MATLAB EXPO 2019

Predictive Maintenance with MATLAB

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Agenda:

1. What is Predictive Maintenance? Who is benefiting by doing it?
2. How can you develop a predictive maintenance algorithm using MATLAB?
3. How can you get started quickly?

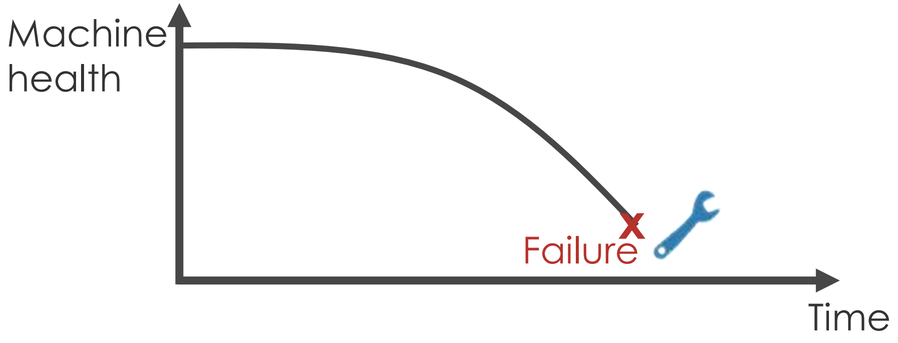
Types of maintenance

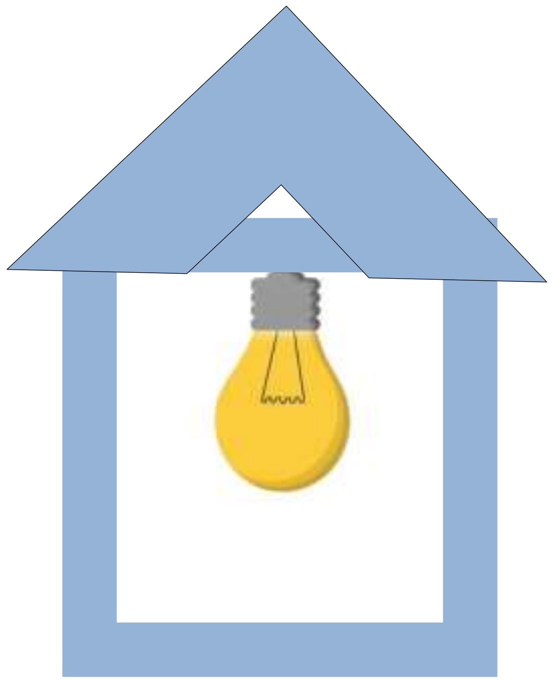
Reactive maintenance

Preventive maintenance

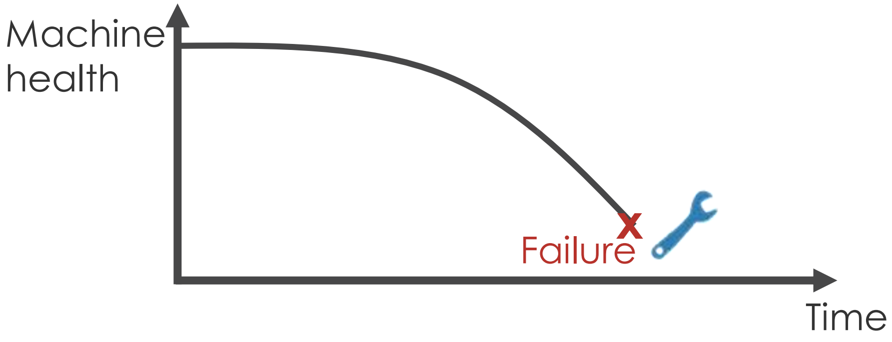
Predictive maintenance

Reactive maintenance

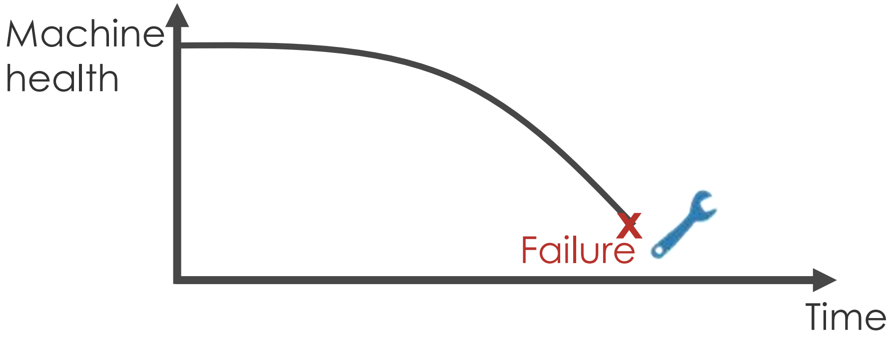




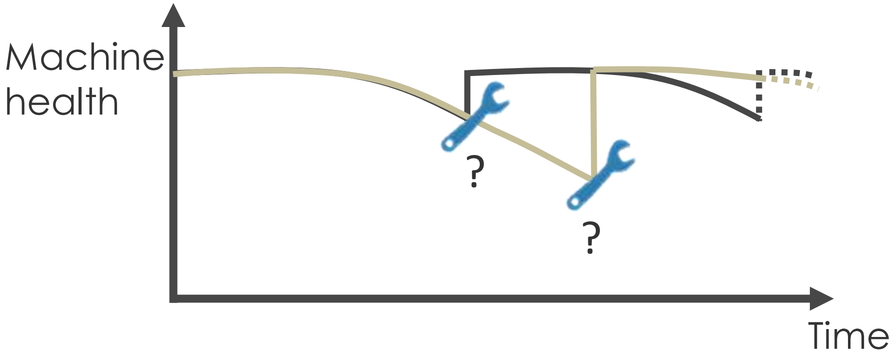
Reactive maintenance



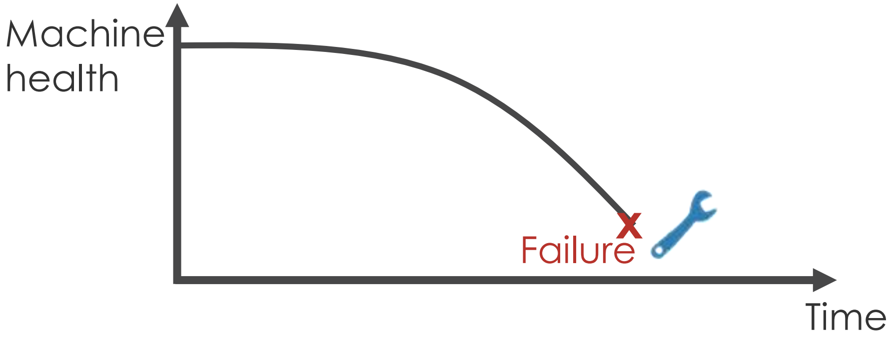
Reactive maintenance



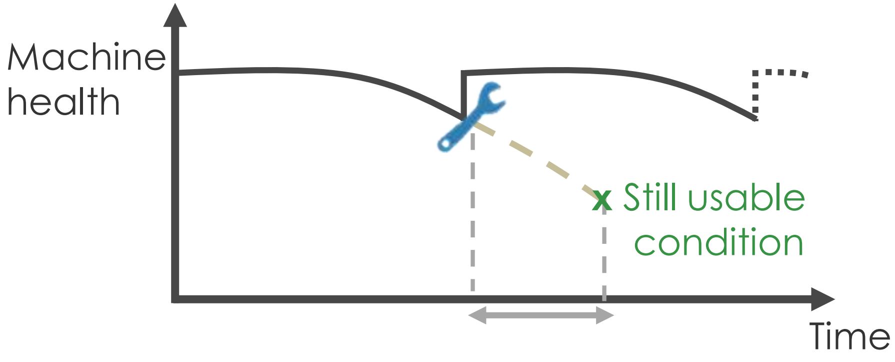
Preventive maintenance



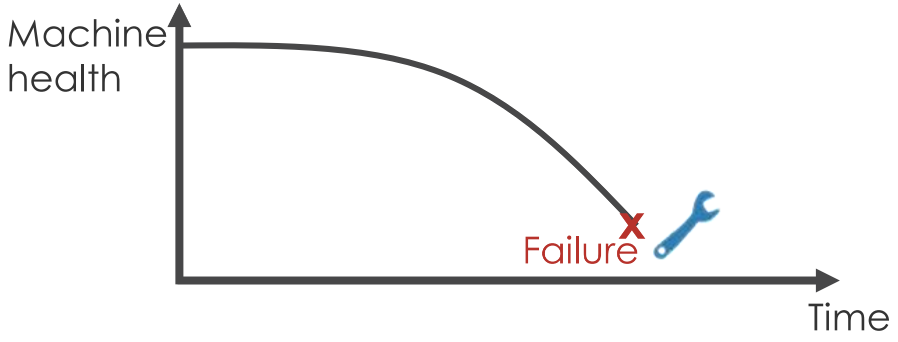
Reactive maintenance



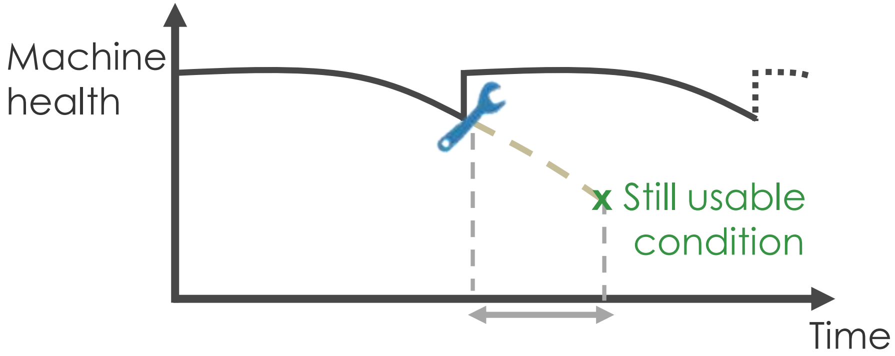
Preventive maintenance



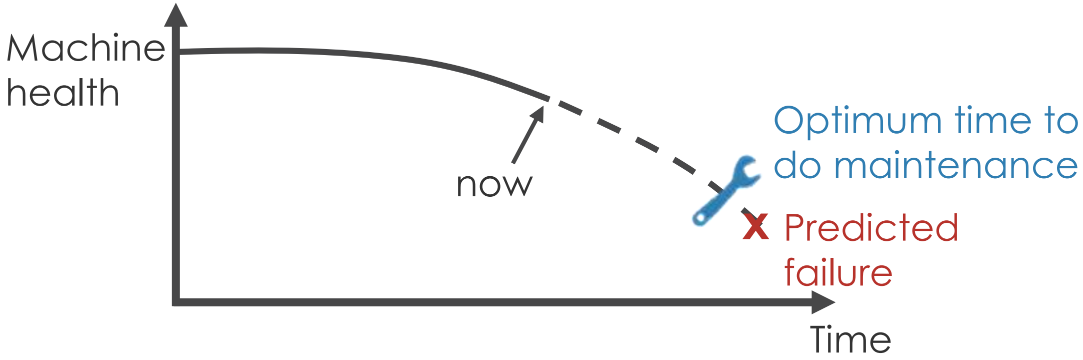
Reactive maintenance



Preventive maintenance



Predictive maintenance



A Predictive Maintenance Algorithm Answers These Questions

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**

For example:

I need help.

One of my cylinders is blocked.

I will shut down your line in 15 hours.

Predictive Maintenance Success Stories

BAKER HUGHES

Pump Health Monitoring System

- Spectral analysis and filtering on binary sensor data and neural network model prediction
- More than $10 million projected savings

SAFRAN Snecma

Online engine health monitoring

- Real-time analytics integrated with enterprise service systems
- Predict sub-system performance (oil, fuel, liftoff, mechanical health, controls

mondi

Production machinery failure warning

- Reduce waste and machine downtime
- MATLAB based HMI warns operators of potential failures
- > 200,000 € savings per year

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Condition and Performance Monitoring of Blowout Preventer (BOP) at Transocean

Mete Mutlu, John Kozicz, Transocean, Inc.

[Link to user story]

Transocean uses MATLAB tools to transition from preventative maintenance to CPM* for a critical deep sea drilling component

*Condition and Performance Monitoring

Challenges

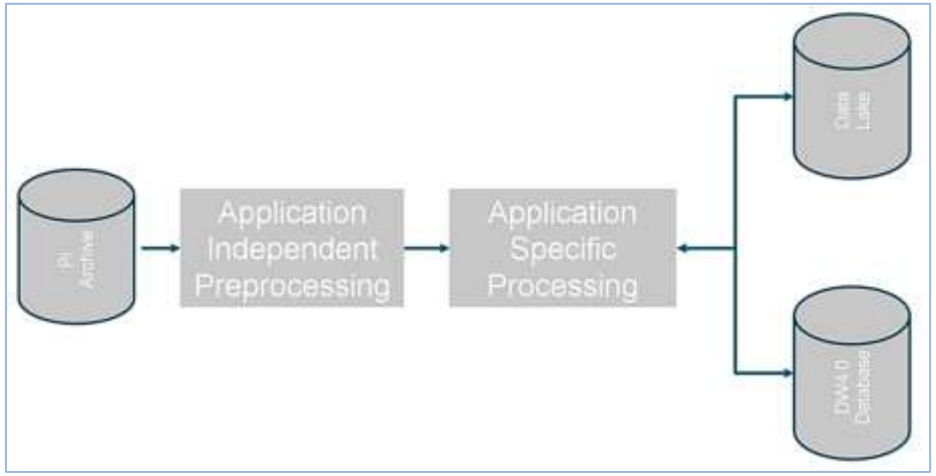
- Minimize unplanned downtime of the component
- Use as-close-to-real-time data for CPM
- Deploy CPM solution to components in other locations

Solution

- Monitoring data from the drill is collected in a PI archive. MATLAB is used to create an app that takes in the data, preprocesses the data, and generates a quality indicator.
- The app is deployed onto MATLAB Production Server for real-time use; results are stored back on the PI archive.

Results

Able to move to CPM for their component(s) with improved decision-making capabilities through faster access to data and quicker analytics deployment.

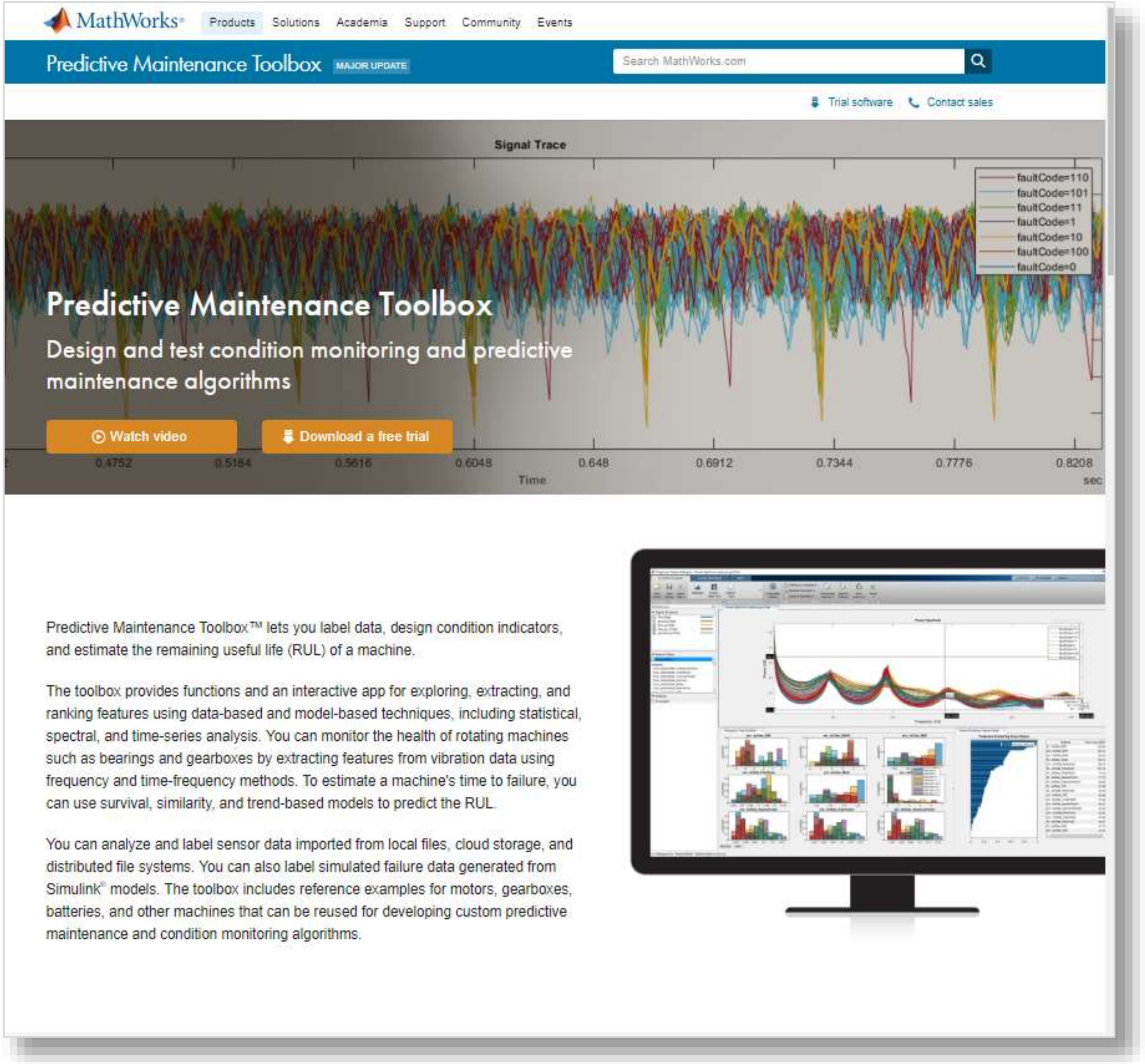


Drilling data is stored in an OSISoft PI Archive. MATLAB Production Server is used in the application specific processing

