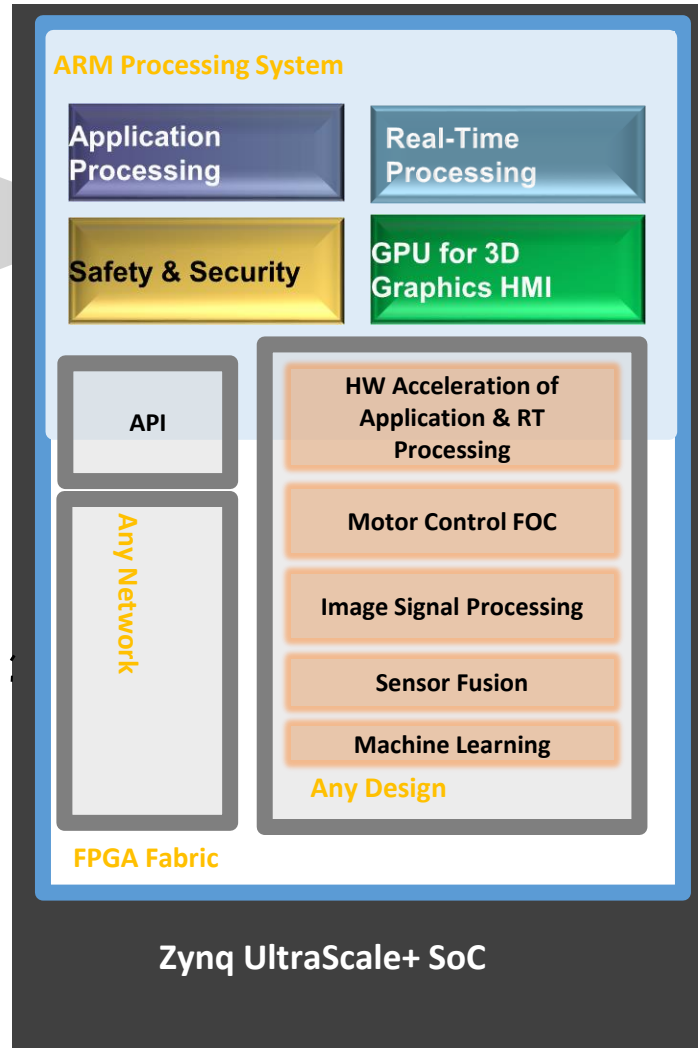


- **Intelligent Gateway:**

- Zynq Programmable SOC (Xilinx)
 - Integrated ARM Processing System w/Programmable Logic
- Tasks:
 - Sensor fusion:
 - Data acquisition from sensors, PLC and CNC.
 - Fuse data from multiple sensor domains
 - To impute data when different sampling rates
 - Feature subset selection:
 - Perform multivariate variable selection
 - Pre-processing
 - Filtering , FFT, etc
 - Processing
 - Perform on-line machine learning analytics



Platform Tier - IIoT Programmable SoC

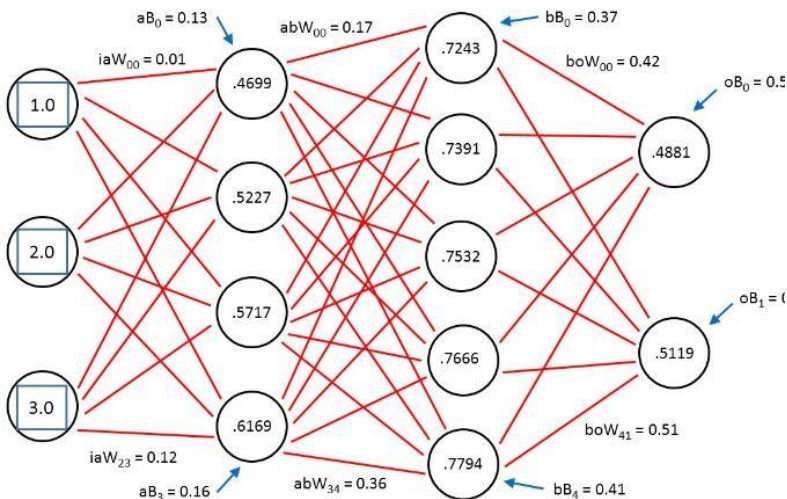
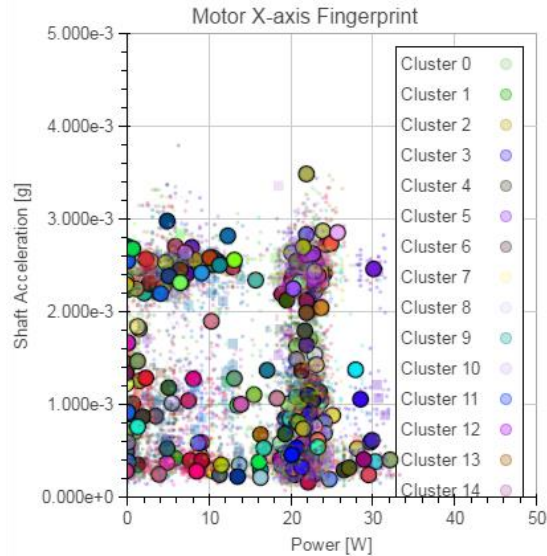


