

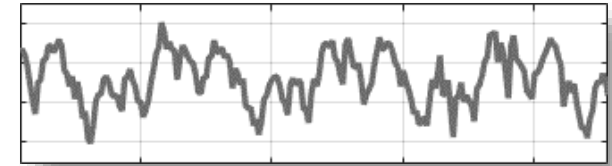
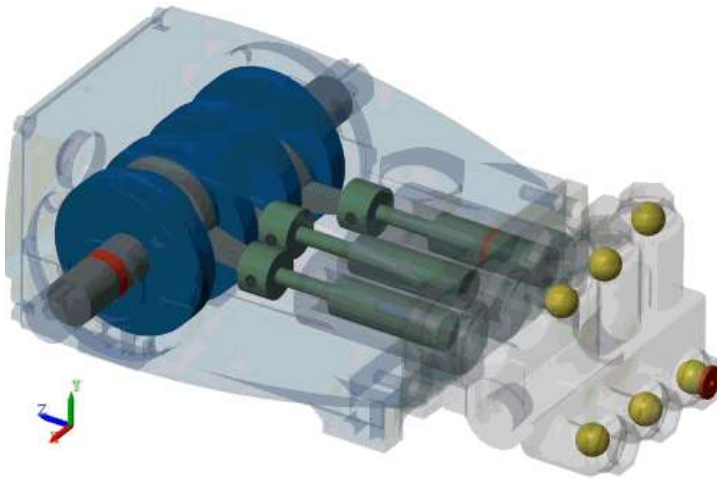
# MATLAB EXPO 2019

건정성 관리 예측 모델 개발을 위한  
MATLAB 활용 방안

엄준상



# What is Predictive Maintenance?



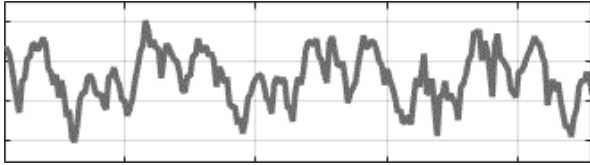


English Spanish French Pump - detected ▼



English Russian Greek ▼

Translate



1/5000

I need help.



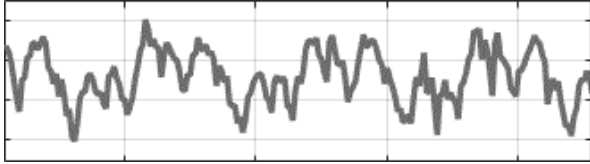


English Spanish French Pump - detected ▼



English Russian Greek ▼

Translate



1/5000

**I need help. One of my cylinders is blocked. I will shut down your line in 15 hours**



# A Predictive Maintenance Algorithm Answers These Questions

**Is my machine  
operating  
normally?**

**Anomaly  
Detection**

**I need help.**

**Why is my  
machine behaving  
abnormally?**

**Condition  
Monitoring**

**One of my cylinders is blocked.**

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

**Remaining  
Useful Life  
Estimation**

**I will shut down your line in 15 hours.**

# Predictive Maintenance Toolbox for Developing Algorithms

**Is my machine  
operating  
normally?**

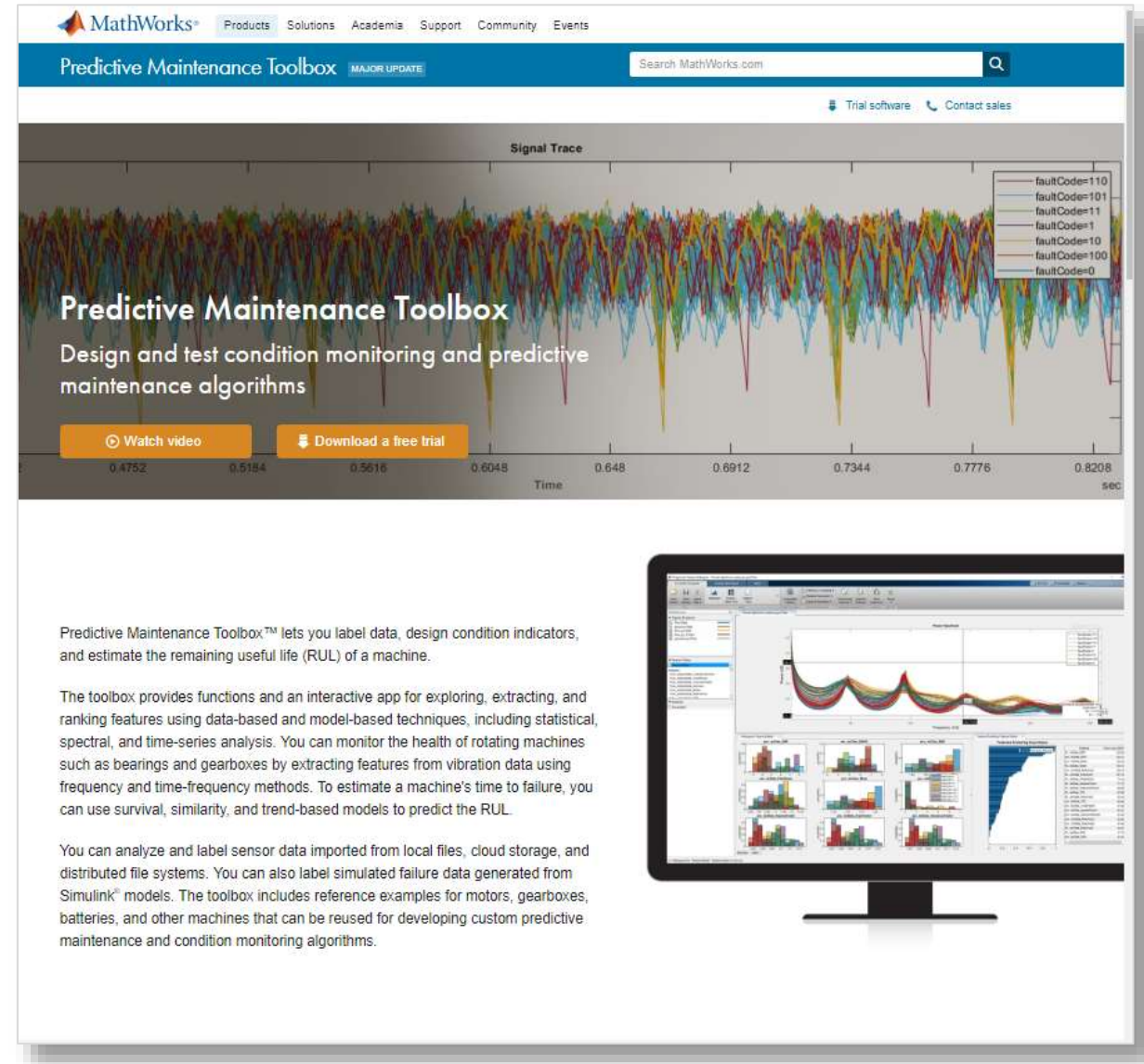
**Anomaly  
Detection**

**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, and 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". The x-axis is labeled "Time" and has values: 0.4752, 0.5184, 0.5616, 0.6048, 0.648, 0.6912, 0.7344, 0.7776, and 0.8208 sec. Below the plot, there is a paragraph describing the toolbox's capabilities: "Predictive Maintenance Toolbox™ lets you label data, design condition indicators, and estimate the remaining useful life (RUL) of a machine." Another paragraph states: "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." A final paragraph mentions: "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." To the right of the text, there is an image of a computer monitor displaying a software interface with various plots and charts, including a large line plot and several smaller bar and area charts.

