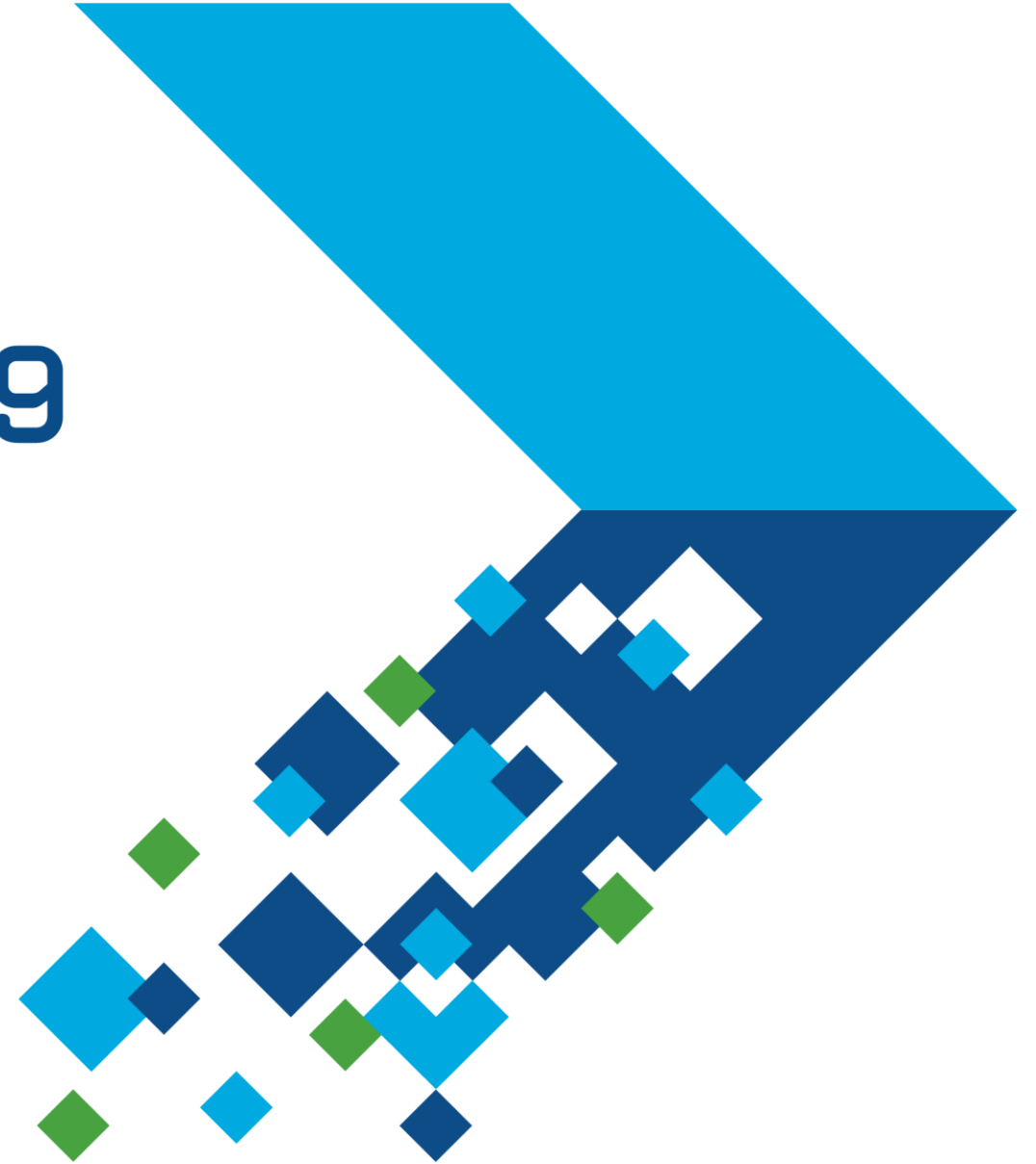


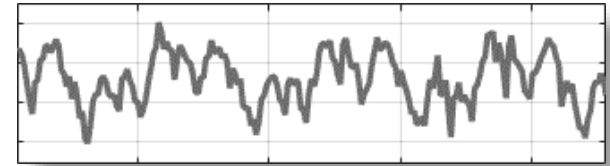
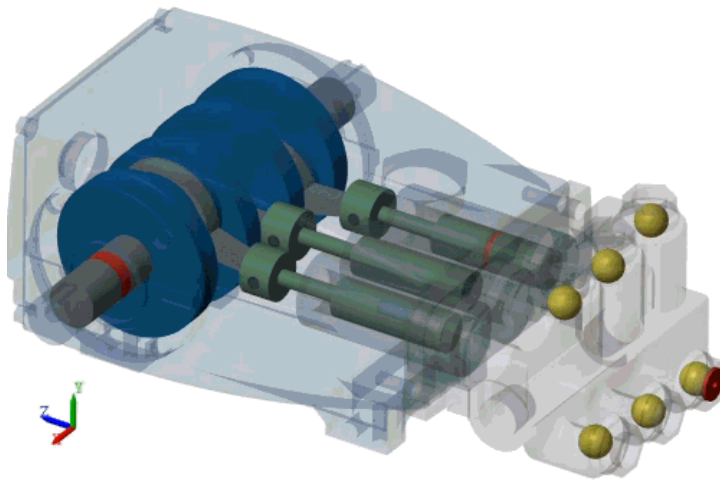
MATLAB EXPO 2019

Manutenzione Predittiva con MATLAB

Francesco Alderisio



What is Predictive Maintenance?





English

Spanish

French

Pump - detected

▼



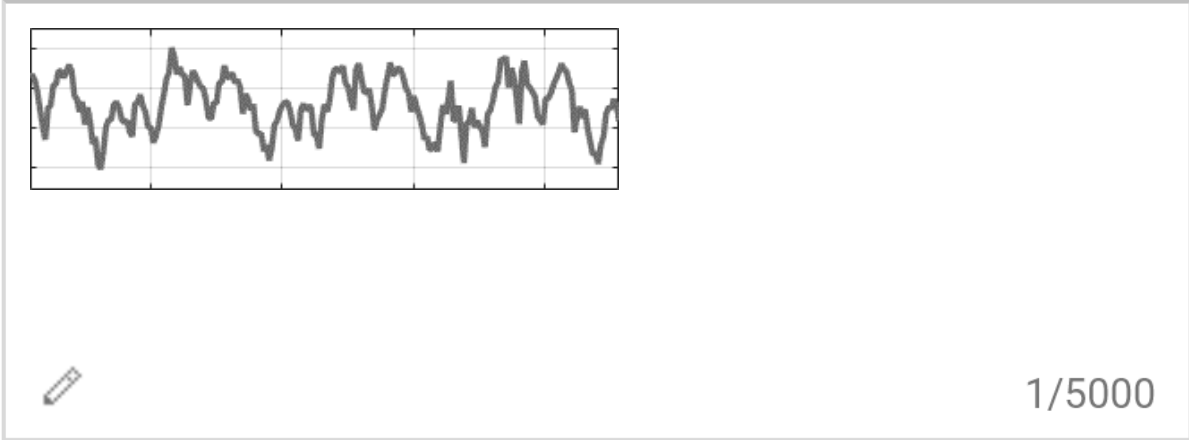
English

Russian


Greek

▼

Translate



I need help.



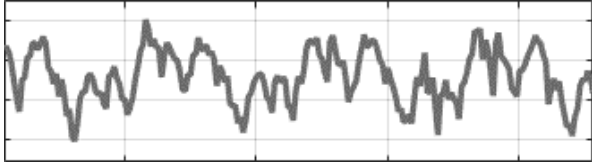


English Spanish French Pump - detected ▼



English Russian Greek ▼

Translate



1/5000

I need help. One of my cylinders is blocked. Your pump might fail in 15 hours

What Does a Predictive Maintenance Algorithm Do?

**Is my machine
operating
normally?**

**Anomaly
Detection**

**Why is my
machine behaving
abnormally?**

**Condition
Monitoring**

**How much longer
can I operate my
machine ?**

**Remaining
Useful Life
Estimation**

I need help.

One of my cylinders is blocked.

Your pump might fail in 15 hours.