ZYNQ
UltraSCALE+

	Running function in SW	Running on FPGA	Running on optimized FPGA
Average Time (in ms)	5057.37	4208.65	257.65
Speed increase over SW	N/A	16.78%	94.91%



Enabling Secure, Safe, Synchronized, Autonomous Operation



- Different approaches for data analysis

- Visual Analytics
- Traditional statistical tools
- Artificial intelligence-based tools
 - Automatic learning
 - Deep Learning
 - Evolution of neural networks

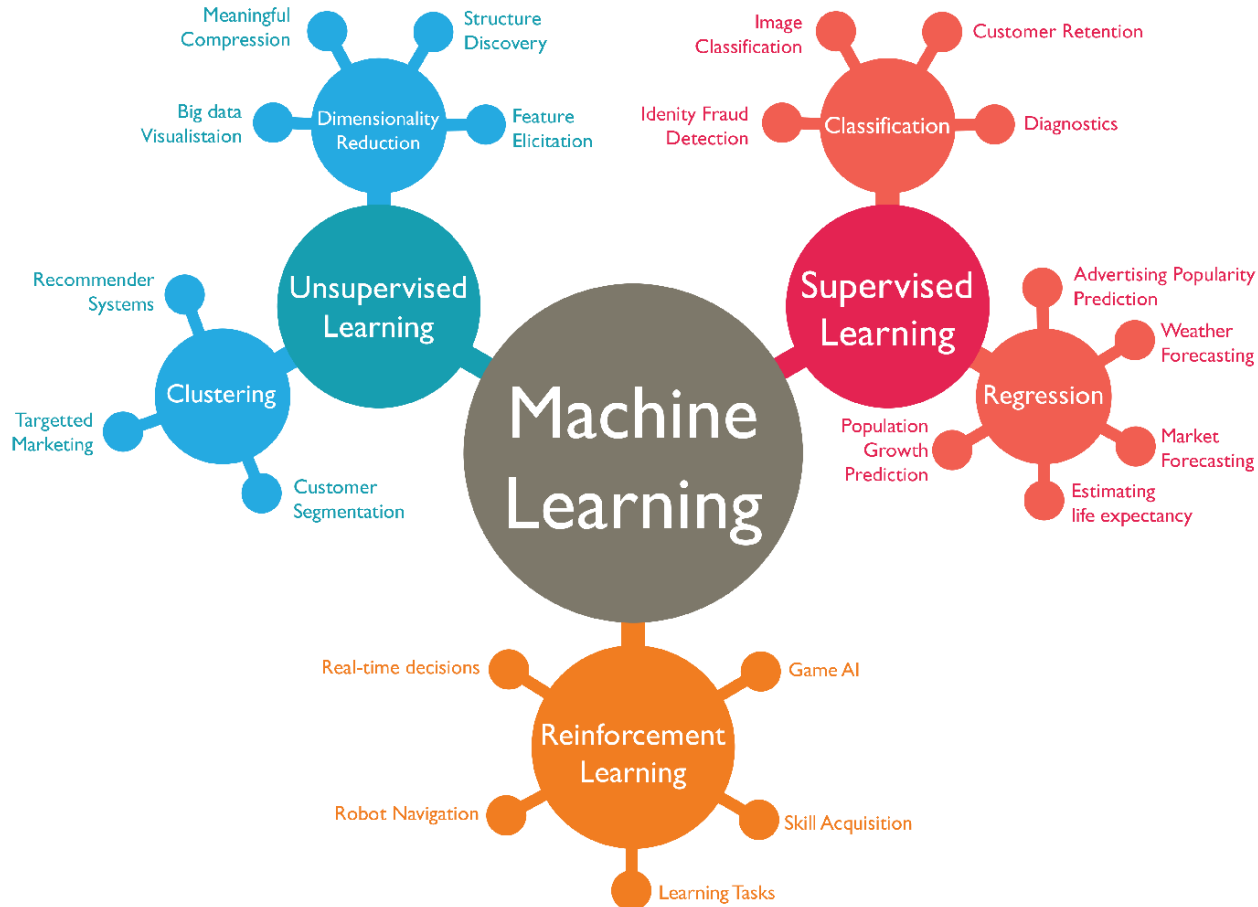
- Method is transparent

- Reduce adverse effects of noise
- Illogical relationships
- Control over system variations