# How are MathWorks Tools Used for Predictive Maintenance?



[Link to user story](#)

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

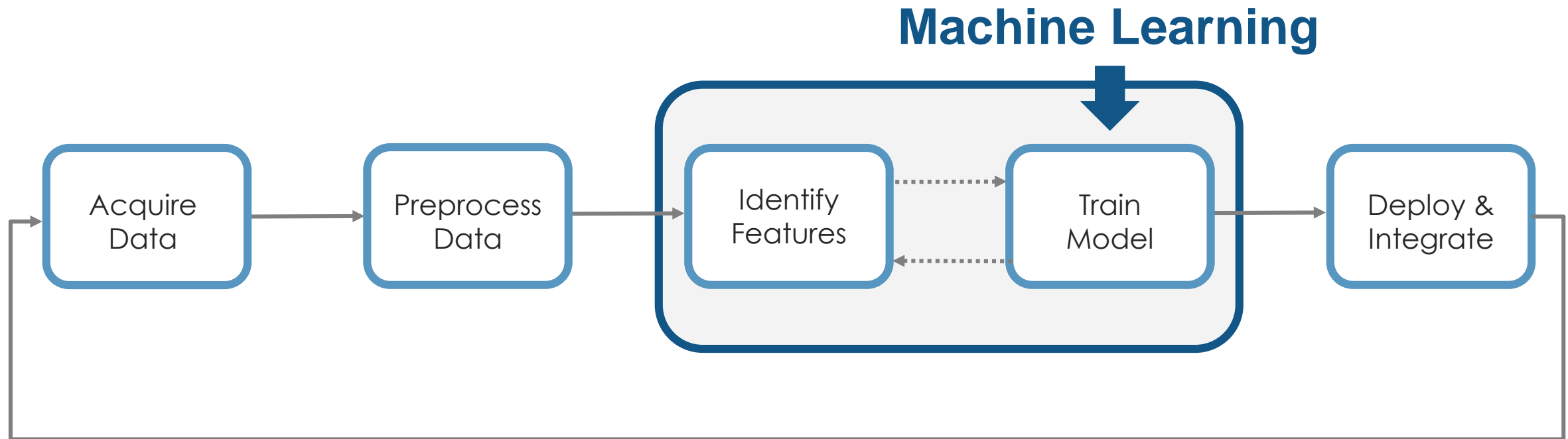


[Link to user story](#)

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



# Workflow for Developing a Predictive Maintenance Algorithm



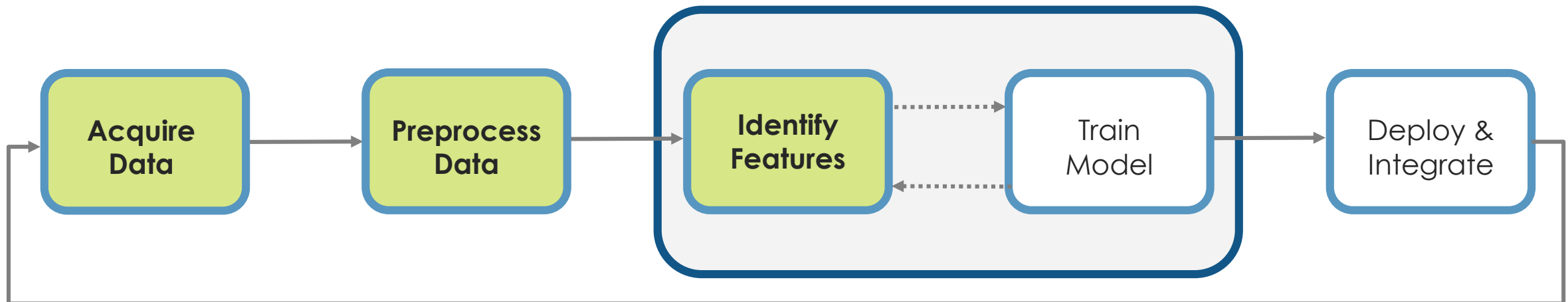


# Why MATLAB & Simulink for Predictive Maintenance

- 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

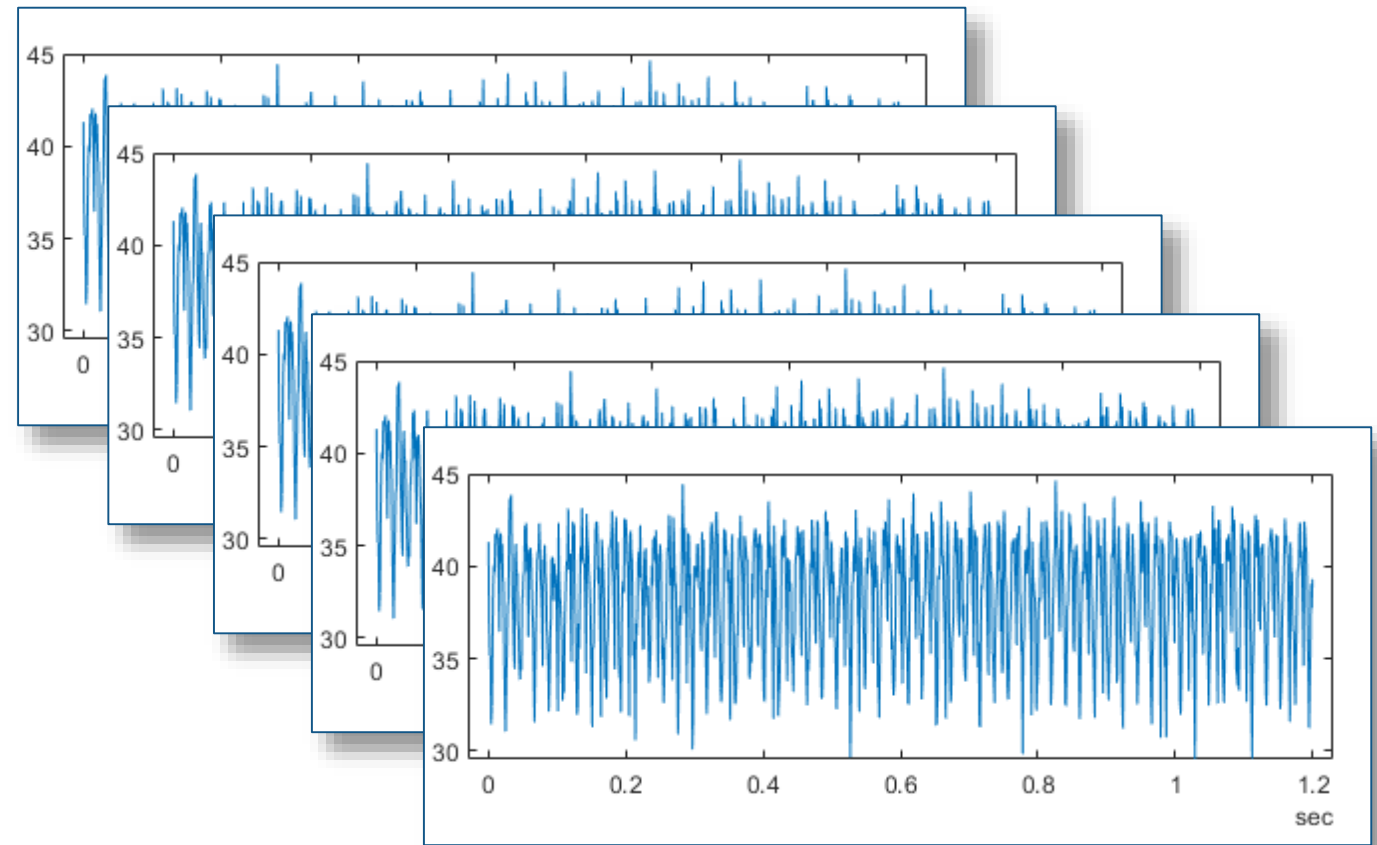
- **Reduce the amount of data you need to store and transmit**
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# Challenges: How do you make sense of the ALL the data being collected?

- 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

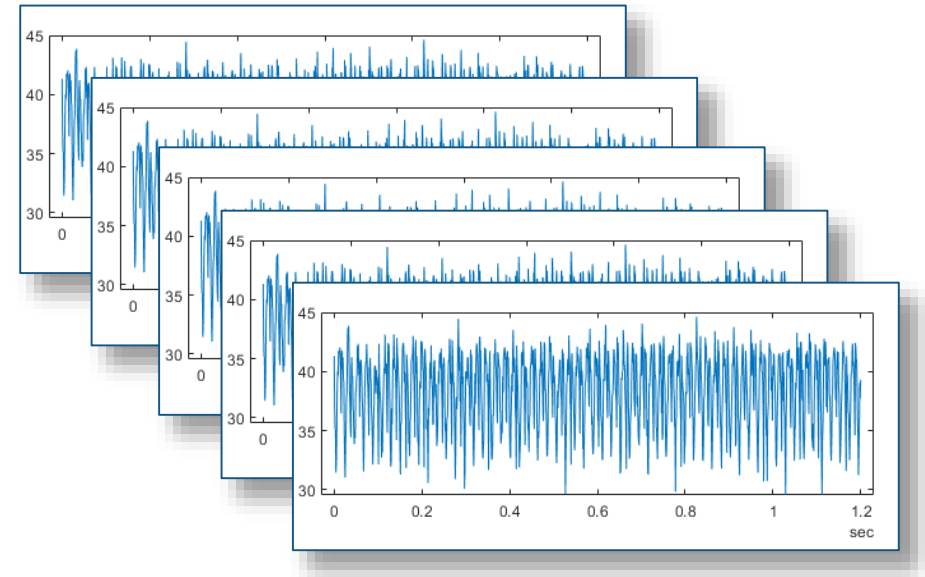
**Pump flow sensor 1 sec ~ 1000 samples ~16kB**



