



NSF I/UCRC since 2001



Integrated PHM and Cyber Physical Systems (CPS) for Maintenance Transformation



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&

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NSF Industry/University Cooperative Research Center on
**Intelligent Maintenance Systems/
Intelligent Cyber Machine Systems**

Univ. of Cincinnati, Univ. of Michigan, Missouri Univ. of S&T, Univ. of Texas-Austin



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Outline



- ▶ Evolution of Maintenance and Manufacturing
- ▶ Industrial Big Data Analytics and Cyber Physical Systems, and Industry 4.0
- ▶ Tools and Case Studies on Predictive Analytics for Smarter Industrial/Manufacturing Systems and Case Studies
- ▶ Conclusions



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UC at a Glance



Neil Armstrong
UC Faculty 1970-77

Dean Herman
Schneider
1872 -1939



- UC has over 196 years of history. Origin of 2nd Industry Revolution
- The first German-System (*apprenticeship*) Engineering Education 1906--Dean Schneider invented **Cooperative Education (Co-op)** in U.S. in 1906 and 1,500 employers involved in UC Co-op.
- Distinguished Alumni including William Taft, 27th U.S. president and Joe Strauss, Chief Architect of the Golden Gate Bridge, Dr. Eugene Merchant, etc.
- UC ME Spin-off :SDRC →EDS → UGS→ Siemens PLM.
- Established the 1st Co-op with Shanghai Jiao Tong Univ. (2+3 Program) in China, Sept. 2008.
- Launched Univ.-wide Co-op Program in China with Chongqin Univ., July 2013.



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The IMS Center



ALSTOM HIWIN Linear Motion Products & Technology TOYOTA SAMSUNG NISSAN

TEXAS INSTRUMENTS API SPIRIT AEROSYSTEMS OMRON

TechSolve ADVANTECH UNIVERSITY OF CINCINNATI FORCAM GE Aviation

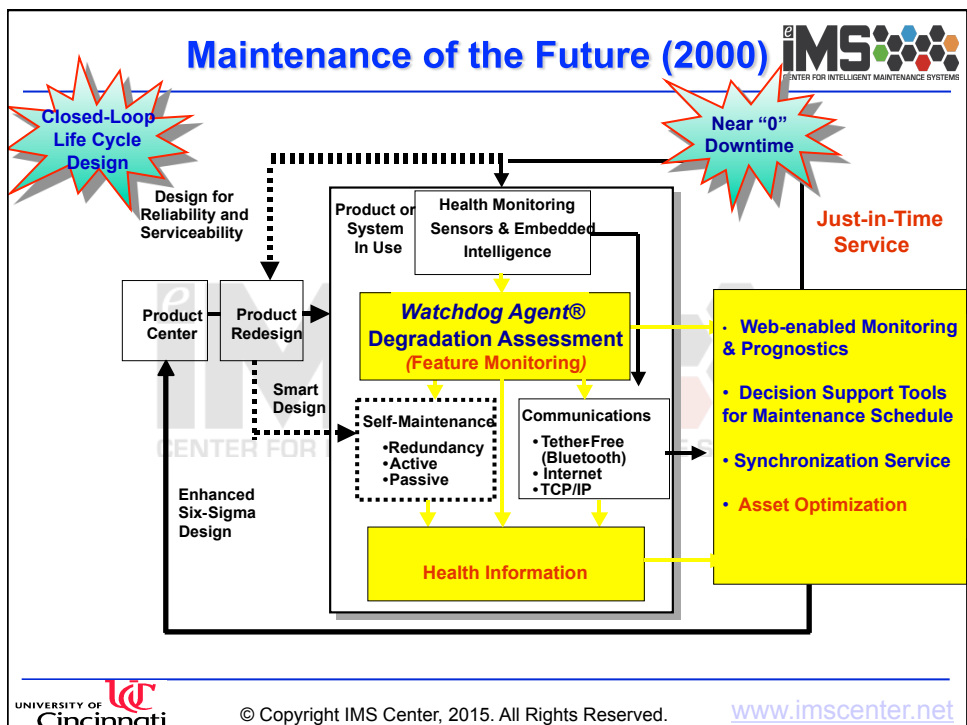
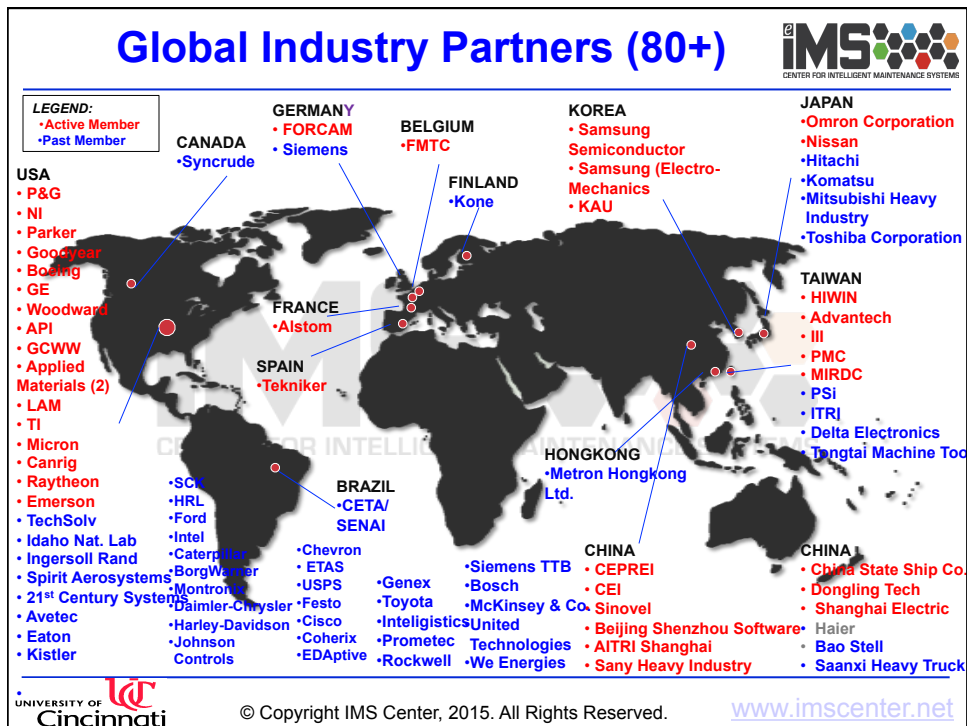
EATON P&G GOODYEAR PARKER SANY SINOVEL HONEYWELL CATERPILLAR THE UNIVERSITY OF TEXAS AT AUSTIN MIRDc METAL INDUSTRIES RESEARCH & DEVELOPMENT CENTRE NATIONAL INSTRUMENTS APPLIED MATERIALS FMTc PMC SIEMENS

MISSOURI S&T THE UNIVERSITY OF MICHIGAN KISTLER measure. analyze. innovate. BOSCH 400 100 Years in USA 1906 | 2006 Ford



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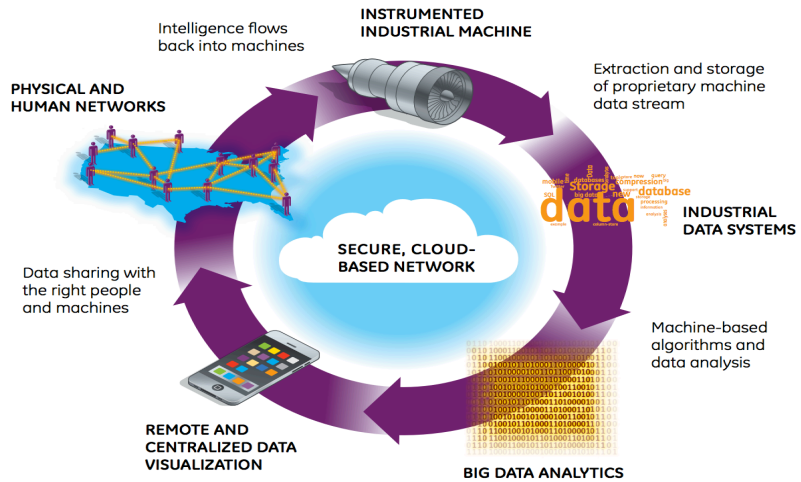
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GE Industrial Internet System