Predictive Maintenance Toolbox for Developing Algorithms

**Is my machine
operating
normally?**

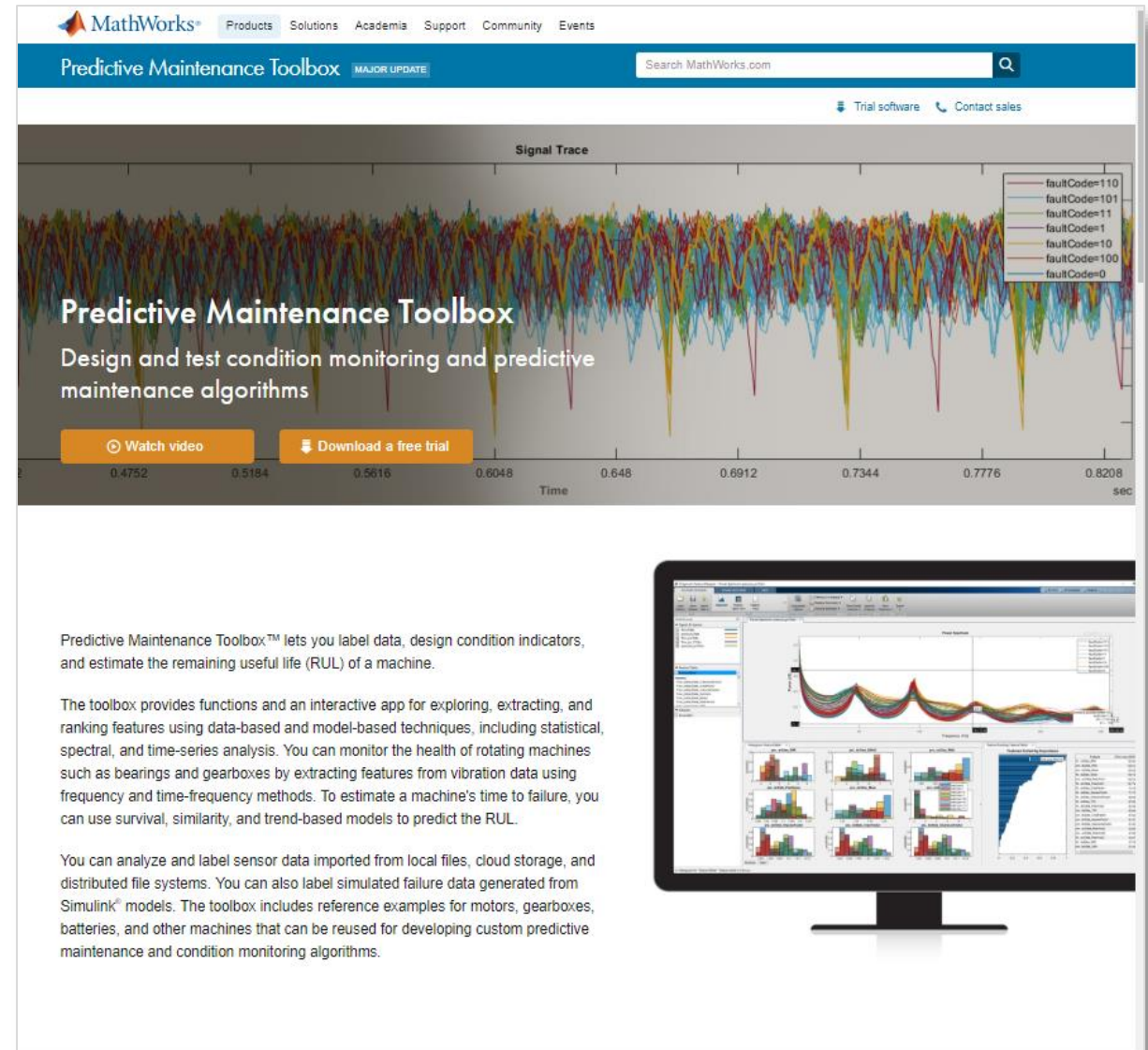
**Anomaly
Detection**

**Why is my
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**Condition
Monitoring**

**How much longer
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**Remaining
Useful Life
Estimation**



The screenshot shows the MathWorks Predictive Maintenance Toolbox website. The header includes the MathWorks logo and navigation links: Products, Solutions, Academia, Support, Community, Events. Below the header, the title "Predictive Maintenance Toolbox" is displayed with a "MAJOR UPDATE" badge. A search bar is on the right. The main content area features a "Signal Trace" plot showing multiple colored lines representing different fault codes over time. The plot is titled "Signal Trace" and has a legend on the right listing fault codes: faultCode=110, faultCode=101, faultCode=11, faultCode=1, faultCode=10, faultCode=100, and faultCode=0. Below the plot, the text "Predictive Maintenance Toolbox" is followed by "Design and test condition monitoring and predictive maintenance algorithms". Two buttons are present: "Watch video" and "Download a free trial".

Below the website screenshot, a computer monitor displays a software interface with various plots and charts, including a large line plot and several smaller bar and area charts, representing the analysis results of the toolbox.

Predictive Maintenance Toolbox™ lets you label data, design condition indicators, and estimate the remaining useful life (RUL) of a machine.

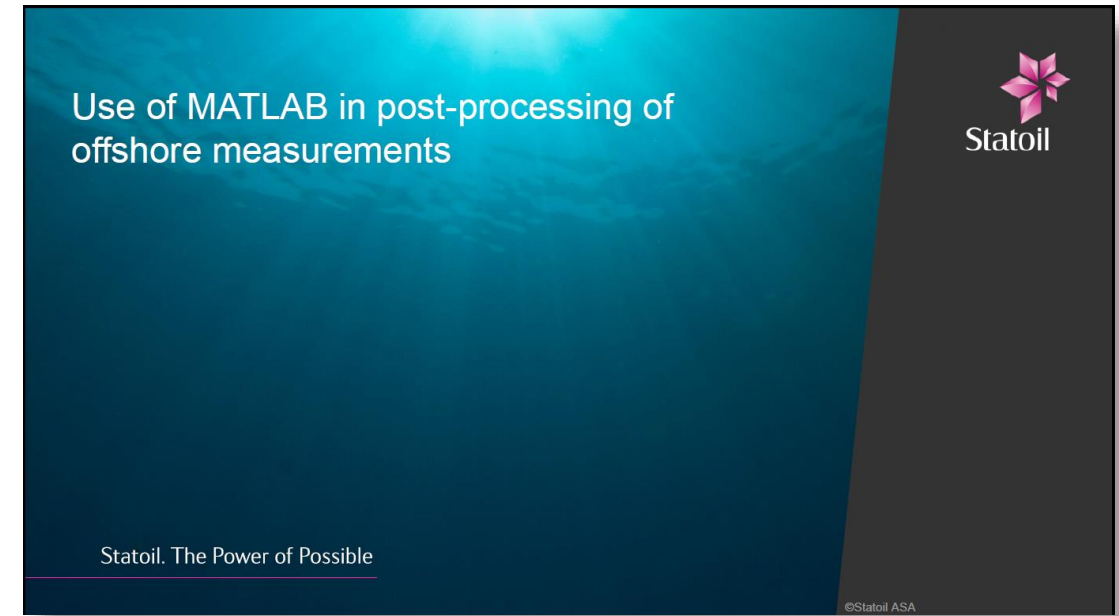
The toolbox provides functions and an interactive app for exploring, extracting, and ranking features using data-based and model-based techniques, including statistical, spectral, and time-series analysis. You can monitor the health of rotating machines such as bearings and gearboxes by extracting features from vibration data using frequency and time-frequency methods. To estimate a machine's time to failure, you can use survival, similarity, and trend-based models to predict the RUL.

You can analyze and label sensor data imported from local files, cloud storage, and distributed file systems. You can also label simulated failure data generated from Simulink® models. The toolbox includes reference examples for motors, gearboxes, batteries, and other machines that can be reused for developing custom predictive maintenance and condition monitoring algorithms.

How are MathWorks Tools Used for Predictive Maintenance?



“...Subject Matter Expert Familiarity...”



“... [MATLAB is] Popular across the company...”

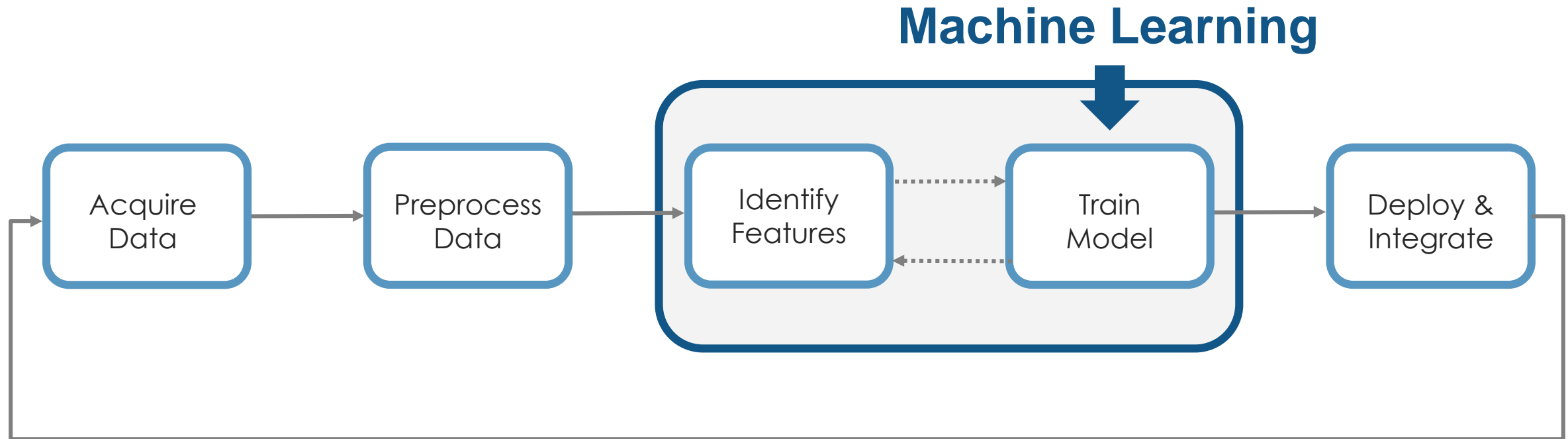


Mercedes-Benz



BOSCH

Workflow for Developing a Predictive Maintenance Algorithm

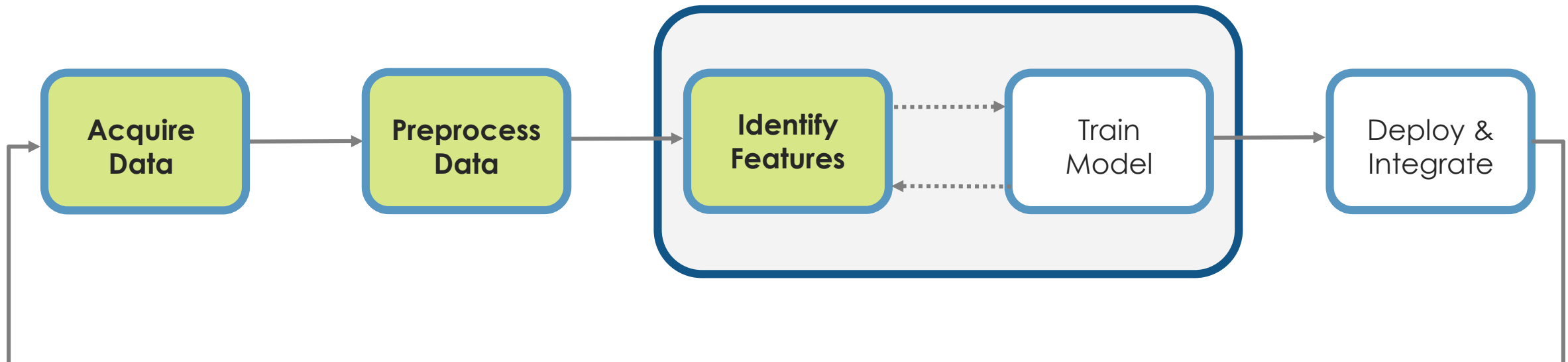


Why MATLAB & Simulink for Predictive Maintenance

- Reduce the amount of data you need to store and transmit
- Explore approaches to feature extraction and predictive modeling
- Deliver the results of your analytics based on your audience
- Get started quickly...especially if you are an engineer