# Solution: Feature Extraction

Reduce the amount of data you need to store and transmit

- How do you extract features?
  - Signal processing methods
  - Statistics & model-based methods
- Which features should you extract?
  - Depends on the data available
  - Depends on the hardware available
- How do I deal with streaming data?
  - Determine buffer size
  - Extract features over a moving buffer window



qMean	qVar	qSkewness	qKurtosis
38.4945	9.2306	-0.5728	2.4662
qPeak2P...	qCrest	qRMS	qMAD
15.2351	1.1553	38.6141	2.5562

# Diagnostic Feature Designer App

Predictive Maintenance Toolbox 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

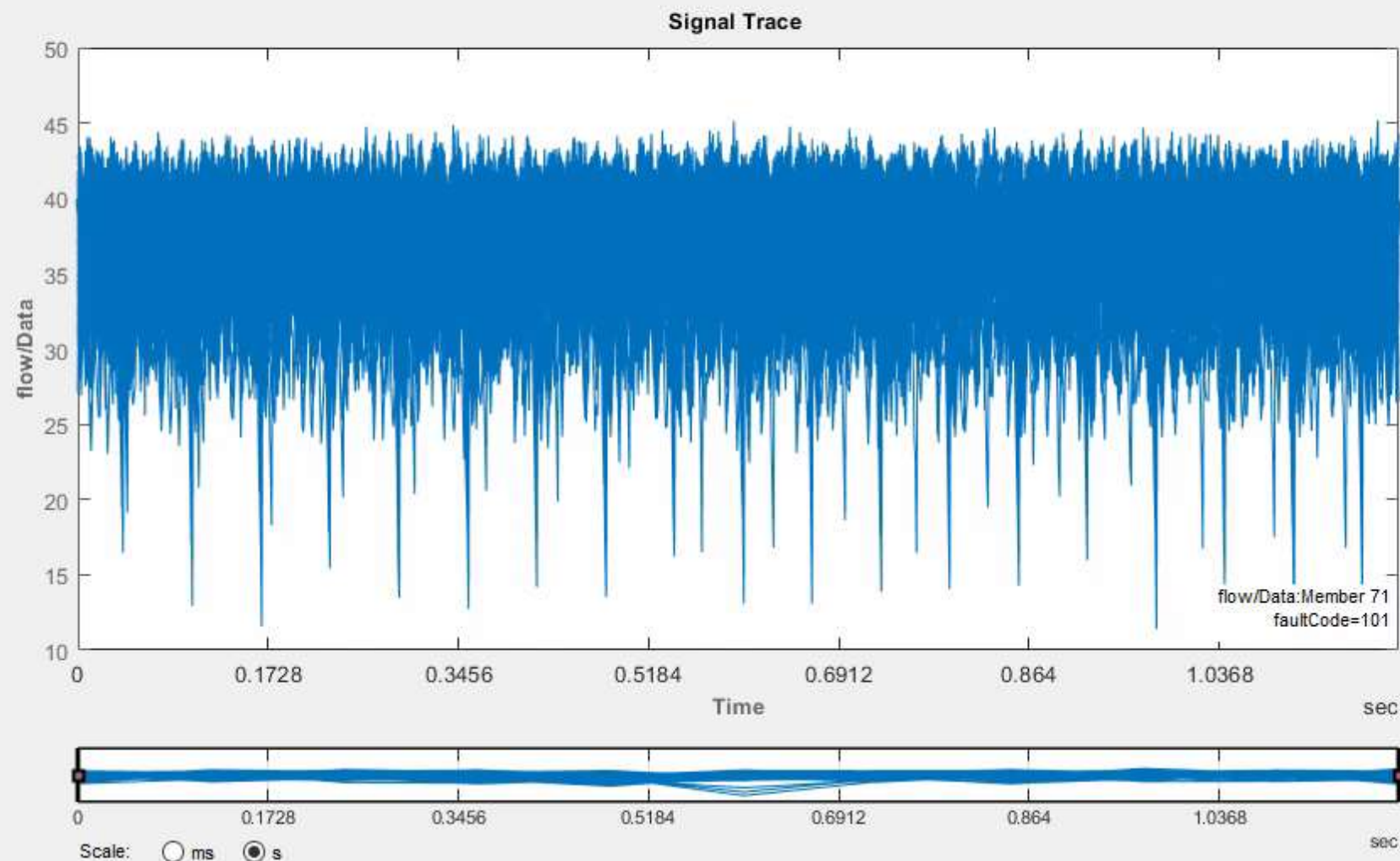
- flow/Data
- pressure/Data

▼ Feature Tables

▼ Datasets

- Ensemble1

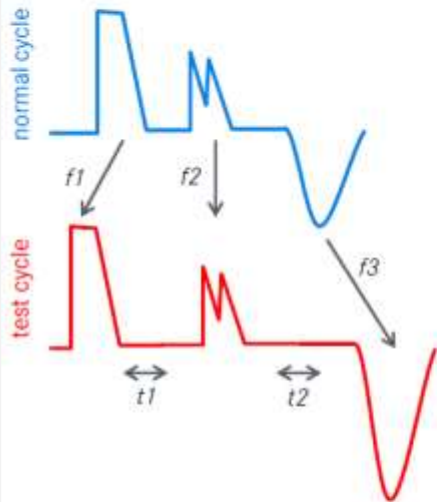
Signal Trace: flow/Data





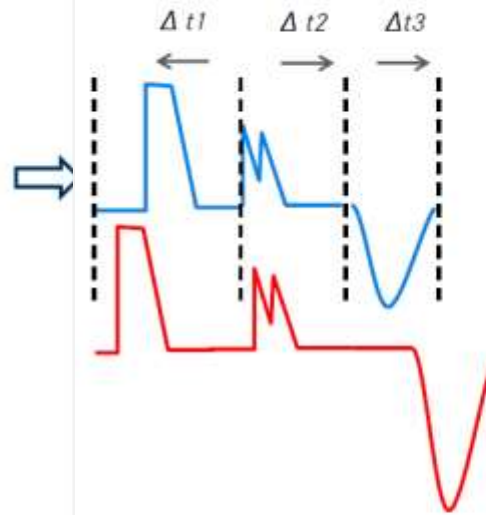
# Daimler are Using MATLAB Today for Anomaly Detection

## Algorithm principle

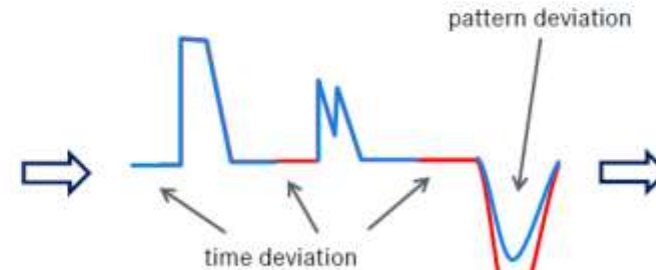


- Cycle can be described as sequence of features  $f1, f2, f3$
- Each cycle can show some delays in time  $t1, t2$

