

MATLAB EXPO



Predictive Maintenance Solution for Smart Manufacturing

Amit Doshi

Principal Application Engineer- Engineering AI

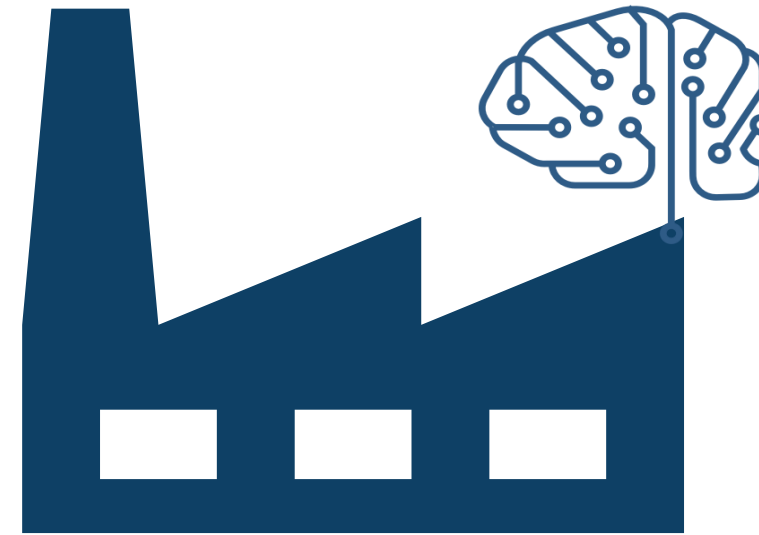


Smart Factories

Smart factories integrate **autonomy** and **big data** for actionable insights

Connected, optimized, pre-emptive, and agile

- Factories are:
 - Incorporating more advanced **systems**
 - Taking advantage of new **technology**
 - Increasing **connectivity** between components
 - Enhancing **infrastructure** to reach Industrial IoT



Making Factories Smarter: What's the change?

Factories: Traditional Automation

Systems

Fixed-position robots

Technology

Task automation

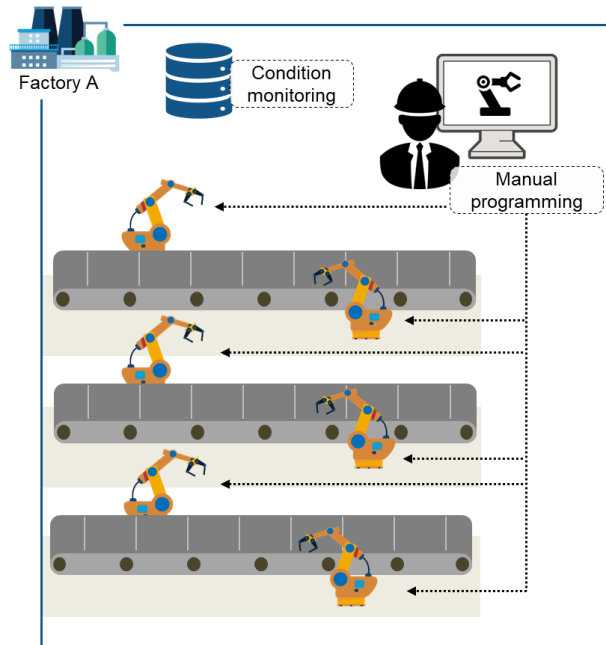
Manual programming

Connectivity

Condition monitoring

Infrastructure

Historians, SCADA



Factories: Leading towards 'Smart'

Systems

Autonomous systems: Collaborative robots, Autonomous Mobile Robots (AMR, AGV)

Technology

AI and Deep Learning
(Automated inspections, etc.)

Visualization / AR / VR

Digital twin

Connectivity

Intelligent logistics

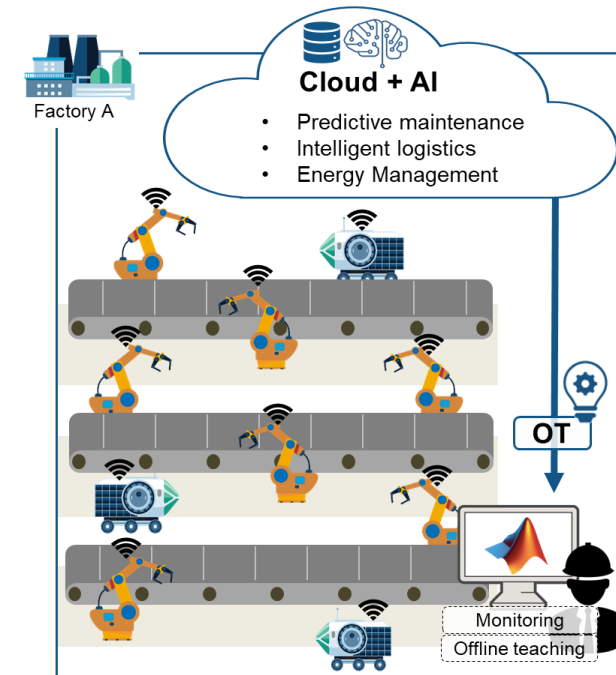
Predictive Maintenance

Infrastructure

Cloud computing

Energy Management

OT (Operational Technology)



Agenda For Today's Talk

- 1** Predictive Maintenance Algorithm Development
 - Predictive Maintenance Toolbox
- 2** Algorithm Test & Deployment To Edge Device
 - Simulink Real Time & Simulink Coder
- 3** Algorithm Deployment to Azure-based IT System
 - MATLAB Compiler & MATLAB Production Server



Predictive Maintenance Promises Improved Operating Efficiency, New Revenue Streams, & A Competitive Differentiator

Siemens @Siemens

Follow

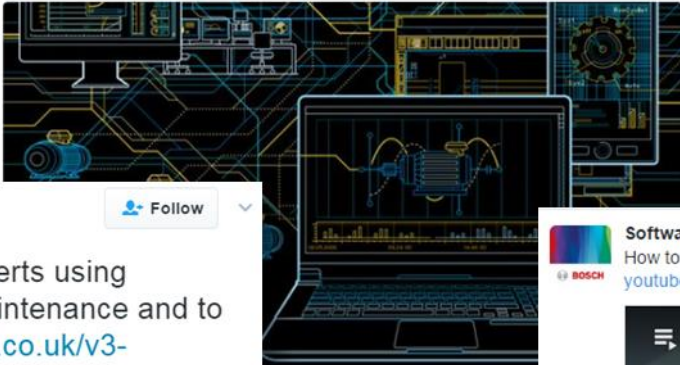
Thanks to predictive maintenance the #Velaro E trains between Barcelona and Madrid run w/ 99.9% availability #GartnerSYM



ABB Global @ABBgroupnews

Follow

A game changer that opens the door to predictive maintenance ow.ly/4nc2TT #IIoT #HM16

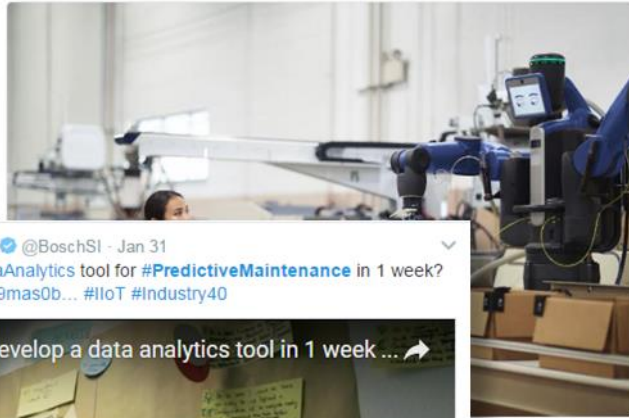


Intel IoT @IntelIoT

Follow

#DYK predictive maintenance can cut yield losses by 25%? Major benefits of #IIoT: intel.ly/2dg7Otm

Impact
Downtime Rat



SAP IoT @SAP_IoT

Follow

John Deere uses machine alerts using #telematics for predictive maintenance and to lower downtime of assets v3.co.uk/v3-uk/news/234 ... #IoT



John Deere: Technology vendors need to feed agriculture's big data needs
Farmers are hungry for IT solutions
v3.co.uk

Software Innovations @BoschSI - Jan 31

How to develop a #DataAnalytics tool for #PredictiveMaintenance in 1 week? youtube.com/watch?v=9mas0b... #IIoT #Industry40



How to develop a data analytics tool in 1 week (Part 1)
A team of data scientists, manufacturing & software experts at Bosch Software Innovations developed a data analytics tool for predictive maint...
youtube.com

Planned
Maintenance Approach

Predictive Maintenance Matters To Every Single Industry That Is Manufacturing Or Operating Machinery