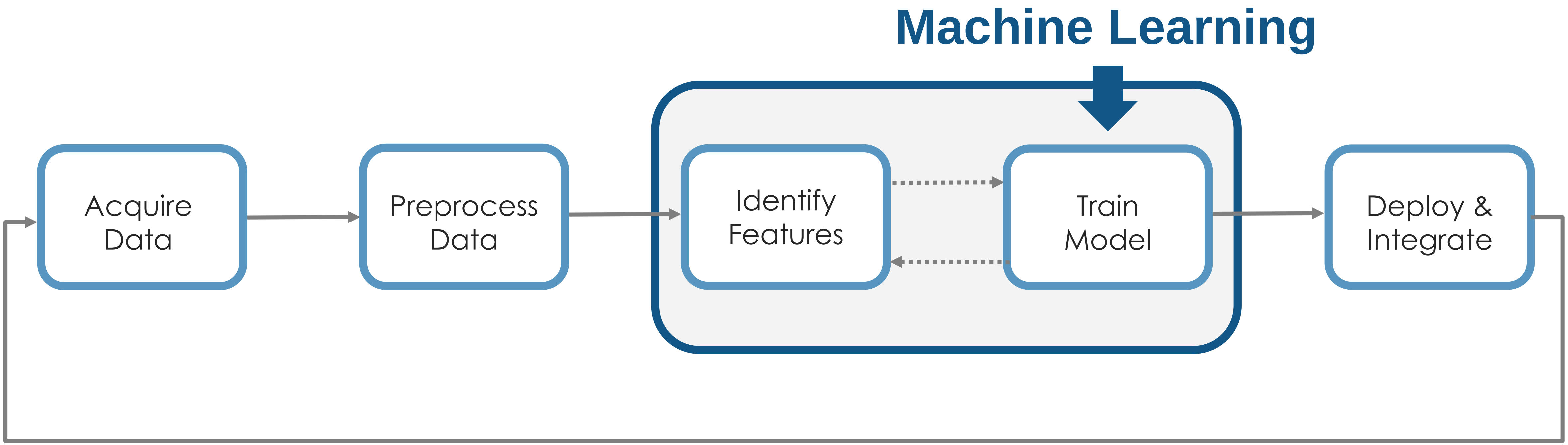
Interfacing directly with data in PI gives you increased performance at the cost of having to write/deal with low-level code ("getting under the hood"). It was noted that using MATLAB parallel tools (which entails a higher-level interface) was not only easier but also it provided "hands-down" faster performance than interfacing with PI directly.

Predictive Maintenance Toolbox for Developing Algorithms

Question	Task
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



Workflow for Developing a Predictive Maintenance Algorithm



Agenda:

1. What is Predictive Maintenance? Who is benefiting by doing it?
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3. How can you get started quickly?

Develop Predictive Maintenance Algorithm: Use cases

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

Develop Predictive Maintenance Algorithm for -

Use case 1: Fault Classification

Why is my machine behaving abnormally?

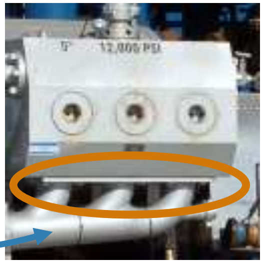
Condition Monitoring

Condition indicators

Predictive maintenance algorithm

Identify fault type

- Healthy
- Blocked Inlet
- Seal Leakage
- Worn Bearing
- Blocked Inlet & Worn Bearing
- Seal Leakage & Worn Bearing
- Seal Leakage & Blocked Inlet

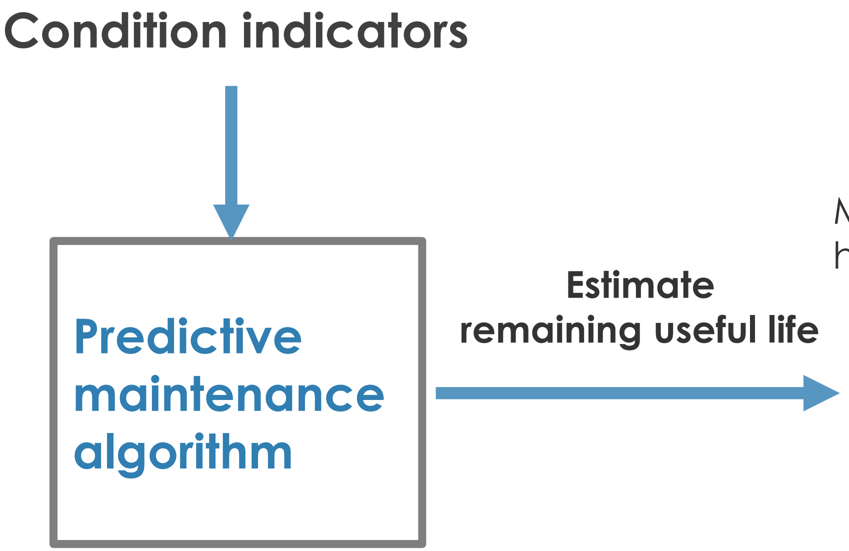


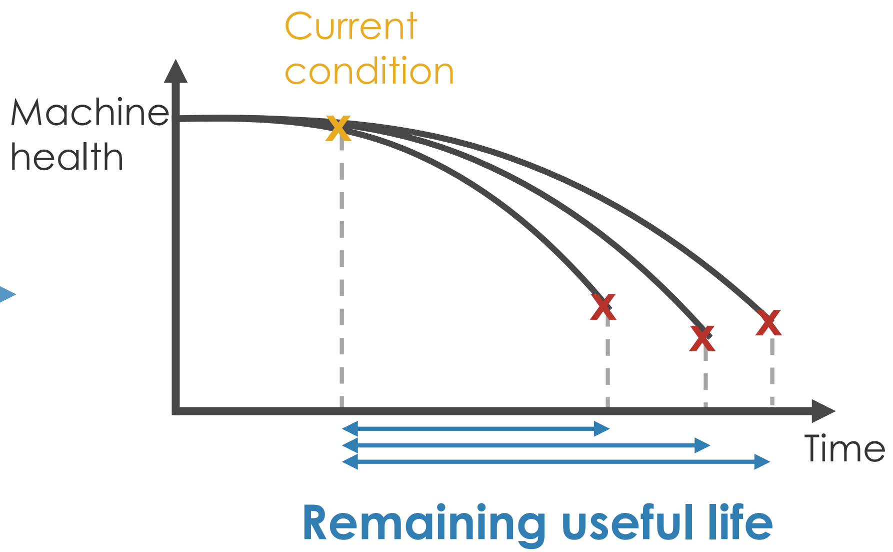
Determine what needs to be fixed

Develop Predictive Maintenance Algorithm for -

Use case 2: **Remaining useful life**

How much longer can I operate my machine ? → **Remaining Useful Life Estimation**






5"
12,000 PSI

Predictive Maintenance Algorithm

Acquire Data
- Sensor Data
- Generated Data

→ Preprocess Data → Identify Condition Indicators → Train Model → Deploy & Integrate

healthy
+
faulty

Triplex pump

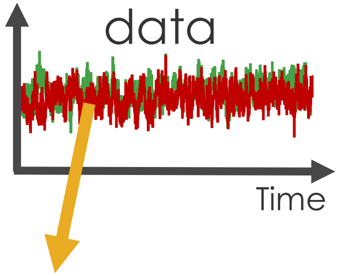
Collect data using sensors

Temperature

Flow

Pressure

Sensor data



*For simplification purposes, healthy and faulty operation are represented by single measurements. In a realistic scenario, there may be hundreds of measurements for both types of operations.

Predictive Maintenance Algorithm

Acquire Data → Preprocess Data → Identify Condition Indicators → Train Model → Deploy & Integrate

healthy
+
faulty

Triplex pump

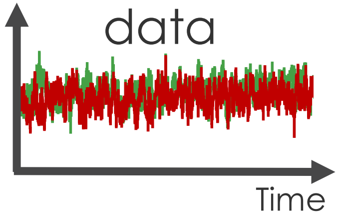
Collect data using sensors

Temperature

Flow

Pressure

Sensor data



*Quality data->Robust Algorithms

Predictive Maintenance Algorithm

Acquire Data → Preprocess Data → Identify Condition Indicators → Train Model → Deploy & Integrate

healthy
+
faulty

Triplex pump

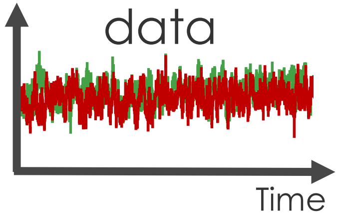
Collect data using sensors

Temperature

Flow

Pressure

Sensor data



Predictive Maintenance Algorithm

Acquire Data → Preprocess Data → Identify Condition Indicators → Train Model → Deploy & Integrate

healthy
+
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Triplex pump

Collect data using sensors

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Flow

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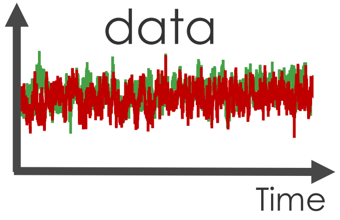
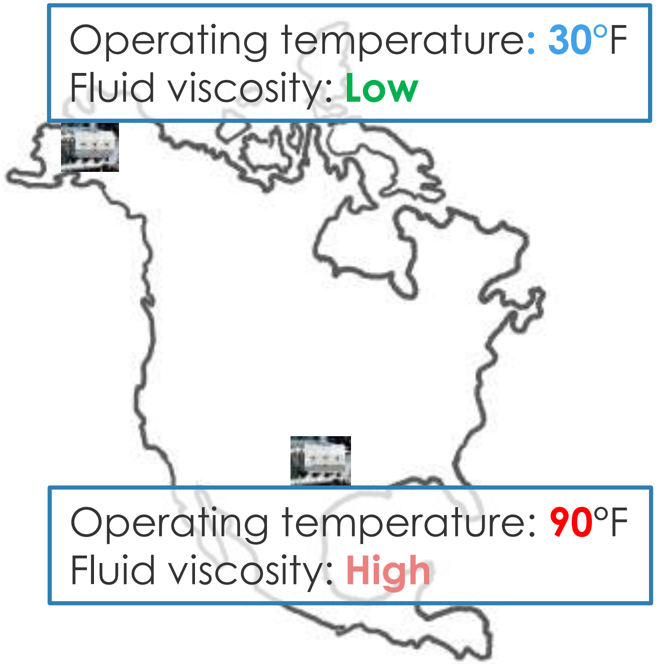
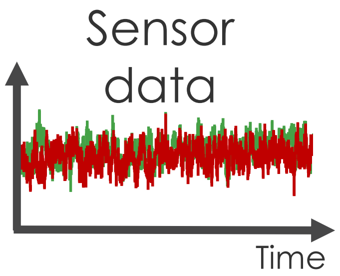




Predictive Maintenance Algorithm

Acquire Data → Preprocess Data → Identify Condition Indicators → Train Model → Deploy & Integrate

Triplex pump



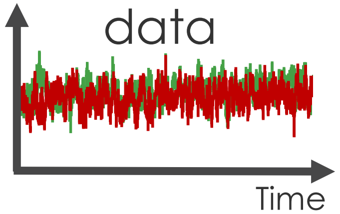
What if real failure data is not available?

Predictive Maintenance Algorithm

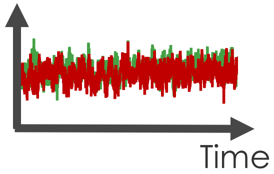
Acquire Data → Preprocess Data → Identify Condition Indicators → Train Model → Deploy & Integrate

Triplex pump

Sensor data



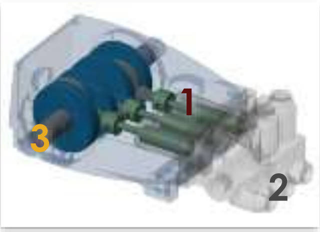
Sensor data



Refine model

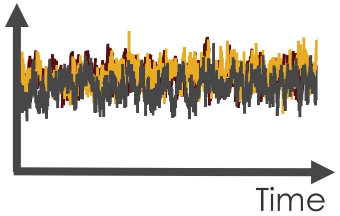
1 Seal leakage
2 Blocked inlet
3 Worn bearing

Inject faults



Mathematical model of the triplex pump (Digital Twin)

Synthetic data



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Current Folder

Name

- PredictiveMaintenanceWit...
- savedPumpData.mat

Details

Workspace

Name	Value
pumpData	240x3 table

Live Editor - AnalyzeAndSelectFeaturesForPumpExample.mlx | Command Window

AnalyzeAndSelectFeaturesForPumpExample.mlx

The measurements cover conditions where none, one, or multiple fa in a table where each row is a different measurement.

```
load('savedPumpData')
pumpData
```

pumpData = 240×3 table

	Flow	Pressure	faultCode
1	1201×1 tim...	1201×1 time...	0
2	1201×1 tim...	1201×1 time...	0
3	1201×1 tim...	1201×1 time...	100
4	1201×1 tim...	1201×1 time...	100
5	1201×1 tim...	1201×1 time...	100
6	1201×1 tim...	1201×1 time...	100
7	1201×1 tim...	1201×1 time...	100
8	1201×1 tim...	1201×1 time...	100
9	1201×1 tim...	1201×1 time...	100

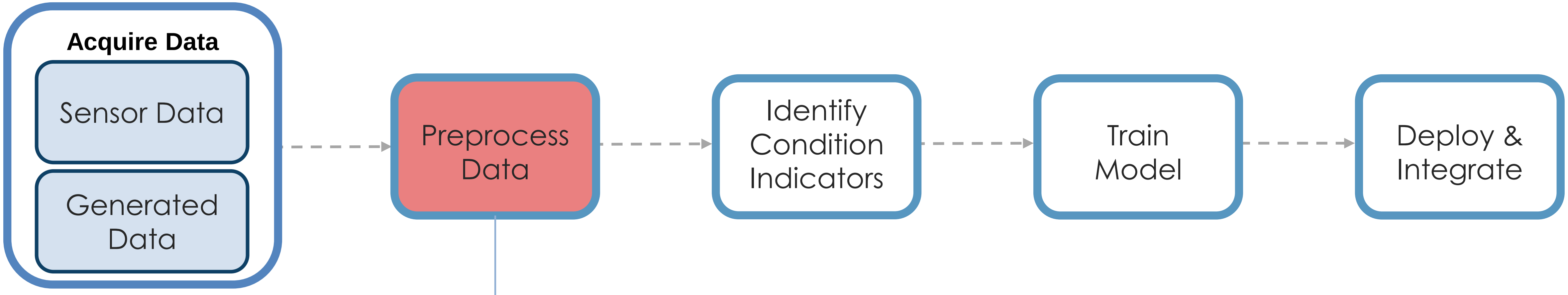
Health condition (fault code)

- Healthy (0)
- Blocked inlet (010)
- Worn bearing (001)
- Seal Leakage (100)
- Blocked inlet, worn bearing (011)
- Seal leakage, worn bearing (101)
- Seal leakage, blocked inlet (110)
- Seal leakage, blocked inlet, worn b

240 measurements of flow and pressure with a duration of 1.2 seconds

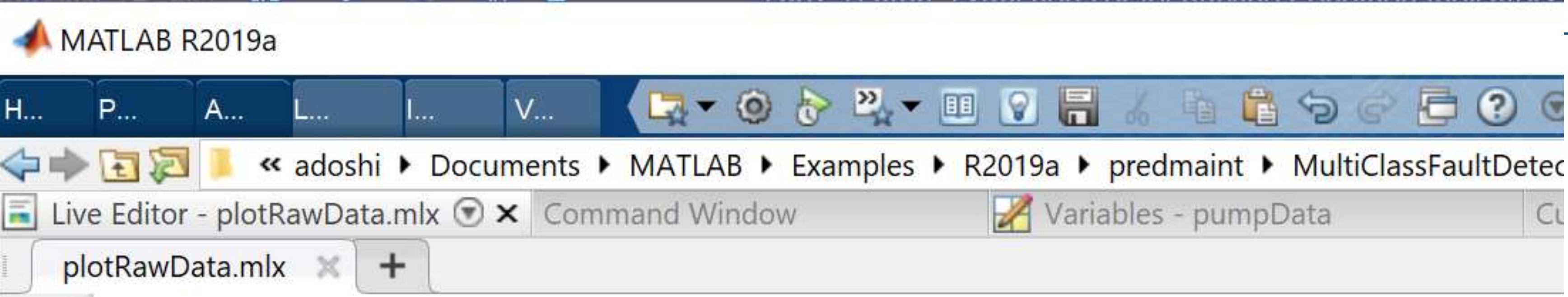
[Learn further: Data Ensembles]