IMS Adventure in 2001 (Watchdog Agent®) vs GE Venture in 2011 (Predix®)



Ref: GE Industrial Internet



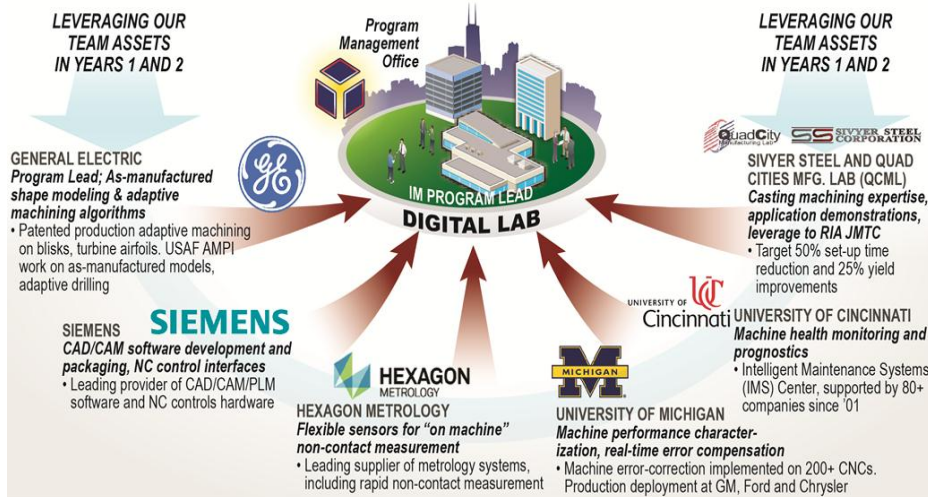
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White House Digital Manufacturing and Design Innovation (DMDI) —Led by UI Lab (Feb. 2014)



Self-Aware Machines



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Outline



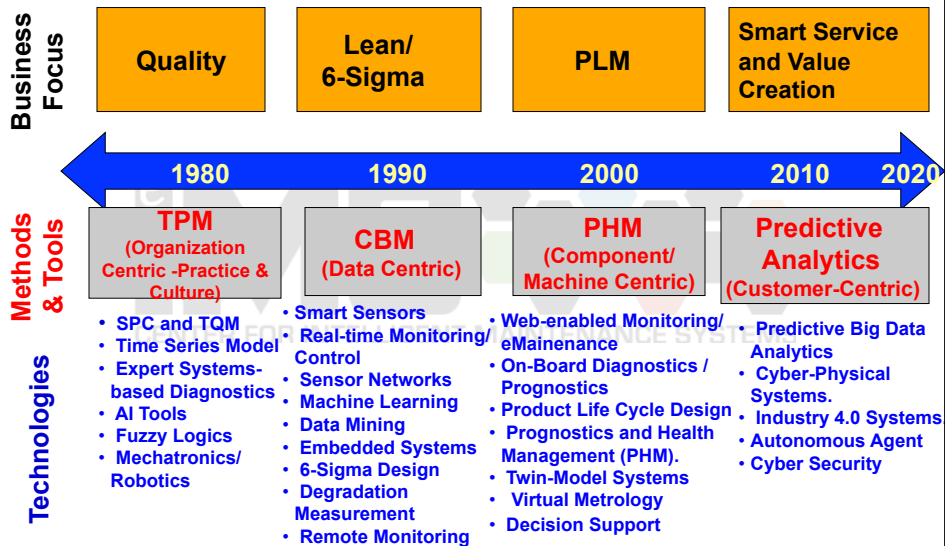
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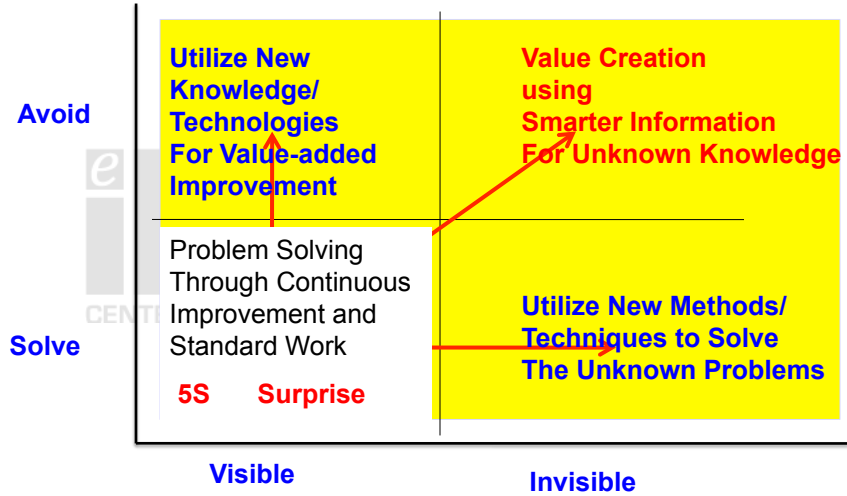
Evolution of Manufacturing



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Competitiveness Transformation Strategy