Aerospace and Defense



Automotive



Medical Devices



Electronics



Energy Production



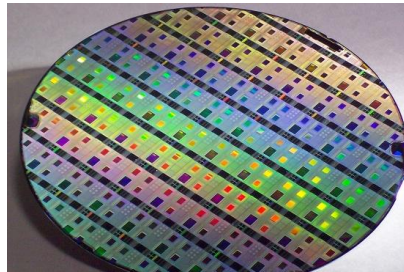
Industrial Machinery



Process Manufacturing



Railway Systems



Semiconductors

MATLAB & Simulink Are Being Used Today For Predictive Maintenance



BOSCH

Baker Hughes



equinor



NEWCREST
MINING LIMITED



Transocean



mondi



SAFRAN



Metro de Madrid



NIO



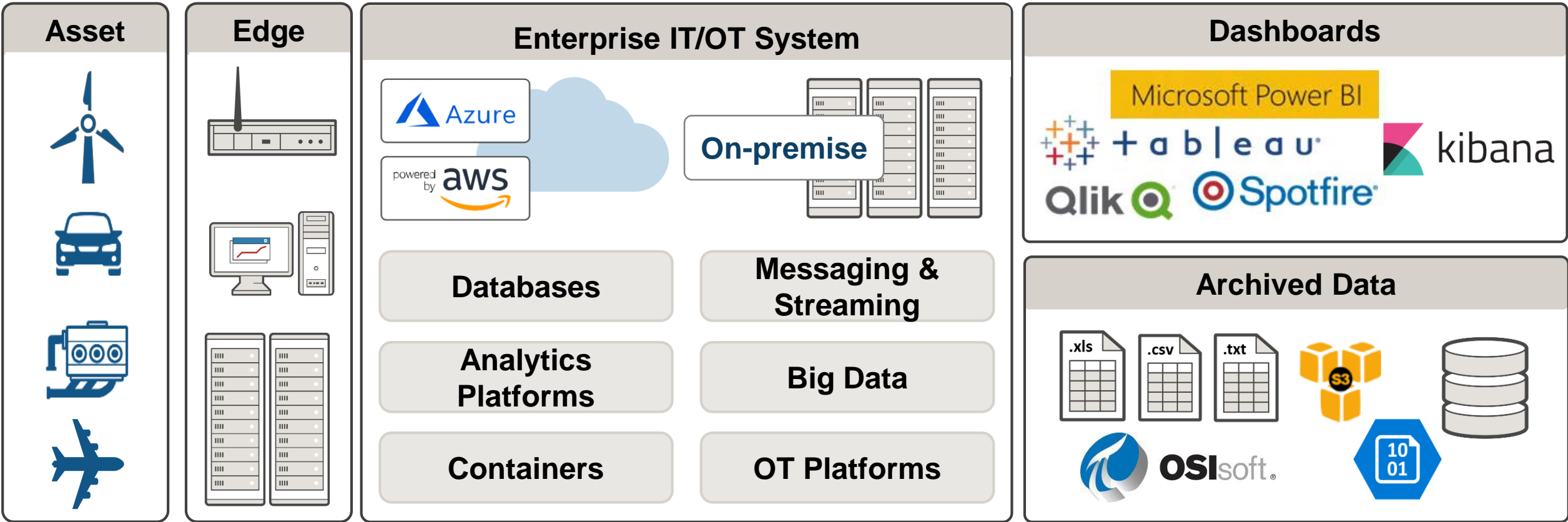
Daimler
Mercedes-Benz

+GF+

GF Machining Solutions

Atlas Copco

...But Deploying a Predictive Maintenance Algorithm Successfully Is Much More Complicated



The Challenges Associated With Predictive Maintenance Are Consistent Across Industries, for both Data Scientists & Engineers



Too many options for machine learning, feature extraction, etc.



Integrating algorithms with existing infrastructure



Lack of failure data



Hard to get started

Case Study: Flow Pack Machine

Objective:

Using machine data, determine what needs to be fixed and estimate RUL

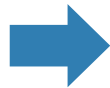
Challenge:

Failure sensor data is not available



Data

PdM Algorithm Development



Debug



Package & Deploy

1

- Motor Current
- Motor Speed
- Position Error

3

Dashboard for the end users

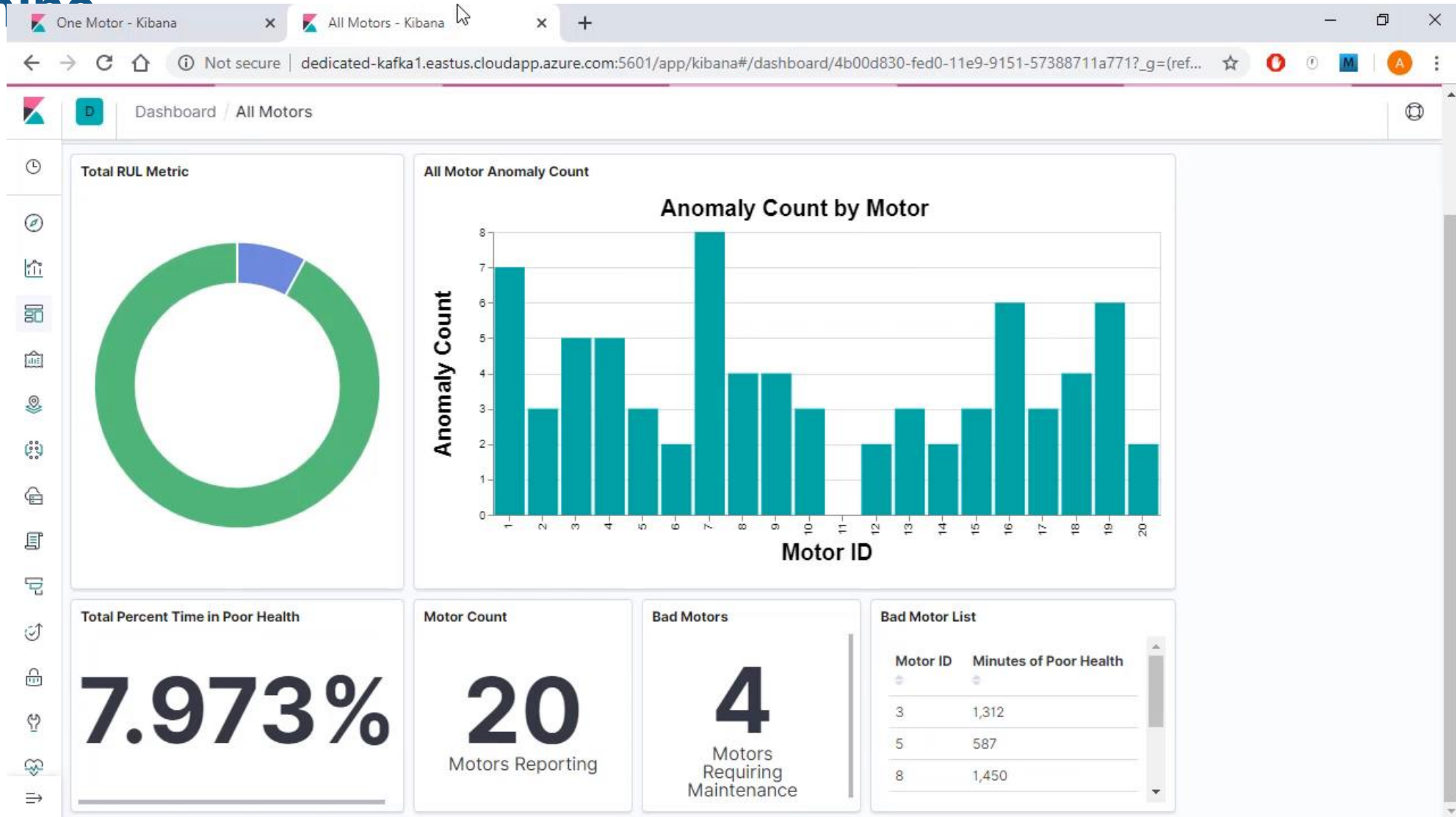


2

Deploy PdM on the edge



Case Study: Flow Pack Machine



Algorithm Development Includes Remaining Useful Life Estimation, Anomaly Detection, Fault Classification, & Condition Monitoring