Predictive Maintenance Algorithm



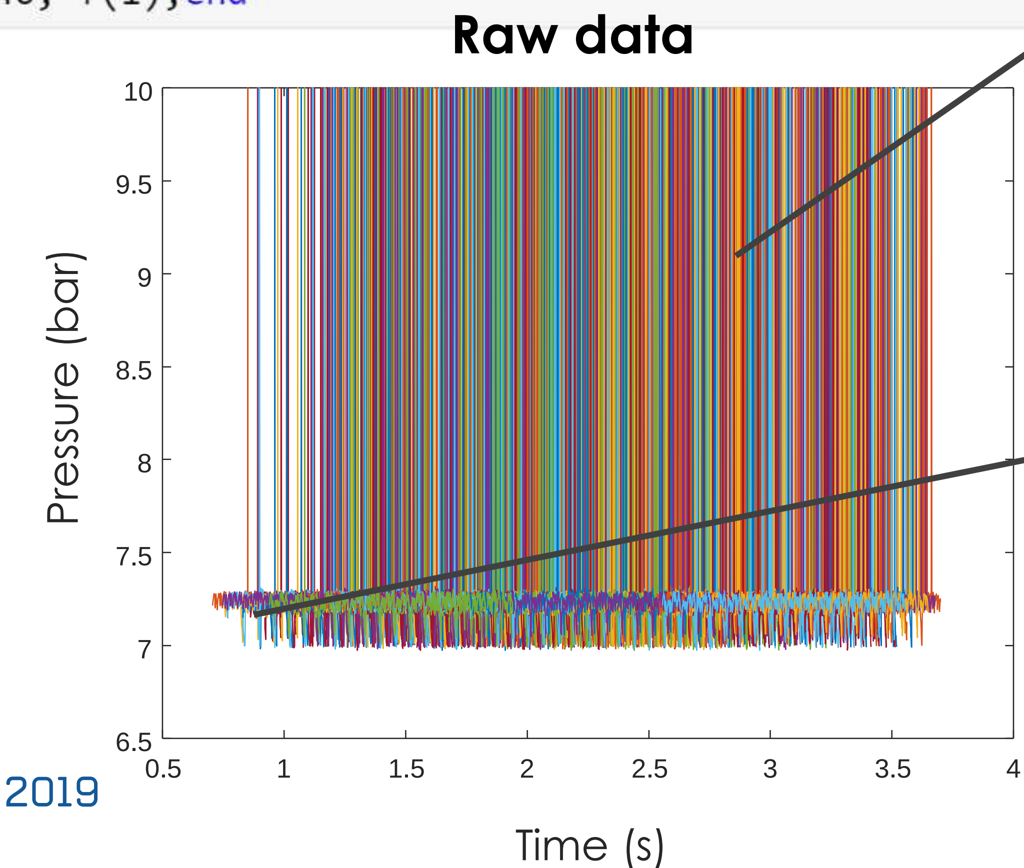
Challenges

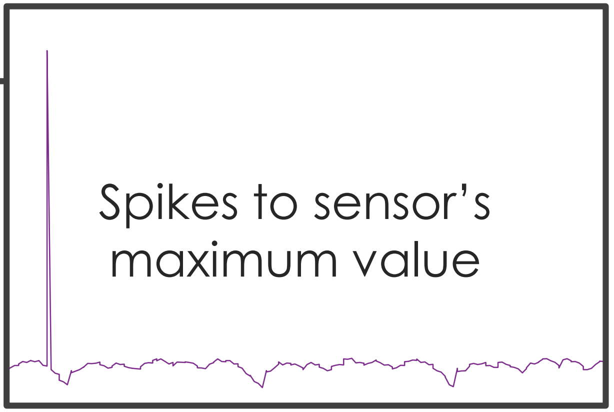
- Data clean up
  - Poorly formatted files
  - Irregularly sampled data
  - Redundant data, outliers, missing data etc.
- Data specific processing
  - Signals: Smoothing, resampling, denoising, Wavelet transforms, etc.
  - Images: Image registration, morphological filtering, deblurring, etc.

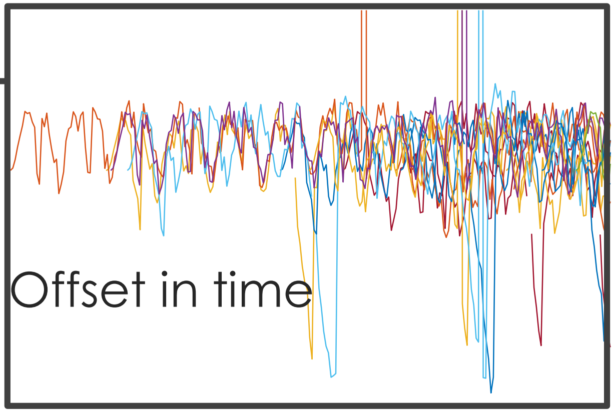


Plot time vs presssure data for all the 240 runs

```
f= @(x) plot(pumpData.pressure{x,1}.Time,pumpData.pressure{x,1}.Data);
for i=1:240, f(i),end
```

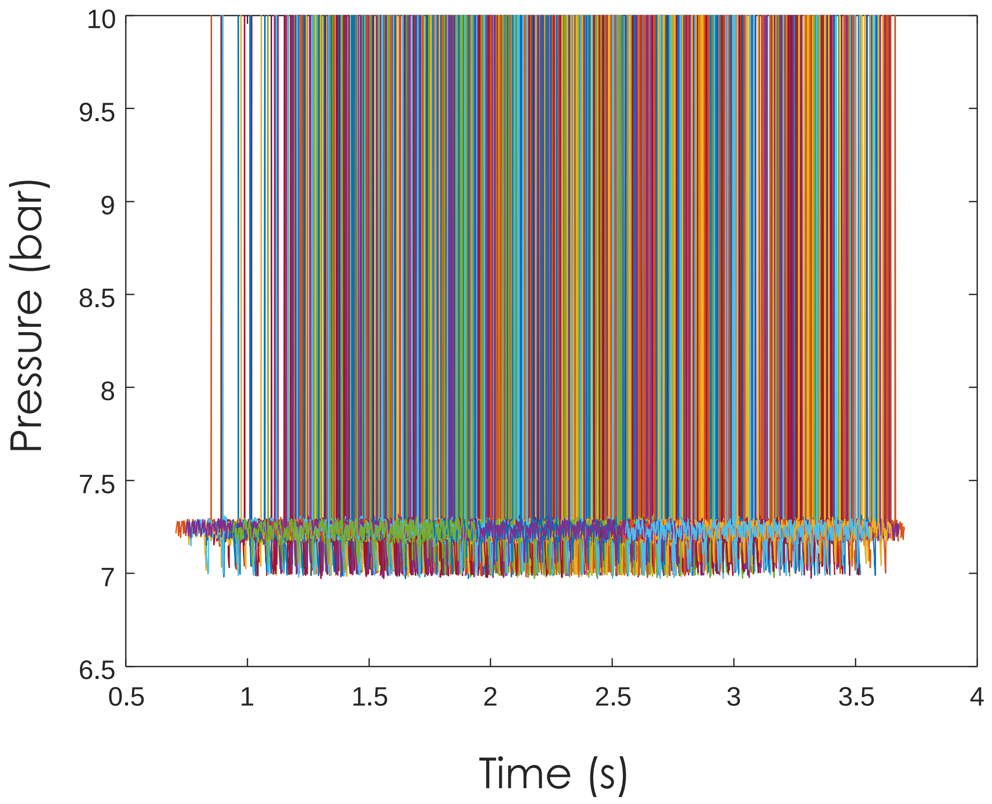




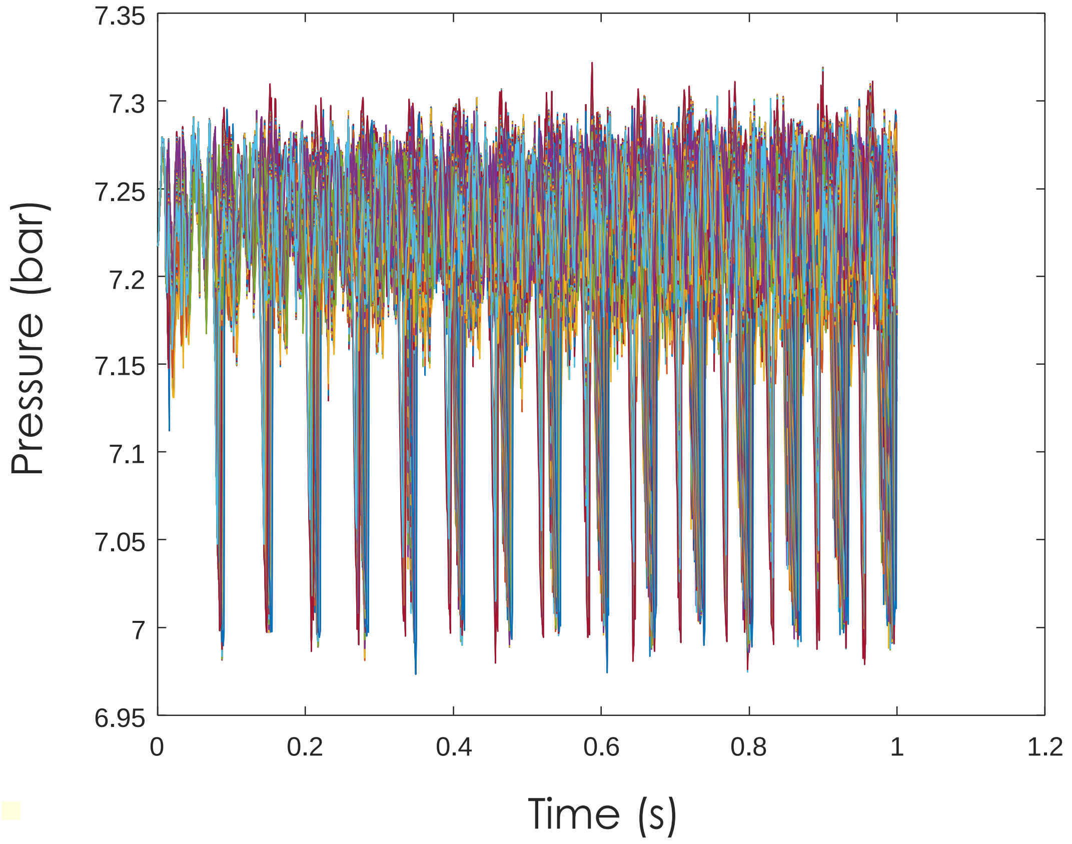


```matlab
function [dataToWrite] = preprocess(data)

tMin = seconds(0.8);

flow = data.qOut_meas{1};
flow = flow(flow.Time >= tMin,:);
flow.Time = flow.Time - flow.Time(1);
pressure = data.pOut_meas{1};
pressure = pressure(pressure.Time >= tMin,:);
pressure.Time = pressure.Time - pressure.Time(1);

% Ensure the flow and pressure is sampled at a uniform sample rate
flow = retime(flow,'regular','linear','TimeStep',seconds(1e-3));
pressure = retime(pressure,'regular','linear','TimeStep',seconds(1e-3));
```

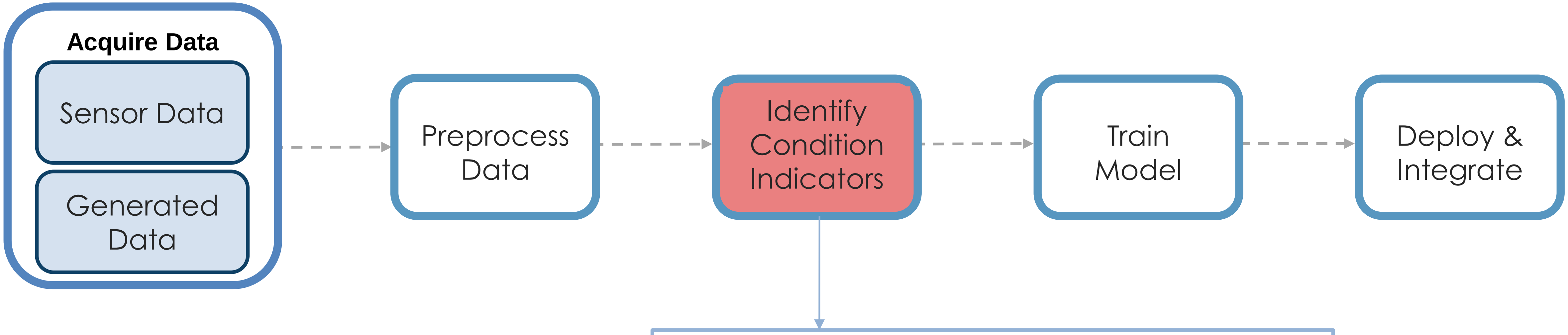
Raw data



Preprocessed data



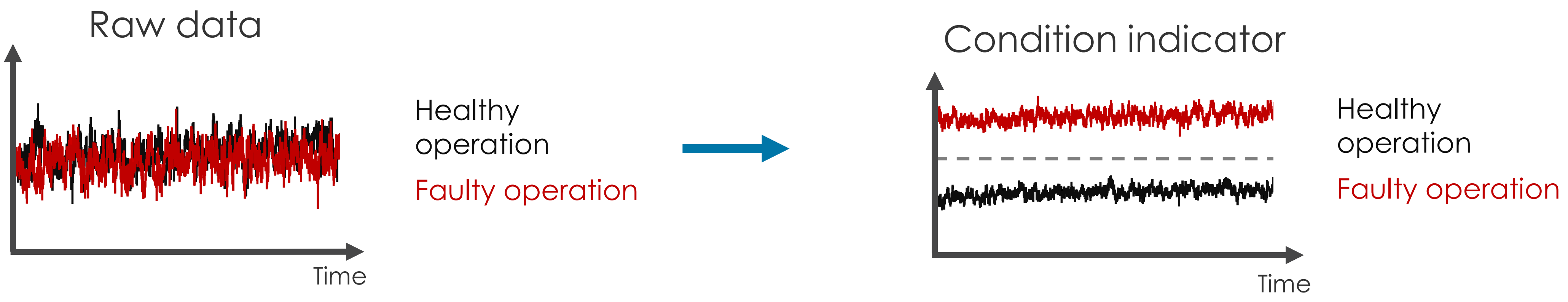
Predictive Maintenance Algorithm



- What are Condition Indicators?
- Why are they important?
- How to identify significant ones?

A condition indicator can be any feature that is useful -

- for distinguishing normal from faulty operation or
- for predicting remaining useful life