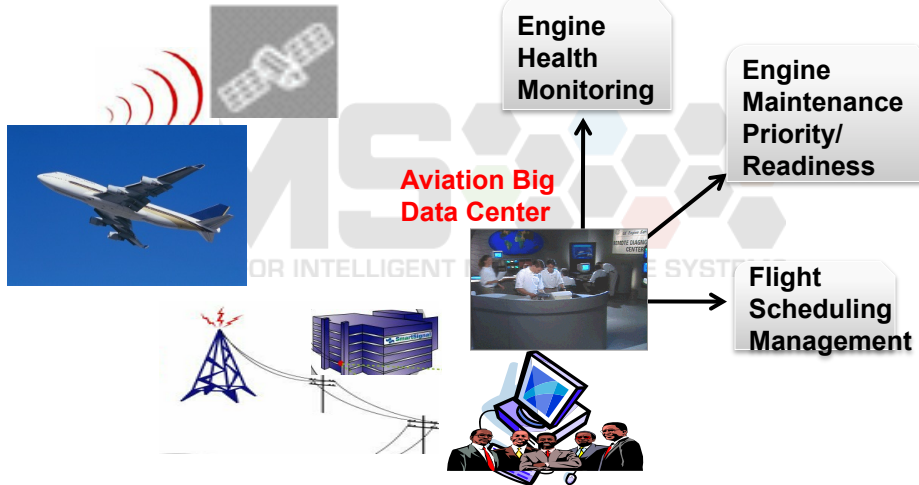


GE Aviation Service Systems



Aircraft Engine

Aviation



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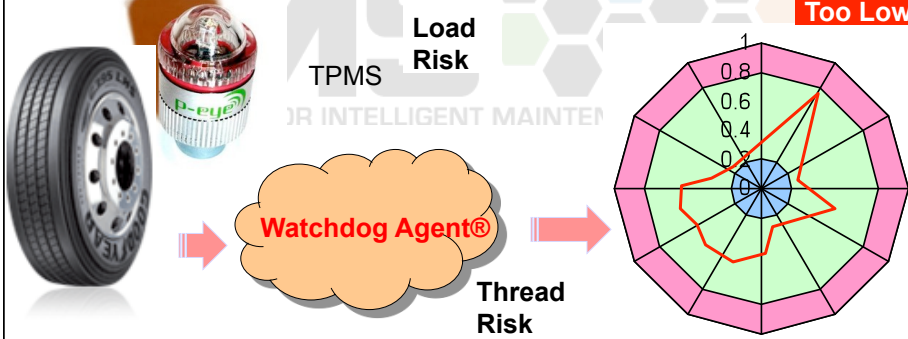
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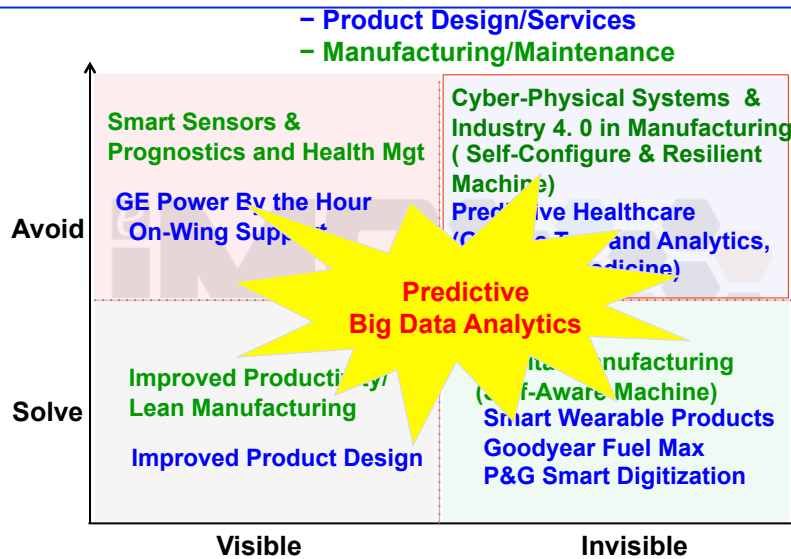
Goodyear Smart Tire & Service System



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Evolution of Industrial Systems



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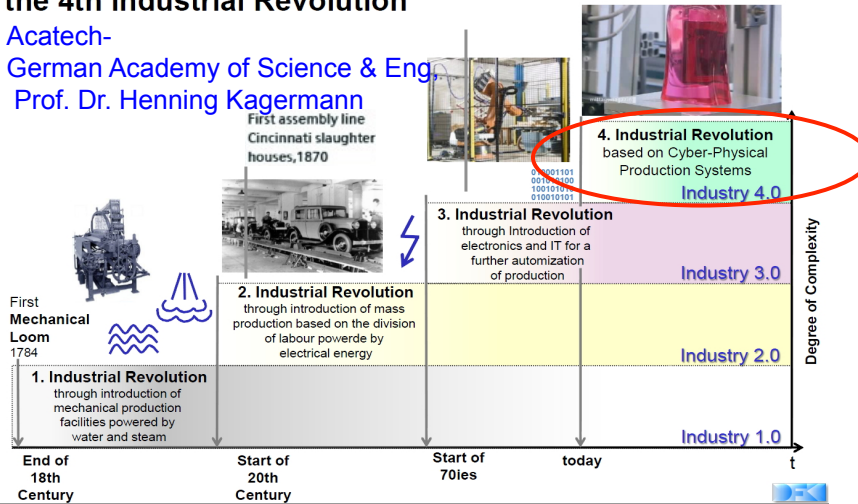
Industry 4.0 Manufacturing in Germany

CENTER FOR INTELLIGENT MAINTENANCE SYSTEMS

From Industry 1.0 to Industry 4.0

From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution

Acatech-
German Academy of Science & Eng.,
Prof. Dr. Henning Kagermann



<http://www.uber2b.com/b4b-presents-the-first-industry-4-0-mini-conference/>

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Data Analytics



Data Analytics is the scientific process of transforming data into insight for making better decisions.

- 1. Descriptive Analytics:** data queries, descriptive statistics, and data visualization
- 2. Prescriptive Analytics:** simulation, decision analysis, and optimization.
- 3. Predictive Analytics:** forecasting, predictive modeling, data mining, machine learning, support vector machines, etc.



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Predictive Industrial Big Data Analytics



- ▶ Apply Data Analytics to large amounts of data of a variety of types to uncover **hidden patterns, unknown correlations and other useful information** from industrial and manufacturing systems and integrate with business automation software for improved productivity and innovation.



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What are Cyber-Physical Systems?



- ▶ **Cyber**
 - computation, communication, and control that are discrete, logical, and switched
- ▶ **Physical**
 - natural and human-made systems governed by the laws of physics and operating in continuous time
- ▶ **Cyber-Physical Systems**
 - systems in which the cyber and physical components are tightly integrated at all scales and levels

Ref: NSF CPS Program, 2007

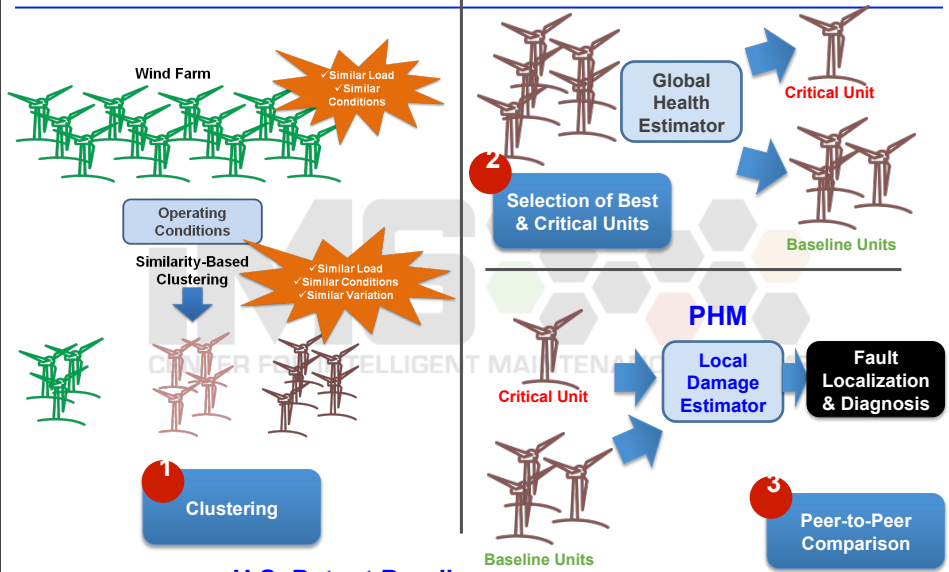


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Turbine-to-Turbine (T2T) Prognostics for Wind Farms



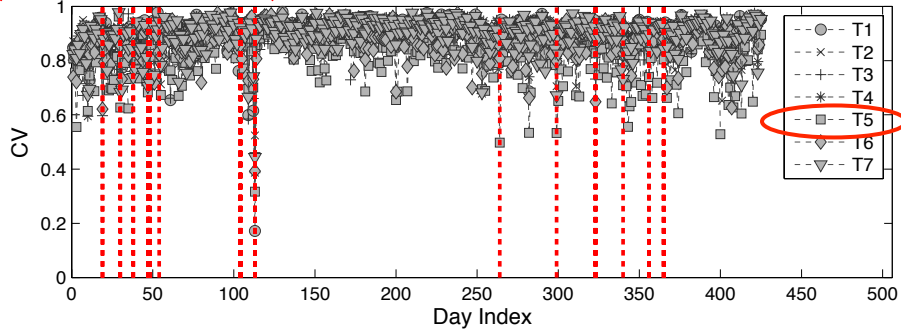
U.S. Patent Pending

Fleet Cluster-based Health Analytics



- » Data was prepared similarly with unit-specific modeling method.
- » Daily wind speed measurements were used for regime similarity evaluation, power curve data was used for health metric evaluation.