1 Predictive Maintenance Algorithm Development

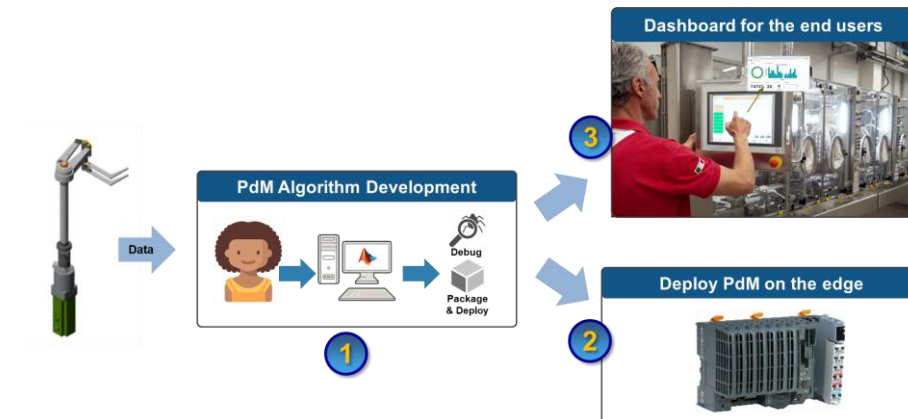
- Predictive Maintenance Toolbox

2 Algorithm Test & Deployment To Edge Device

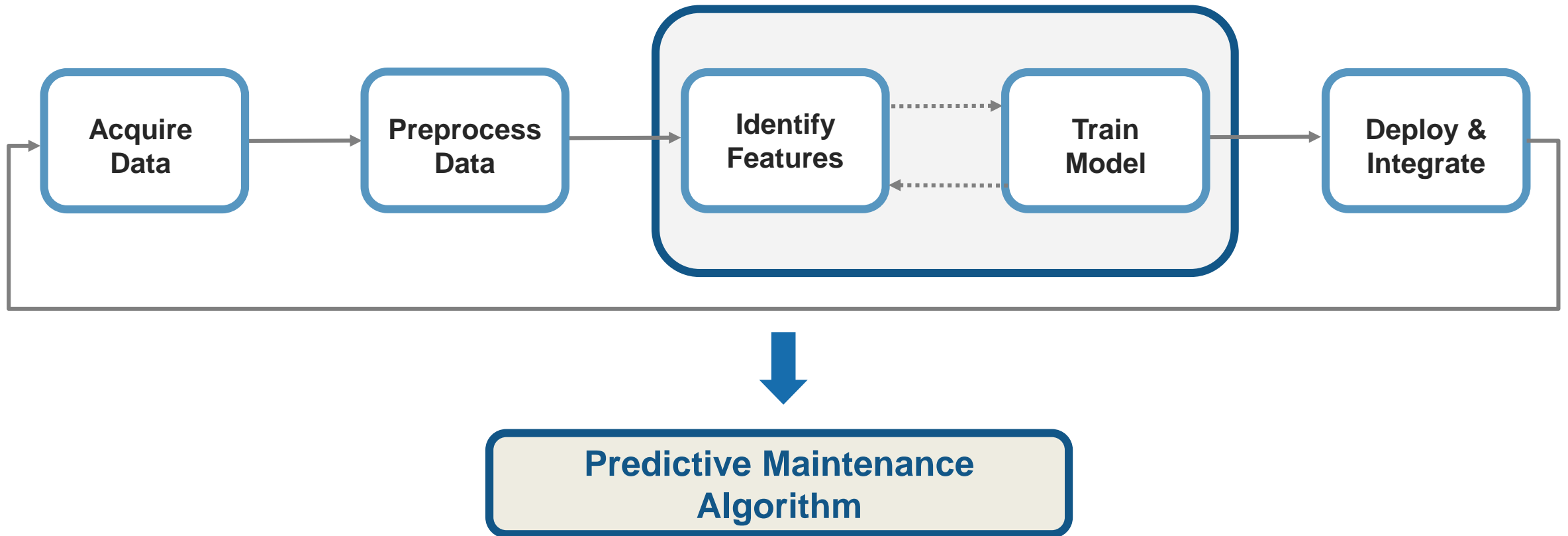
- Simulink Real Time & Simulink Coder

3 Algorithm Deployment to Azure-based IT System

- MATLAB Compiler & MATLAB Production Server

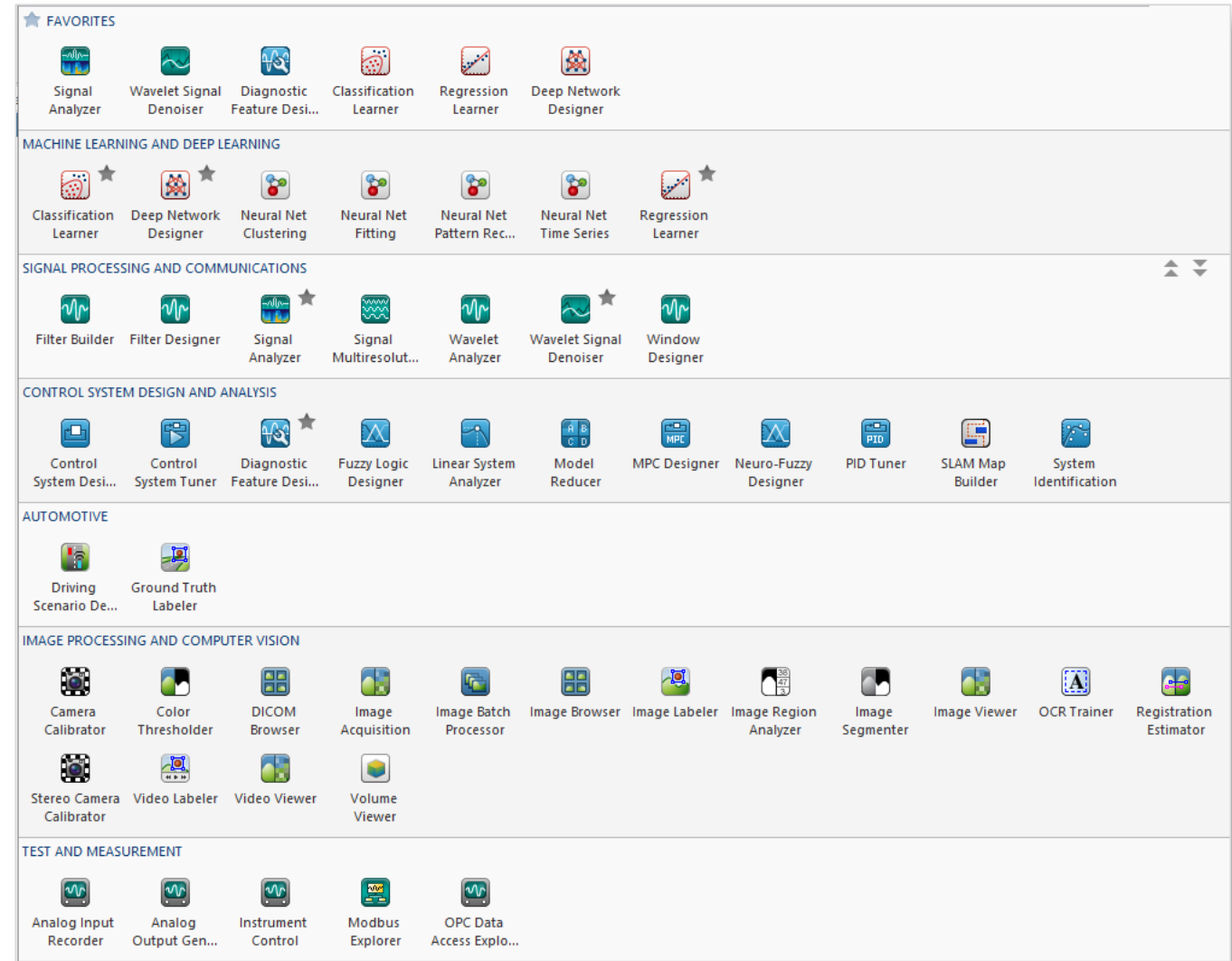


Developing A Predictive Maintenance Algorithm Requires Domain Expertise and Machine Learning Techniques...



Explore and automate feature extraction & machine learning tasks using MATLAB Apps

- Signal Analyzer
- Wavelet Denoiser
- Diagnostic Feature Designer
- Classification Learner
- Regression Learner
- Deep Network Designer
- ...and many more



Signal-Based Condition Indicators

Time-domain features

Mean
Standard deviation
Skewness
Root-mean square
Kurtosis
•
•
•

Frequency-domain features

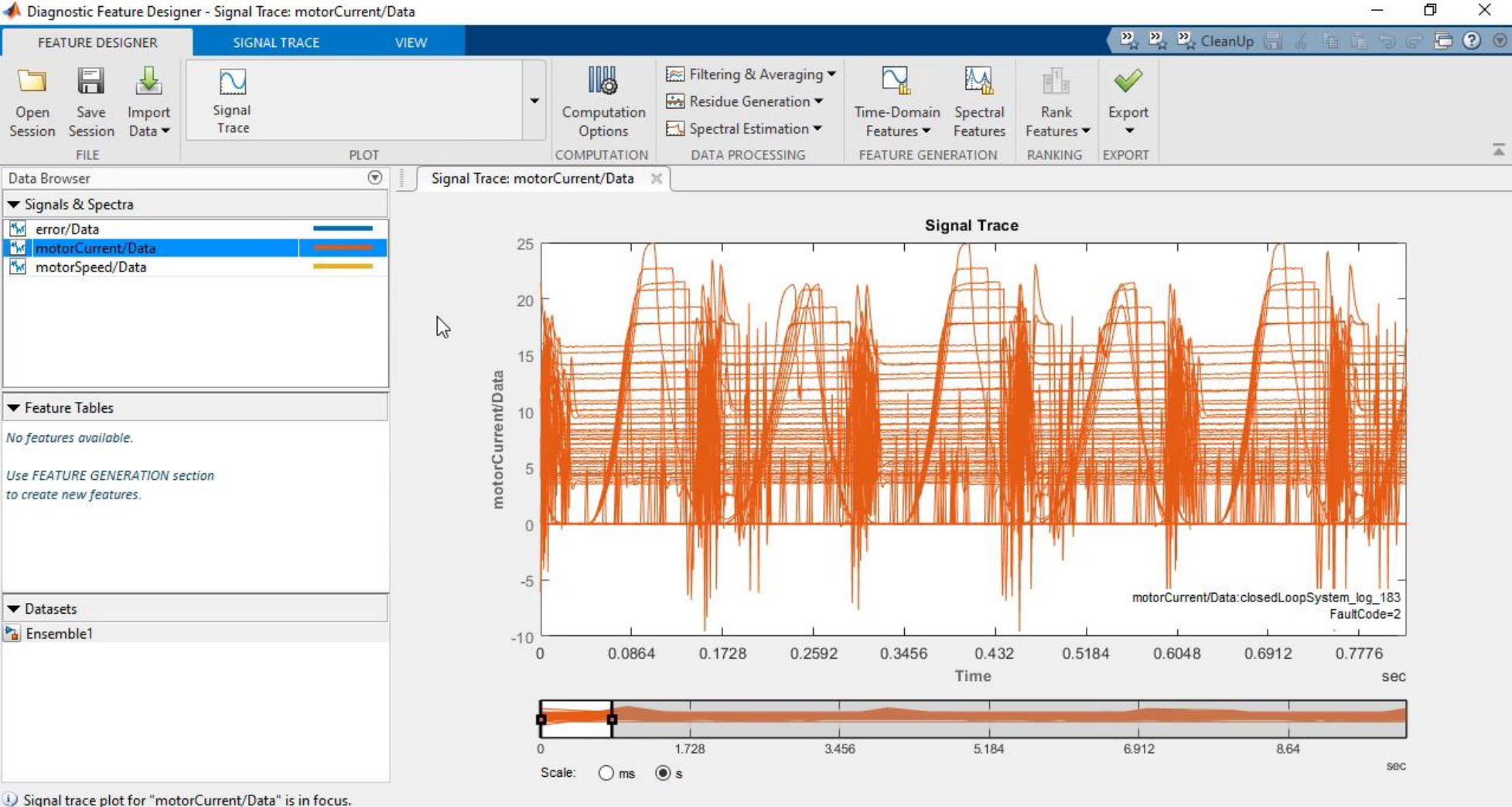
Power bandwidth
Mean frequency
Peak values
Peak frequencies
Harmonics
•
•
•