Platform Tier - Machine Learning Analysis

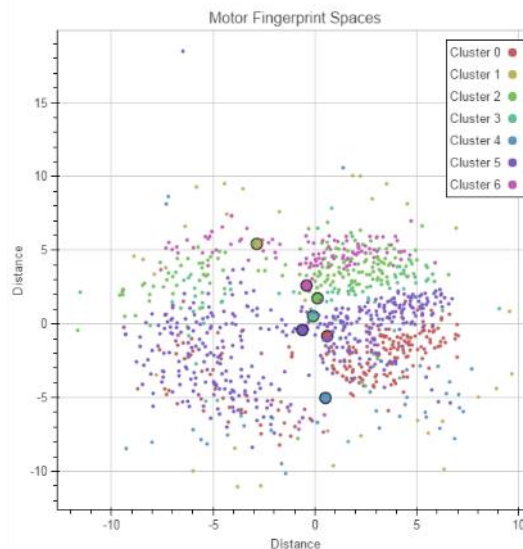
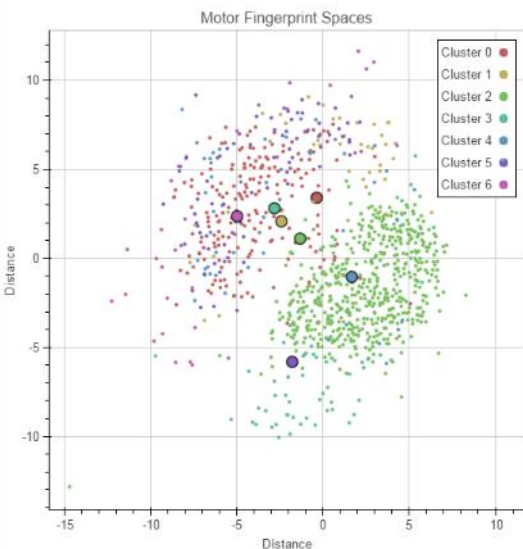
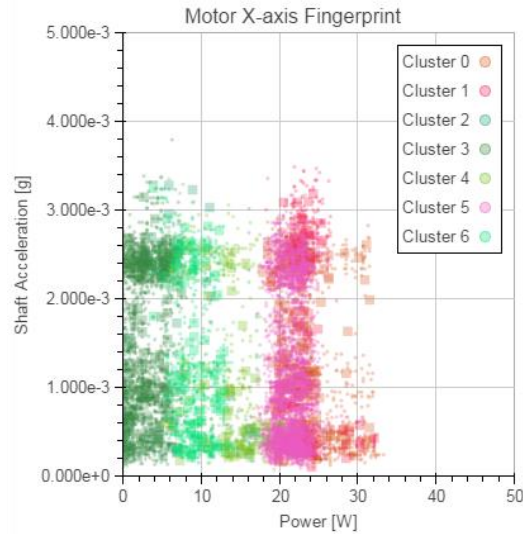
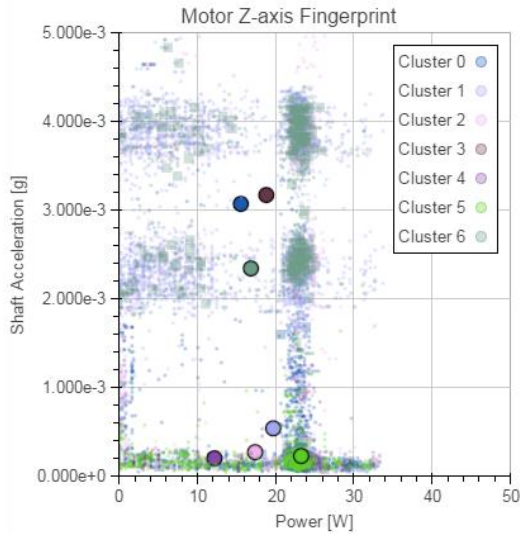


- Goal: Identify structural patterns in the data
 - Classify
 - Predict
 - Extract new knowledge
- Three types
 - Exploratory analysis
 - Descriptive modeling
 - Predictive modeling





Platform Tier – Static Machine Learning



- Exploratory analysis

- Explore in the data without clear idea
- For small amounts of data, conventional visualization methods
- For large amounts of data, dimensional reduction