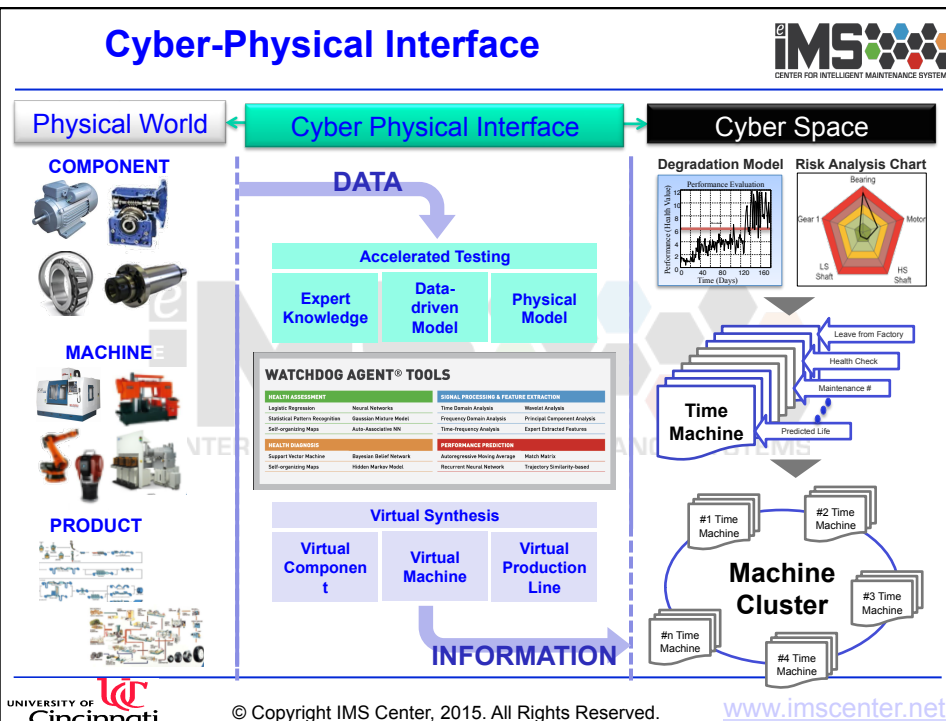
(Confidence Value)



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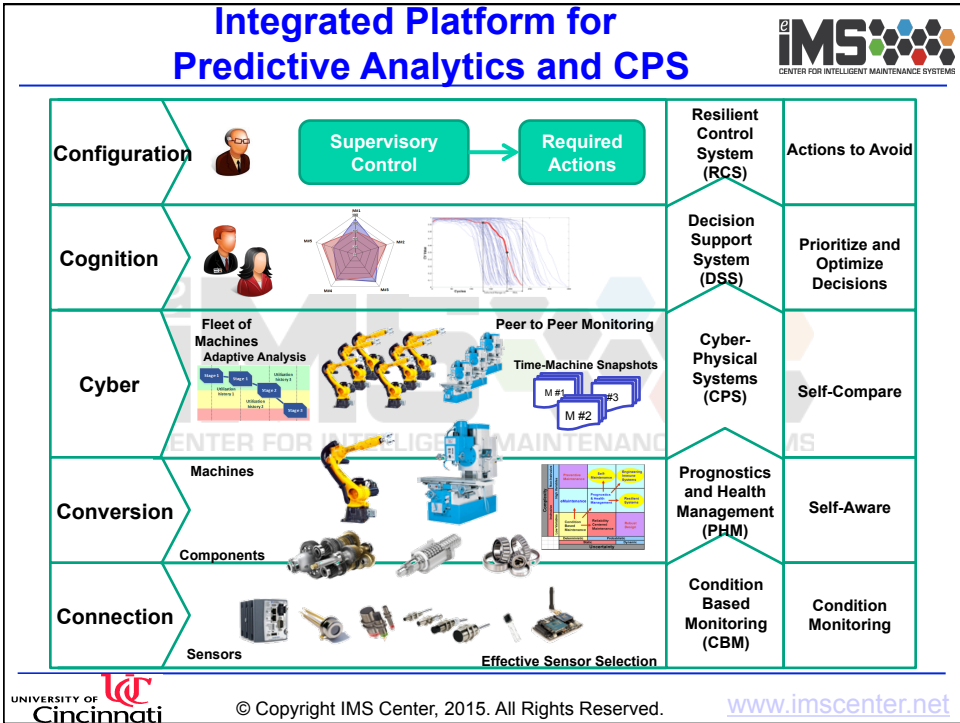
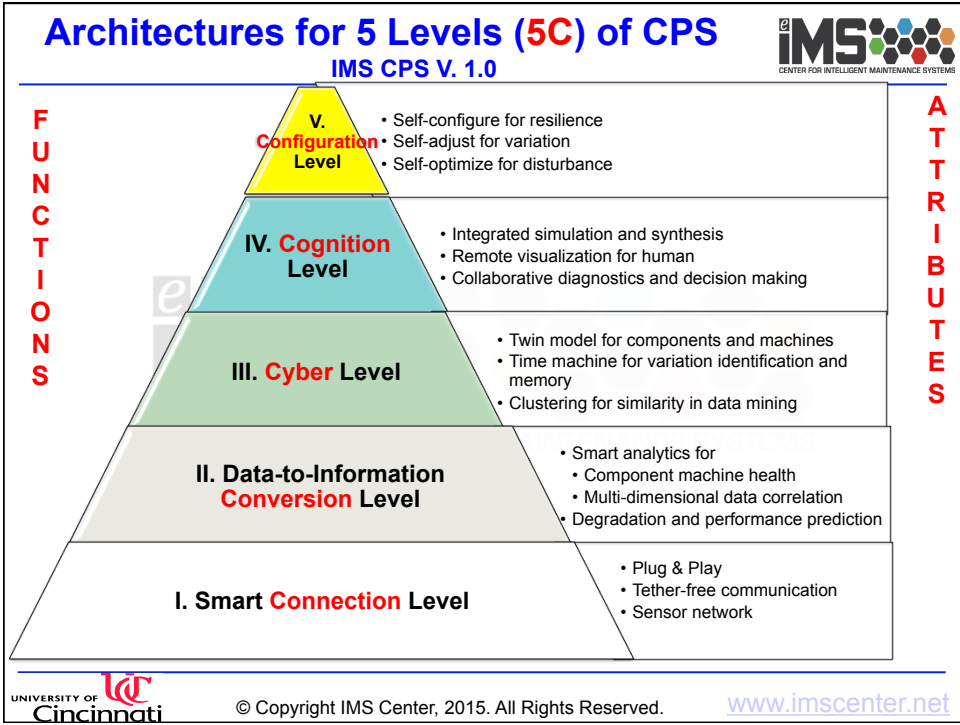
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Cyber-Physical Interface



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Comparison of Industry 4.0 Factory vs. Today's Factory



		Today Factory		Industry 4.0 Factory	
	Data Source	Attributes	Key Technologies	Attributes	Key Technologies
Component	Sensor	Precision	Sensing	Self-Aware	Degradation Measurement
Machine	Controller	Quality & Performance	Monitoring & Diagnostics	Self-Predict Self-Compare	Health Prognostics
Production Systems	Networked Systems	Efficiency & Productivity	Lean & Green Manufacturing	Self-Reconfigure Self-Optimize	Worry-Free Production

Jay Lee, Germany Harting Tech New 26 ,2013



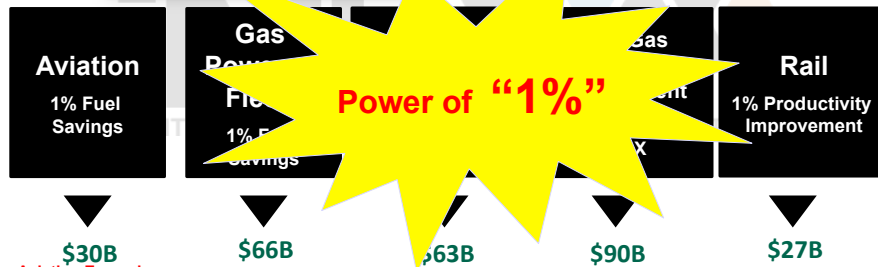
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The Internet of Things” gives \$10-15 Trillion Impacts