Time-frequency domain features

Spectral entropy
Spectral kurtosis
•
•
•

[Learn more about Condition Indicators](#)

Visualize Data, Try Different Feature Extraction Methods & Compare Results Without Writing Any MATLAB Code



Design App Get More Apps Install App Package App

FILE

Current Folder
C:\> Docum

Workspace

Name

- featureData
- featureDataNormalized
- featureDataNormalizedf
- featureDataTraining

★ FAVORITES

- Classification Learner
- Regression Learner
- Diagnostic Feature Designer
- System Identification
- Signal Analyzer
- MATLAB Coder
- Optimization
- Curve Fitting
- Application Compiler

MACHINE LEARNING AND DEEP LEARNING

- Classification Learner
- Deep Network Designer
- Experiment Manager
- Neural Net Clustering
- Neural Net Fitting
- Neural Net Pattern Recog...
- Neural Net Time Series
- Regression Learner

MATH, STATISTICS AND OPTIMIZATION

- Curve Fitting
- Distribution Fitter
- Optimization

CONTROL SYSTEM DESIGN AND ANALYSIS

- Control System Designer
- Control System Tuner
- Diagnostic Feature Designer
- Linear System Analyzer
- Model Reducer
- PID Tuner
- System Identification

AUTOMOTIVE

- MBC Model Fitting
- MBC Optimization

SIGNAL PROCESSING AND COMMUNICATIONS

- Audio Labeler
- Filter Builder
- Filter Designer
- Impulse Response Me...
- Signal Analyzer
- Signal Labeler
- Window Designer

IMAGE PROCESSING AND COMPUTER VISION

- Camera Calibrator
- Color Thresholder
- DICOM Browser
- Image Acquisition
- Image Batch Processor
- Image Browser
- Image Labeler
- Image Region Analyzer
- Image Segmenter
- Image Viewer
- Map Viewer
- OCR Trainer

```

25
your classification model.
(md1.FeatureWeights>=1);
Reduced(:,end)];
with err_Var and

```

Metro de Madrid and IMA Are Using MATLAB For Developing Predictive Maintenance Algorithms

Metro de Madrid Adopts Machine Learning for Predictive Maintenance in Tunnels

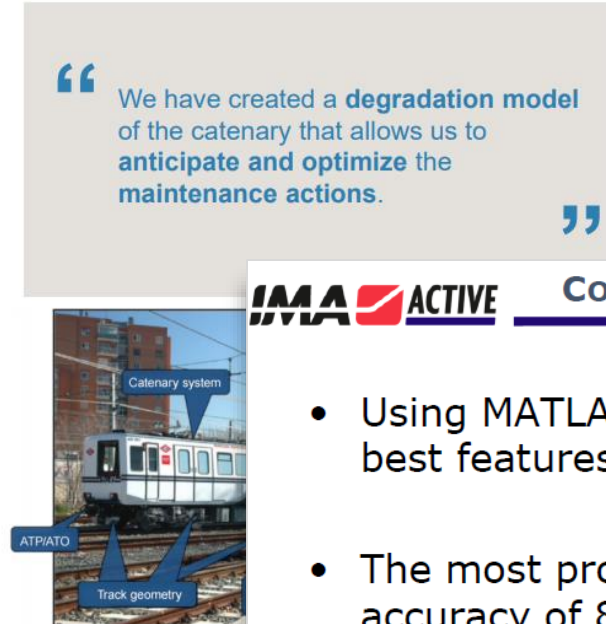
Raúl Rico, Metro de Madrid

Every day, Metro de Madrid stores more than 10 GB of new data acquired from different sources. Many available tools can only analyze data from a single sensor, and such approaches lack domain expertise. In order to use all the data they acquire for predictive maintenance, Metro de Madrid needed to integrate the data from a wide variety of sensors and customize their signal analysis algorithms.

Metro de Madrid used MATLAB® and Statistics and Machine Learning Toolbox™ to automate the data merging, signal analysis, and algorithm sharing, which enables people without MATLAB experience to perform advanced signal analysis.

Advantages of using MATLAB:

- Save time in the data validation and analysis phase
- Integrate data from different sources
- Share algorithms with non-MATLAB users

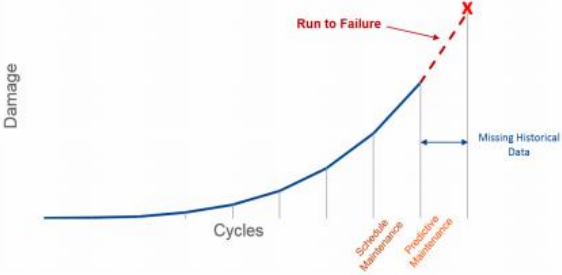
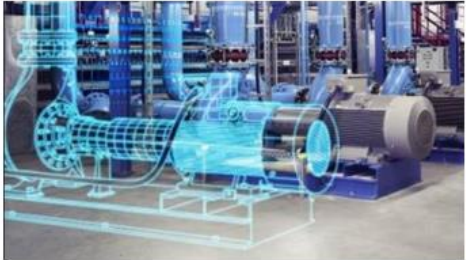


CONCLUSIONS AND FUTURE ACTIVITIES

- Using MATLAB tools we managed to extract and select the best features to build a classification model
- The most promising algorithm uses 5 features and has an accuracy of 89%
- Ongoing: check capability of generalization using data of other parts that did not break
- In the future: acquire new data and test the model on-line

Safran Uses Simulink to Generate Failure Data To Train Neural Networks To Detect Anomalies and Predict Failures in Factories

Engineering Technology – Digital Twin



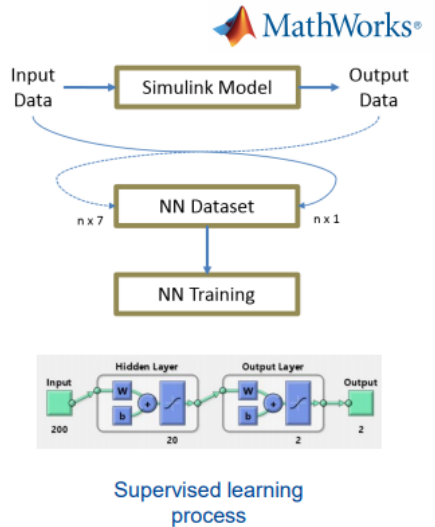
1. Due to traditional Maintenance Cycles, run-to-failure data are normally missing from collected Data Base.
2. Run-to-failure data are necessary for Smart Prediction.
3. Digital Twins simulate anomalies to generate these data.
4. Digital Twins follow Physical Responses.



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Application – Hydraulic Press

1. **Data base**
 - NN Dataset & Training is developing by switching Input-Output.
2. **ANN Generation**
 - Build the ANN architecture with Deep Learning Toolbox.
3. **Training**
 - Adjust relative neural parameters to reach desired values.
4. **Validation**
 - Iterative process using physical inputs to validate ANN and Virtual Model.