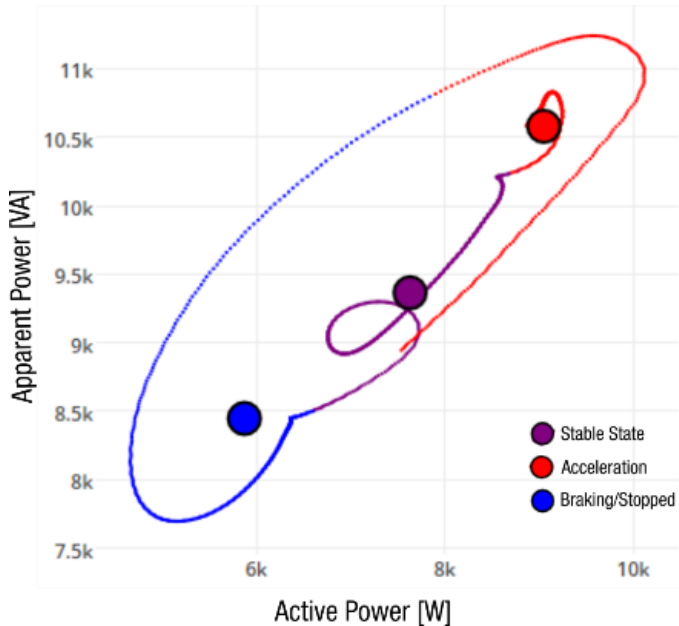
- Example

- Real Application on machine tool
- Performance analysis of 3 servomotors
- 13 variables per servo





Platform Tier – Dynamic Machine Learning



- Remaining useful life:

- Machine Learning

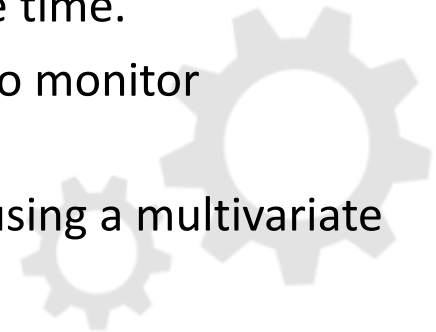
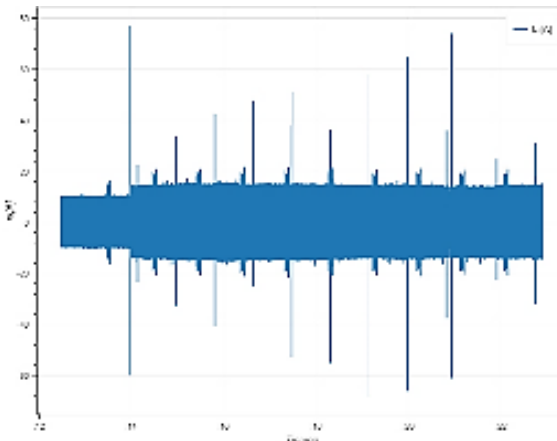
- Data stream analysis

- There are not enough bad cases

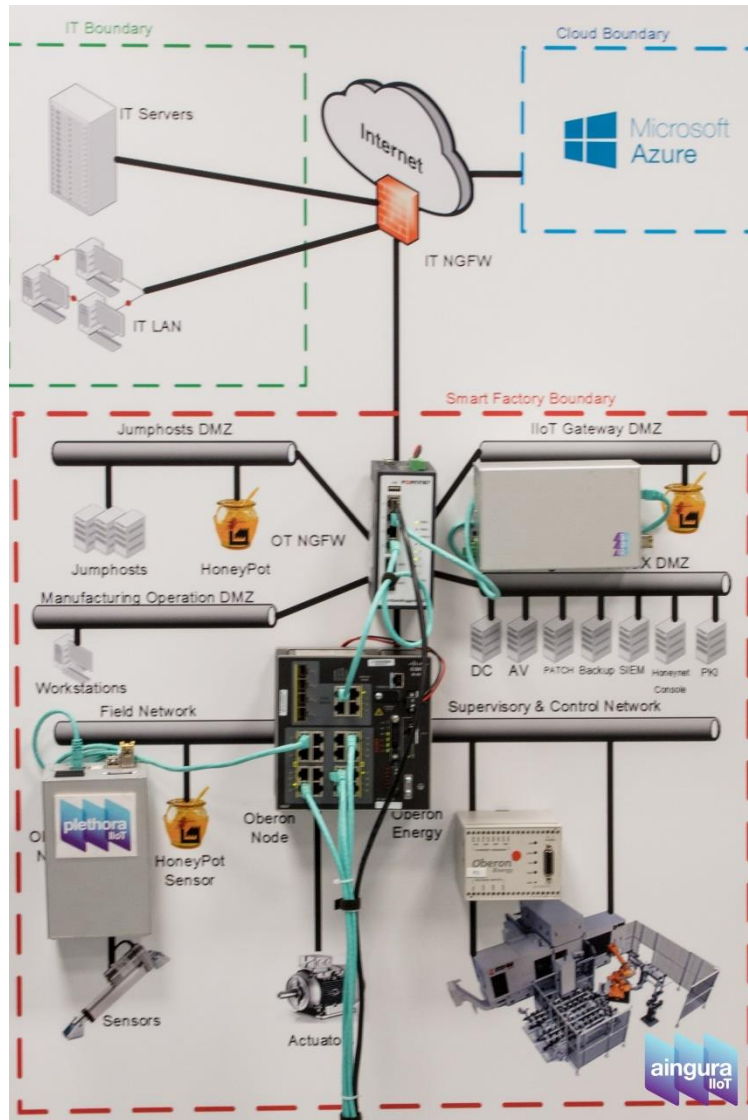
- Extremely unbalanced data → Novelty Detection
 - ML algorithm is measuring abnormal changes of the behavior pattern.