Why MATLAB & Simulink for Predictive Maintenance

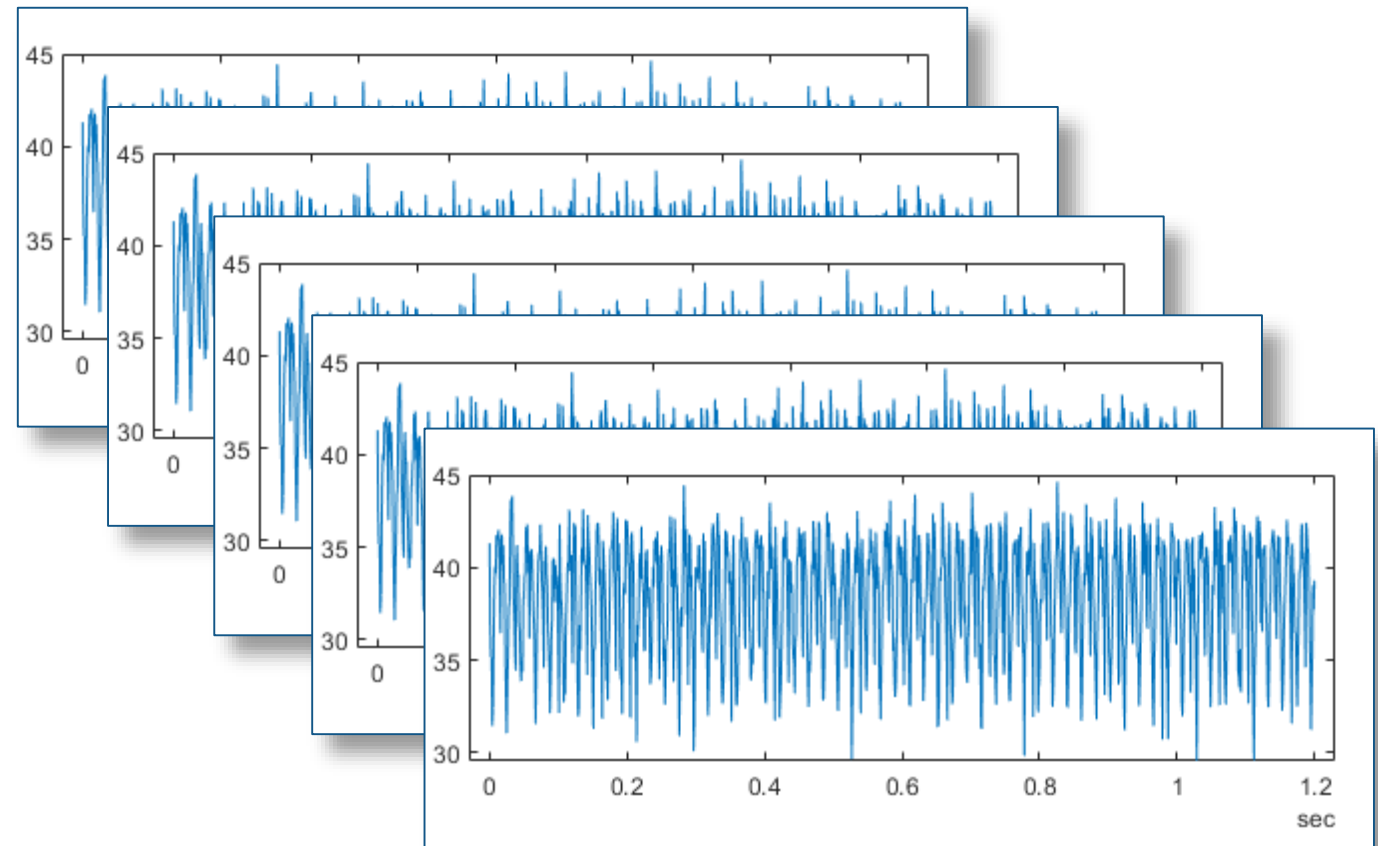
- **Reduce the amount of data you need to store and transmit**
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Challenges: How do you make sense of the ALL the data being collected?

- 1 day ~ 1.3 GB
- 20 sensors/pump ~26 GB/day
- 3 pumps ~ 78 GB/day
- Satellite transmission
 - Speeds approx. 128-150 kbps,
 - Cost \$1,000/ 10GB of data
- Needle in a haystack problem

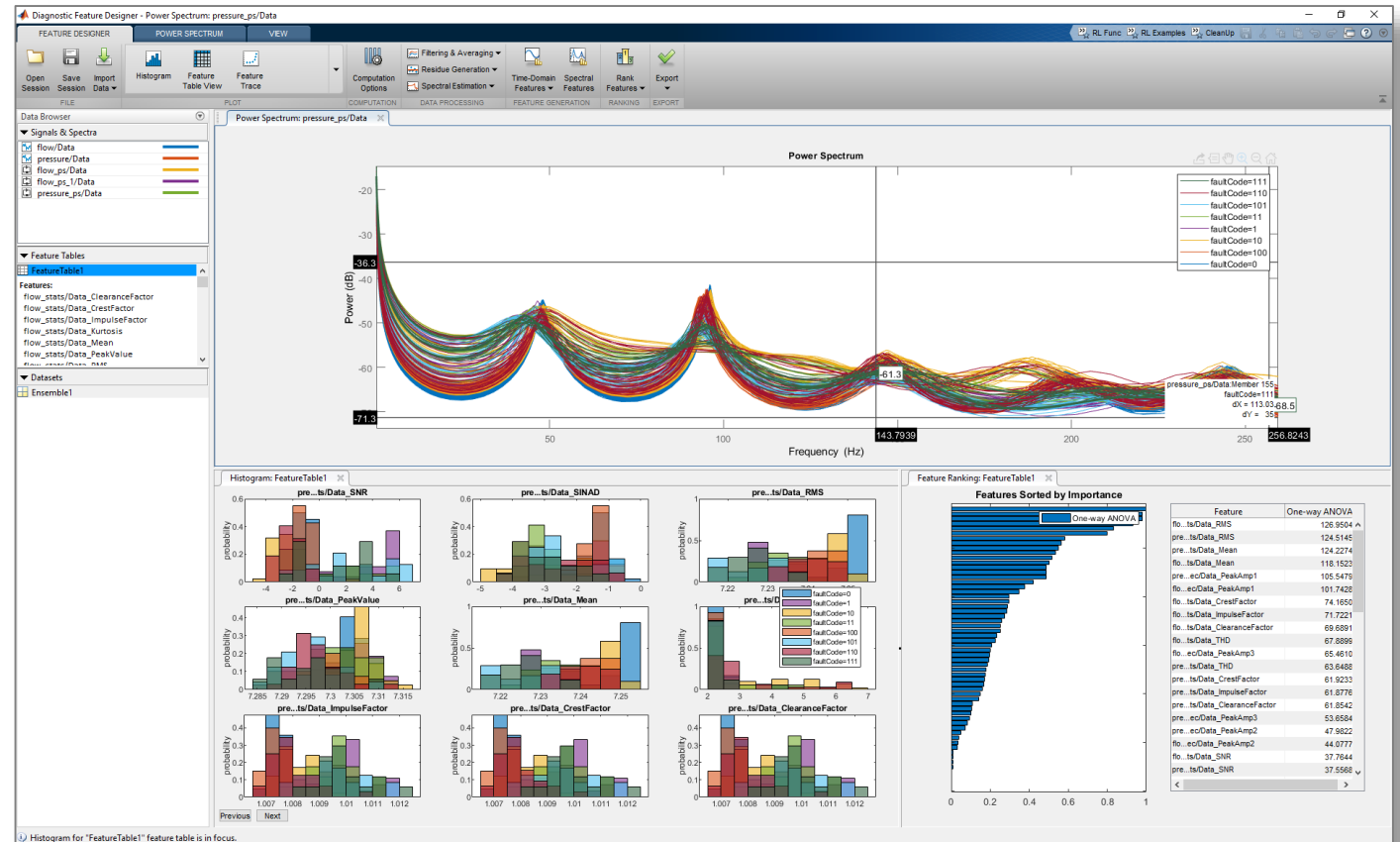
Pump flow sensor 1 sec ~ 1000 samples ~16kB



Diagnostic Feature Designer App

Predictive Maintenance Toolbox R2018b & R2019a

- Extract, visualize, and rank features from sensor data
- Use both statistical and dynamic modeling methods
- Work with out-of-memory data
- Explore and discover techniques without writing MATLAB code