Jeff Immelt, Chairman & CEO, GE



Aviation Example:

- 43,000 commercial jet engines in service, imagine the efficiencies in:
 - engine maintenance
 - fuel consumption
 - crew allocation and scheduling

Ref: GE



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Outline



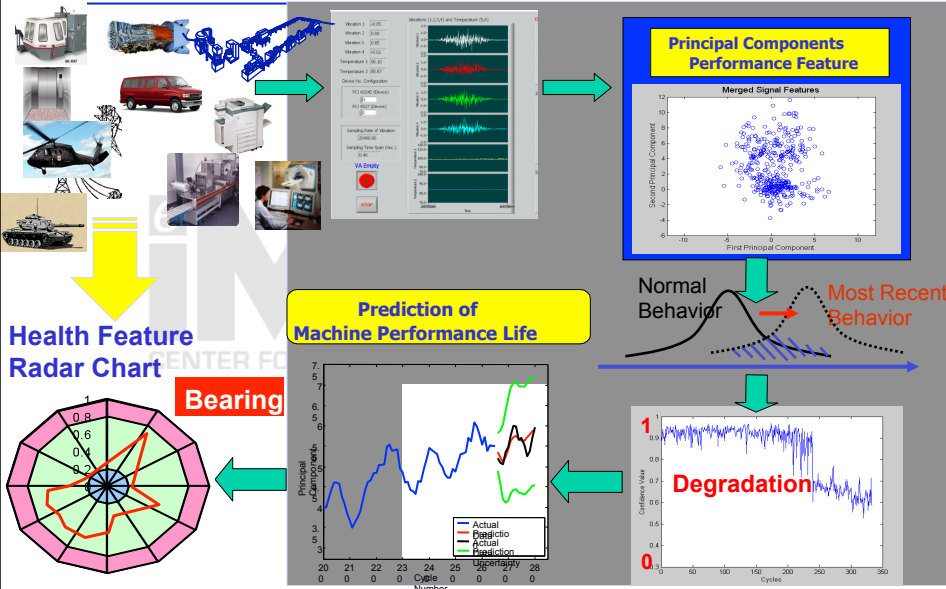
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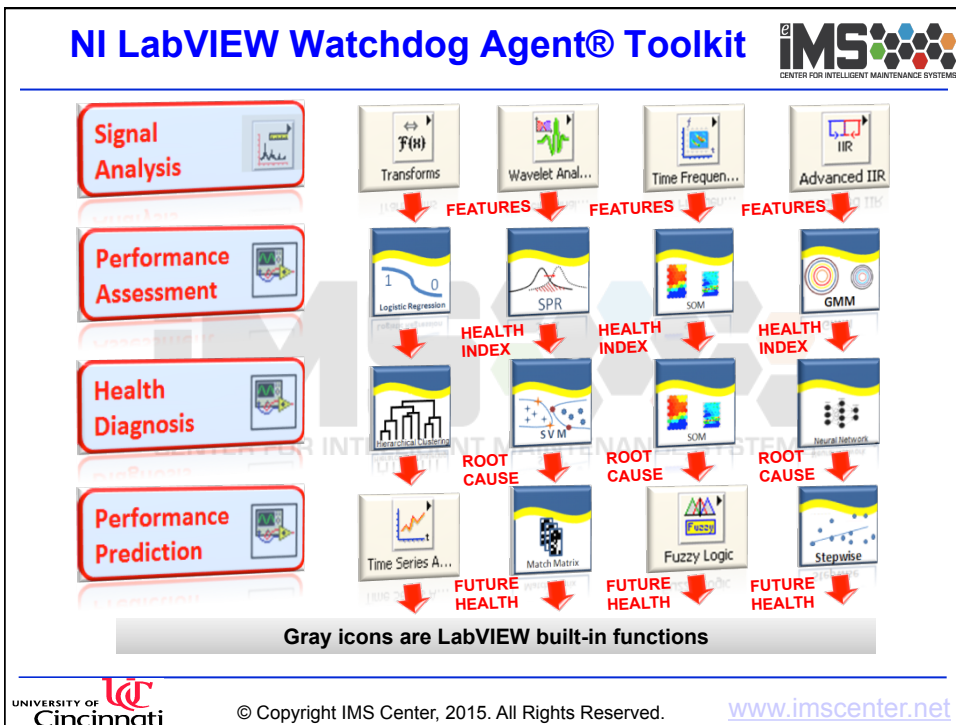
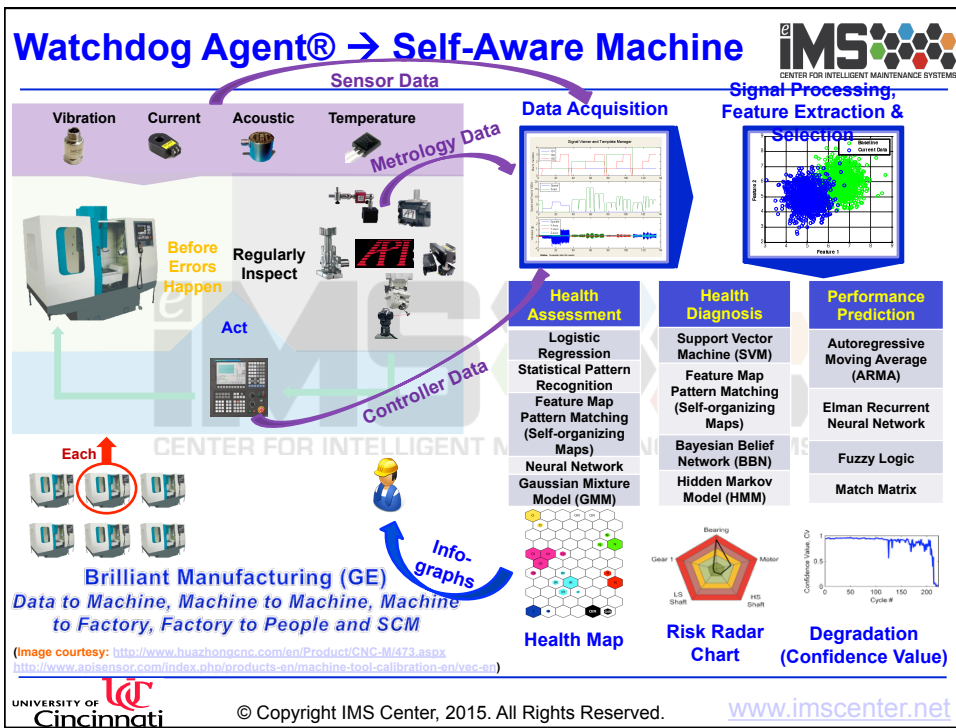
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Predictive Analytics and Instrumentation

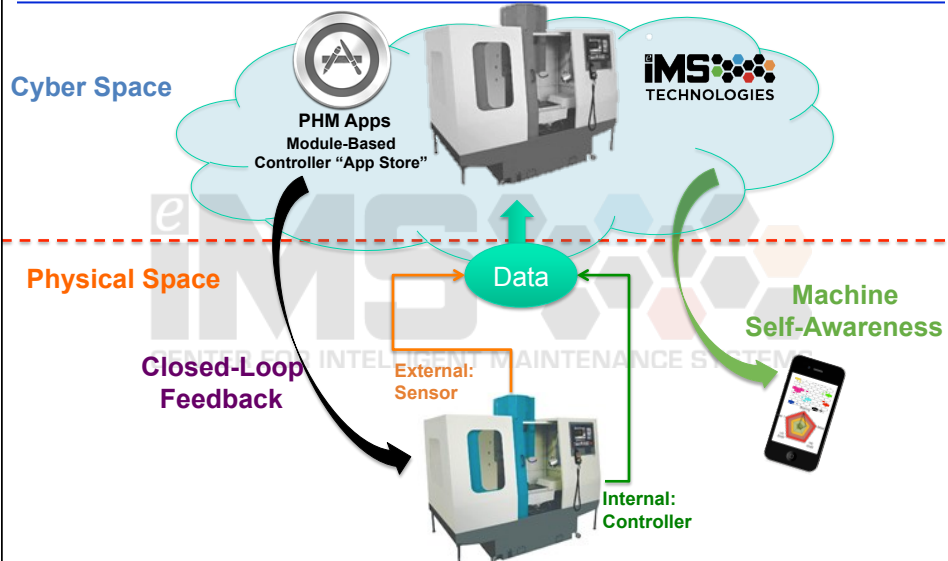


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IMS Self-Aware Machine Tools