- Detects early degradation that can affect the expected useful life.

- Degradation can affect the expected service time.
 - It take data coming from the second stage to monitor anomalies.
 - Added value: early degradation measured using a multivariate approach.



Cloud Tier - Services



- Microsoft-Azure
 - MQTT-based communication
 - USD 10 per 52 MB/h
 - Analytics & Business oriented
 - Transmission speed dependent
- GE Digital – Predix/APM
 - Communication based on OPC-UA
 - Industry-oriented
 - KPI developed for maintenance
- Ability to integrate
 - ERP, MES and other business services



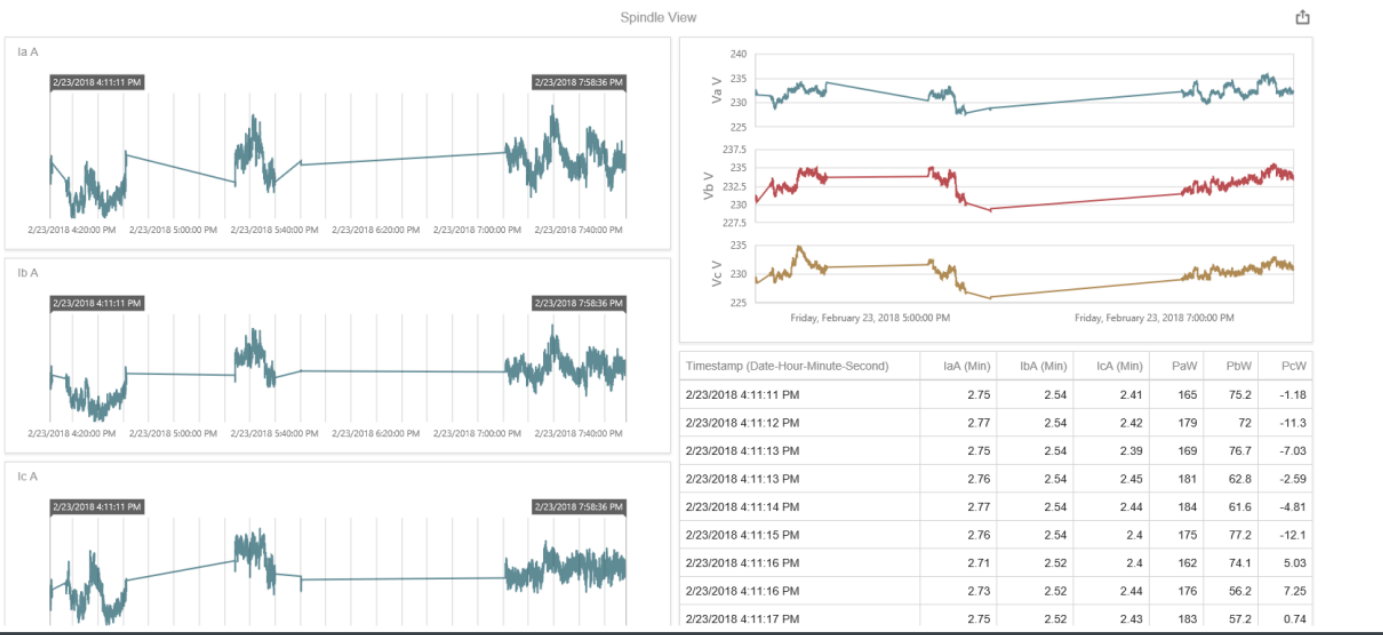
Cloud Tiers – Business Services



config.xmpro365.com/SFMLTestbed/main.aspx?page=http%3A//config.xmpro365.com/SFMLTestbed/ActionItem.aspx%3Fg%3D10067%26d%3D2070