FEATURE DESIGNER

SIGNAL TRACE VIEW

Open Session Save Session Import Data

Signal Trace

Computation Options

Filtering & Averaging
Residue Generation
Spectral Estimation

Time-Domain Features
Spectral Features
Rank Features
Export

FILE PLOT COMPUTATION DATA PROCESSING FEATURE GENERATION RANKING EXPORT

Data Browser

▼ Signals & Spectra

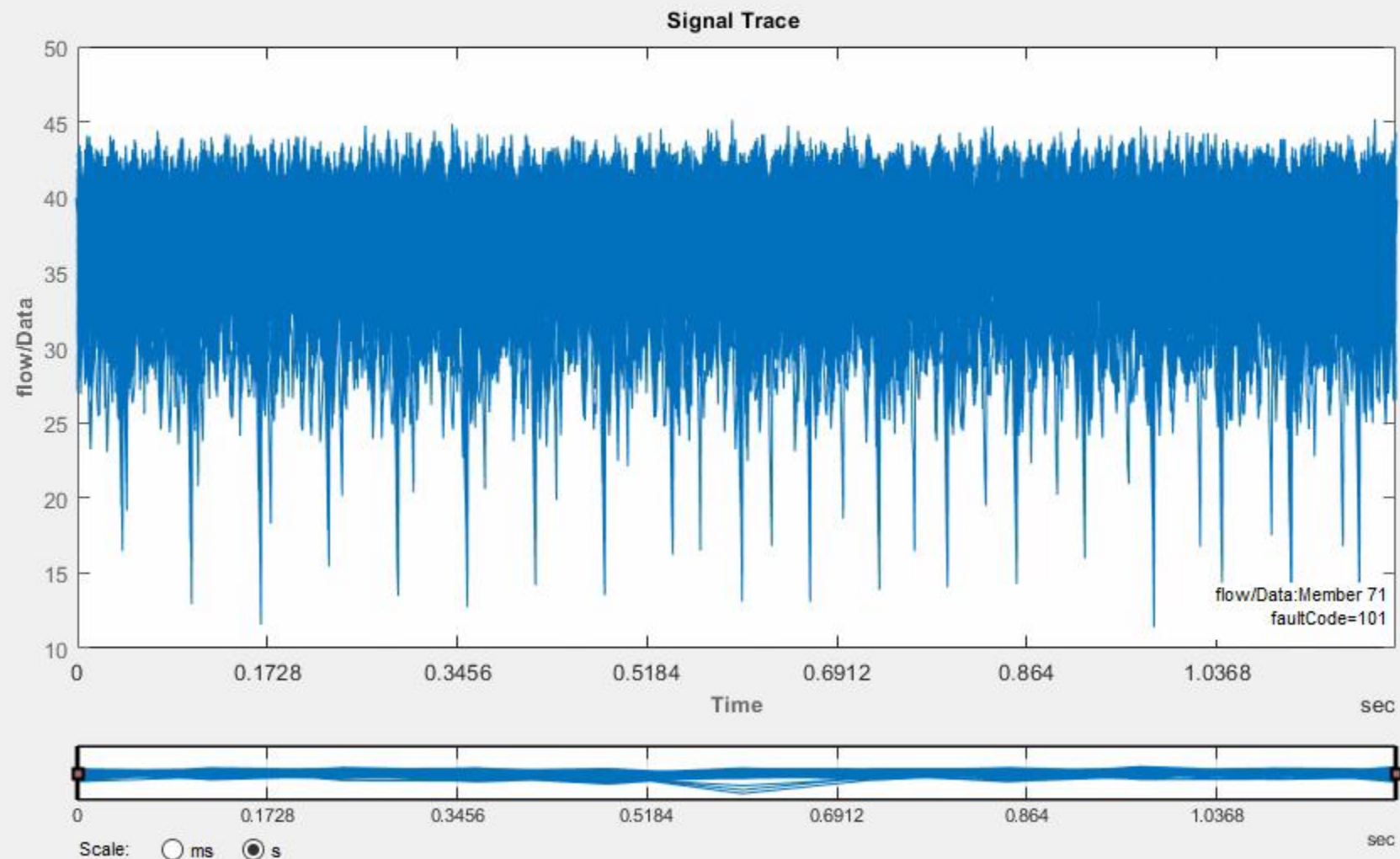
flow/Data
pressure/Data

▼ Feature Tables

▼ Datasets

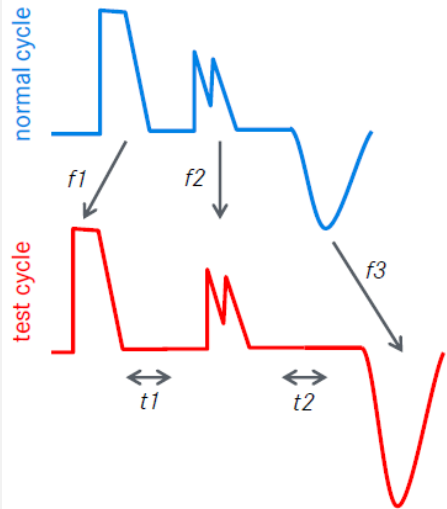
Ensemble1

Signal Trace: flow/Data



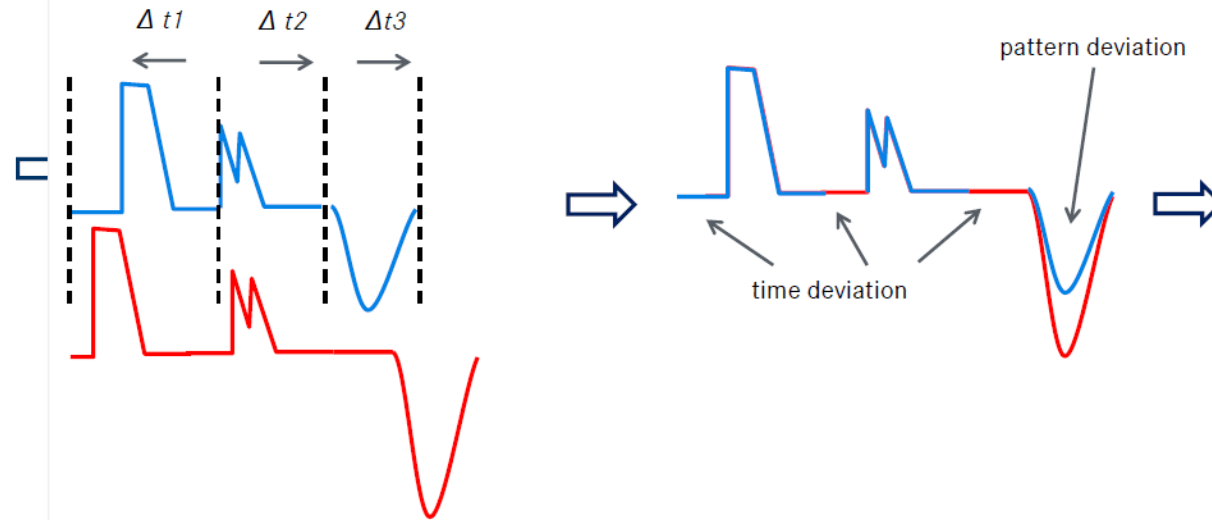
Daimler are Using MATLAB Today for Anomaly Detection

Algorithm principle



- Cycle can be described as sequence features $f1$, $f2$, $f3$
- Each cycle can show some delays in time $t1$, $t2$

Algorithm principle



- Pattern matching through shift of feature along time axis ($\Delta t1$, $\Delta t2$, $\Delta t3$): minimization of SRS

- Description of a cycle as feature sequence
- For each feature time and pattern deviation can be calculated

$f1$	$f2$	$f3$	
$\Delta t1$	$\Delta t2$	$\Delta t3$	Time deviation
No	No	Yes	Pattern deviation

- Time and pattern deviation for each feature are used as characteristic numbers for test cycle

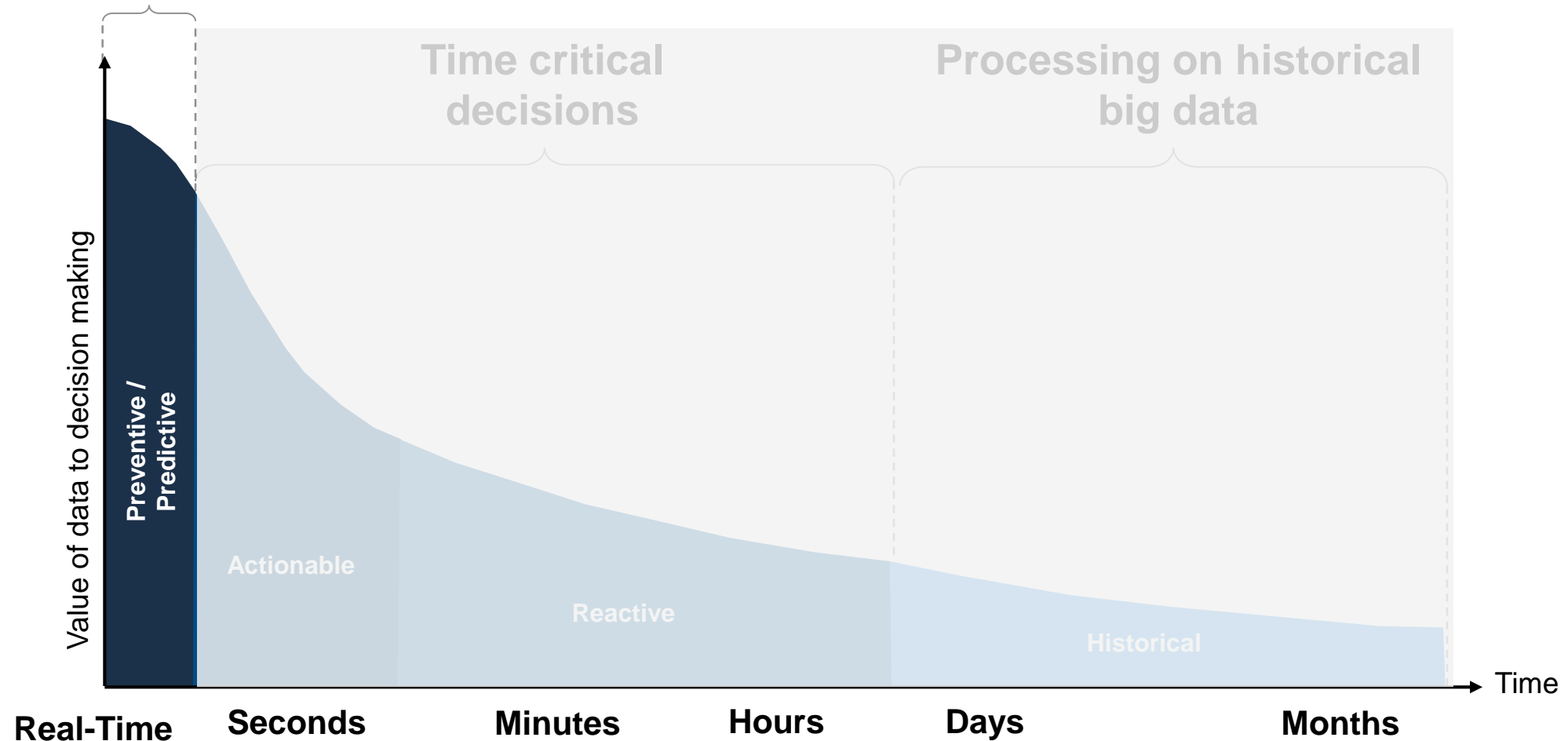


Data reduction!