## 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

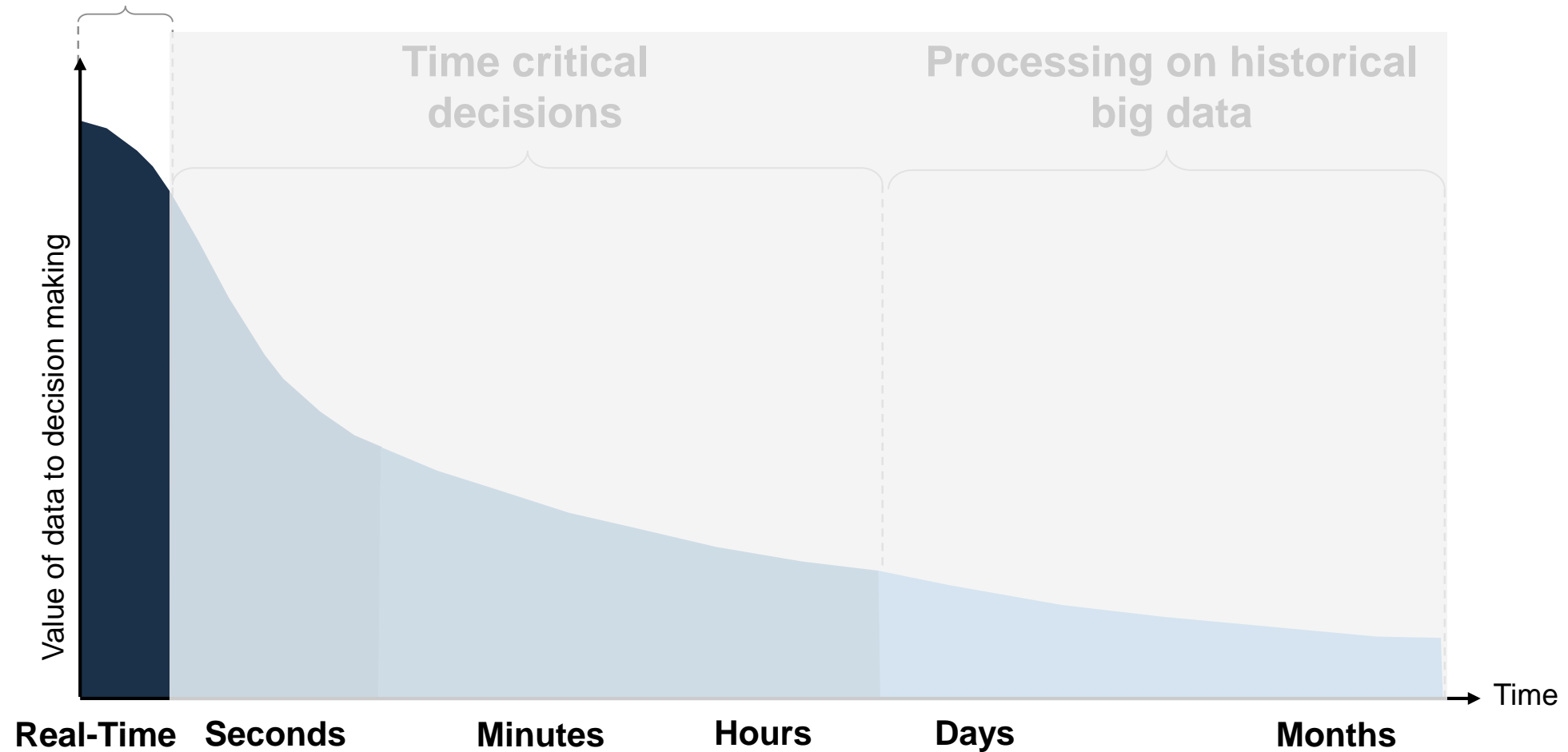


Data reduction!

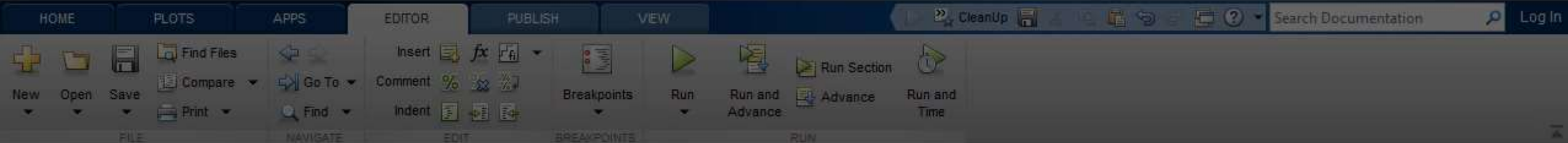
Data reduction of time series by a factor of **250x** without a significant loss of information  
MATLAB EXPO 2019

# When is Your Data Most Valuable?

## Near real-time decisions







C:\Users\abaru\Desktop\Expo 2018\FinalDemo\Demo\_Files\Data\_Reduction

Current Folder: C:\Users\abaru\Desktop\Expo 2018\FinalDemo\Demo\_Files\Data\_Reduction

```
function [feature_list] = featureExtractionBuffer(data,timestamp)

persistent flow_array
persistent time_array
Np = 1000;

if isempty(flow_array)
    flow_array = nan(Np,1);
end

if isempty(time_array)
    time_array = nan(Np,1);
end

flow_array = [data; flow_array(1:Np-1)];
data = flow_array;

time_array = [timestamp; time_array(1:Np-1)];
timestamp = time_array;

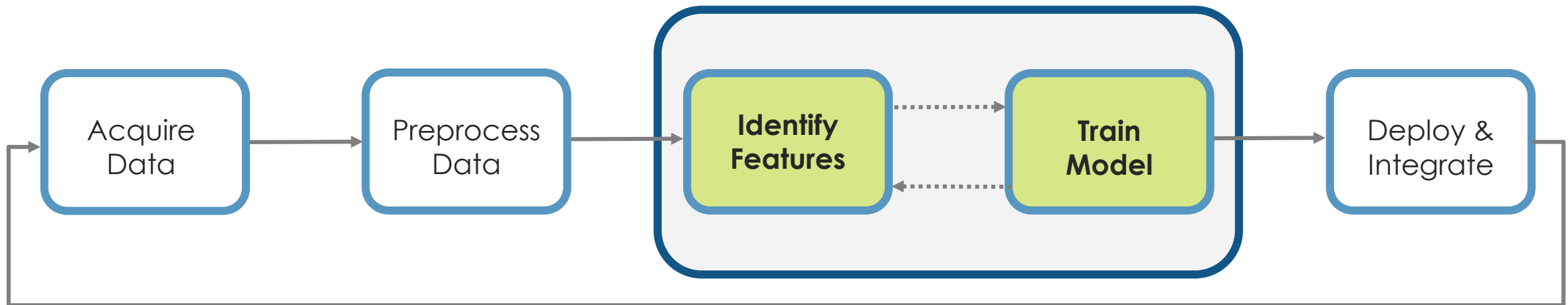
if isempty(find(isnan(data),1))

    flow = data;

    % Ensure the flow is sampled at a uniform sample rate
    t_flow = timestamp;
```