Identify condition indicators

Signal-Based Condition Indicators

Time-domain features

Mean

Standard deviation

Skewness

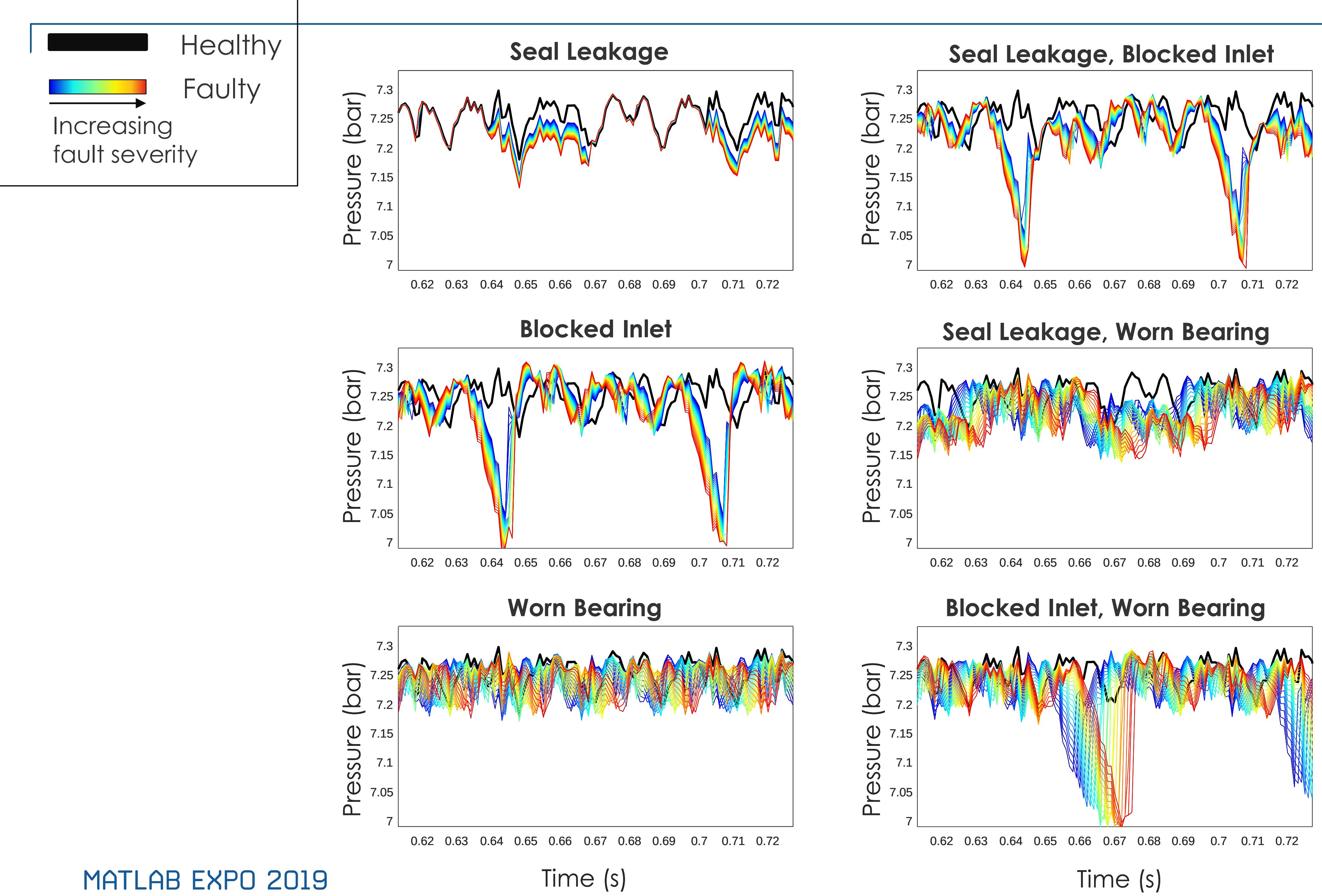
Root-mean square

Kurtosis

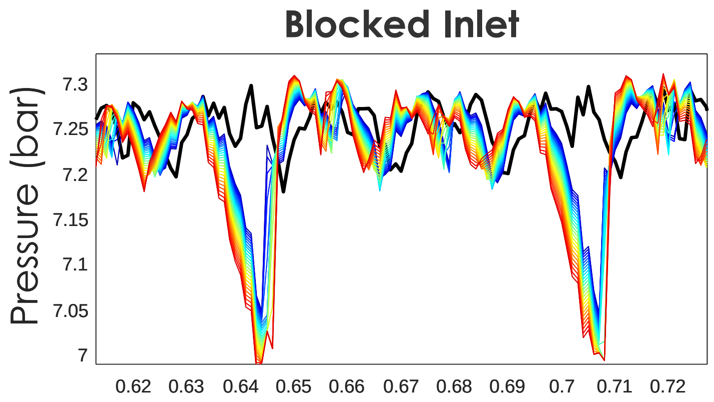
⋮

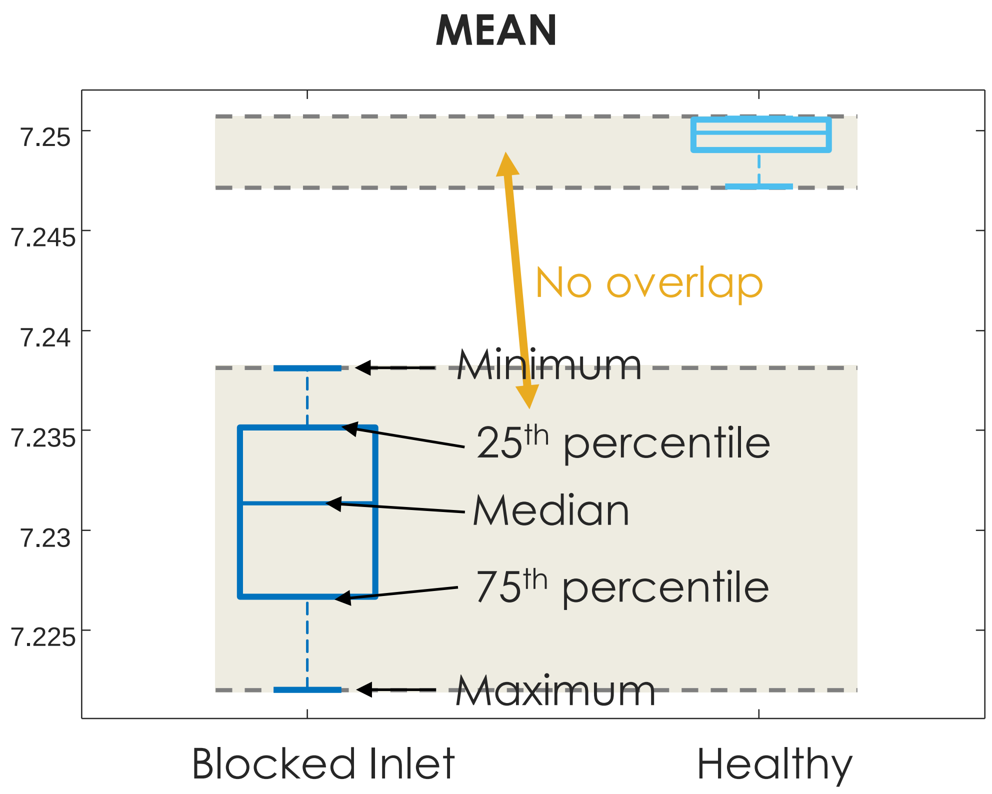
Frequency-domain features

Time-frequency domain features

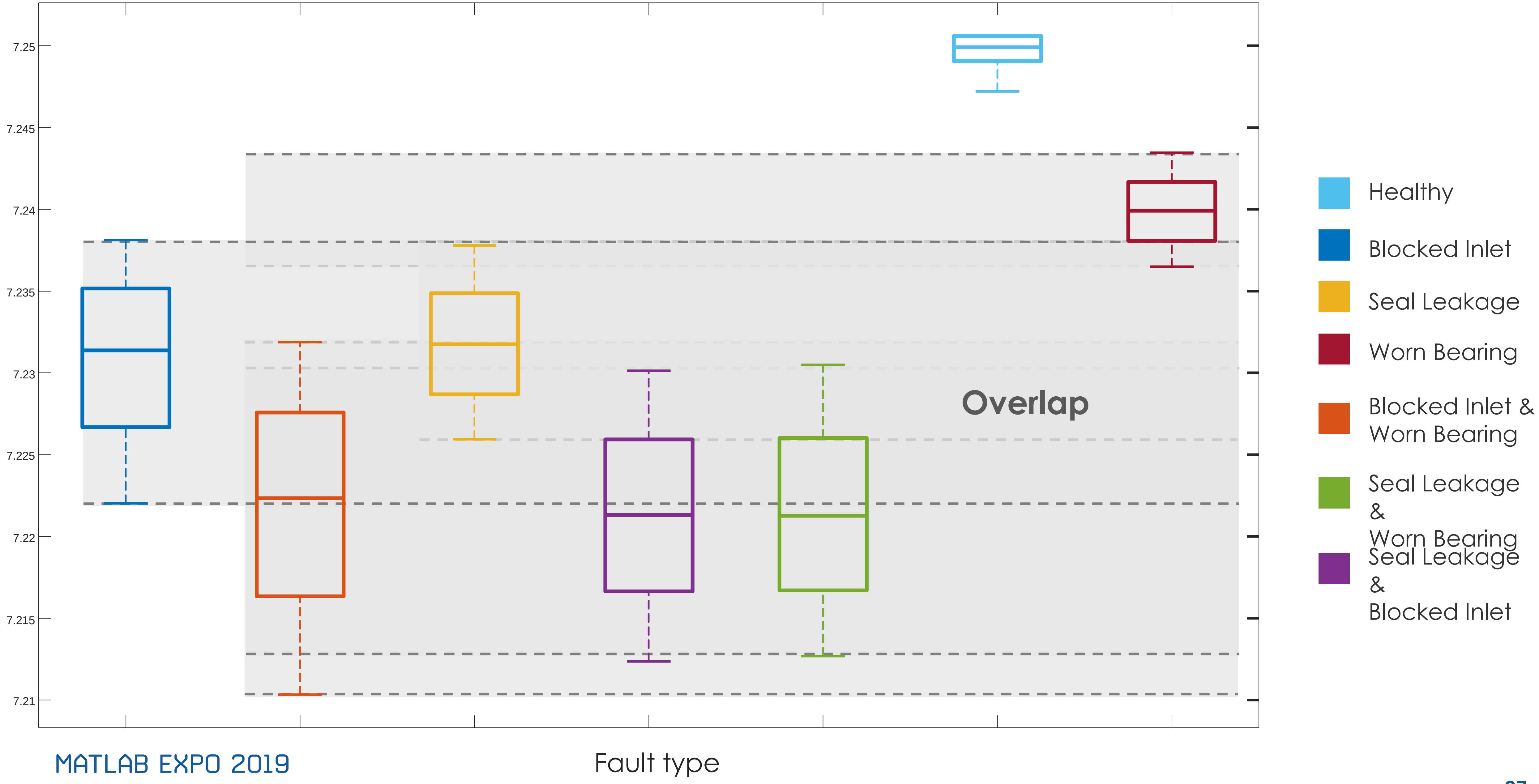


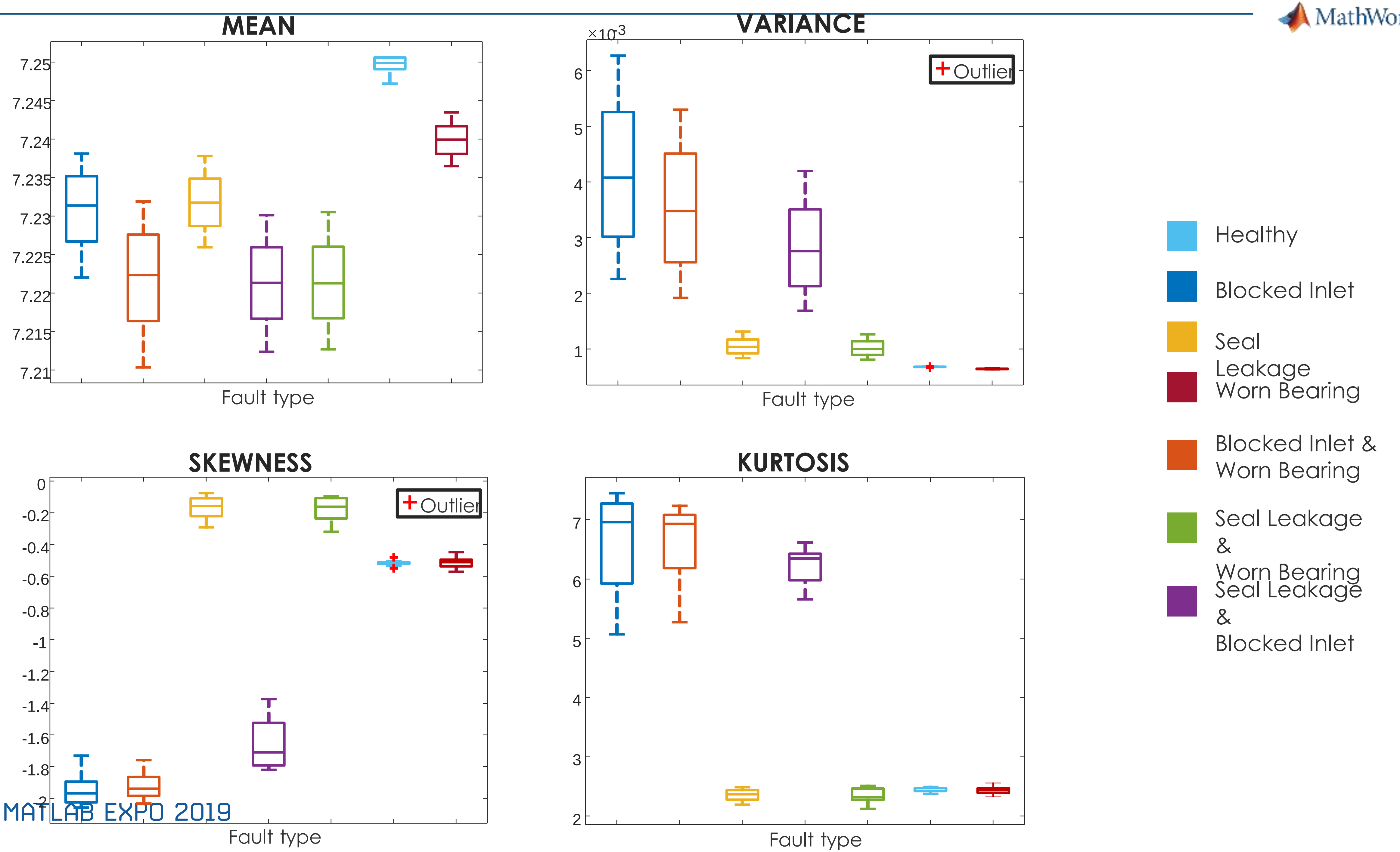
Healthy
Faulty
Increasing fault severity
Seal Leakage
Seal Leakage, Blocked Inlet
Blocked Inlet
Seal Leakage, Worn Bearing
Worn Bearing
Blocked Inlet, Worn Bearing
Pressure (bar)
7.3
7.25
7.2
7.15
7.1
7.05
7
0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.7 0.71 0.72
Time (s)


Blocked Inlet
Pressure (bar)
7.3
7.25
7.2
7.15
7.1
7.05
7
0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.7 0.71 0.72

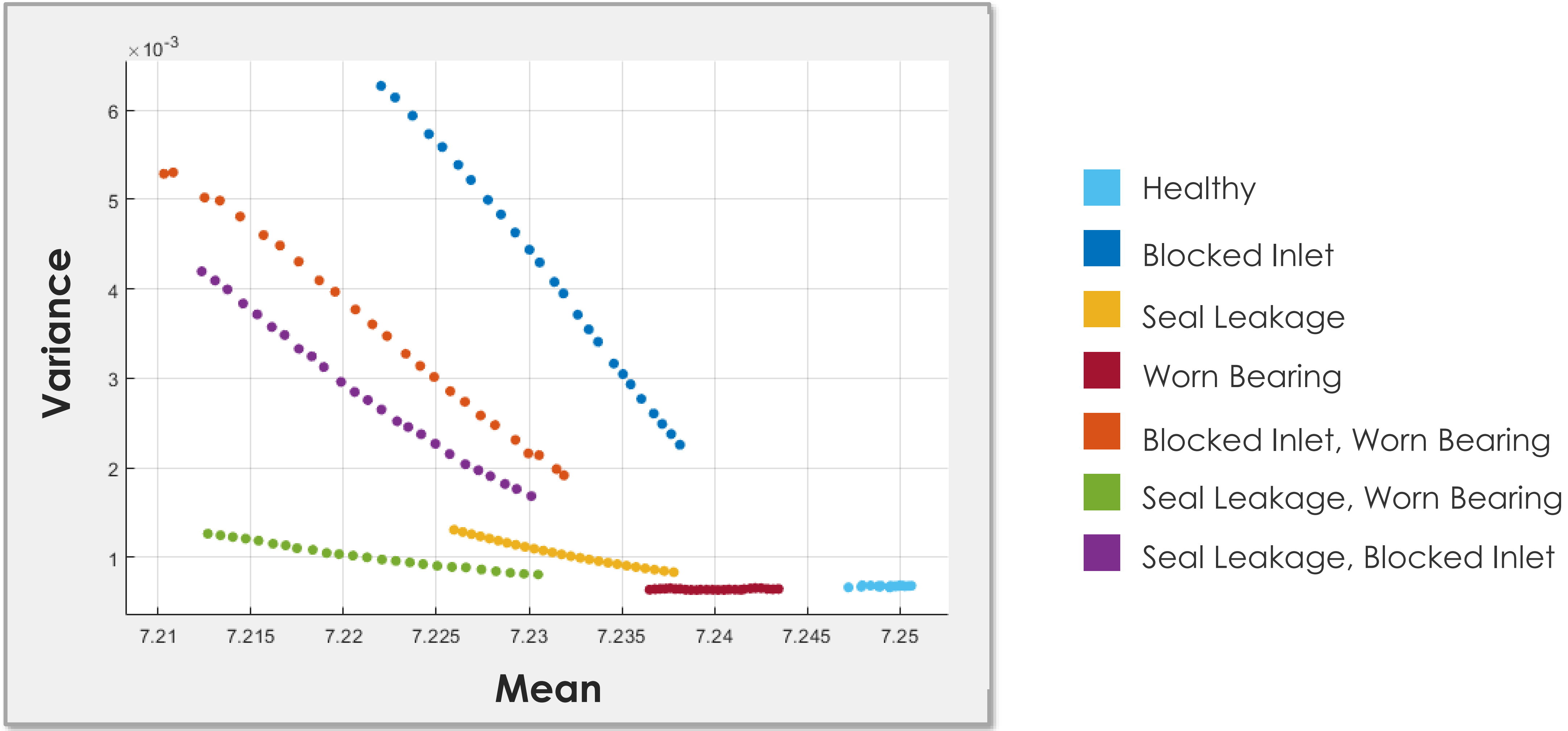

MEAN
7.25
7.245
7.24
7.235
7.23
7.225
No overlap
Minimum
25th percentile
Median
75th percentile
Maximum
Blocked Inlet
Healthy

MEAN


7.25
7.245
7.24
7.235
7.23
7.225
7.22
7.215
7.21
Overlap
Healthy
Blocked Inlet
Seal Leakage
Worn Bearing
Blocked Inlet & Worn Bearing
Seal Leakage & Worn Bearing
Seal Leakage & Blocked Inlet
Fault type



MEAN
7.25
7.245
7.24
7.235
7.23
7.225
7.22
7.215
7.21
Fault type
VARIANCE
×10^3
6
5
4
3
2
1
Outlier
Fault type
SKEWNESS
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
Outlier
Fault type
KURTOSIS
7
6
5
4
3
2
Fault type
Healthy
Blocked Inlet
Seal Leakage
Worn Bearing
Blocked Inlet & Worn Bearing
Seal Leakage & Worn Bearing
Seal Leakage & Blocked Inlet



×10^-3
6
5
4
3
2
1
7.21
7.215
7.22
7.225
7.23
7.235
7.24
7.245
7.25
Variance
Mean
Healthy
Blocked Inlet
Seal Leakage
Worn Bearing
Blocked Inlet, Worn Bearing
Seal Leakage, Worn Bearing
Seal Leakage, Blocked Inlet

Signal-Based Condition Indicators

Time-domain features

Mean

Standard deviation

Skewness

Root-mean square

Kurtosis

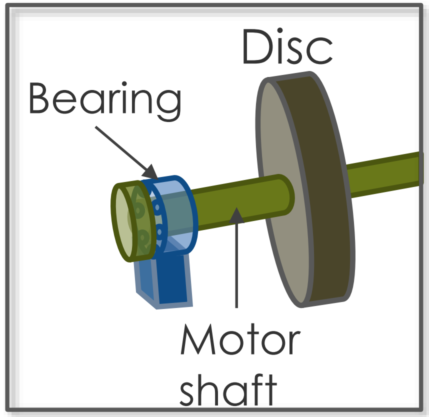
•
•
•

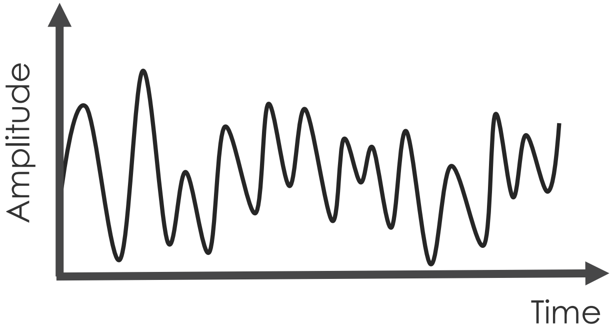
Frequency-domain features

Time-frequency domain features

[Learn more about Condition Indicators]