Data reduction of time series by a factor of **250x** without a significant loss of information

Value of the Data v/s How Old is the Data

Near real-time decisions



MATLAB R2018a

HOME PLOTS APPS EDITOR PUBLISH VIEW

File Edit Breakpoints Run

Current Folder: C:\Users\abaru\Desktop\Expo 2018\FinalDemo\Demo_Files\Data_Reduction

Editor: C:\Users\abaru\Desktop\Expo 2018\FinalDemo\Demo_Files\Data_Reduction\featureExtractionBuffer.m

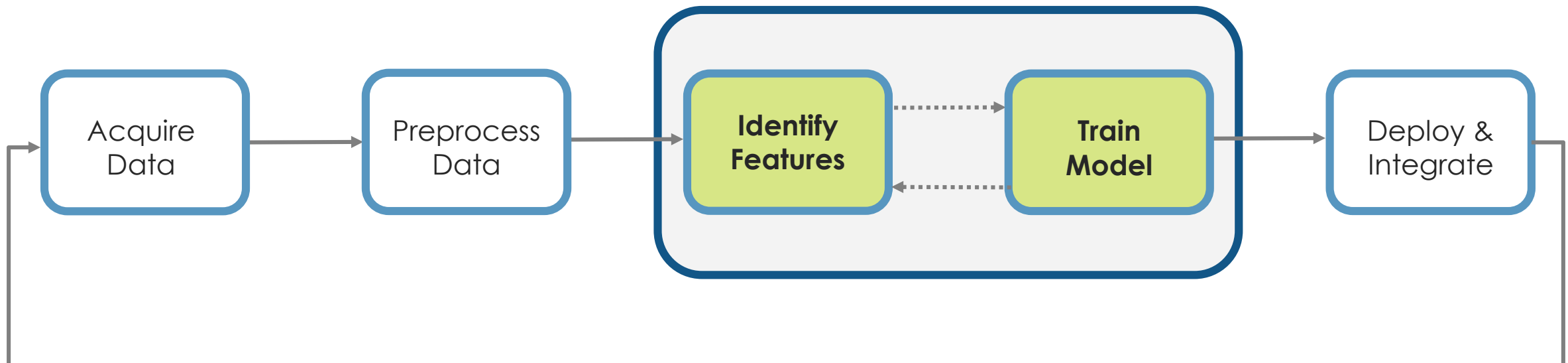
```
1 function [feature_list] = featureExtractionBuffer(data,timestamp)
2
3 persistent flow_array
4 persistent time_array
5 Np = 1000;
6
7 if isempty(flow_array)
8     flow_array = nan(Np,1);
9 end
10
11 if isempty(time_array)
12     time_array = nan(Np,1);
13 end
14
15 flow_array = [data; flow_array(1:Np-1)];
16 data = flow_array;
17
18 time_array = [timestamp; time_array(1:Np-1)];
19 timestamp = time_array;
20
21
22 if isempty(find(isnan(data),1))
23
24     flow = data;
25
26     % Ensure the flow is sampled at a uniform sample rate
27     t_flow = timestamp;
```

featureExtractionBuffer (Function)

featureExtractionBuffer Ln 17 Col 1

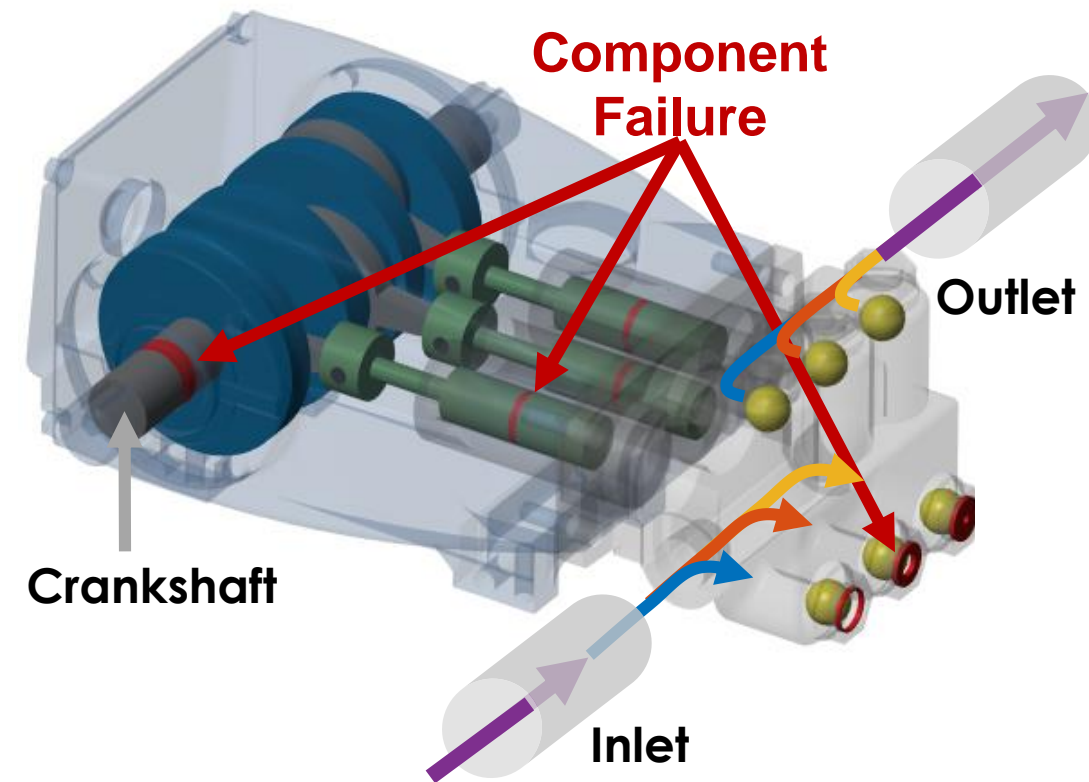
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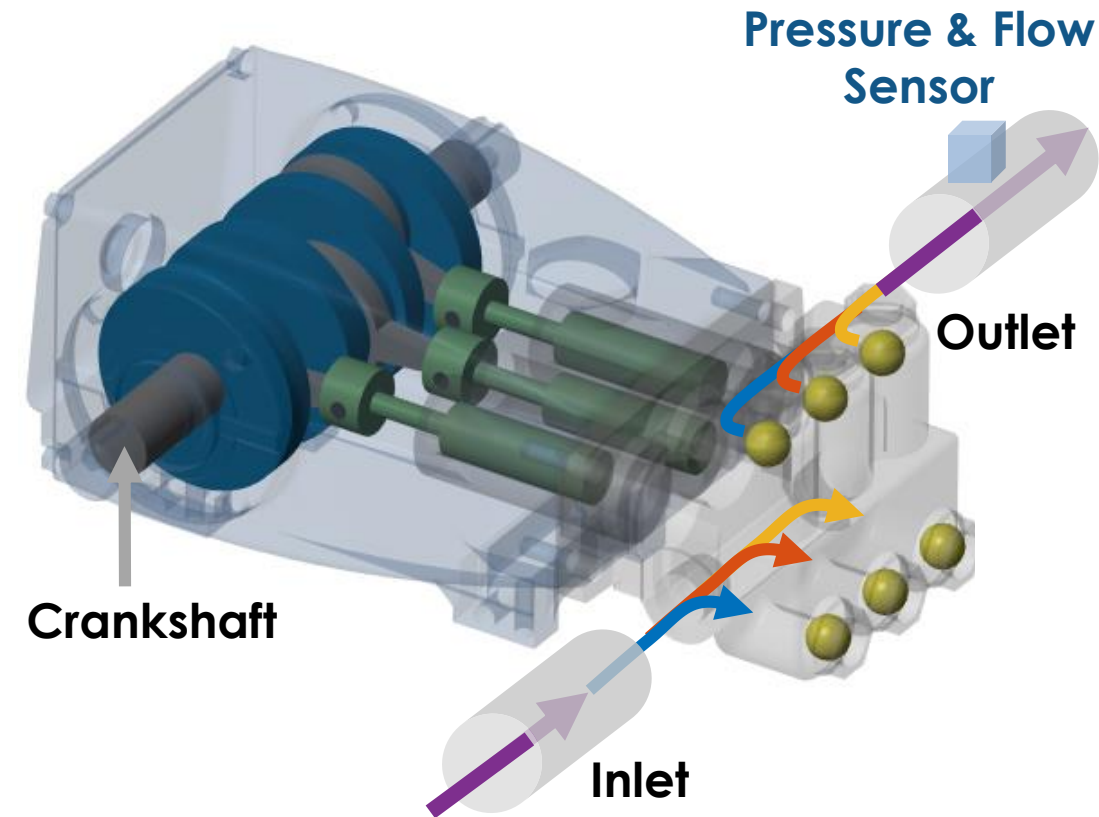
Fault Classification Algorithms Allow You to Identify the Root Cause of Anomalous Behavior