(Image courtesy: <http://www.huazhongcnc.com/en/Product/CNC-M/473.asp>)



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TOYOTA

Predictive Robot Maintenance at Toyota Georgetown, KY



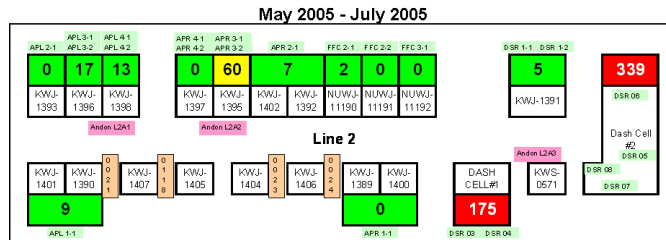
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Robot Health Map by Location



- ▶ Show whether certain areas (of process) were failing more often than others.
- ▶ Display bottlenecks of the process.



Colors for Line Stop Data

- Less than 30 minutes (Green)
- Greater than 30 and less than 120 minutes (Yellow)
- Greater than 120 minutes (Red)

Dash Cell #2 #1 and KWJ-1395 units cause most line stop time

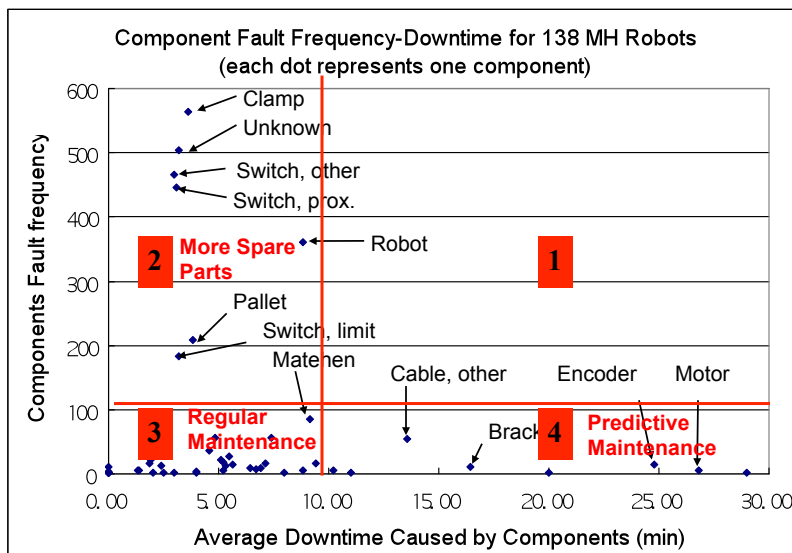
- Robots from different manufactures
- Used Zone 3A as an example
- Based on line stop time



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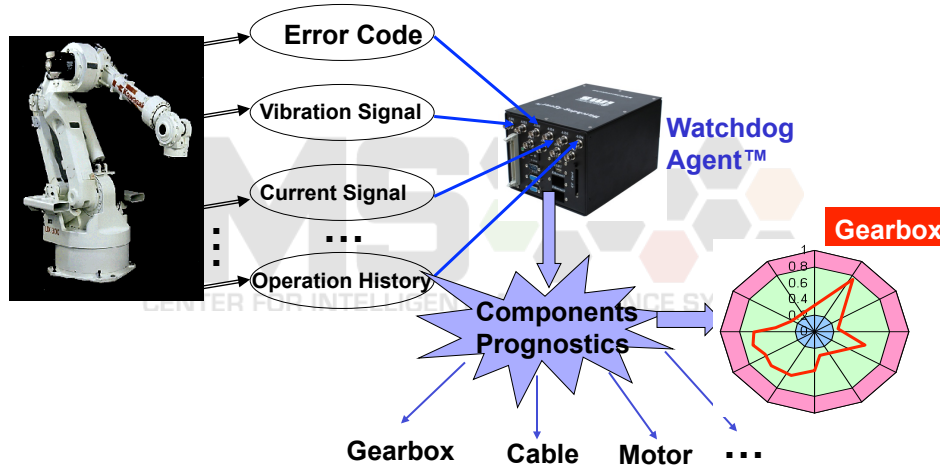
Critical Components



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IMS Self-Maintenance Robots in Toyota Georgetown Plant, KY



Watchdog Agent™ hardware platform allows multi-components prognosis



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Robot Health Monitoring Nissan Manufacturing Plant Smyrna, Tennessee



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Health Assessment -Example



Health Assessment Result for Third Servo-motor Robot Joint



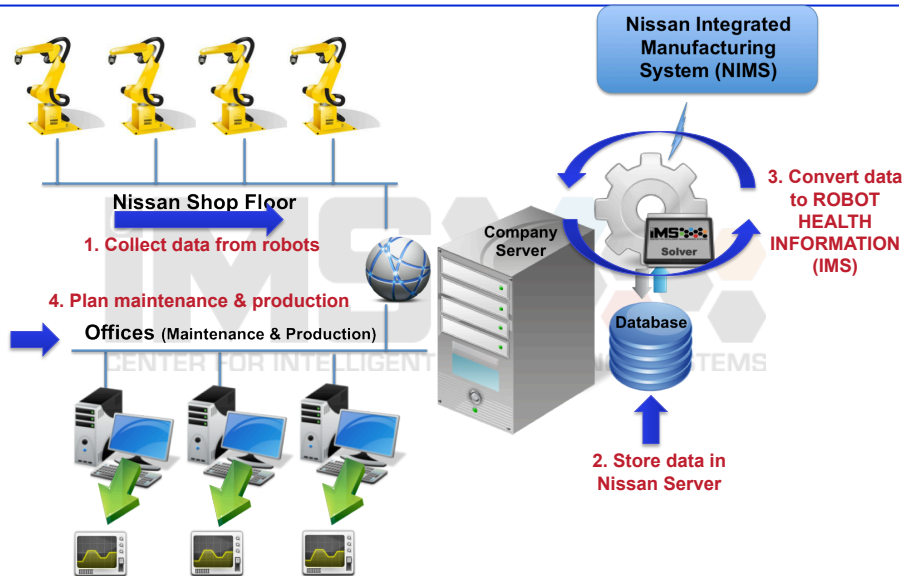
- ▶ Applying the IMS logistic regression algorithm included using the moving average and RMS torque value of the low-speed regime segmented data set as the two features used in training the model using the unacceptable (degraded) state data and acceptable (healthy) state data.
- ▶ The results of applying this method for the third robot joint servo motor are shown above, which shows that early signs of degradation can be seen as early as in cycle 125 but failure does not actually occur until cycle 220.