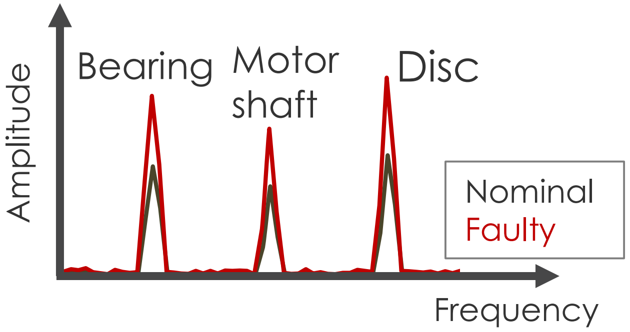
Machine with rotating components



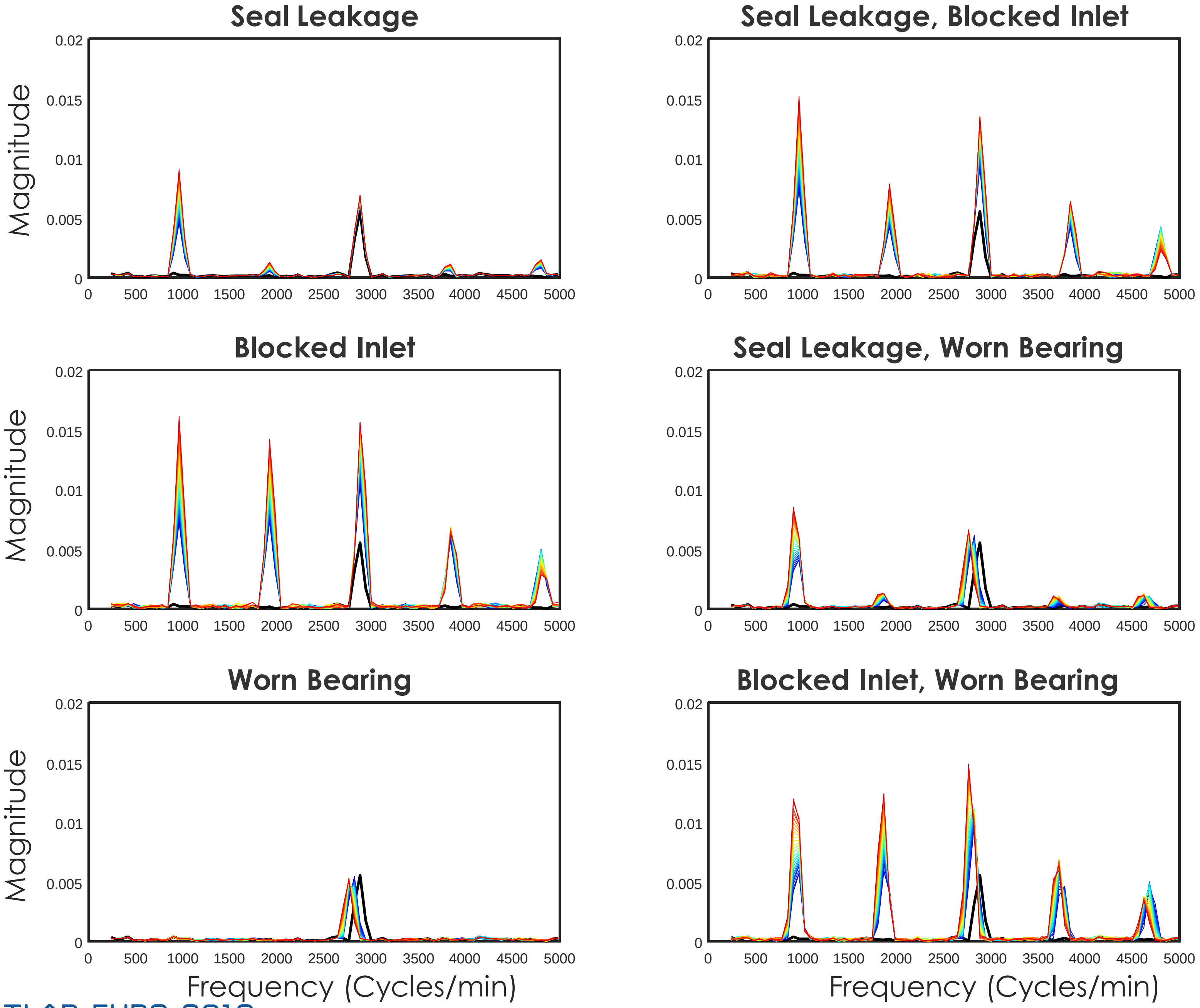


- In time-domain, we observe the combined effect of different sources of vibration.

Three different vibration sources:
- Bearing
- Motor shaft
- Disc



- Using frequency-domain analysis, we can distinguish different sources of vibration.

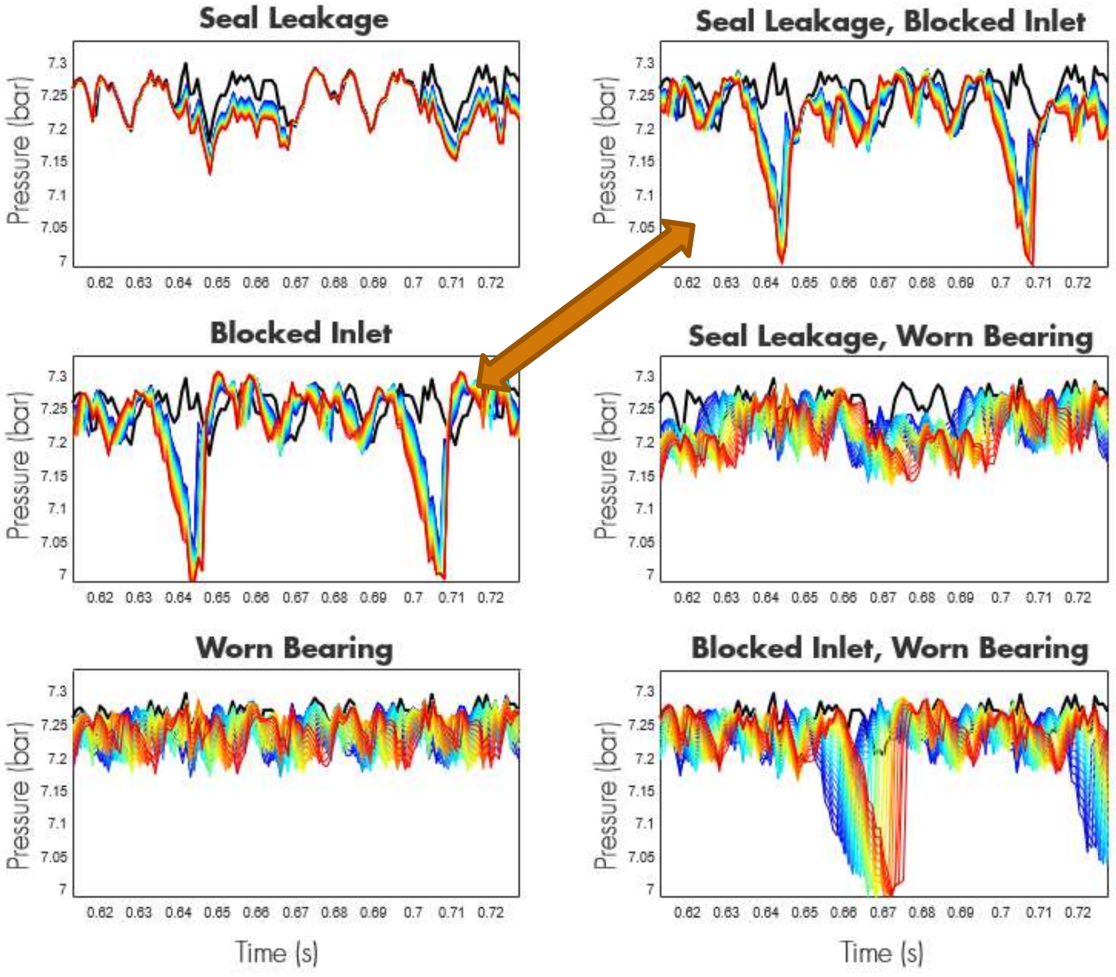


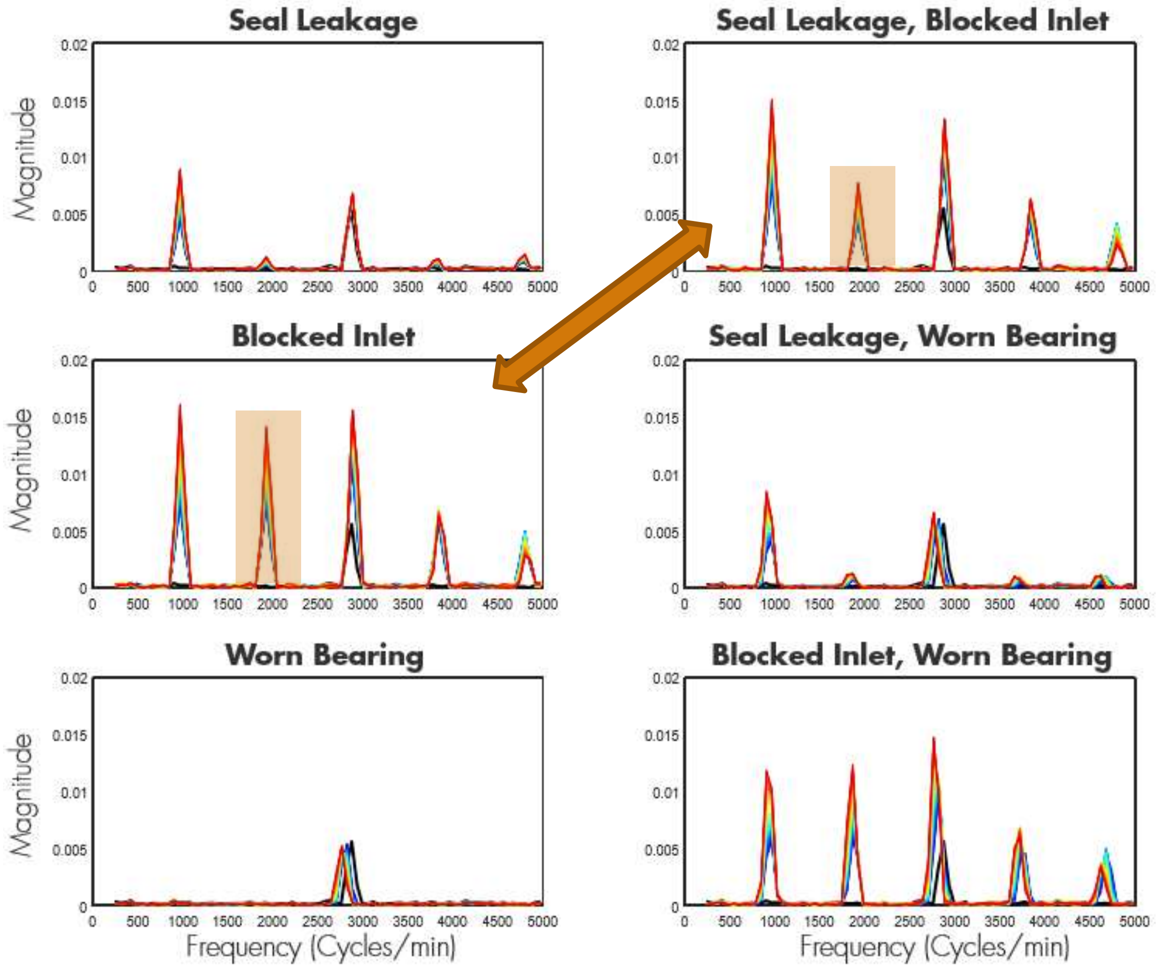
Frequency-domain features:

- Peaks
- Peak frequencies

Time-domain

Frequency-domain





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

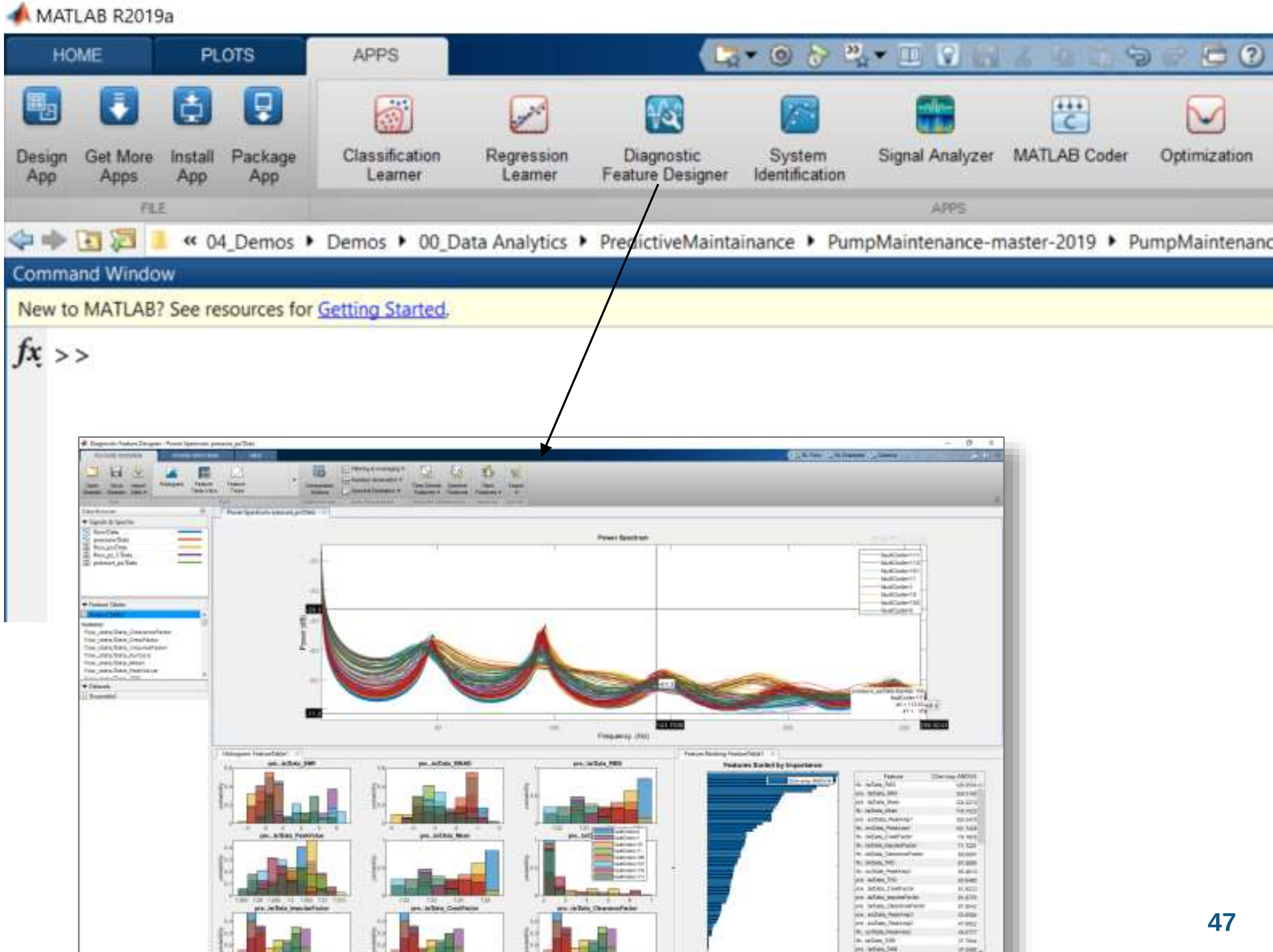
⋮

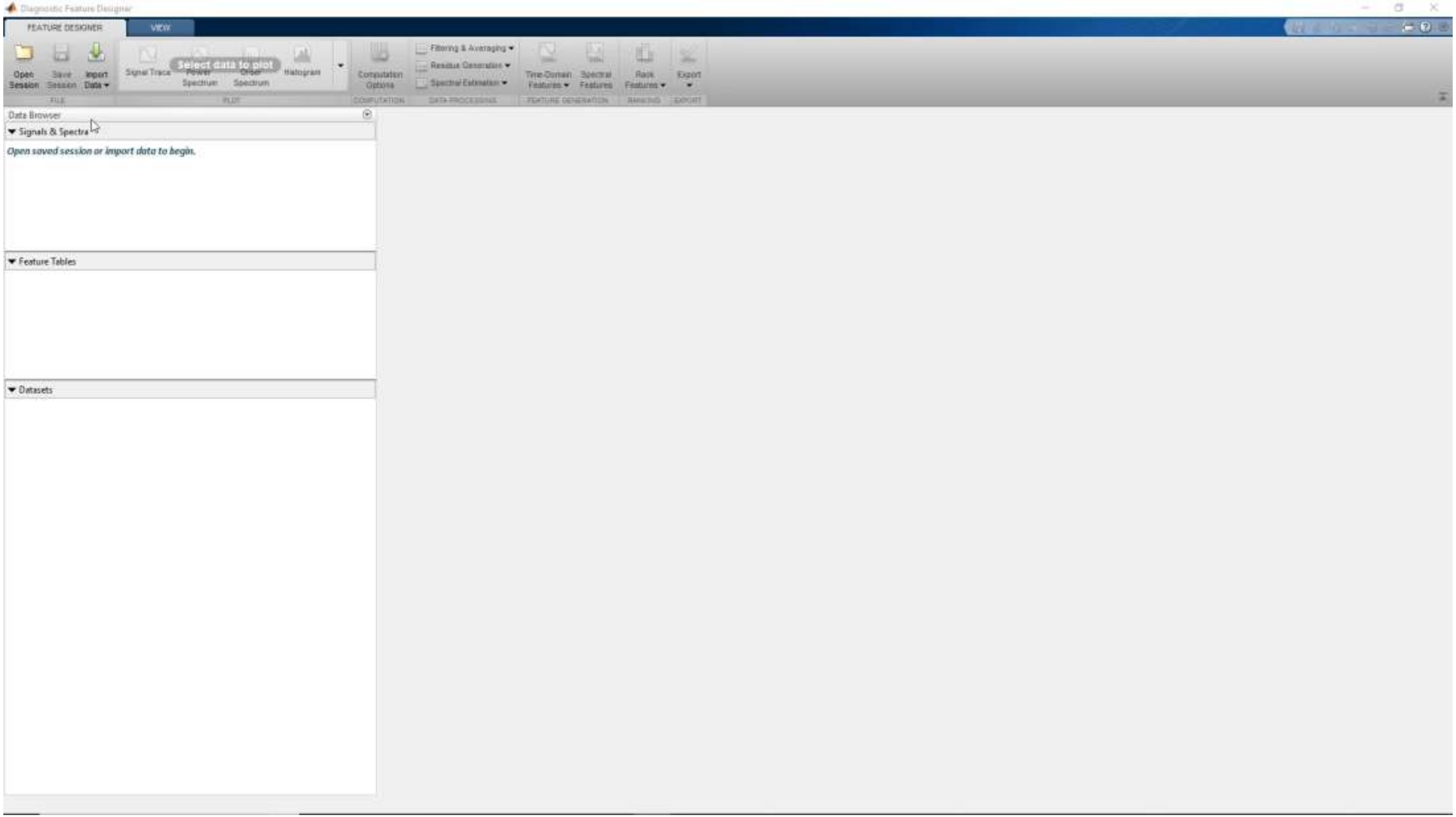
[Learn more about Condition Indicators]