- Three-phase pump commonly used for drilling and servicing oil wells
 - Three plungers try to ensure a uniform flow
- Condition monitoring to detect:
 - Seal leak
 - Inlet blockage
 - Bearing degradation



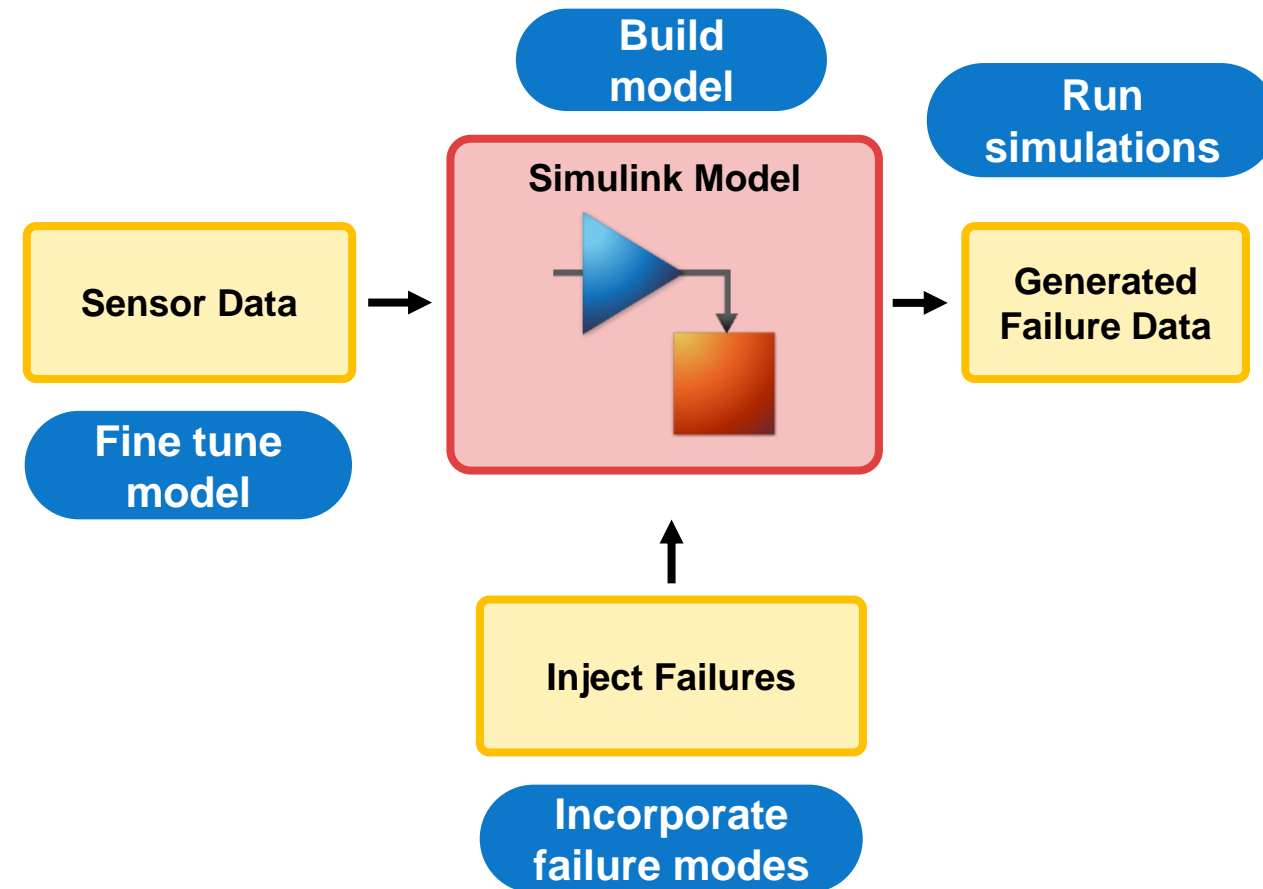
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 - Three plungers try to ensure a uniform flow
- Condition monitoring to detect:
 - Seal leak
 - Inlet blockage
 - Bearing degradation
- Identify fault present in system using **only** pressure and flow sensor data



Generate Synthetic Failure Data from Simulink Models if Real Failure Data is Unavailable

- Model failure modes
 - Work with domain experts and the data available
 - Vary model parameters or components
- Customize a generic model to a specific machine
 - Fine tune models based on real data
 - Validate performance of tuned model



FEATURE DESIGNER | SIGNAL TRACE | VIEW

Open Session | Save Session | Import Data

Select data to plot

Signal Trace | Power Spectrum | Order Spectrum | Histogram

Computation Options

Filtering & Averaging | Residue Generation | Spectral Estimation

Time-Domain Features | Spectral Features | Rank Features | Export

FILE | PLOT | COMPUTATION | DATA PROCESSING | FEATURE GENERATION | RANKING | EXPORT

Data Browser

▼ Signals & Spectra

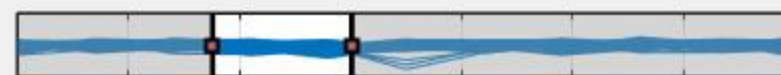
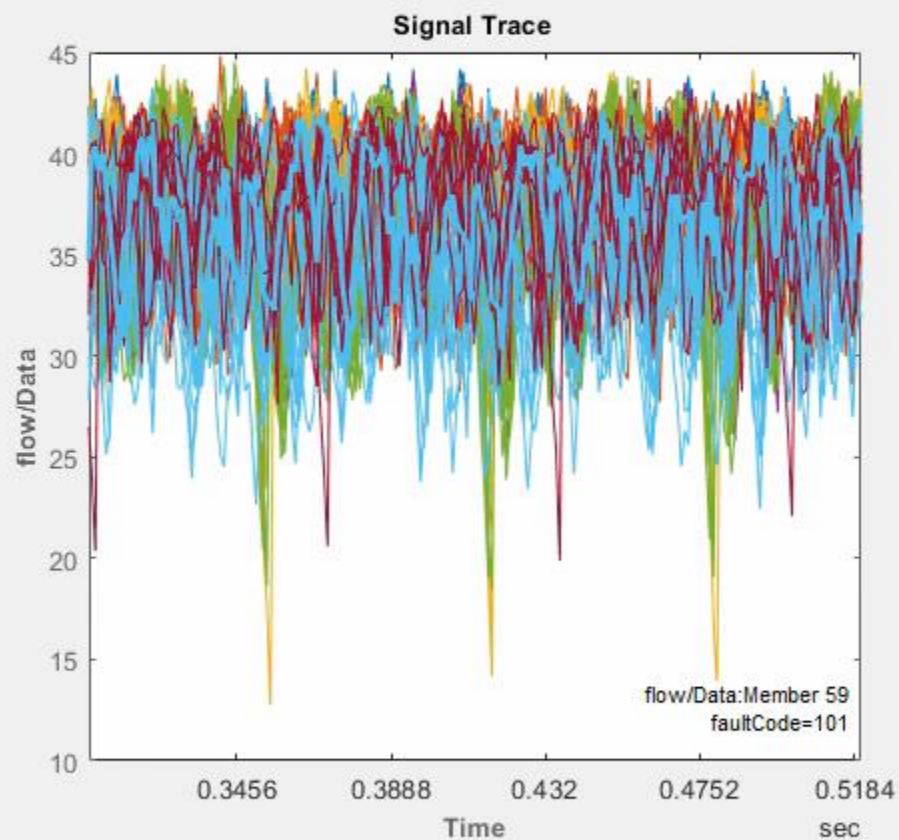
- flow/Data
- pressure/Data
- flow_ps/Data