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Cloud-based Factory



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Factory Sentinel – Log-in Page



Factory Sentinel

User Name: Administrator
Password: *****

Login Exit



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Factory Sentinel – Robot Monitor – Line View



Factory Sentinel
Advanced Robot Prognostics

Robot Monitor
Plant A
Body Weld
Line i
Line ii
Dept 2
Plant B

Signal Viewer
Reporting
Software Management
Log out

Current Date: 10/10/12
Current Time: 05:31 PM
Logged in as: Shanhu Yang

Robot: HCL 1312 | Signal Viewer: HC... | Line i | Reporting

Plant A > Body Weld > Line i

HCL 3311, HCL 1532, HCL 9872, HCL 3412, HCL 2786, HCL 1312, HCL 1432, HCL 1112

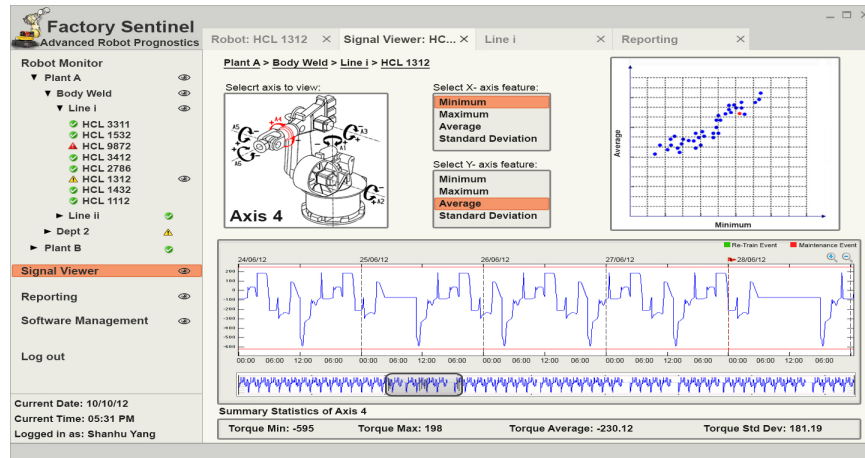
HCL 3311, HCL 1532, HCL 9872, HCL 3412, HCL 2786, HCL 1312, HCL 1432, HCL 1112



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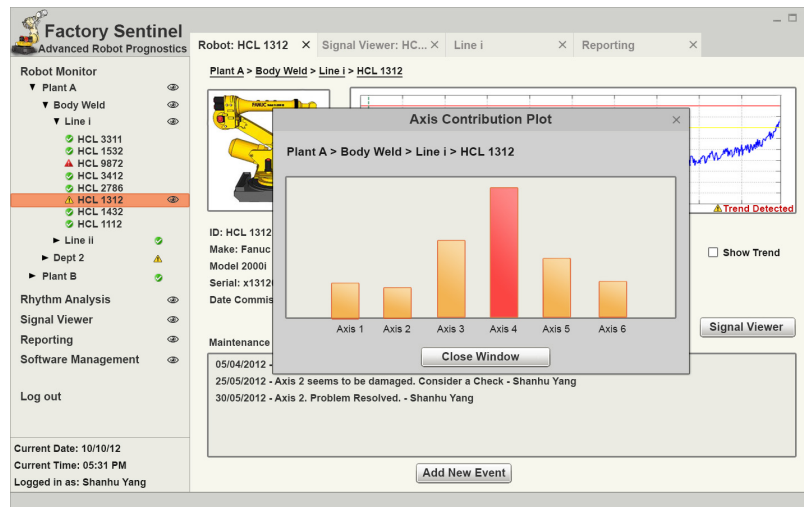
Factory Sentinel – Signal Viewer – Zoom-in Option



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ROBOT MONITOR – DIAGNOSE DIALOG BOX



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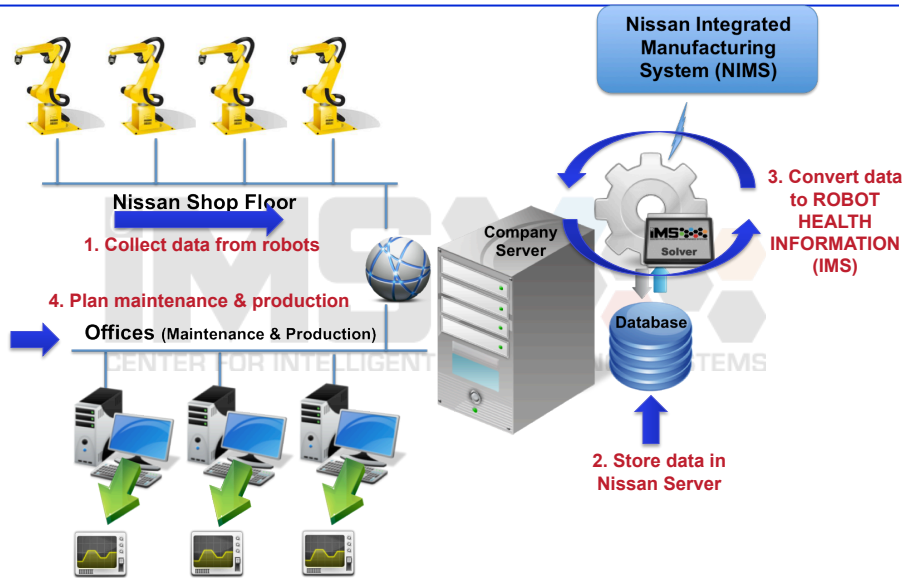
46

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Robot Health Monitoring
Nissan Manufacturing Plant
Smyrna, Tennessee

Cloud-based Factory



Factory Sentinel – Log-in Page



Factory Sentinel

User Name: Administrator
Password: *****

Login Exit



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Factory Sentinel – Robot Monitor – Line View



Factory Sentinel
Advanced Robot Prognostics

Robot Monitor

- Plant A
 - Body Weld
 - Line i
 - HCL 3311
 - HCL 1532
 - HCL 9872
 - HCL 3412
 - HCL 2786
 - HCL 1312
 - HCL 1432
 - HCL 1112
 - Line ii
 - Dept 2
 - Plant B
- Signal Viewer
- Reporting
- Software Management
- Log out

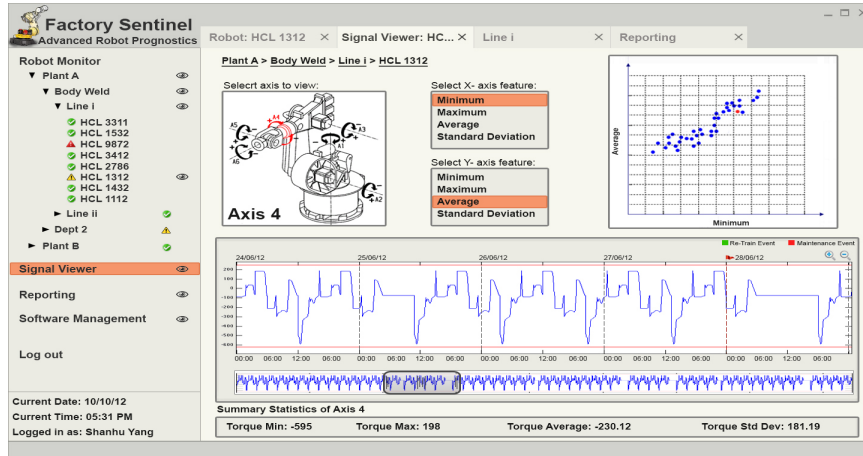
Current Date: 10/10/12
Current Time: 05:31 PM
Logged in as: Shanhu Yang