Diagnostic Feature Designer App

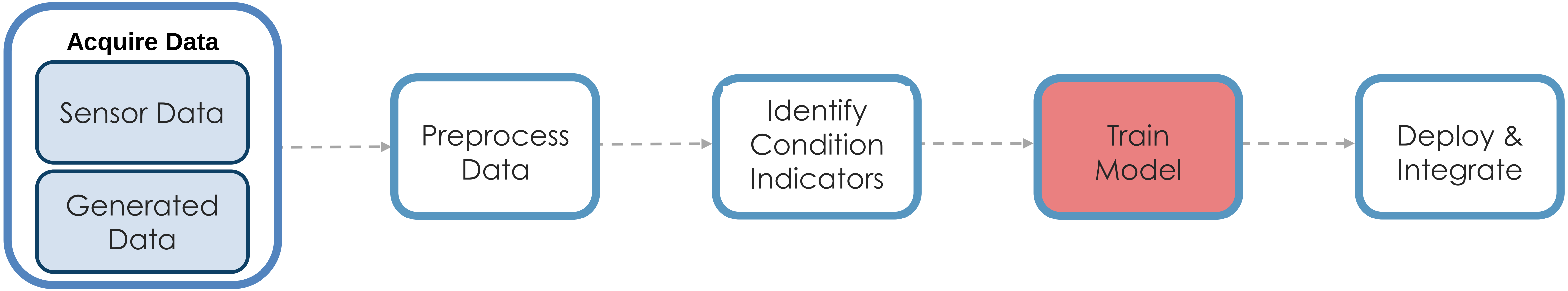
Predictive Maintenance Toolbox R2019a

- 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
VIEW
Open Session
Save Session
Import Data
Signal Trace
Select data to plot
Power Spectrum
Order Spectrum
Histogram
Computation Options
Filtering & Averaging
Residue Generation
Spectral Estimation
Time-Domain Features
Spectral Features
Rank Features
Export
Data Browser
Signals & Spectra
Open saved session or import data to begin.
Feature Tables
Datasets

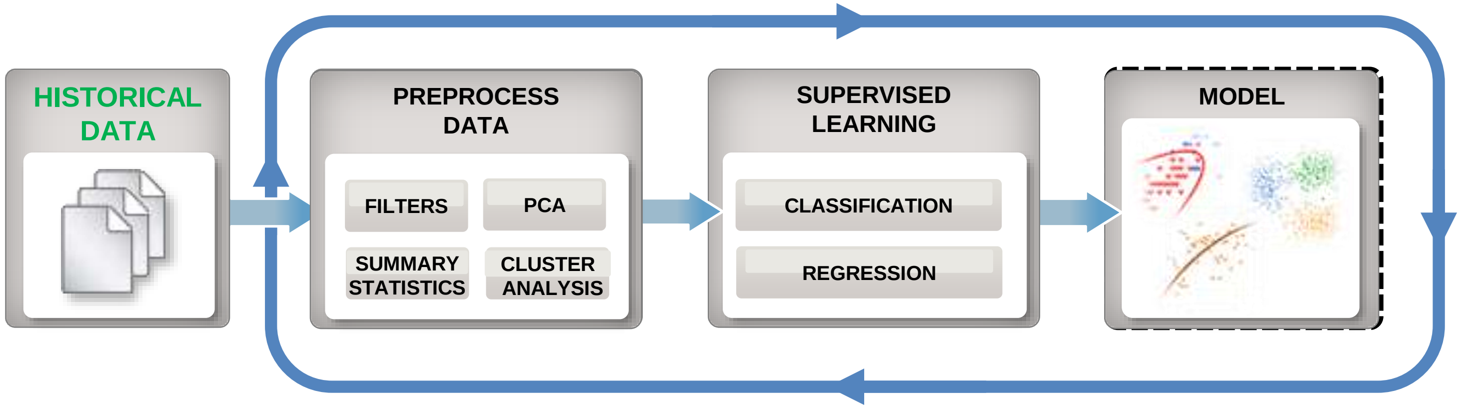
Predictive Maintenance Algorithm



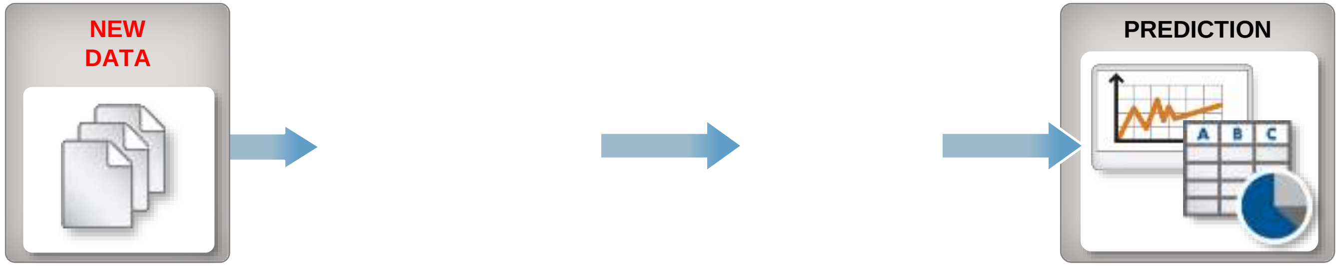
Machine Learning Workflow

Machine learning uses data and produces a program to perform a task

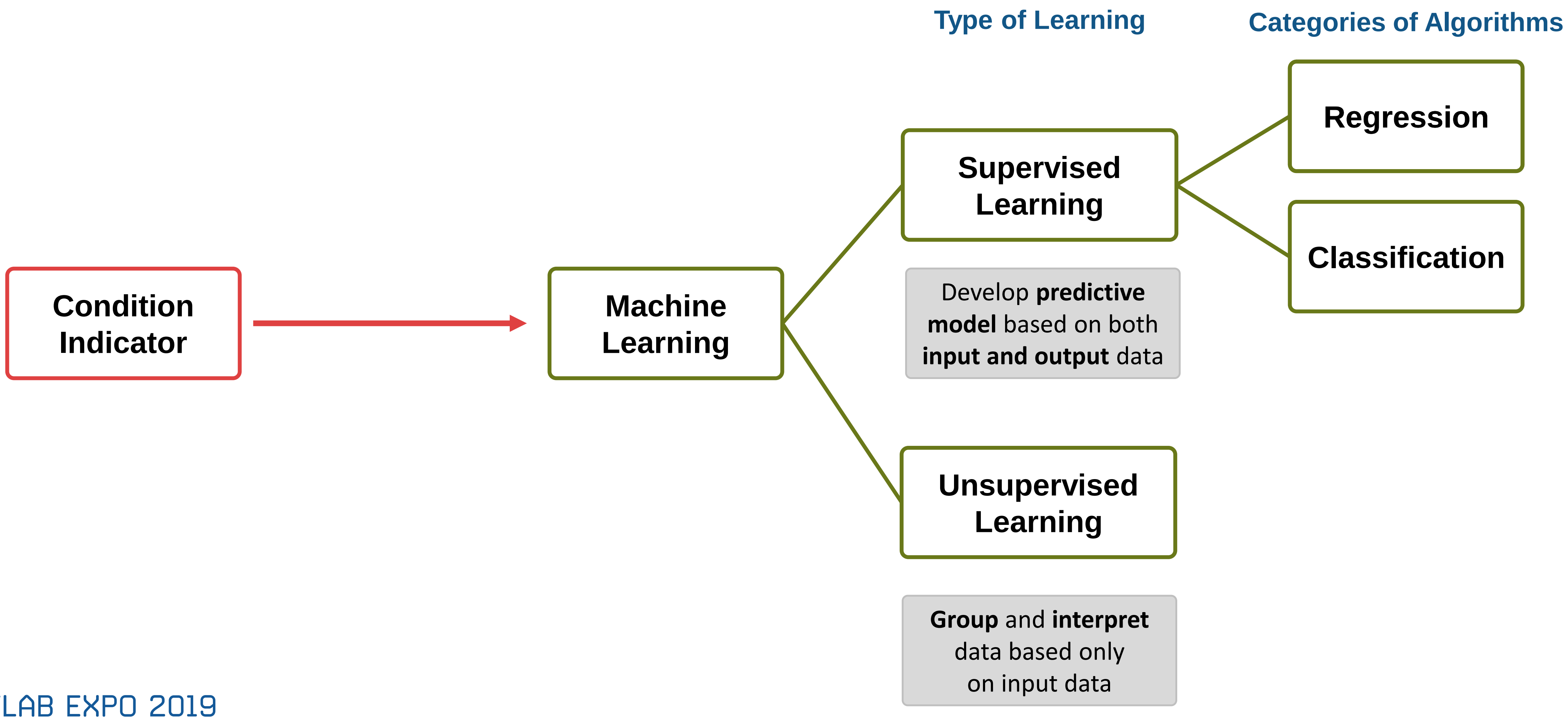
Train: Iterate till you find the best model using historical data



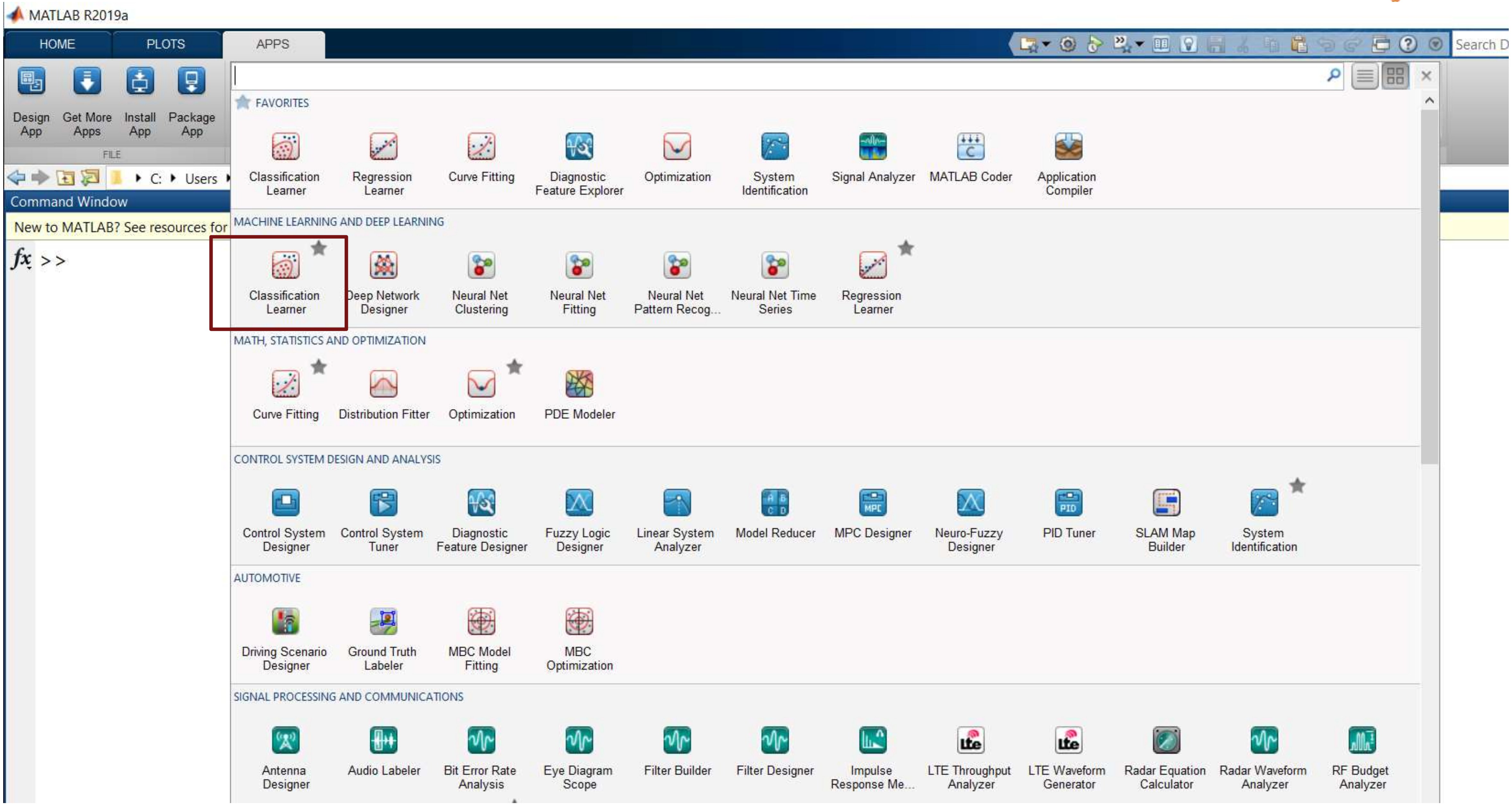
Predict: Integrate trained models into applications