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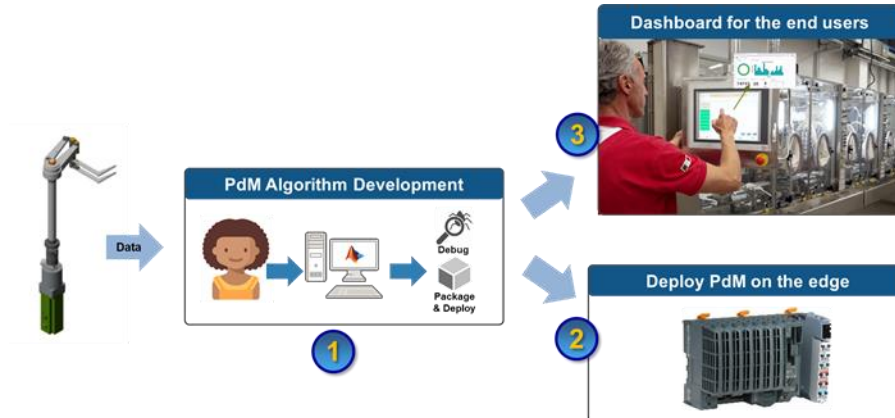
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[MATLAB Expo Talk Link](#)

Edge Device Deployment Enables Data Reduction & Faster Results

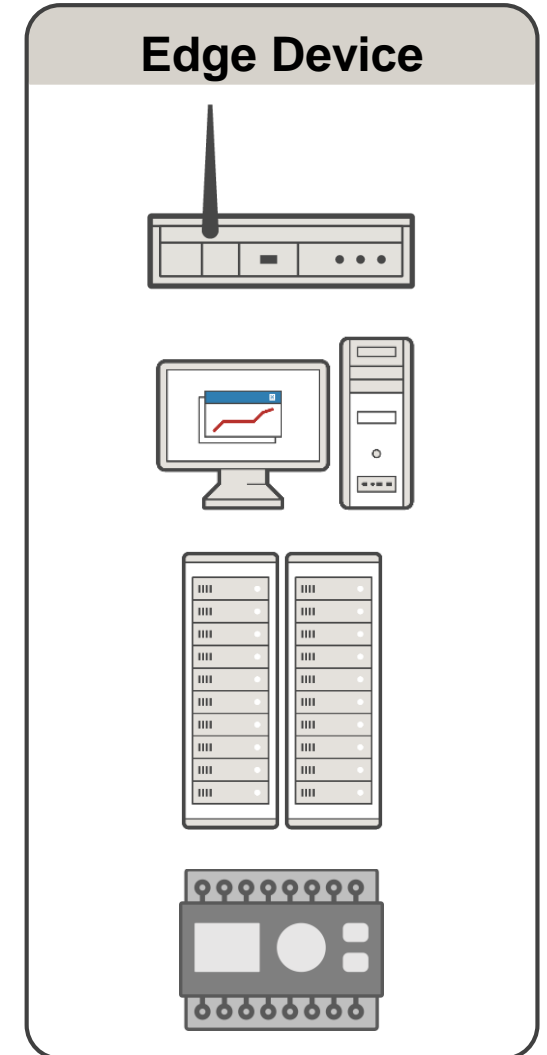
- 1 Predictive Maintenance Algorithm Development
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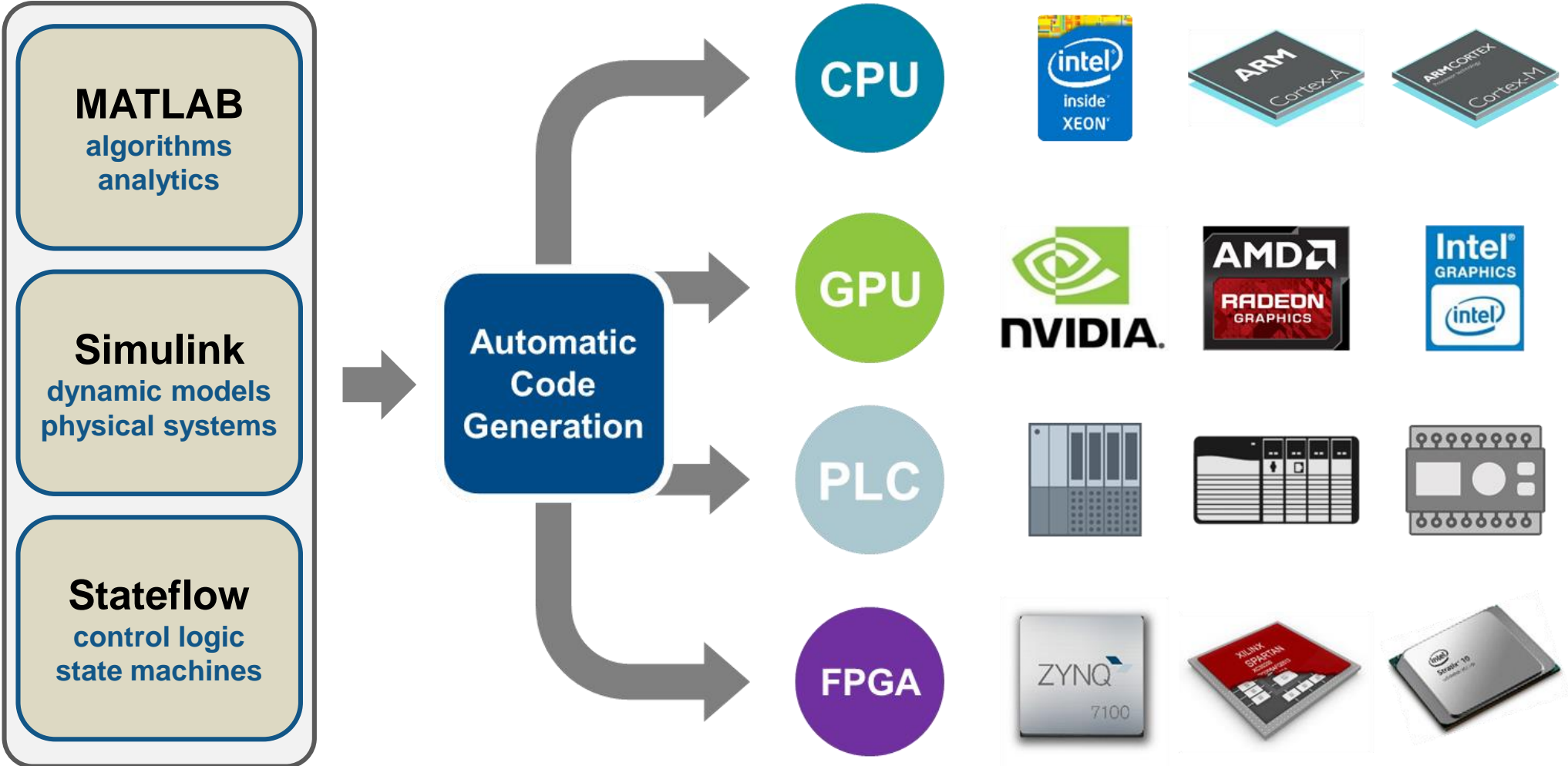
The Steps Associated With Deploying To Hardware Are Complex, But Model-Based Design Is Perfectly Suited To This Application

1. Develop algorithm that can run on a resource-constrained edge device
2. Test algorithm in simulation
3. Verify performance using real-time testing
4. Deploy to actual hardware

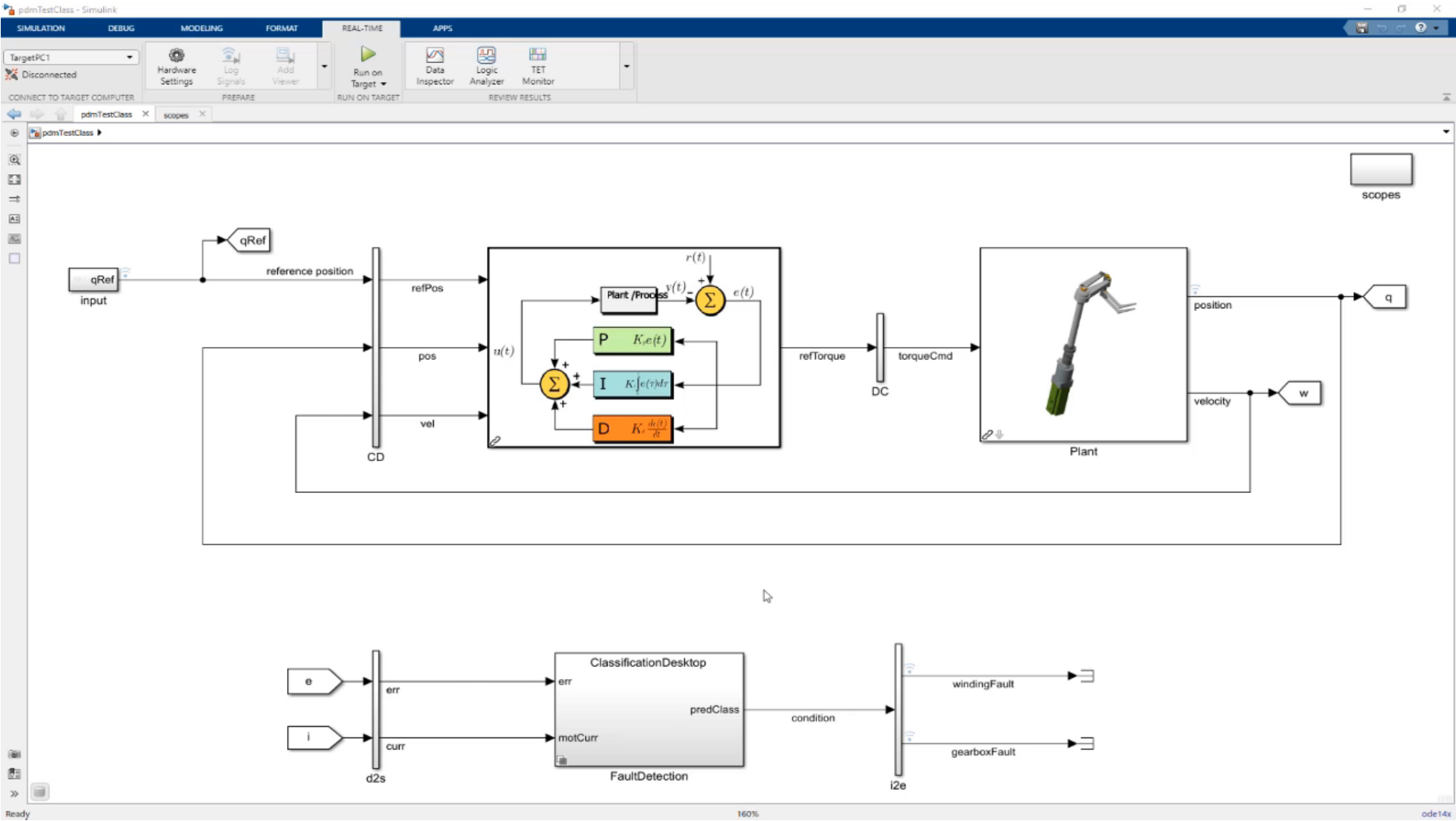
**Predictive
Maintenance
Algorithm**



Automatic Code Generation From MATLAB & Simulink Simplifies This Process



Check If Fault Classification Algorithm Behaves As Expected Using Simulation



Deploy Algorithm To PLC Using Automatic Code Generation & Verify Performance Using Real-Time Testing