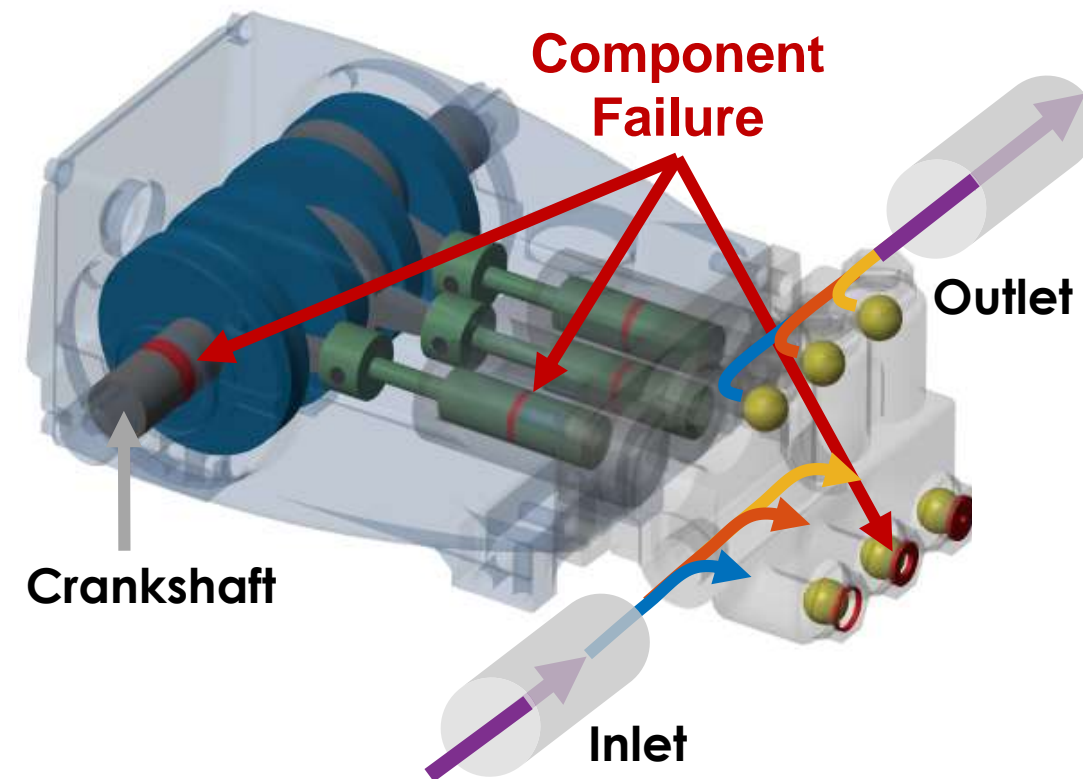
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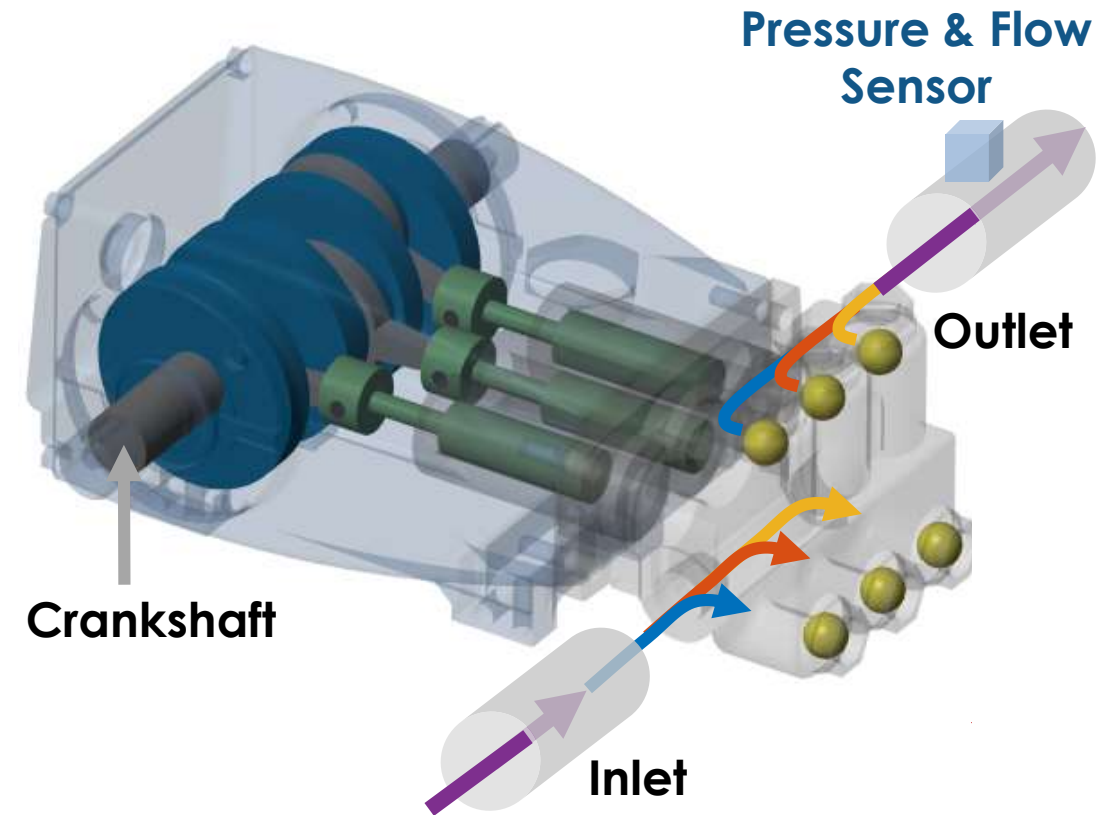
# Fault Classification Algorithms Allow You to Identify the Root Cause of Anomalous Behavior

- 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



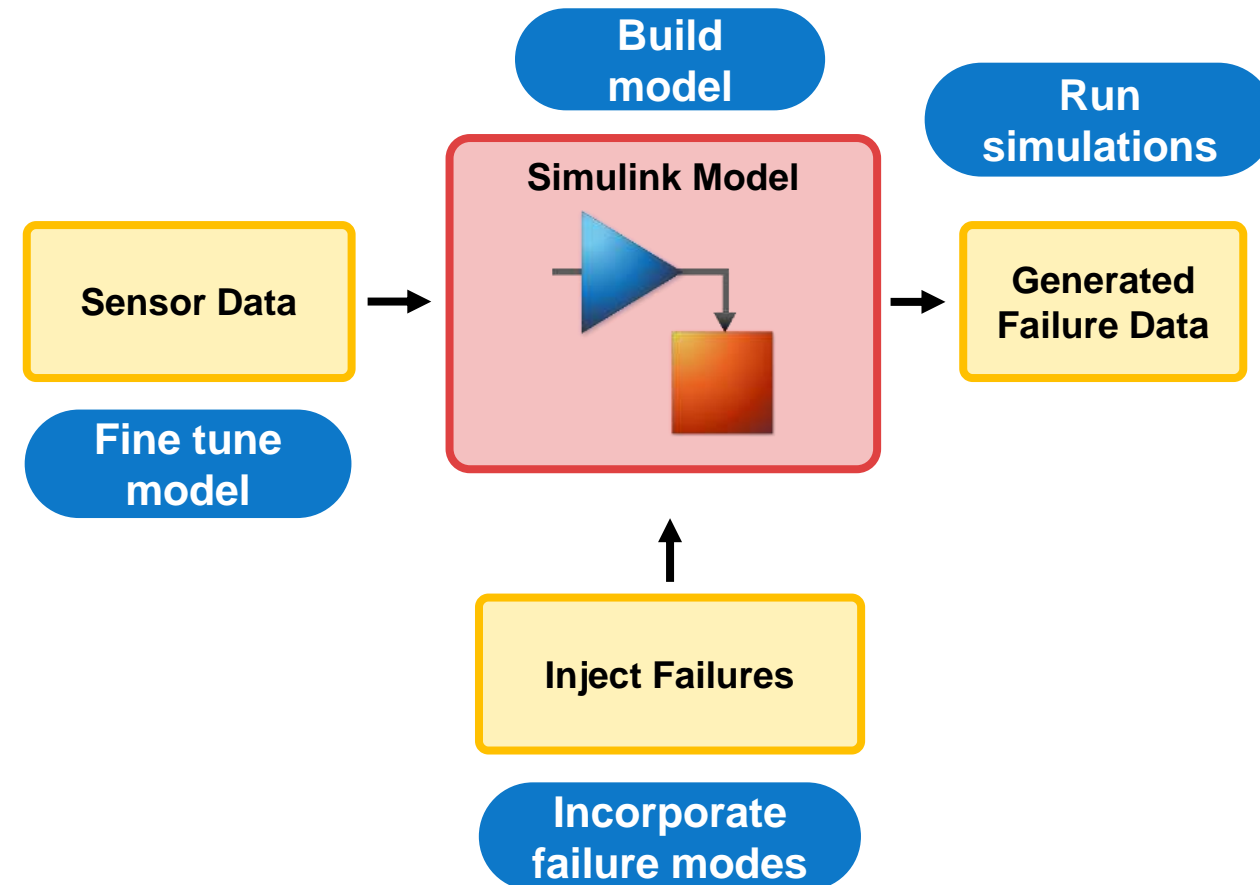
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- Three-phase pump commonly used for drilling and servicing oil wells
  - Three plungers try to ensure a uniform flow
- Condition monitoring to detect:
  - Seal leak
  - Inlet blockage
  - Bearing degradation
- Identify fault present in system using **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 &amp; Spectra