▼ Feature Tables

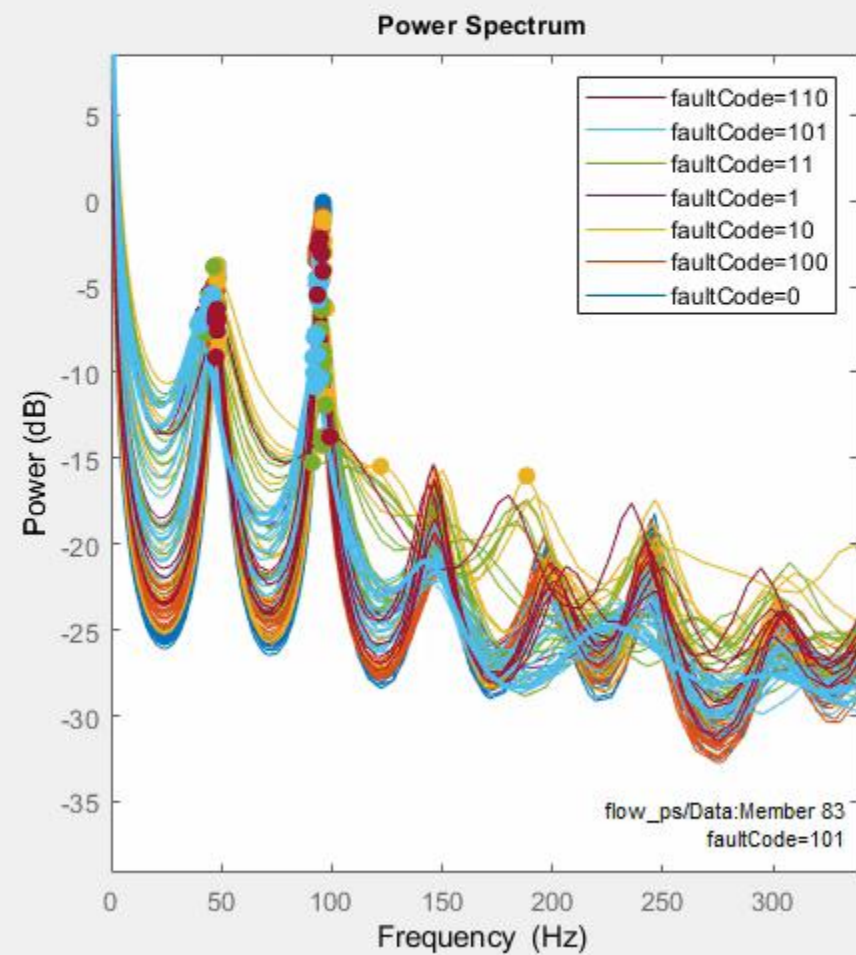
▼ Datasets

- Ensemble1

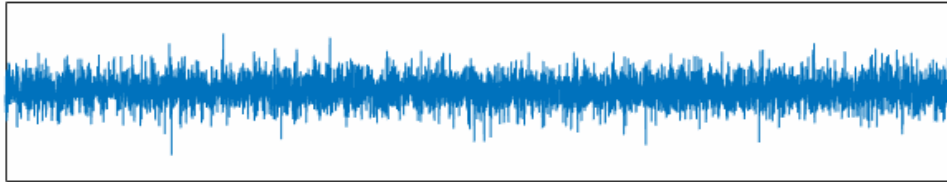
Signal Trace: flow/Data

Scale: ☐ ms ☒ s

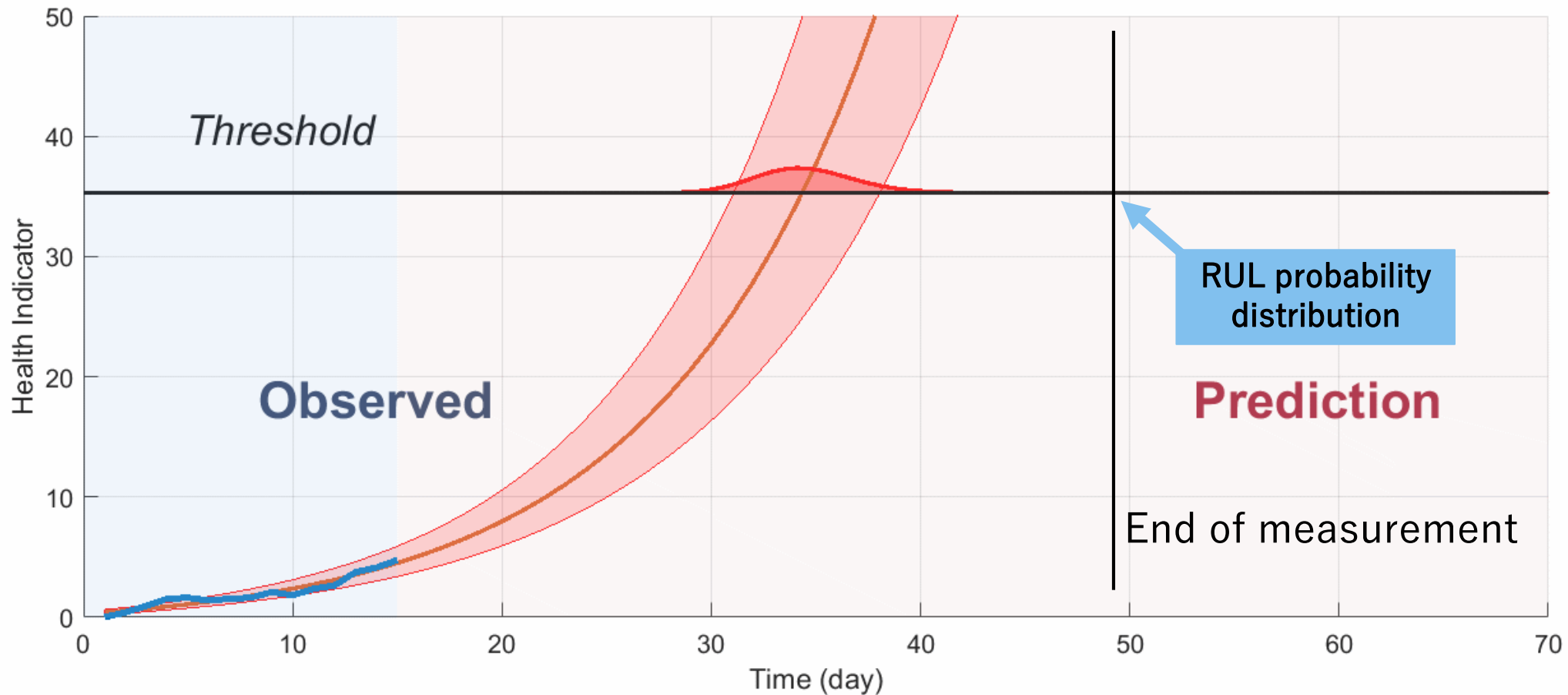
Power Spectrum: flow_ps/Data



Estimate Remaining Useful (RUL) to Determine When You Should Perform Maintenance



RUL: 459 hours
(95%CI: 374-558 hours)



Baker Hughes Develops Predictive Maintenance Software for Gas and Oil Extraction

Challenge

Develop a predictive maintenance system to reduce pump equipment costs and downtime

Solution

Use MATLAB to analyze nearly one terabyte of data and create a machine learning model that can predict failures before they occur

Results

- Savings of more than \$10 million projected
- Development time reduced tenfold
- Multiple types of data easily accessed



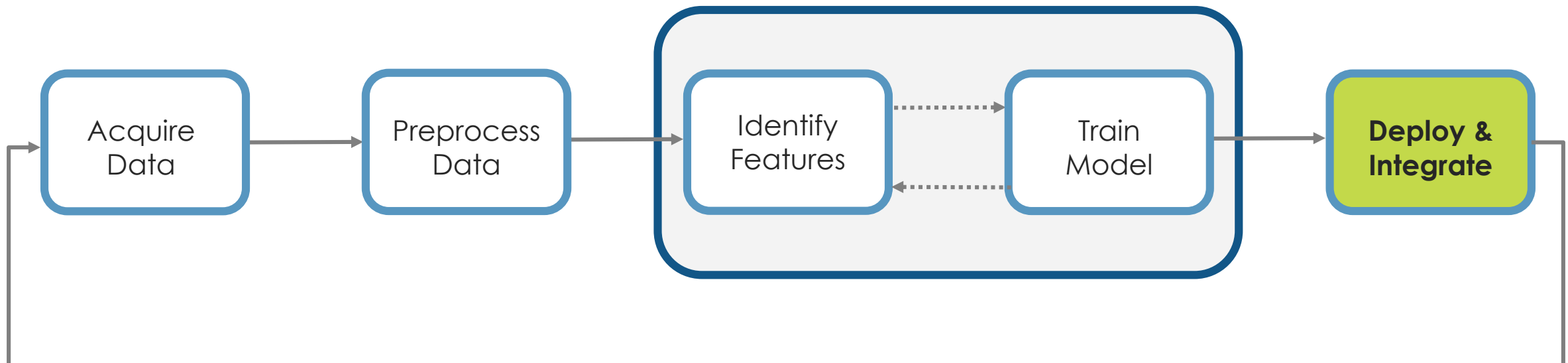
Truck with positive displacement pump.

“MATLAB gave us the ability to convert previously unreadable data into a usable format; automate filtering, spectral analysis, and transform steps for multiple trucks and regions; and ultimately, apply machine learning techniques in real time to predict the ideal time to perform maintenance.”

- Gulshan Singh, Baker Hughes

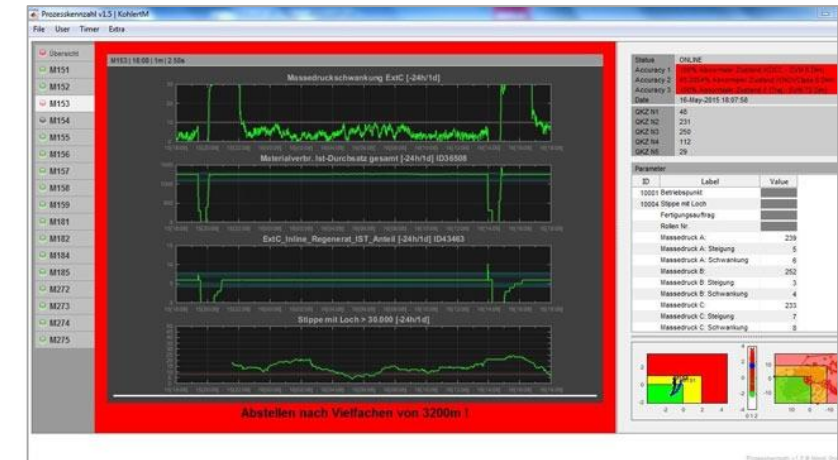
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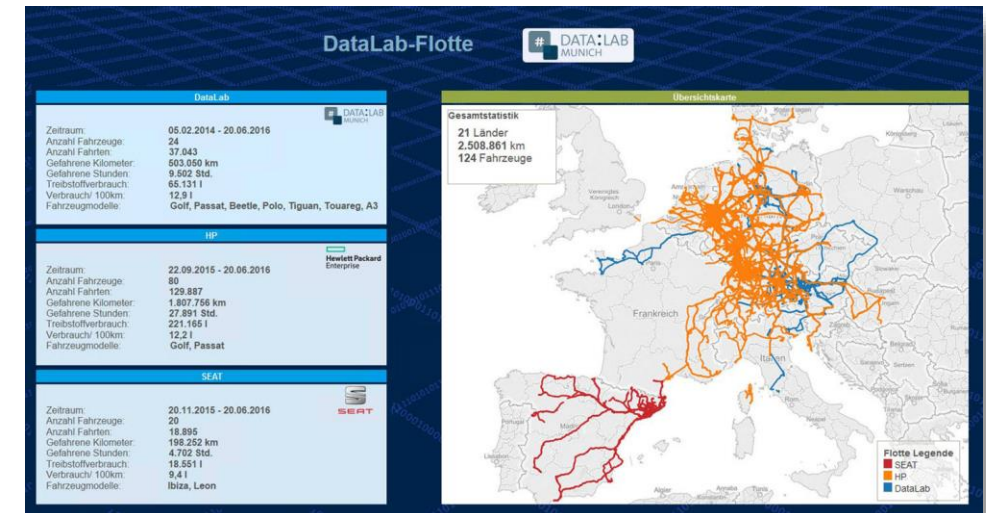