Atlas Copco Is Using Model Based Engineering and Digital Twins For Minimizing Cost

As Maintained: > 120.000 Machines Connected

Condition Monitoring

Data analytics to improve Design

Predictive maintenance

Optimize maintenance

Atlas Copco

As Designed: MBE Framework

Physical Framework
"As a calculation engineer, I want to simulate dynamic behaviour of my system to optimize my components."

Interface Framework
"As a marketer, I want to have easy access to the validated engineering data to create my technical data sheets."

Core Framework
"As a calculation engineer, I want to find optimal gear ratio's and element sizings."

Controller Framework
"As a control engineer, I want to simulate the effect of my control strategy on the system."

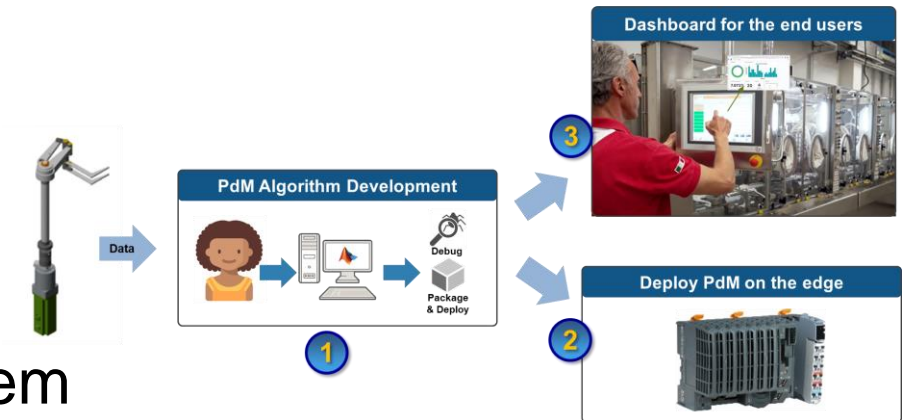
Community Tools
Software platform enabling community development
Wiki, bug trackers, source control,...

MathWorks Atlas Copco

[MATLAB Expo Talk Link](#)

End Users Require Easy Access To Actionable Information. Dashboards Integrated With IT & OT Systems Make This Possible

- 1 Predictive Maintenance Algorithm Development
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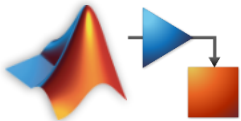


Building Such A System Requires 3 Different Skill Sets: Algorithm Development, Data Visualization, & Data Management



Engineer & Data Scientist

Develops algorithms in MATLAB and Simulink



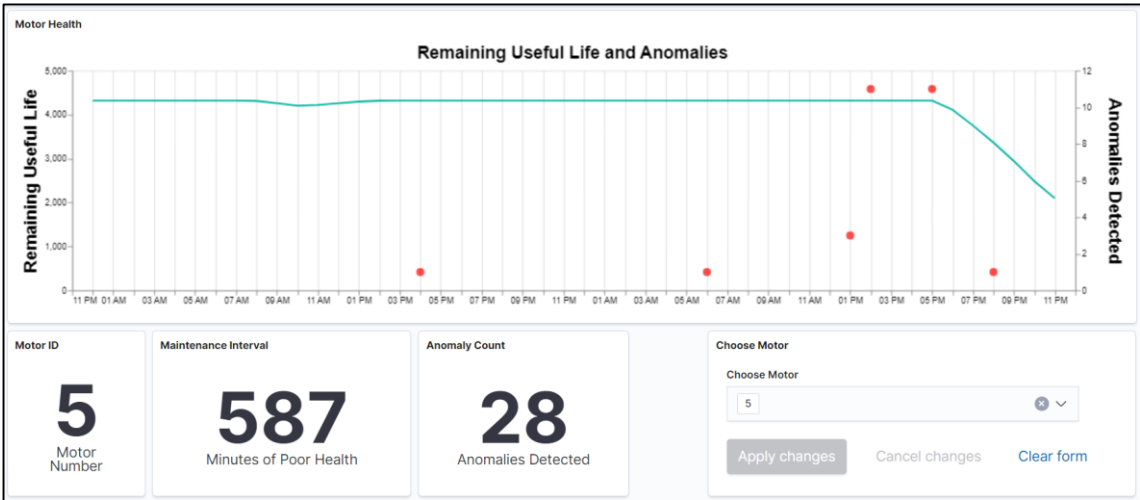
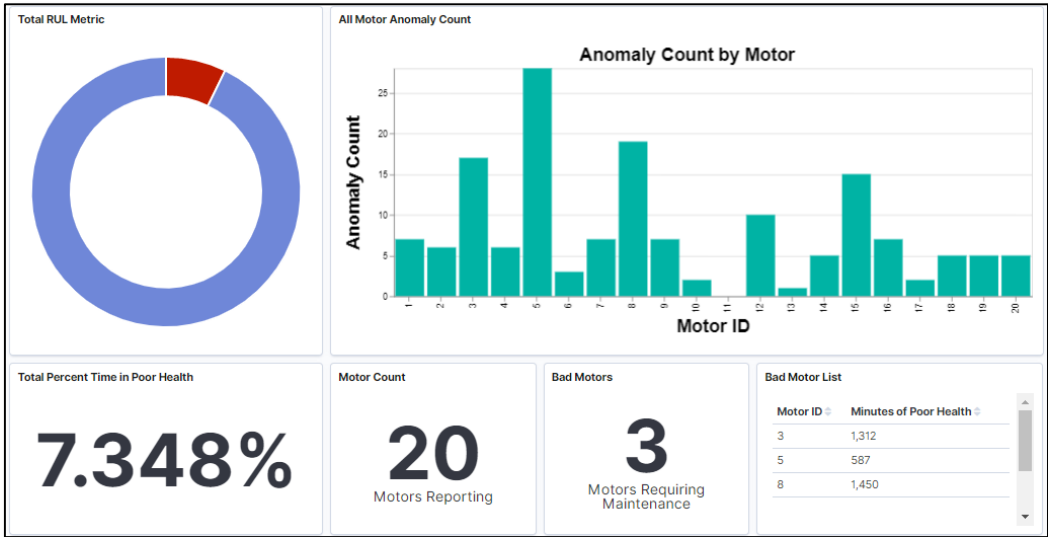
Dashboard Builder