XMPRO Maintenance Request - Milling Spindle AA665 - (#8088) Keith Miller

- Main
- View Details
- Spares List
- Current Maintenance
- Notes
- Curve Diagram
- Fault Finding
- CAD Drawing View



- Select Action
- Request Spares
 - Escalate for Review
 - Close Out
 - Request Override for Work Order
 - Create Work Order
 - Save and Return
 - Reset

config.xmpro365.com/SFMLTestbed/ActionItem.aspx%3Fg%3D10067%26d%3D2070

XMPRO Keith Miller

Curve Diagram | Fault Finding | CAD Drawing View

Request Details

Overall Wear: 73%

Code: AA665

Family: Spindle

98 99 100 Page size: 20

	Pb W	Pc W	Sa V A	Sb V A	Sc V A	Va V	Vb V	Vc V
2.272446	92.776726	6.806586	657.279480	624.874207	584.626526	232.311127	233.719864	231.014099
3.761795	82.936768	20.789680	652.840393	622.506653	586.624146	232.357452	233.706329	231.083435
5.575623	92.406807	13.021295	658.981079	621.544861	580.927307	232.339691	233.650055	230.912064
7.790344	89.521400	11.541602	658.537170	619.473328	581.223267	232.273346	233.384521	230.651413
9.611420	79.385506	24.932821	654.320068	613.998474	584.108643	232.220246	233.476974	230.914032
148.043243	88.263664	6.214709	663.790100	630.497009	586.550171	232.203918	233.509583	230.796860
136.279694	102.912621	1.405708	659.351013	627.167725	579.965515	232.474701	233.816360	230.997940
140.570801	100.471130	2.811416	657.649353	626.057922	576.562195	232.557953	233.773895	230.979523
157.957184	85.304276	1.331723	662.754333	625.688049	581.667175	232.129776	233.190399	230.537720
145.527771	93.664543	-0.591877	657.279480	623.986389	582.037109	232.206543	233.461288	230.780991
131.692642	101.063004	6.658617	648.401306	618.955444	575.008545	232.362427	233.621017	230.894211
145.601746	95.070251	1.849616	657.353455	625.318115	583.812744	232.154587	233.347412	230.596634
138.351257	102.690666	3.033370	660.534790	626.131897	581.815125	232.498291	233.763550	231.021057
129.103180	92.554771	21.233589	654.246094	621.692871	584.478577	232.130539	233.542847	230.811707
150.262787	77.683861	13.835126	662.680359	622.358704	587.068054	232.132217	233.466553	230.807297
139.239075	87.745773	13.687157	651.804565	621.840820	584.700562	232.280121	233.659546	230.948044

- Select Action
- Request Spares
 - Escalate for Review
 - Close Out
 - Request Override for Work Order
 - Create Work Order
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 - Reset

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02/23/2018 19:58:32	2.858410	2.700246	2.540861	148.043243	88.263664	6.214709	663.790100	630.497009	586.550171	232.203918	233.509583	230.796860
02/23/2018 19:58:30	2.839262	2.685321	2.510073	136.279694	102.912621	1.405708	659.351013	627.167725	579.965515	232.474701	233.816360	230.997940
02/23/2018 19:58:28	2.829499	2.677155	2.496369	140.570801	100.471130	2.811416	657.649353	626.057922	576.562195	232.557953	233.773895	230.979523
02/23/2018 19:58:27	2.855688	2.682224	2.522557	157.957184	85.304276	1.331723	662.754333	625.688049	581.667175	232.129776	233.190399	230.537720
02/23/2018 19:58:27	2.829030	2.671241	2.523308	145.527771	93.664543	-0.591877	657.279480	623.986389	582.037109	232.206543	233.461288	230.780991
02/23/2018 19:58:26	2.790827	2.650121	2.489516	131.692642	101.063004	6.658617	648.401306	618.955444	575.008545	232.362427	233.621017	230.894211
02/23/2018 19:58:25	2.831095	2.679877	2.532320	145.601746	95.070251	1.849616	657.353455	625.318115	583.812744	232.154587	233.347412	230.596634
02/23/2018 19:58:23	2.837666	2.677061	2.521149	138.351257	102.690666	3.033370	660.534790	626.131897	581.815125	232.498291	233.763550	231.021057
02/23/2018 19:58:23	2.819268	2.663544	2.532226	129.103180	92.554771	21.233589	654.246094	621.692871	584.478577	232.130539	233.542847	230.811707
02/23/2018 19:58:22	2.854186	2.666642	2.542551	150.262787	77.683861	13.835126	662.680359	622.358704	587.068054	232.132217	233.466553	230.807297
02/23/2018 19:58:21	2.806596	2.660541	2.531662	139.239075	87.745773	13.687157	651.804565	621.840820	584.700562	232.280121	233.659546	230.948044