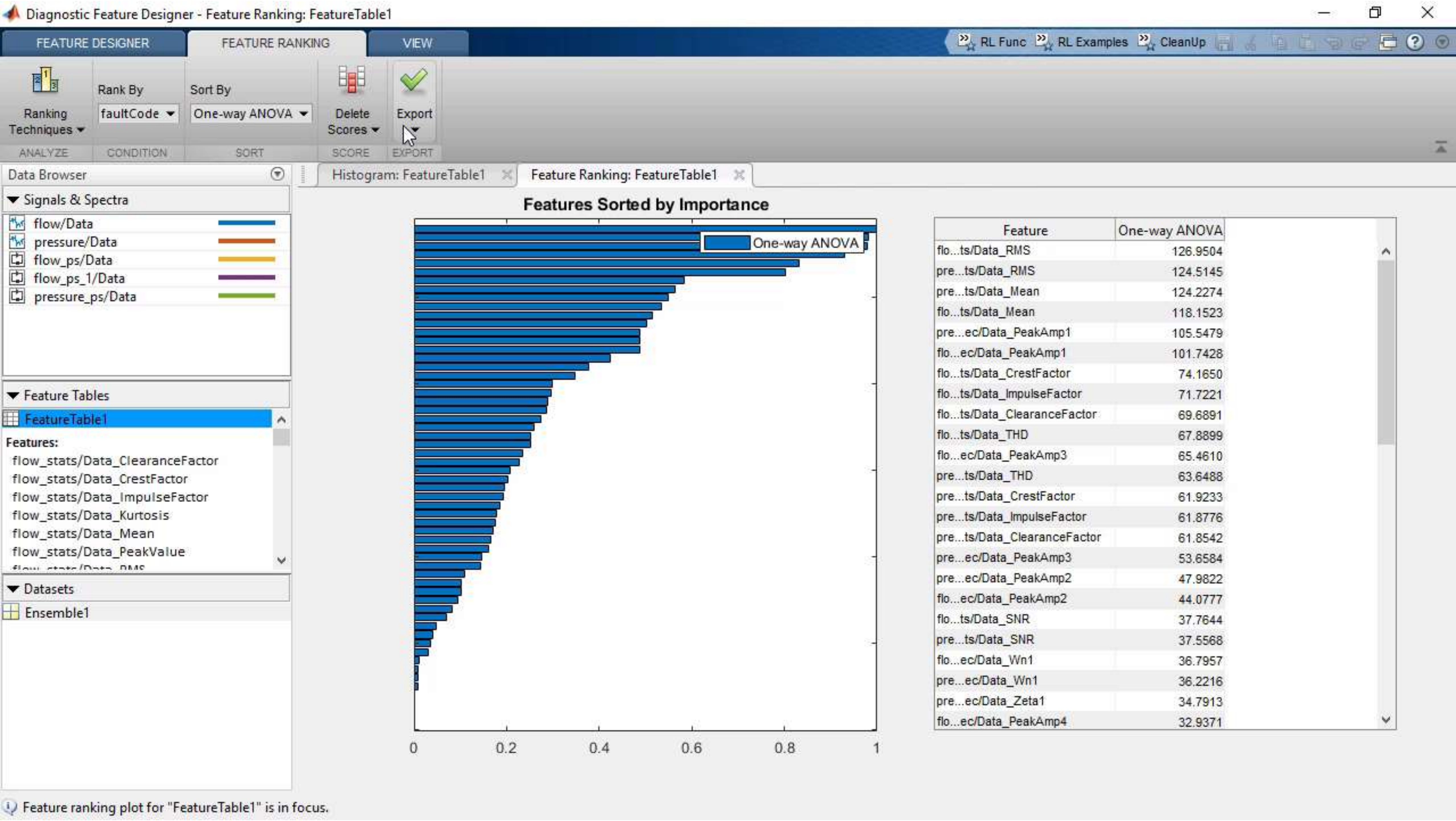


Machine Learning: Types



MathWorks

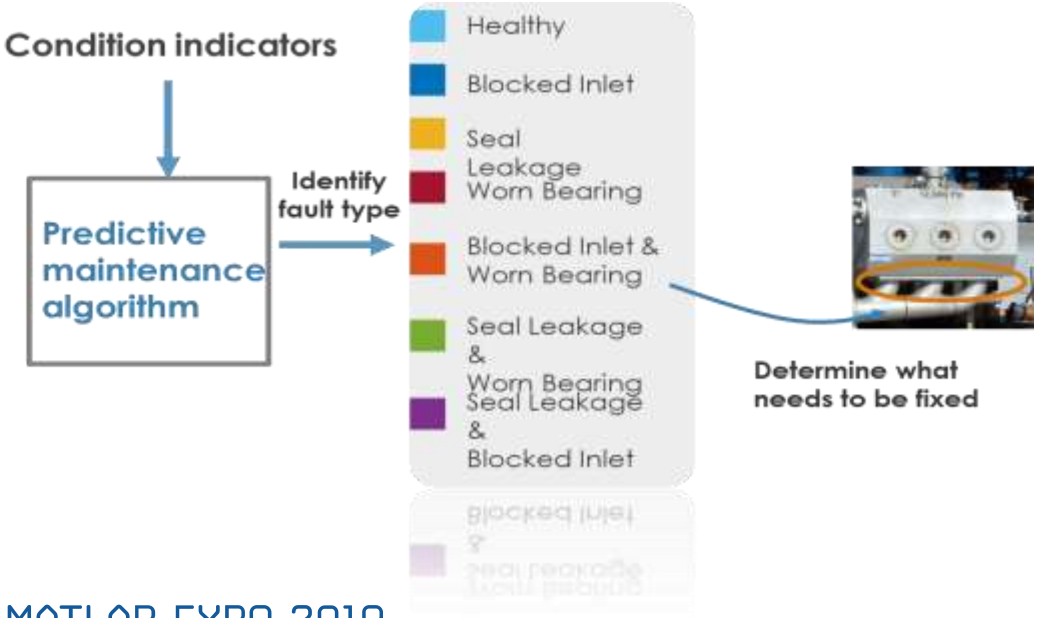

MATLAB R2019a
HOME
PLOTS
APPS
Design App
Get More Apps
Install App
Package App
FILE
C: Users
Command Window
New to MATLAB? See resources for
fx >>
FAVORITES
Classification Learner
Regression Learner
Curve Fitting
Diagnostic Feature Explorer
Optimization
System Identification
Signal Analyzer
MATLAB Coder
Application Compiler
MACHINE LEARNING AND DEEP LEARNING
Classification Learner
Deep Network Designer
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
PDE Modeler
CONTROL SYSTEM DESIGN AND ANALYSIS
Control System Designer
Control System Tuner
Diagnostic Feature Designer
Fuzzy Logic Designer
Linear System Analyzer
Model Reducer
MPC Designer
Neuro-Fuzzy Designer
PID Tuner
SLAM Map Builder
System Identification
AUTOMOTIVE
Driving Scenario Designer
Ground Truth Labeler
MBC Model Fitting
MBC Optimization
SIGNAL PROCESSING AND COMMUNICATIONS
Antenna Designer
Audio Labeler
Bit Error Rate Analysis
Eye Diagram Scope
Filter Builder
Filter Designer
Impulse Response Me...
LTE Throughput Analyzer
LTE Waveform Generator
Radar Equation Calculator
Radar Waveform Analyzer
RF Budget Analyzer

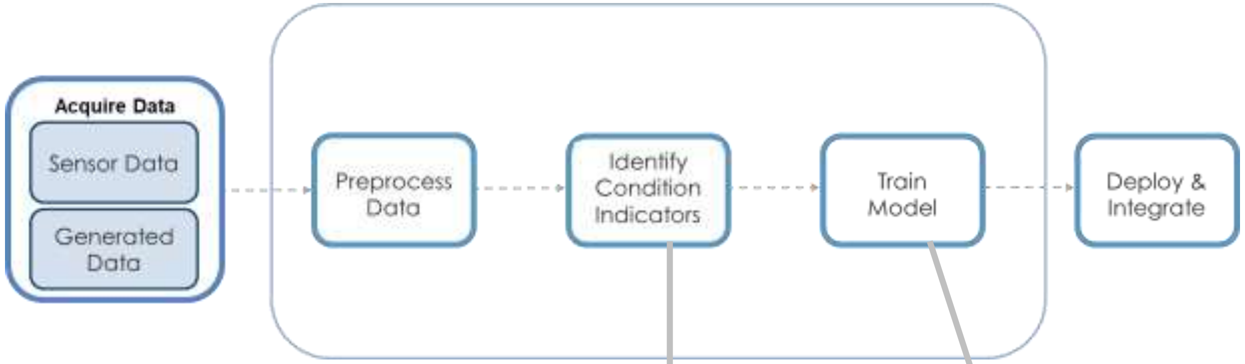


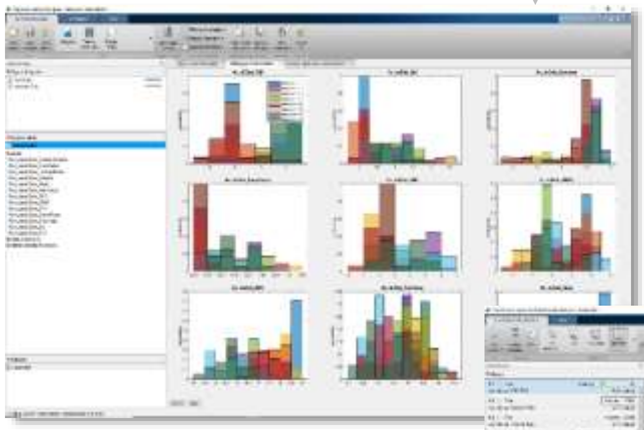
Diagnostic Feature Designer - Feature Ranking: FeatureTable1
FEATURE DESIGNER
FEATURE RANKING
VIEW
RL Func
RL Examples
CleanUp
Ranking Techniques
Rank By
faultCode
Sort By
One-way ANOVA
Delete Scores
Export
ANALYZE
CONDITION
SORT
SCORE
EXPORT
Data Browser
Signals & Spectra
flow/Data
pressure/Data
flow_ps/Data
flow_ps_1/Data
pressure_ps/Data
Feature Tables
FeatureTable1
Features:
flow_stats/Data_ClearanceFactor
flow_stats/Data_CrestFactor
flow_stats/Data_ImpulseFactor
flow_stats/Data_Kurtosis
flow_stats/Data_Mean
flow_stats/Data_PeakValue
Datasets
Ensemble1
Histogram: FeatureTable1
Feature Ranking: FeatureTable1
Features Sorted by Importance
One-way ANOVA
0
0.2
0.4
0.6
0.8
1
Feature
One-way ANOVA
flo...ts/Data_RMS 126.9504
pre...ts/Data_RMS 124.5145
pre...ts/Data_Mean 124.2274
flo...ts/Data_Mean 118.1523
pre...ec/Data_PeakAmp1 105.5479
flo...ec/Data_PeakAmp1 101.7428
flo...ts/Data_CrestFactor 74.1650
flo...ts/Data_ImpulseFactor 71.7221
flo...ts/Data_ClearanceFactor 69.6891
flo...ts/Data_THD 67.8899
flo...ec/Data_PeakAmp3 65.4610
pre...ts/Data_THD 63.6488
pre...ts/Data_CrestFactor 61.9233
pre...ts/Data_ImpulseFactor 61.8776
pre...ts/Data_ClearanceFactor 61.8542
pre...ec/Data_PeakAmp3 53.6584
pre...ec/Data_PeakAmp2 47.9822
flo...ec/Data_PeakAmp2 44.0777
flo...ts/Data_SNR 37.7644
pre...ts/Data_SNR 37.5568
flo...ec/Data_Wn1 36.7957
pre...ec/Data_Wn1 36.2216
pre...ec/Data_Zeta1 34.7913
flo...ec/Data_PeakAmp4 32.9371
Feature ranking plot for "FeatureTable1" is in focus.

Summary: Develop Predictive Maintenance Algorithm:

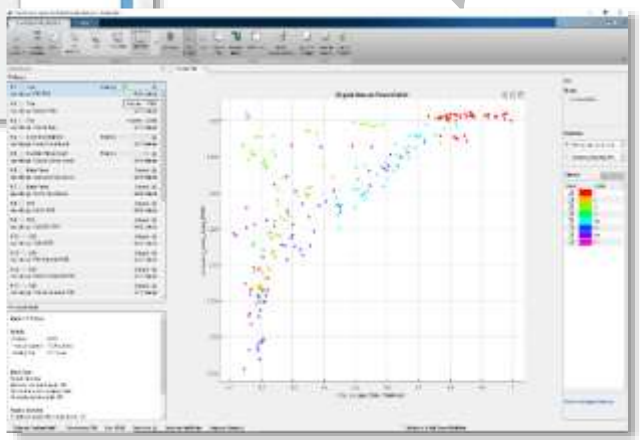
Use case 1: Fault Classification







Diagnostic Feature Designer



Classification Learner App

Develop Predictive Maintenance Algorithm: Use case 2

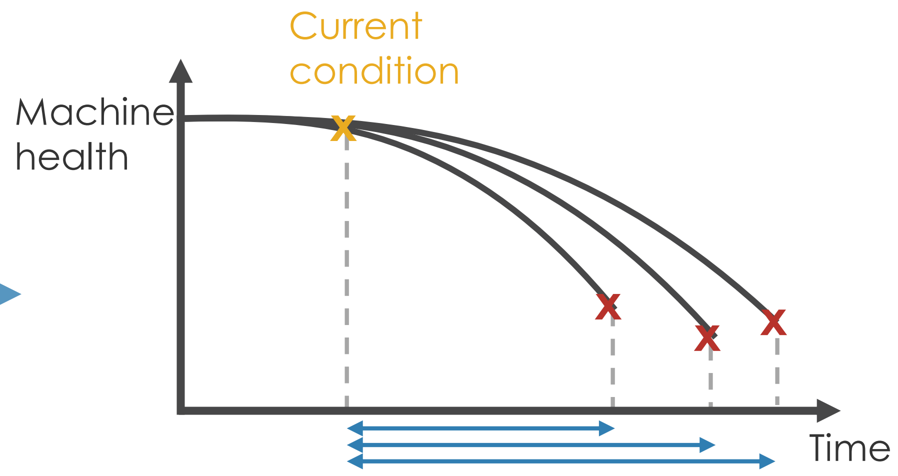
How much longer can I operate my machine ?

Remaining Useful Life Estimation

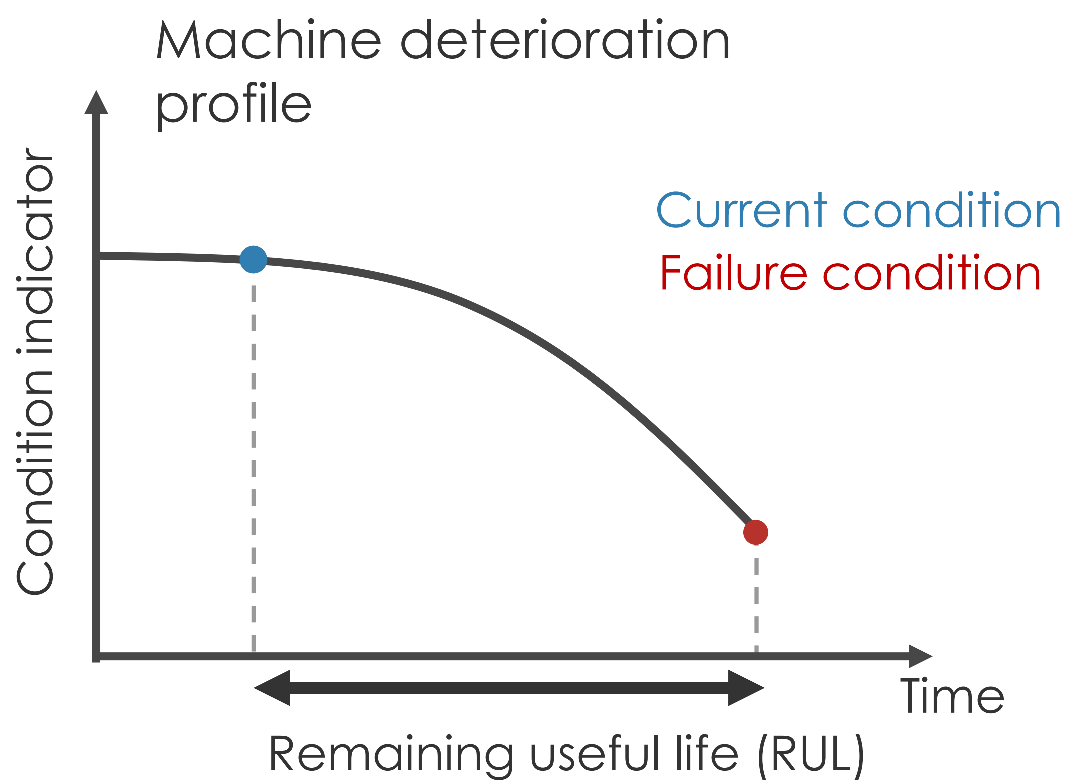
Condition indicators

Predictive maintenance algorithm

Estimate remaining useful life



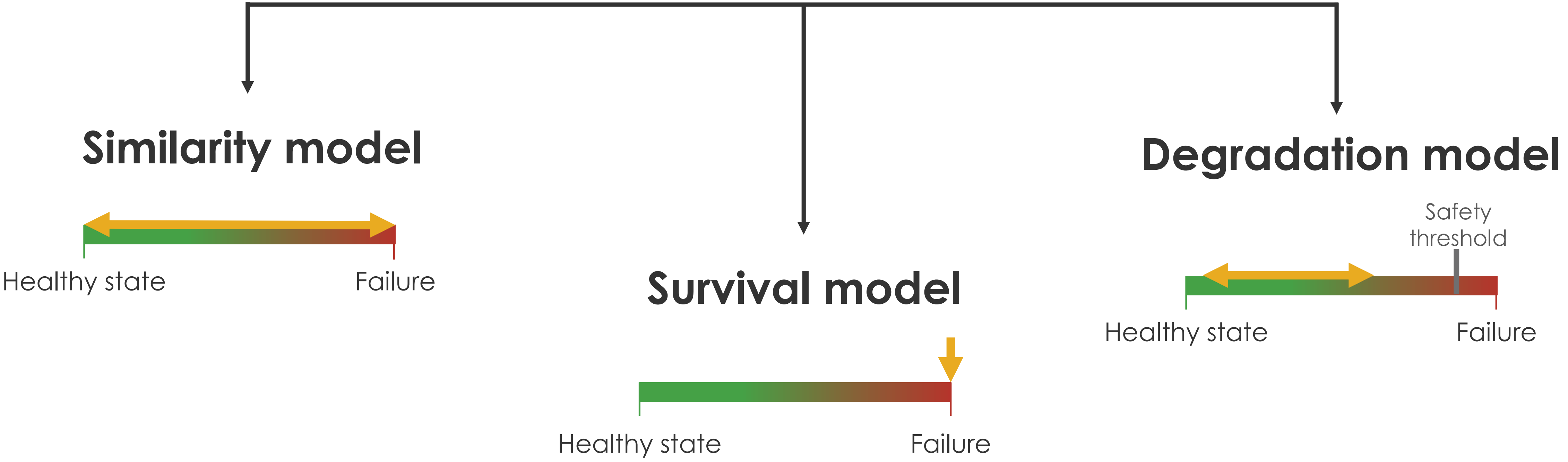
Remaining useful life



[Number of days]
[Miles]
[Cycles]
⋮

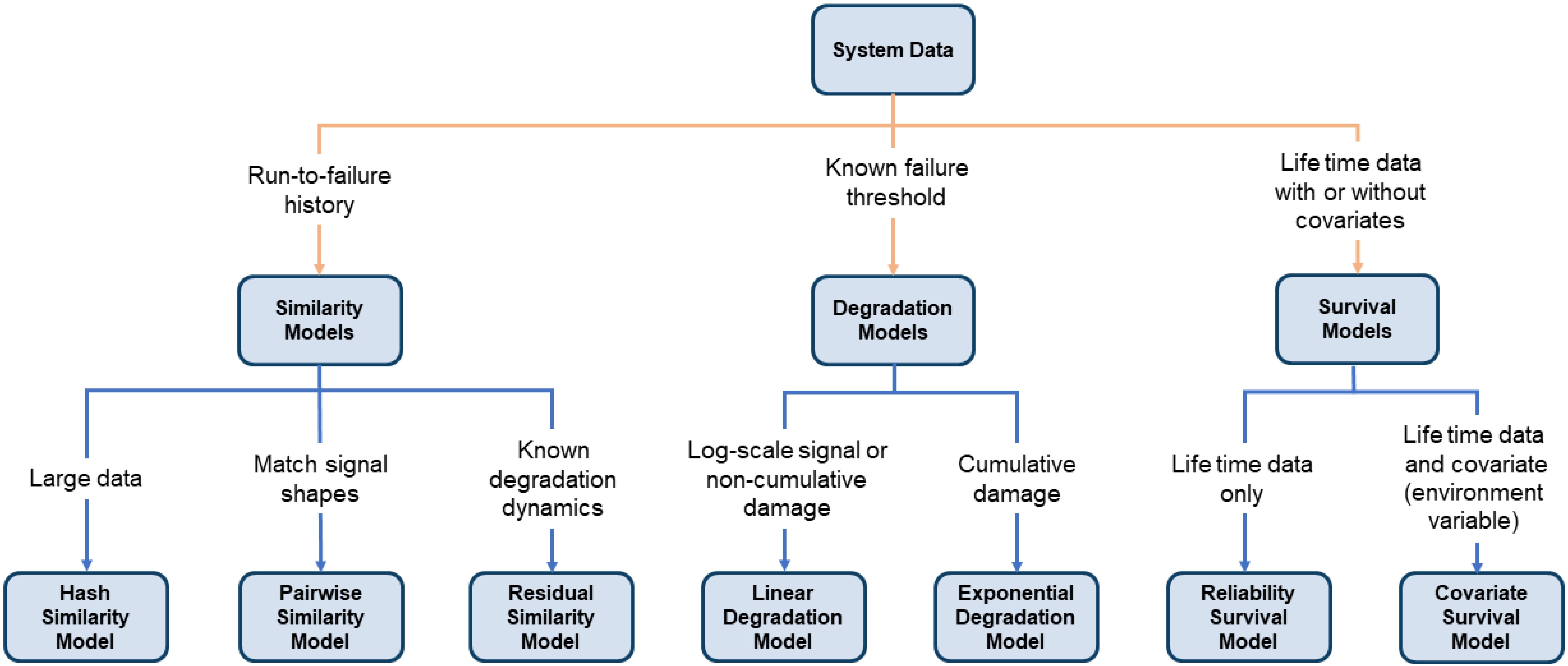
What is RUL?