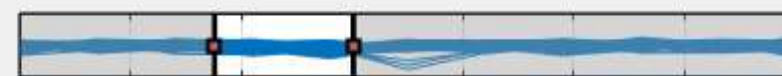
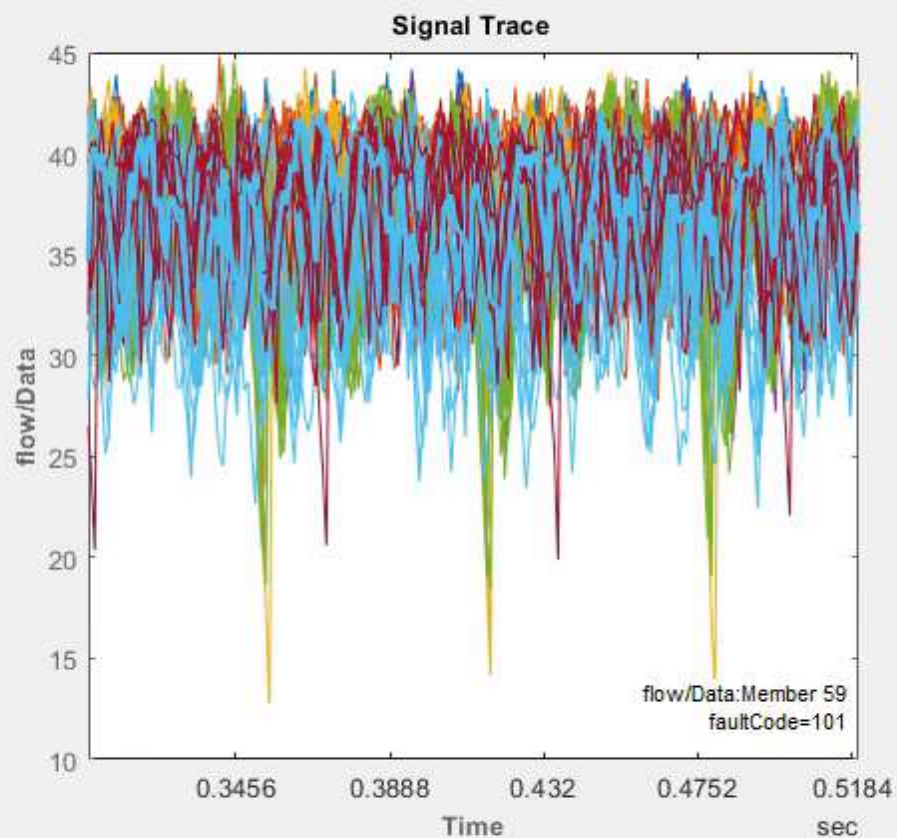
- flow/Data
- pressure/Data
- flow\_ps/Data

## ▼ Feature Tables

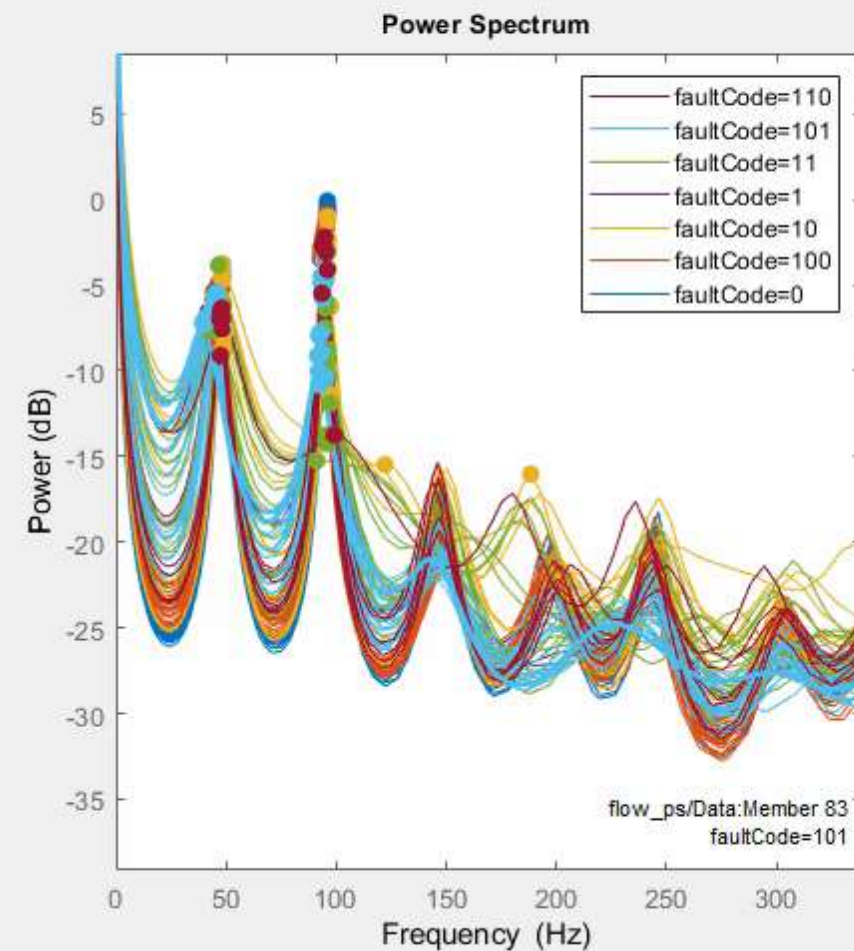
## ▼ Datasets

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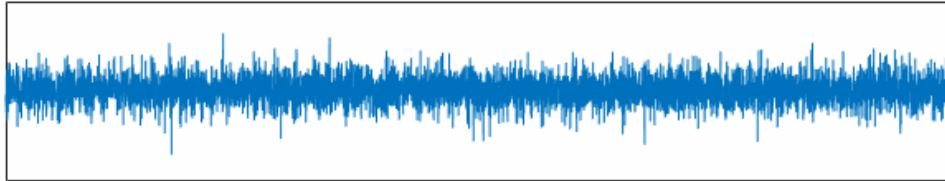
Signal Trace: flow/Data