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Extensible Integration Connectors

Listeners	Transformations	Context Providers	Action Agents	Functions
<p>Enter text to search...</p> <ul style="list-style-type: none"> MatrikonOPC Listener This listener allows you to read sensor data from MatrikonOPC MQTT This is a generic MQTT Listener MQTT Advanced This listener allows you to listen/read data from the configured MQTT system OData This allows for listening to OData service and supports where and expand operations OPC UA A listener to read tag values from an OPC UA server OSISoft PI A OSISoft PI listener to read data from OSISoft PI Systems using the AFSDK 	<p>Enter text to search...</p> <ul style="list-style-type: none"> Aggregate This transformation aggregates a stream by using a window and allows aggregate functions to be performed Data Conversion This transformation allows you to convert data type in another column Derived Column This transformation allows you to create new column values. Edge Analysis This transformation enables identification and analysis of changes in a stream Filter This transformation allows to filter a stream of data Join This transformation joins two streams 	<p>Enter text to search...</p> <ul style="list-style-type: none"> Microsoft SharePoint The stream object provides context/static data using XMPro Connector for Microsoft SharePoint. OData The stream object provides context/static data using the XMPro Connector for OData Oracle The stream object provides context/static data using XMPro Connector for Oracle. OSISoft PI The stream object provides context/static data using XMPro Connector for OSISoft PI. SAP The stream object provides context/static data using the XMPro Connector for SAP 	<p>Enter text to search...</p> <ul style="list-style-type: none"> Email This action agent sends an email and allows email templating GE Predix This action agent allows you to perform REST operations on GE Predix IBM Watson This action agent allows you to perform operations using IBM Watson APIs IBM Watson IoT This action agent allows you to send device data to IBM Watson IoT Platform Microsoft Chat Bot An Action Agent to send a trigger to a Microsoft Bot. Microsoft Dynamics AX Action agent to perform POST, PUT and DELETE operations on an AX OData service. 	<p>Enter text to search...</p> <ul style="list-style-type: none"> FFT This Function allows you to run FFT algorithm RScript A Function for user-created scripts in the R language.