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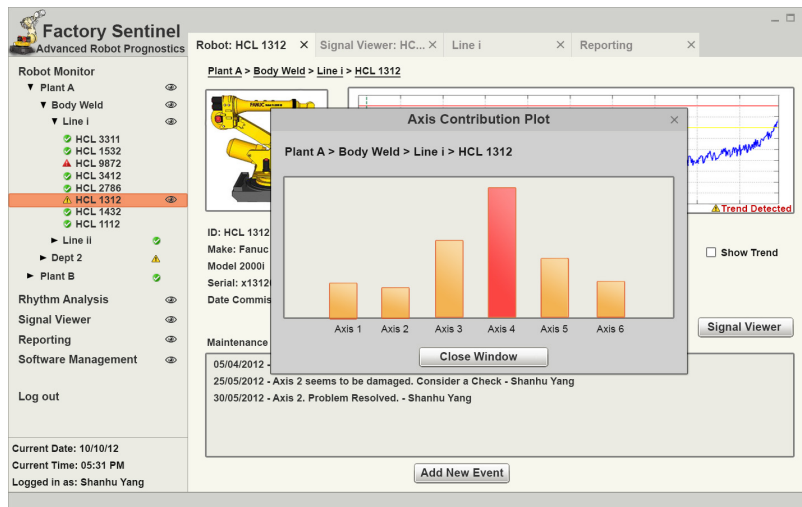
Factory Sentinel – Signal Viewer – Zoom-in Option



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ROBOT MONITOR – DIAGNOSE DIALOG BOX



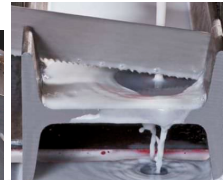
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Industry 4.0 Machine Demonstration

at
IMS
IMTS Chicago
 CENTER FOR INTELLIGENT MAINTENANCE SYSTEMS
Sept. 2014

Case Study with Cosen Band Saw Machine



<http://www.directindustry.com/prod/starrett/band-saw-blades-11639-534692.html>

Domain Knowledge

Failure Modes

Cutting Parameters

Blade Types

- OEM
- Material
- Tooth configuration

Material

- Geometry
- Cross-section
- Hardness

IMS PHM Tools

Signal Processing

Health Assessment

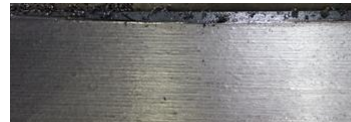
- Adaptive clustering
- Statistical pattern recognition

Prognostics

- Utilization based prediction
- Proportional hazard model

CPS objective

- » Maintenance & utilization suggestion
- » Product quality control

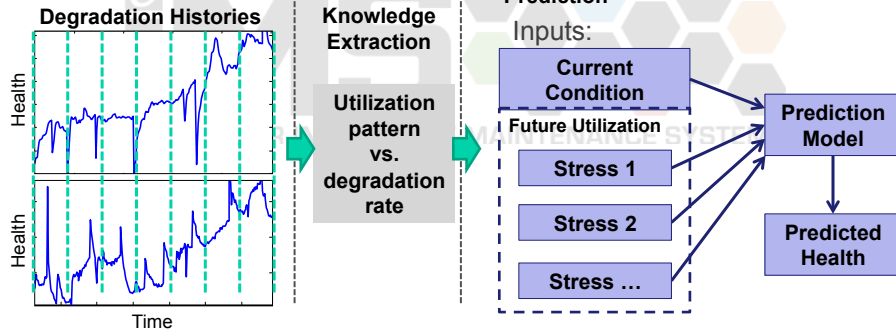


On-Machine Agent for Utilization based Prognostics



Rotating machine:

	High Load	Low Load
High Speed	Rate 1	Rate 2
Low Speed	Rate 3	Rate 4



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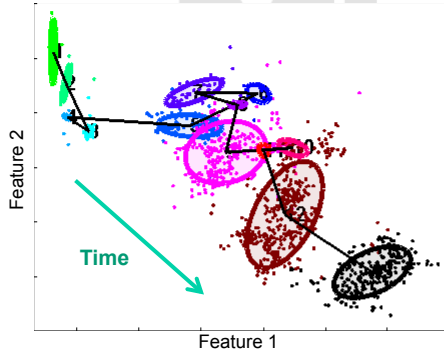
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Band Saw Degradation Analysis Results

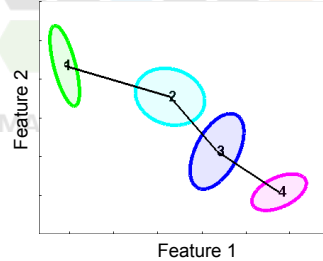


- ▶ After each cut, features are extracted as health indicators:
 - Energy percentage of frequency range [3750 4000] Hz
 - Blade downward pressure
- ▶ After each feature extraction, adaptive clustering is used to perform machine health assessment in real-time.

Step 1: on-line adaptive local clustering



Step 2: hierarchical clustering



Step 3: prediction and decision making under each cluster



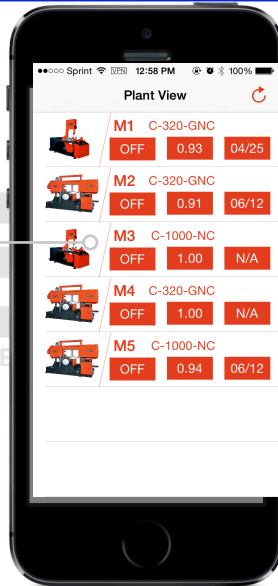
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Machine Mobile Agent (APP)- New Way of Machine Management



List of Machines in factory plant with abstract information about each machine including: working status, Latest health value and last timestamp of historical data



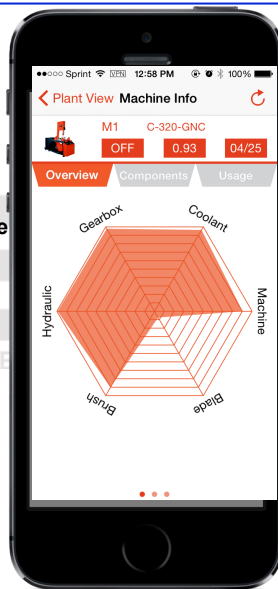
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Cognition & Analytics on Demand



By clicking on each machine, detailed information of that machine will be displayed. In the first section (overview) a radar chart for overall health status of machine components is displayed



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Outline



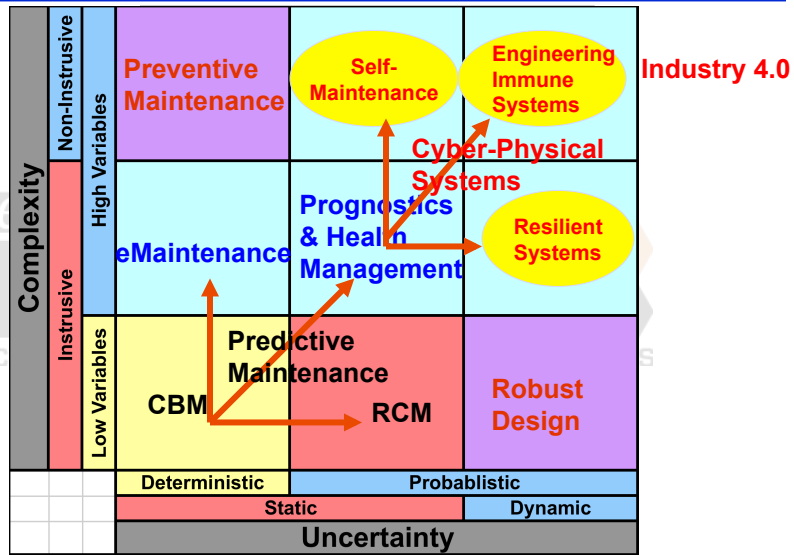
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- ▶ **Conclusions**



Conclusions

A large, semi-transparent watermark of the IMS logo is centered on the slide. It consists of the letters 'IMS' in a large, bold font, with a cluster of colorful hexagons to the right. Below the letters, the text 'CENTER FOR INTELLIGENT MAINTENANCE SYSTEMS' is written in a smaller, all-caps font.

PHM and CPS Transformation Map



Ref: Jay Lee, *Annual Reviews in Control*, Volume 35, Issue 1, April, 2011.



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Thank You !

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Google Jay Lee, Prognostics, E-Manufacturing, E-Maintenance, Dominant Innovation



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