Designs visualization for plant operator

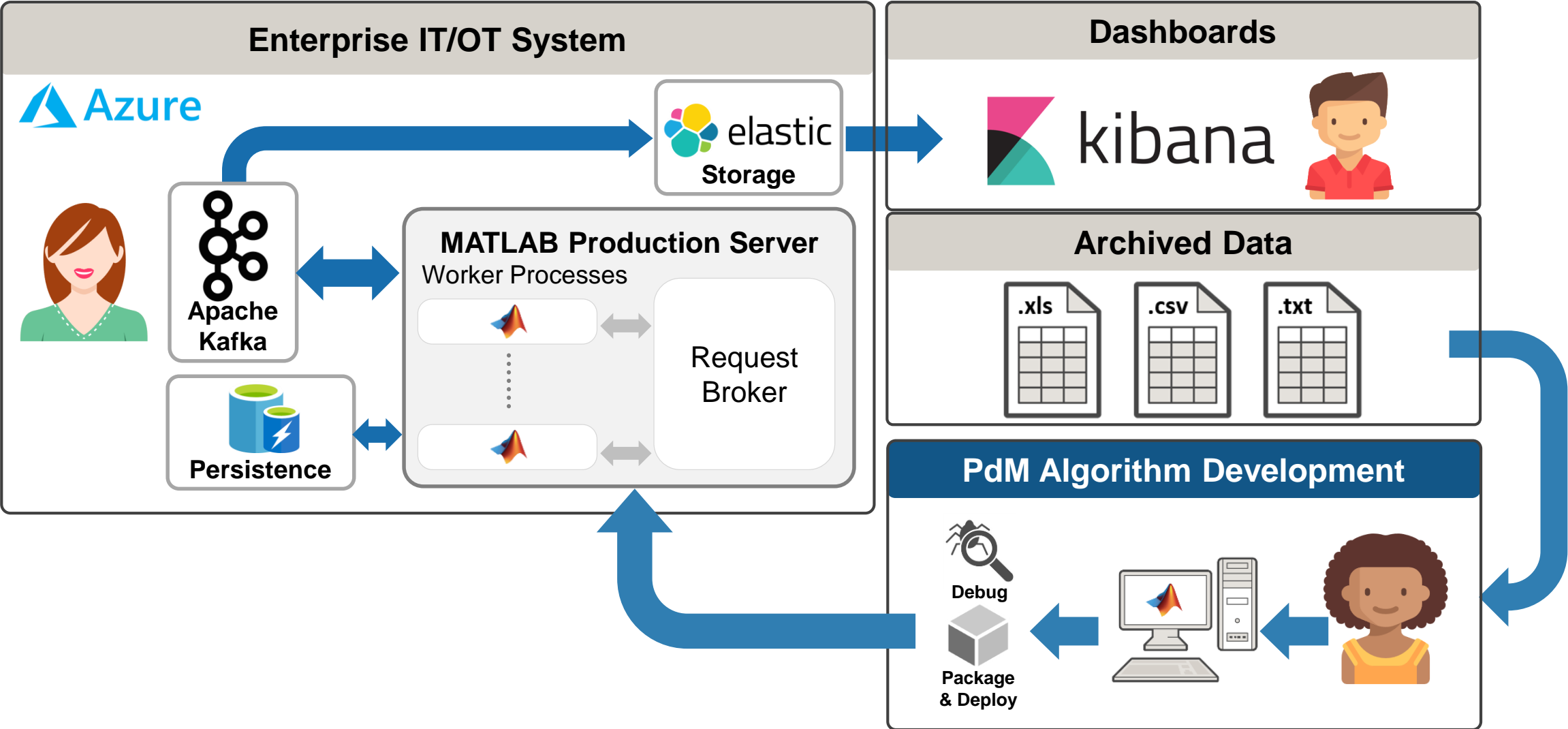


System Architect

Deploys and operationalizes model on Azure cloud



Engineers & Data Scientists Can Package Their Algorithms As Standalone Executables Or Shareable Libraries Using MATLAB



Well Defined Interfaces For Cloud Architectures & One-Click Creation of Cloud-Deployable Applications

The screenshot displays the MATLAB R2019b environment. The main window is titled 'ah-pwebb' and shows the 'EDITOR' tab. The current file is 'remainingMotorLife.m'. The editor contains the following MATLAB code:

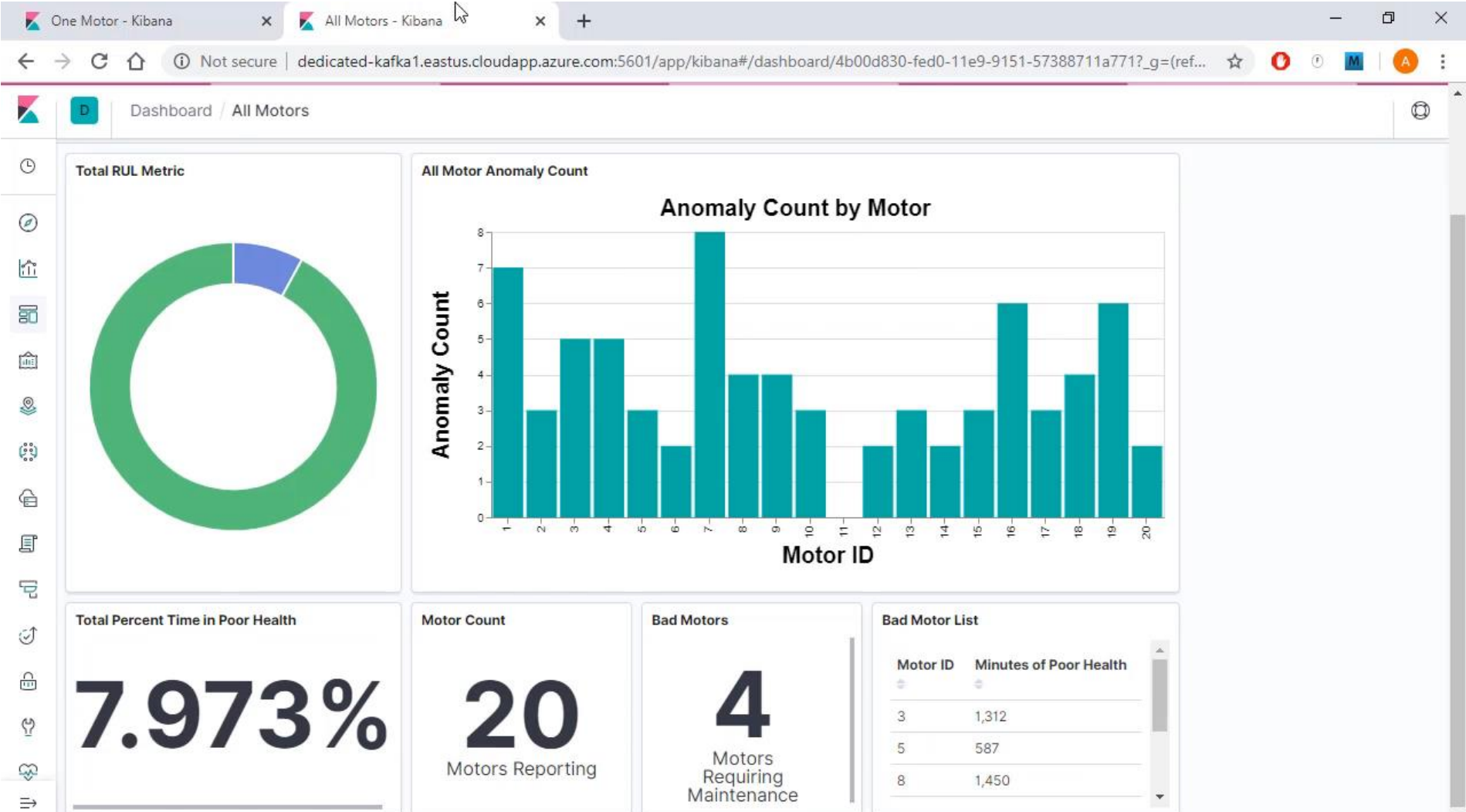
```
1 function [nextModel, results] = remainingMotorLife(tbl, prevModel)
2 %Compute remaining useful life for a given motor. Input
3 %data must be for a single motor.
4
5 % Load the information needed to transform the incoming data,
6 transformData = load('rulHealthIndicatorTransformData');
7
8 % Copy the timestamp column, motor_ts, which we don't use for RUL
9 % calculations. We need to attach it to the results table.
10 ts = tbl.motor_ts;
11
12 % Filter the table columns to extract the features required for RUL.
13 %
14 % Remove all those variables that are not features named in the
15 % transformData.
16 rmvars = setdiff(tbl.Properties.VariableNames, ...
17                 transformData.featureNames);
```

The Command Window shows the following output:

```
>> edgeDevice('PackageMachineMotor', 'producer.properties.azure', 1, 'ManyMotors/Motor1.mat')
Publishing from 1 sources
ManyMotors/Motor1.mat
fx >>
```

The interface includes a 'Current Folder' pane on the left showing a project structure with folders like 'AnomalyDetection' and 'R2019a', and files like 'AnomalyDetection.prj', 'connector.properties', 'consume.m', 'detectAnomaly.m', 'detectAnomalyInputs.json', 'detectAnomalyReview.mlx', 'detectAnomalyTemplate.m', 'initAnomalyData.m', 'kafka.properties', 'kafka-mps-client-start.bat', 'kafka-mps-client-stop.bat', 'make_cache_name.m', 'OneClassSVM.m', and 'streamingConfig.json'. The bottom status bar indicates 'remainingMotorLife' at 'Ln 3 Col 34'. The Windows taskbar at the bottom shows the search bar and system tray with the time '11:30 AM' and date '12/17/2019'.

Integrate MATLAB Analytics For Predictive Maintenance With Your Dashboards & Existing IT/OT Infrastructure



GF Machining Solutions Built Condition Monitoring Dashboards To Visualize Maintenance Needs & Predict Failures

Smart adaptive solutions as process building blocks **+GF+**

DEVELOPMENT
OPERATION
MAINTENANCE

AI brings value across entire manufacturing value chain

7 AI Use in Machine Tools | May 2019 | S. Schurov et al.

Dashboard to visualize maintenance needs **+GF+**

Home / Dashboard

Rate of Normal/Abnormal
Rate Of Normal 100%
Rate Of Abnormal 0%

Residual Life Time
639 days
4 hours
32.16 minutes

50.3%
PROBABILITY OF NORMAL OPERATION
MILL S 400 U

Machine Summary
Mill S 400 U
Serial: 107 109 00 0020
Known As: Mill S 400 U - 2
Software: Mill S 400 U - 2