Predictive Maintenance & Machine Learning

Machine-tool System



Identify Degradation
Behavior Pattern Measurement

Manufacturing Cell



Automation Interaction Behavior
M2M Energy Consumption Patterns

Production Line



Energy Consumption Behavior
Production Line Characterization

Factory Production

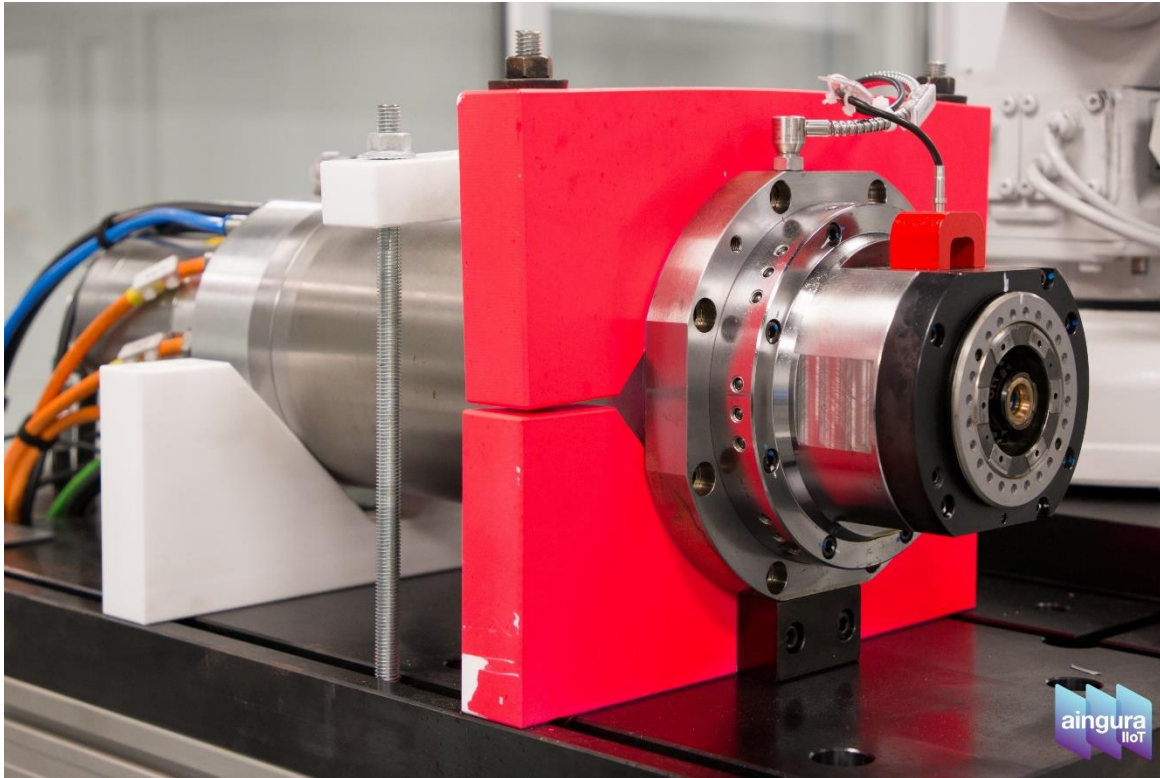


Overall Data Aggregation
Availability Optimization





Machine Tool – Spindle Critical Component



- Machine-tool for powertrain manufacturing
 - Cycle time 60 seconds
 - Utilization over 95%
- Spindle head – Key critical component
 - Power 10 kW
 - Primary function: Material removal
- Failure cost :
 - Costs USD 30,000 up to 250,000
 - Repair time: 5 working shifts
 - Impact: 200 direct jobs





Machine Tool – Spindle Critical Component



- Data acquisition and pre-processing
 - PLC variables: timestamp, in-cycle, dry-cycle
 - CNC variables: power, angular velocity, torque, temperature
 - Sampling rate: 10 Hz
 - 10 machining cycles (20 crankshafts)
 - More than 90.000 instances





Machine Tool – Spindle Critical Component



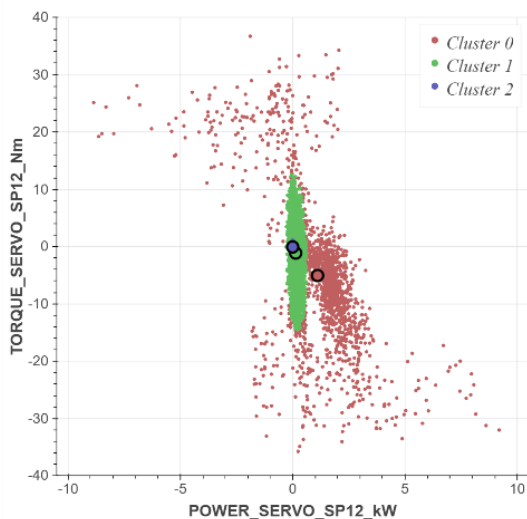
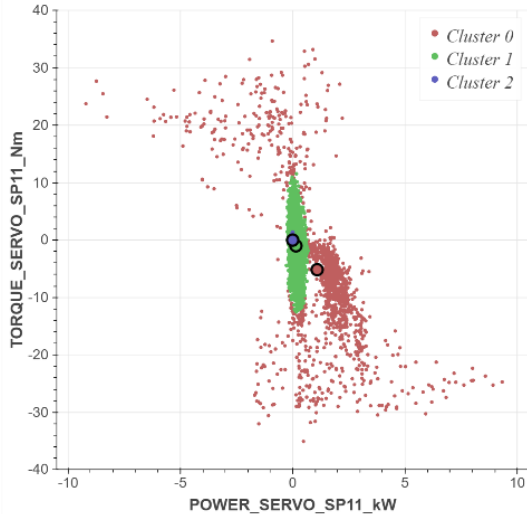
- ¿Vibration levels on the ball-bearings?
- ¿Temperature level on the ball-bearing?
- ¿Temperature level on the windings?
- ¿Tool engagement time?
- ¿General behavior of the spindle?

- Descriptive analytics
 - 8 variables at the same time
 - During as many cycles as possible
 - Looking for a behavior pattern
 - Given by “not obvious” variable correlations
- Objective?
 - Define a behavior reference for a healthy spindle
 - Use the reference to detect deviations
 - Early degradation
- How?
 - Using clustering techniques





Machine Tool – Spindle Critical Component



- Understand Cluster Evolution:
 - Cluster shapes
 - (how the identified machining characteristics change over time)
 - Number of clusters (identify new machining characteristics).
- Gaussian mixtures
 - Provides new information about different states of the spindle
- Real-time operation:
 - Focus on upgrading CPS embedded electronics
 - Enable the algorithm acceleration using the Zynq Programmable SOC / FPGA





Community. Collaboration. Convergence.

Things are coming together.

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