Challenges: Delivering results to your end users

- Maintenance needs simple, quick information
 - Hand held devices, Alarms
- Operations needs a birds-eye view
 - Integration with IT & OT systems
- Customers expect easy to digest information
 - Automated reports

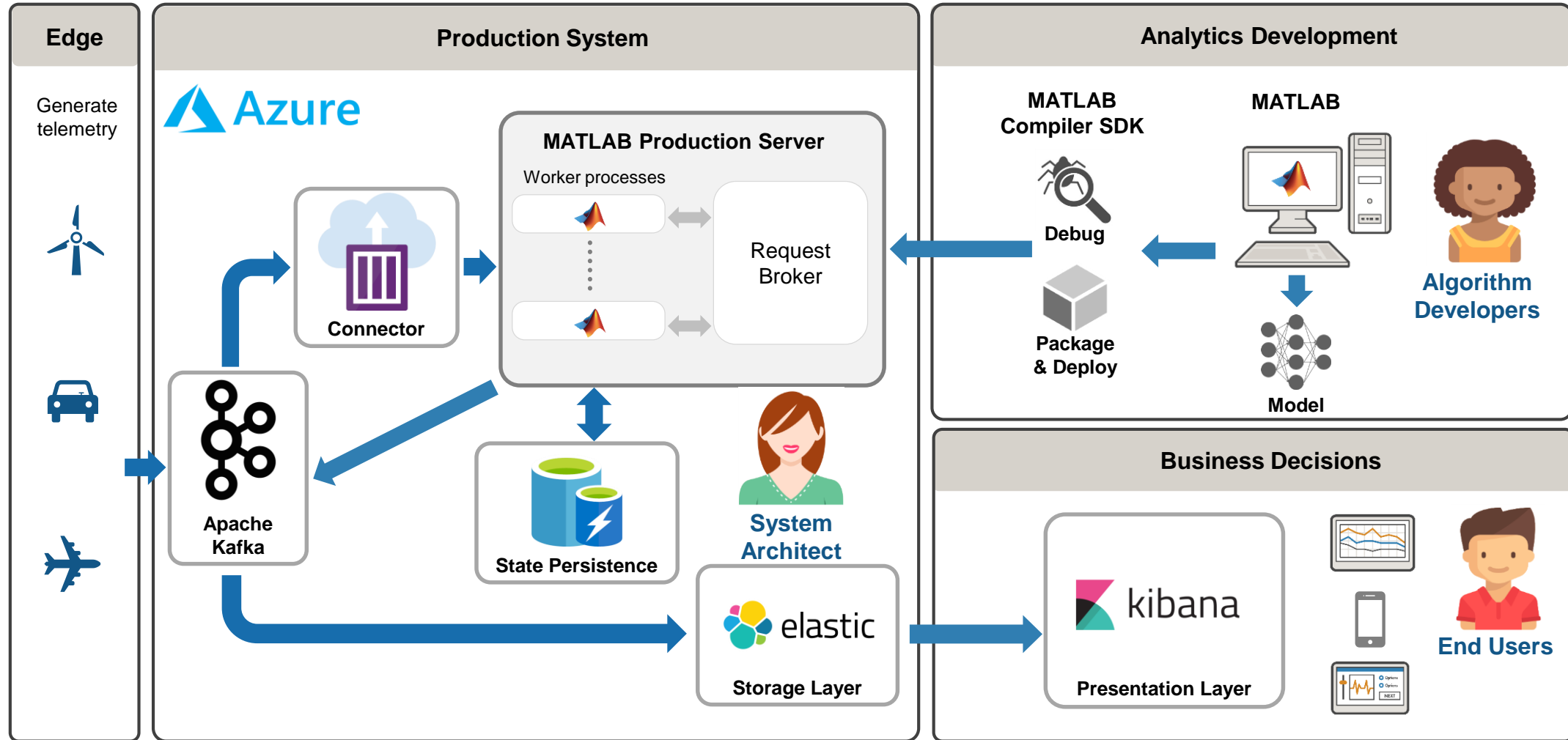


Dashboards

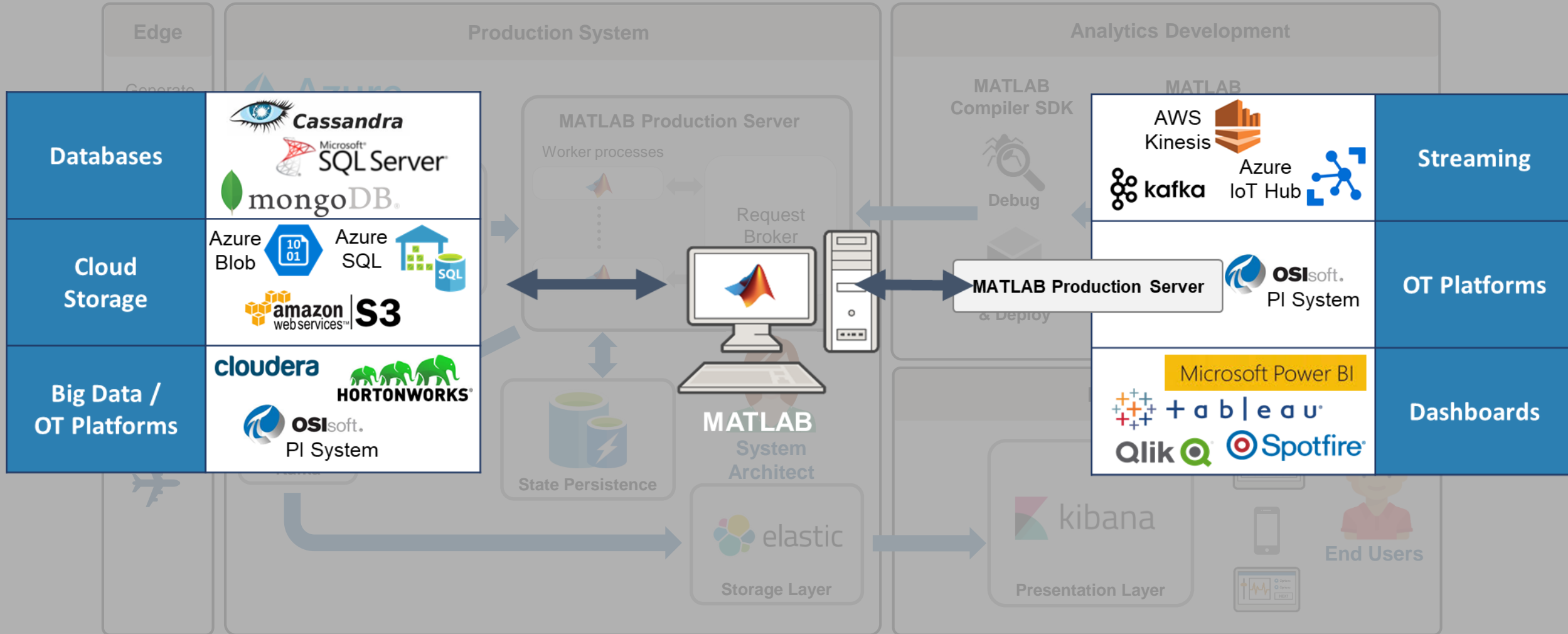


Fleet & Inventory Analysis

Predictive Maintenance Architecture on Azure



Predictive Maintenance Architecture on Azure



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MathWorks can help you get started TODAY

- Documentation & Examples
- Workshops
- Training
- Consulting
- ... Booth !

Documentation
All
More
Search Help

CONTENTS

Predictive Maintenance Toolbox

Design and test condition monitoring and predictive maintenance algorithms

Predictive Maintenance Toolbox™ lets you label data and estimate the remaining useful life (RUL) of a machine. The toolbox provides functions and an interactive app for ranking features using data-based and model-based methods, such as spectral, and time-series analysis. You can monitor machines such as bearings and gearboxes by extracting features using frequency and time-frequency methods. To estimate RUL, you can use survival, similarity, and trend-based models.

You can analyze and label sensor data imported from distributed file systems. You can also label simulated Simulink® models. The toolbox includes reference examples for batteries, and other machines that can be reused for maintenance and condition monitoring algorithms.

Getting Started

Learn the basics of Predictive Maintenance Toolbox

Manage System Data

Import measured data, generate simulated data, organize data

Preprocess Data

Clean and transform data to prepare it for extracting features

Identify Condition Indicators

Explore data at the command line or in the app to identify features

Detect and Predict Faults

Train decision models for condition monitoring and fault detection

Deploy Predictive Maintenance Algorithms

Implement and deploy condition-monitoring and predictive maintenance algorithms

Documentation
All
More
Search Help

CONTENTS

Detect and Diagnose Faults

or pump mechanics ω Δ pump

inverse model pump model

Fault Diagnosis of Centrifugal Pumps Using Steady State Experiments

Use a model-based approach for detection and diagnosis of different types of faults in a pumping system.

[Open Live Script](#)

Fault Diagnosis of Centrifugal Pumps Using Residual Analysis

Use a model parity-equations-based approach for detection and diagnosis of faults in a pumping system.

[Open Live Script](#)

Multi-Class Fault Detection Using Simulated Data

Use a Simulink model to generate faulty and healthy data, and use the data to develop a multi-class classifier to detect different

[Open Live Script](#)

Analyze and Select Features for Pump Diagnostics

Use the Diagnostic Feature Designer app to analyze and select features to diagnose faults in a triplex reciprocating pump.

[Open Live Script](#)

Fault Detection Using an Extended Kalman Filter

Use an extended Kalman filter for online estimation of the friction of a simple DC motor. Significant changes in the estimated friction are

[Open Script](#)

Fault Detection Using Data Based Models

Use a data-based modeling approach for fault detection.

[Open Script](#)