Scale: ☐ ms ☒ s

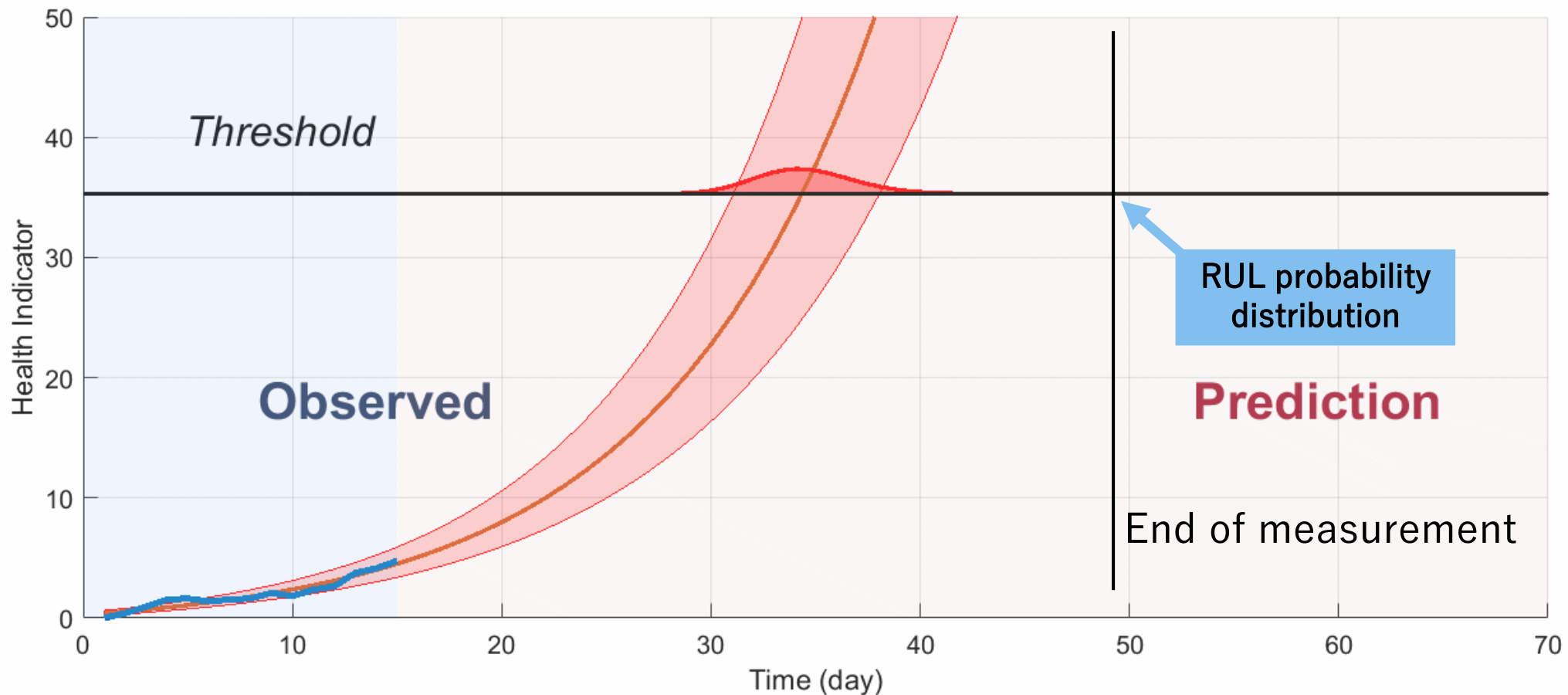
Power Spectrum: flow\_ps/Data



# 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.”*

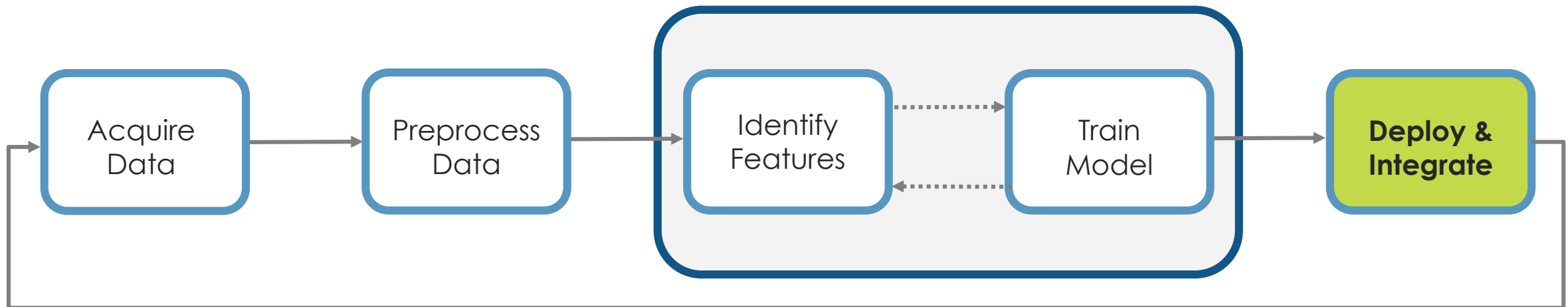
*- Gulshan Singh, Baker Hughes*

[Link to user story](#)



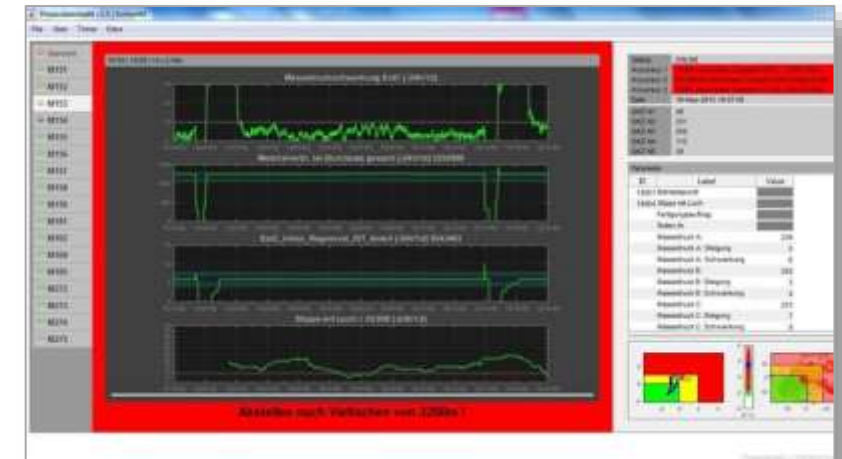
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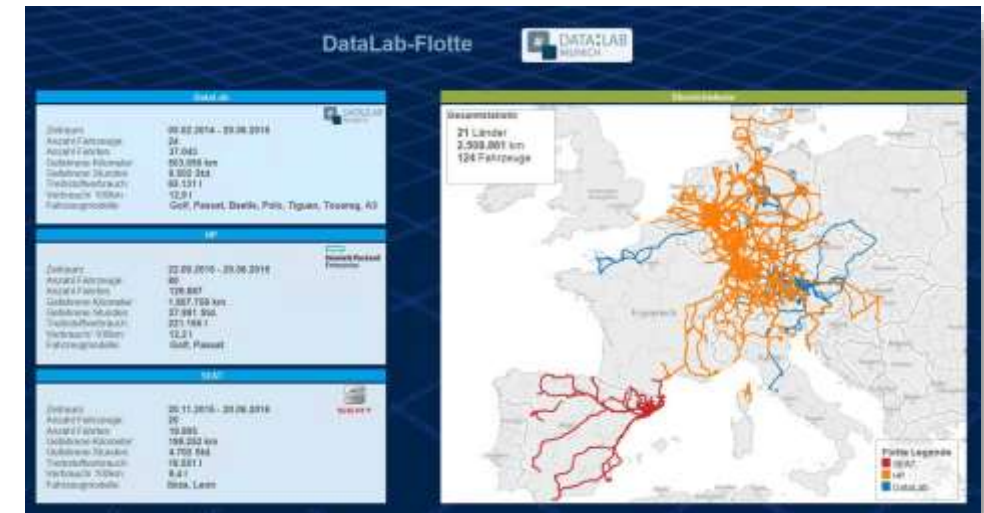