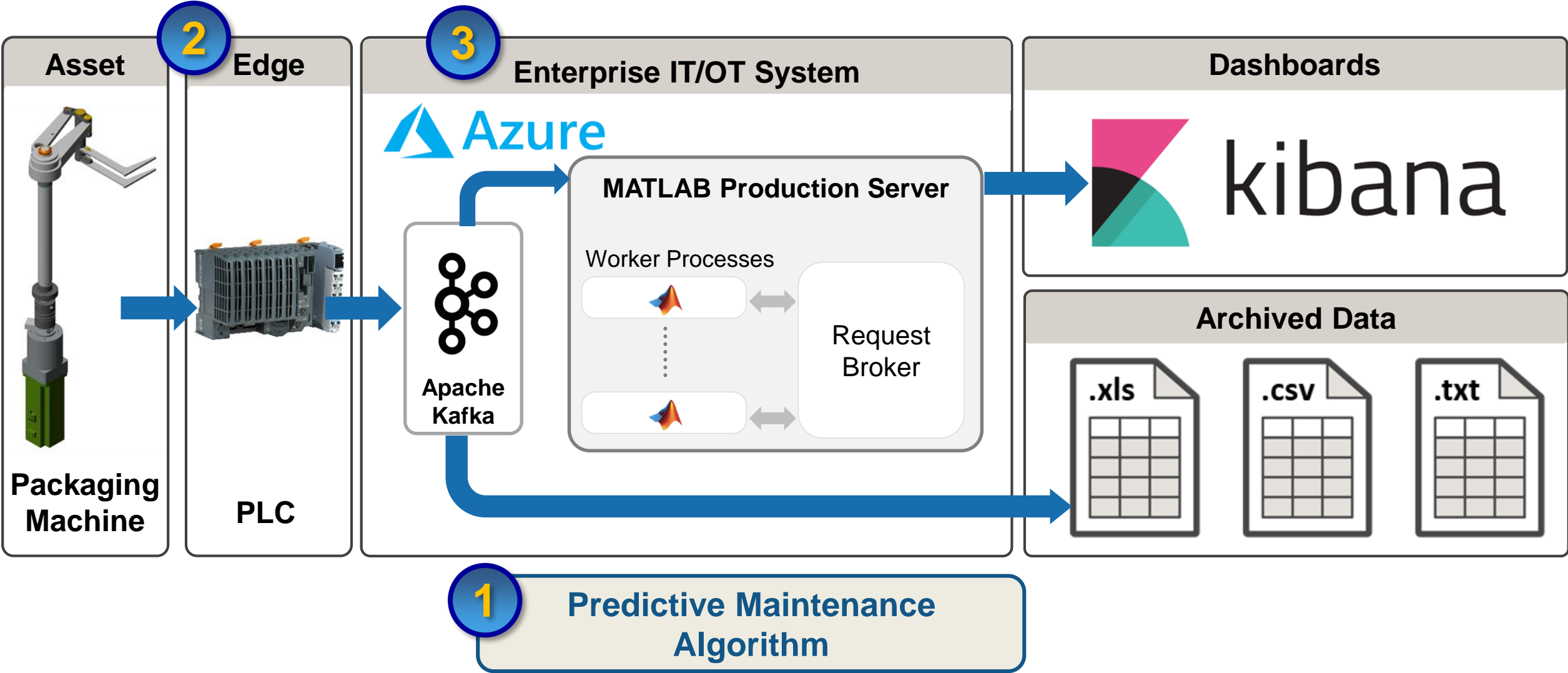
Powered by
+GF+
EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Customer can see maintenance alerts as well as accompanying process data

26 AI Use in Machine Tools | May 2019 | S. Schurov et al.

[MATLAB Expo Talk Link](#)

Today, We Will Demonstrate How To Deploy A Predictive Maintenance Algorithm To The Edge & Enterprise IT/OT Systems



MathWorks can help you get started TODAY

- [Examples](#)
- [Documentation](#)
- Tutorials & Workshops
- [Tech Talk Series](#)

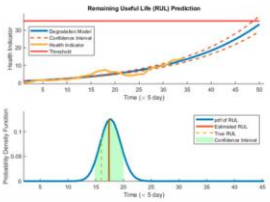
Predictive Maintenance Toolbox NEW PRODUCT

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Overview | Features | Videos

[Trial software](#) [Contact sales](#)

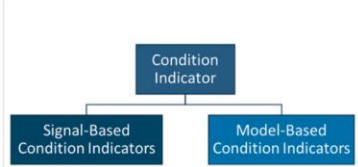
Capabilities



Remaining Useful Life (RUL) Estimation

Use time-series data and lifetime data to forecast RUL and compute confidence intervals.

» [Learn more](#)



Condition Indicator Design

Extract features from sensor data that can be used as inputs to diagnostic and machine learning algorithms.

» [Learn more](#)

```
fileLocation = fullfile('.', 'RollingElementBearingFaultDiagnosis-Data', 'trial');
fileExtension = '.mat';
ensembleData = fileEnsembleDatastore(fileLocation, fileExtension);
ensembleData = initialize(ensembleData);
ensembleDataTable = tall(ensembleData);
```

Data Organization and Labeling

Access and manage data from files stored locally, on the cloud, or in HDFS.

» [Learn more](#)

```
[status,E] = generateSimulationEnsemble(simin,location);
ensemble = simulationEnsembleDatastore(location);
ensembleData = tall(ensemble);
```

Failure Data Generation from Simulink

Create simulation data that is representative of failures and store it automatically in MAT files.

» [Learn more](#)

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- Private customized events



Proven Methods

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- Use of Adult Learning Principles
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- 104% average increase in productivity
- 144% average increase in competence

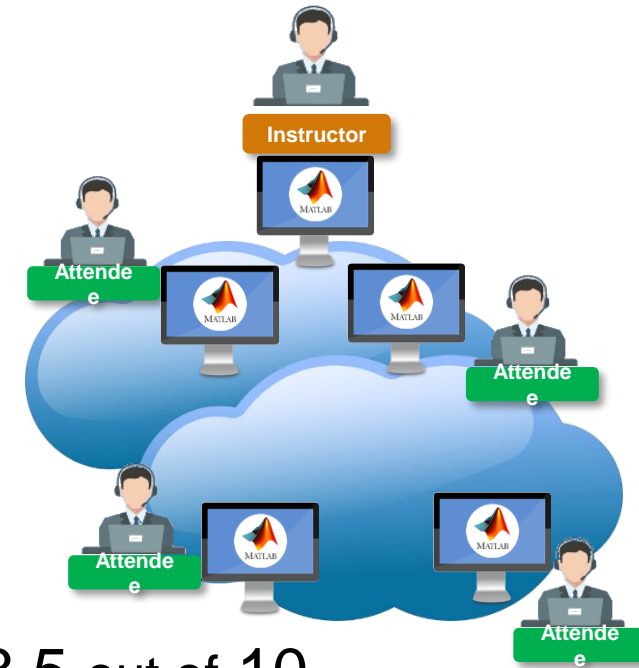


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- Unparalleled products knowledge
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- 96% of attendees recommend to others

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- Virtual classroom provides interactive learning experience
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- Overall customer satisfaction similar to in class training of 8.5 out of 10



“I attended two online trainings hosted by MathWorks. I was impressed with the virtual learning format. The instructor did an outstanding job presenting course material and facilitating attendee understanding.”

Matt Fisher, Ultradent Products, USA

- Consulting – Engineering AI
 - Integration
 - Data analysis/visualization
 - Unify workflows, models, data

Consulting for Predictive Maintenance

<https://www.mathworks.com/services/consulting/proven-solutions/predictive-maintenance.html>

The screenshot shows a web browser window displaying the 'Fleet Data Analysis' application. The page features a navigation bar with 'Fleet Data Analysis', 'Home', 'Summary', 'Cloud Administration', 'Data Administration', and 'Sign out'. A main header section titled 'Fleet Data Analysis' includes a sub-header and a 'Get started >' button. Below this is a 'Welcome back!' message and a 'Fleet Summary' section with 'Start >' and 'Sign Out' buttons. The main content area is divided into three columns: 'Fleet Summary', 'Vehicle Statistics', and 'Forensics'. A large, detailed navigation menu is overlaid on the right side, organized into a grid with categories like 'Requirements', 'Planning', 'Implementation', 'Quality', 'Development', and 'Foundation'. The 'Requirements' section includes 'Non functional requirements', 'Functional requirements', and 'Use Cases'. 'Planning' includes 'Software Design', 'Application Architecture', 'Usability', and 'Migration / Legacy / Integration with other tools'. 'Implementation' includes 'Style guidelines', 'Performance', 'Best Practices', 'Readability / Maintainability', 'Compatibility', and 'Documentation'. 'Quality' includes 'Reviews' (Unit, Functional, System, Acceptance, Etc.) and 'Defect Tracking and Management'. 'Development' includes 'Application Deployment' and 'IT' (Security, Backup and Failover, Data Management, Remote Access, Virtualization, Infrastructure design, Etc.). 'Foundation' includes 'Development Process', 'Configuration Management', 'Project Planning, Management and Measurement', and 'Support and Maintenance'.

Our Solution Addresses Every Challenge By Providing a Workflow That Spans Algorithm Development & Deployment



- Explore and automate feature extraction & machine learning tasks



- Target edge devices through C/C++ codegen
- Integrate with on-premise or cloud-based Enterprise IT/OT systems



- Generate failure data from Simulink & Simscape models of machines



- Get started using Reference Examples
- Work with our Consulting group to scope & define a project

Speaker Details: Amit Doshi

Email: ADoshi@mathworks.com

LinkedIn: <https://www.linkedin.com/in/amit-doshi/>

Share your experience with MATLAB & Simulink
on Social Media:

Use #MATLAB #predictivemaintenance on
LinkedIn

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Attend upcoming webinars:

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webinars/upcoming.html](https://www.mathworks.com/company/events/webinars/upcoming.html)

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Email: info@mathworks.in

Q&A