# Challenges: Delivering results to your end users

- 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

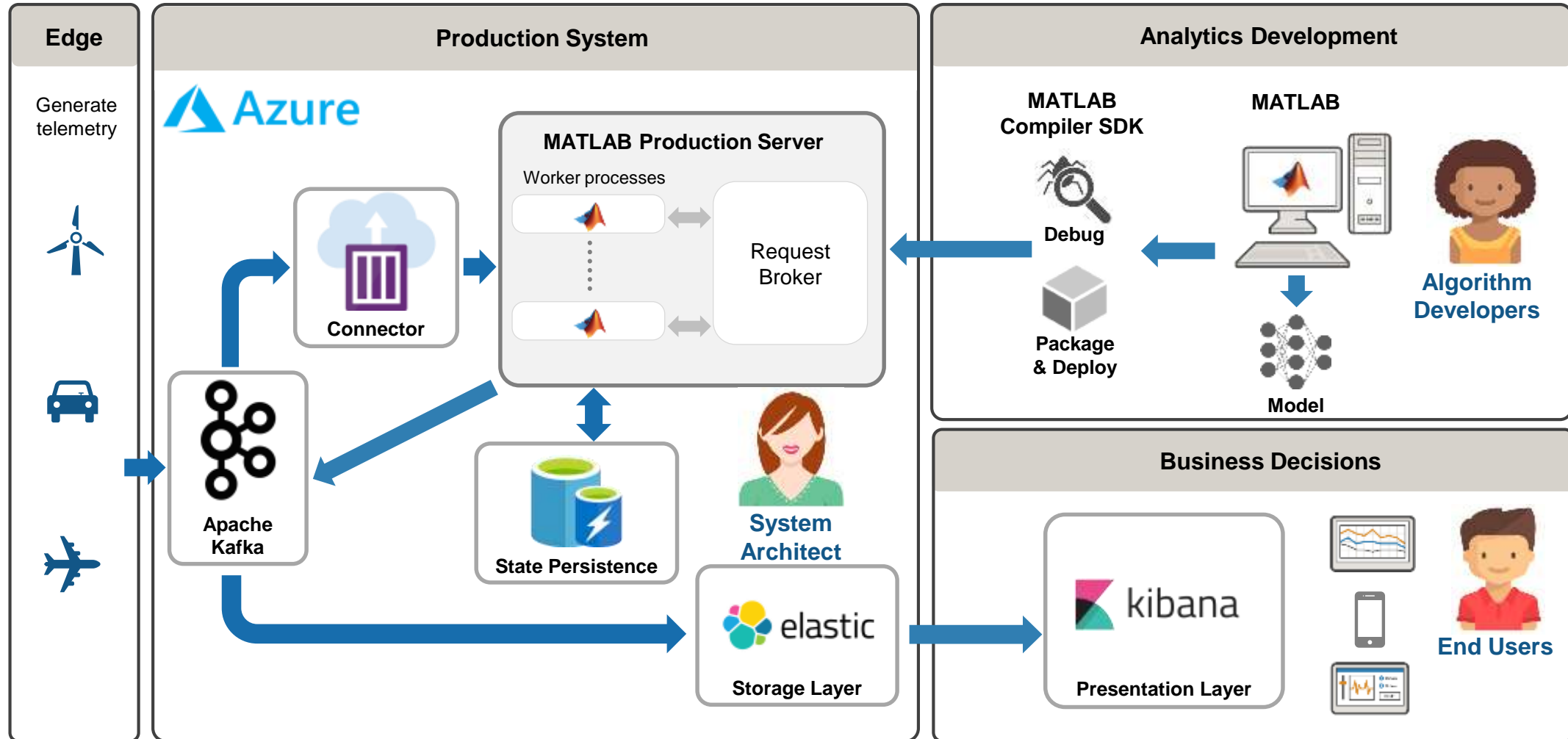


**Dashboards**

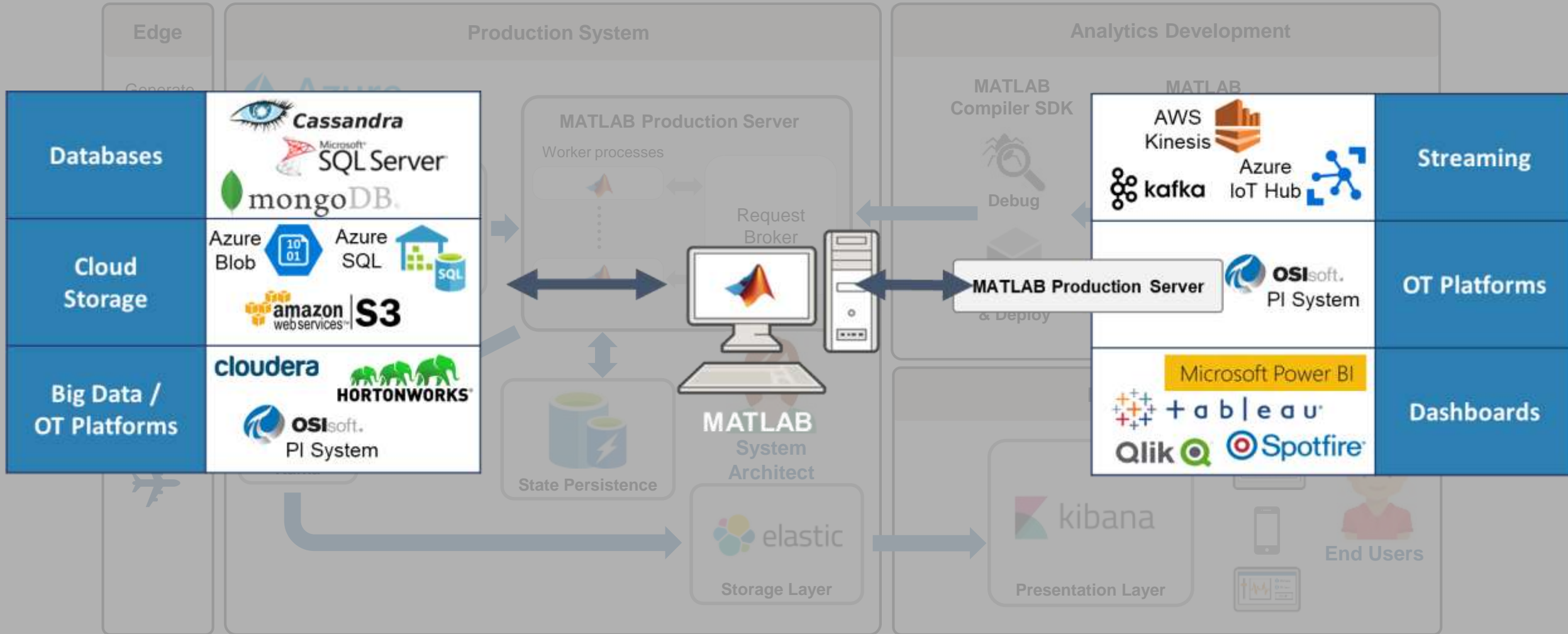


**Fleet & Inventory Analysis**

# Predictive Maintenance Architecture on Azure

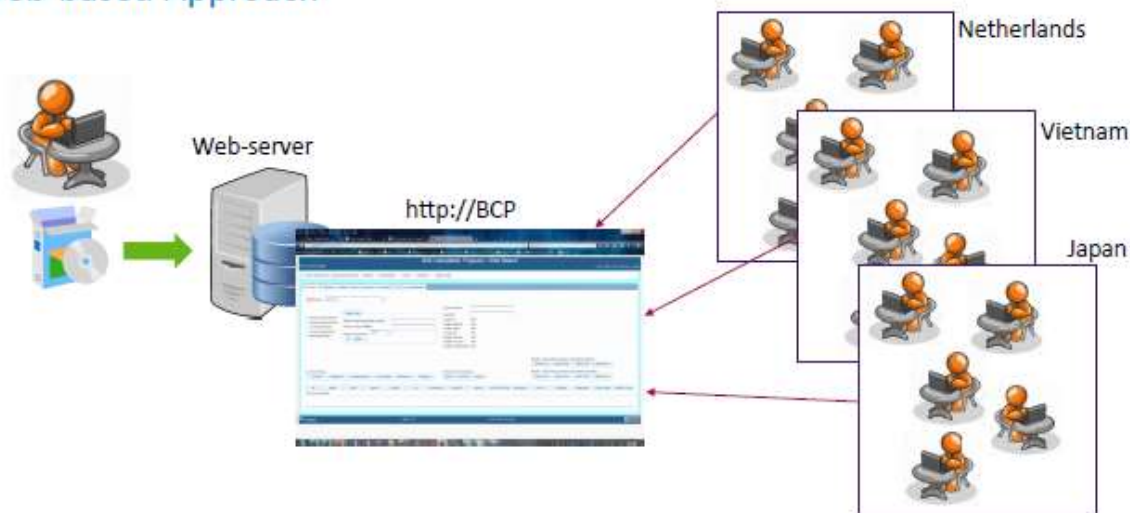


# Predictive Maintenance Architecture on Azure



# Bosch and SNCF Have Implemented Production Systems Running Today

## Web-based Approach



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**BOSCH**

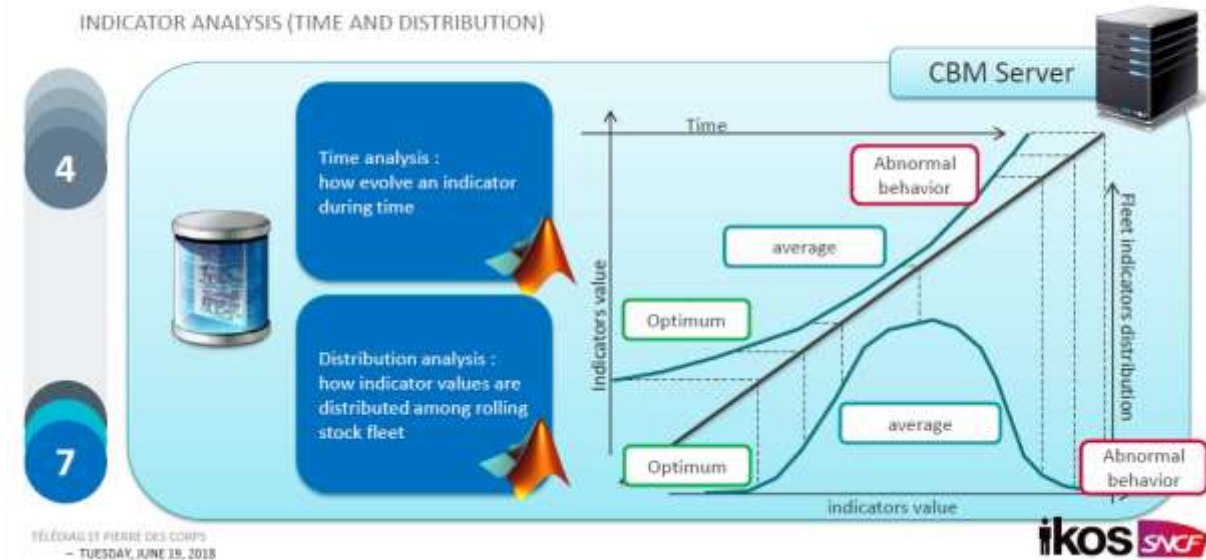
[Link to user story](#)

**“Updating software is required only at 1 location...Maximum of 1 hour downtime for major updates...”**

MATLAB EXPO 2019

## CBM – PROGNOSTIC

INDICATOR ANALYSIS (TIME AND DISTRIBUTION)



[Link to user story](#)

**“...[Our solution] optimizes the whole maintenance process without breaking the existing process...”**

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# MathWorks can help you get started TODAY

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



**Documentation** All More ▾ Search Help

**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 spectral, and time-series analysis. You can monitor faults 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 bearings, 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

**Detect and Diagnose Faults**

**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 faults.  
[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 used to detect faults.  
[Open Script](#)

**Fault Detection Using Data Based Models**  
Use a data-based modeling approach for fault detection.  
[Open Script](#)

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