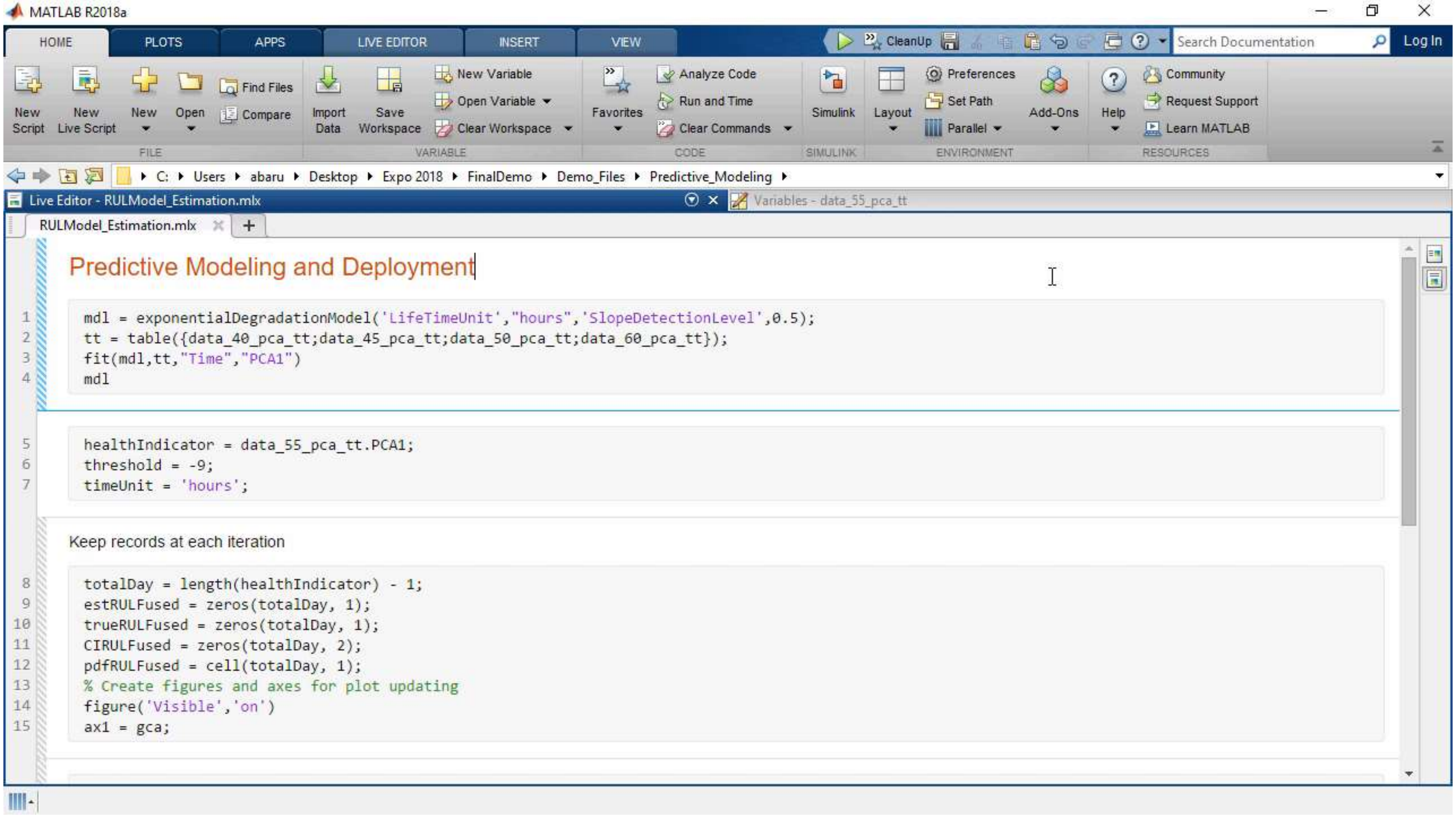
RUL Estimator Models



RUL Methods and when to use them

Requirement: Need to know what constitutes failure data




MATLAB R2018a
HOME
PLOTS
APPS
LIVE EDITOR
INSERT
VIEW
CleanUp
Search Documentation
Log In
New Script
New Live Script
New
Open
Find Files
Compare
FILE
Import Data
Save Workspace
New Variable
Open Variable
Clear Workspace
VARIABLE
Favorites
Analyze Code
Run and Time
Clear Commands
CODE
Simulink
SIMULINK
Layout
Preferences
Set Path
Parallel
Add-Ons
ENVIRONMENT
Help
Community
Request Support
Learn MATLAB
RESOURCES
C: ▸ Users ▸ abaru ▸ Desktop ▸ Expo 2018 ▸ FinalDemo ▸ Demo_Files ▸ Predictive_Modeling ▸
Live Editor - RULModel_Estimation.mlx
Variables - data_55_pca_tt
RULModel_Estimation.mlx
Predictive Modeling and Deployment
mdl = exponentialDegradationModel('LifeTimeUnit',"hours",'SlopeDetectionLevel',0.5);
tt = table({data_40_pca_tt;data_45_pca_tt;data_50_pca_tt;data_60_pca_tt});
fit(mdl,tt,"Time","PCA1")
mdl
healthIndicator = data_55_pca_tt.PCA1;
threshold = -9;
timeUnit = 'hours';
Keep records at each iteration
totalDay = length(healthIndicator) - 1;
estRULFused = zeros(totalDay, 1);
trueRULFused = zeros(totalDay, 1);
CIRULFused = zeros(totalDay, 2);
pdfRULFused = cell(totalDay, 1);
% Create figures and axes for plot updating
figure('Visible','on')
ax1 = gca;

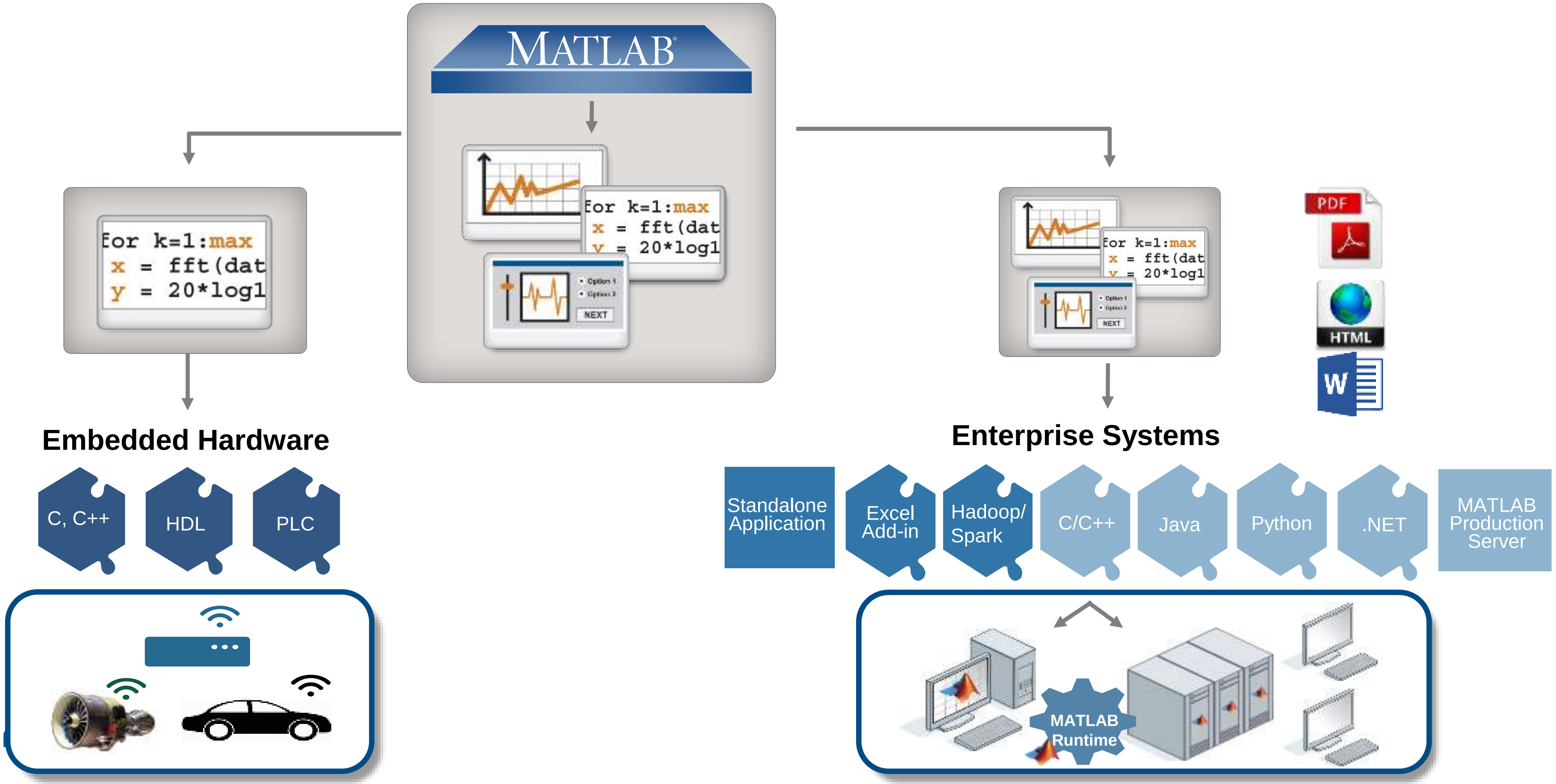
Predictive Maintenance Algorithm

Acquire Data → Preprocess Data → Identify Condition Indicators → Train Model → **Deploy & Integrate**

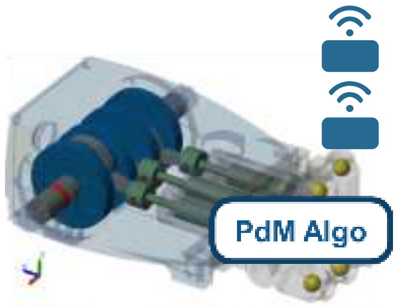
Edge device

Cloud

Deploy & Integrate analytics using MATLAB:

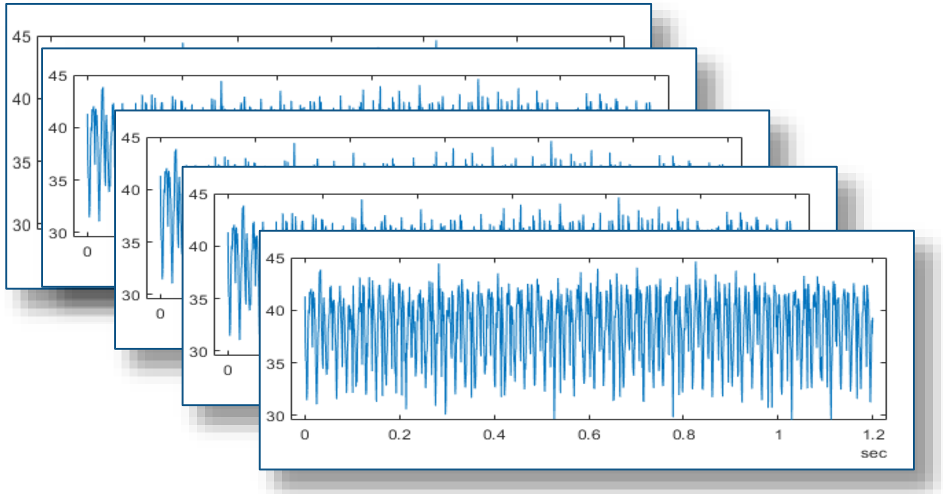


Feature Extraction Algorithm at the Edge



Asset w. smart sensors

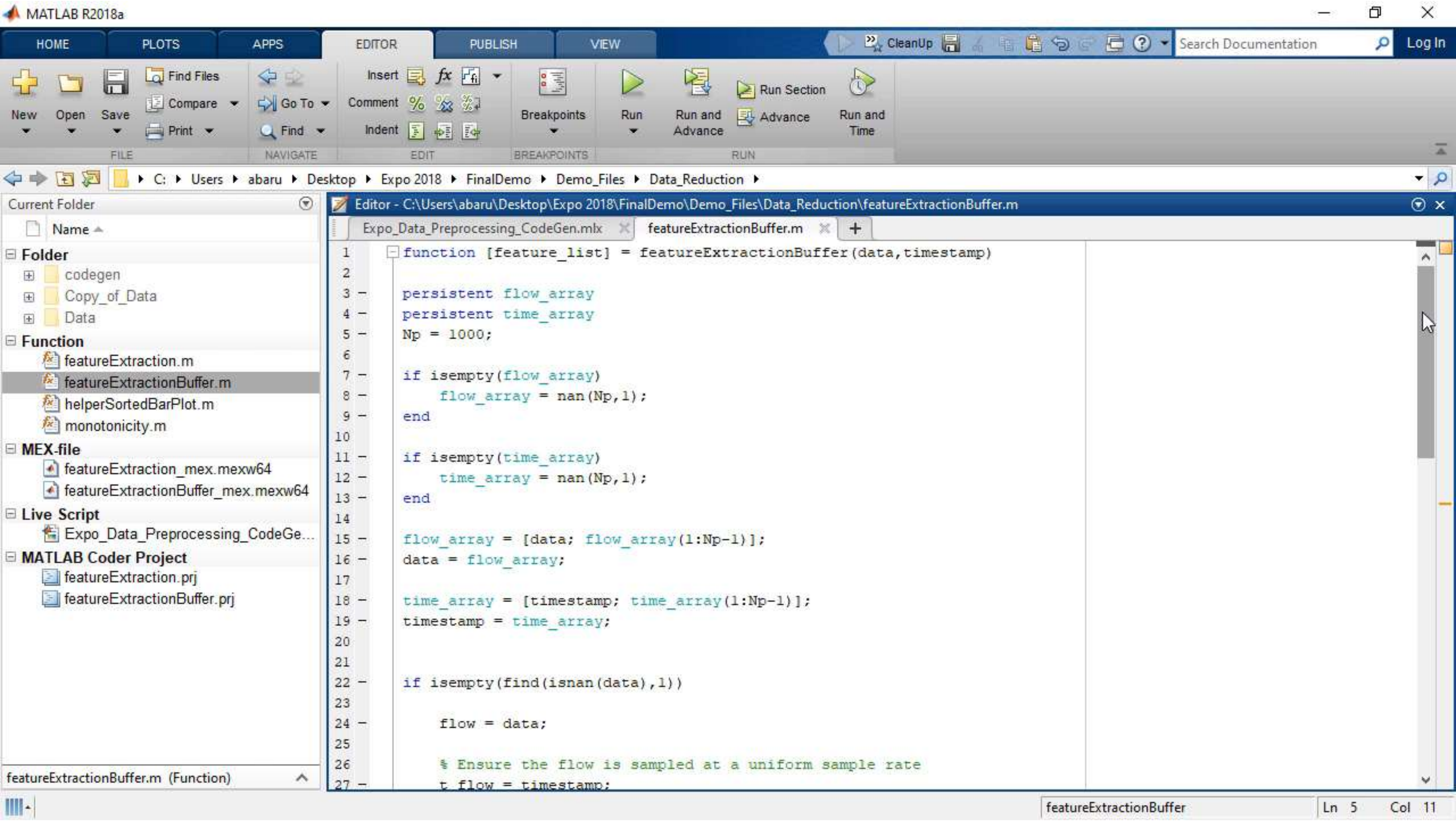
Pump flow sensor *1 sec ~ 1000 samples ~16kB*



- 1 day ~ 1.3 GB
- 20 sensors/pump ~26 GB/day
- 3 pumps ~ 78 GB/day

Challenge:
Data transmission cost is pretty high

Solution:
Extract only relevant information and send it to predictive model


MATLAB R2018a
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Search Documentation
Log In
New
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Find Files
Compare
Print
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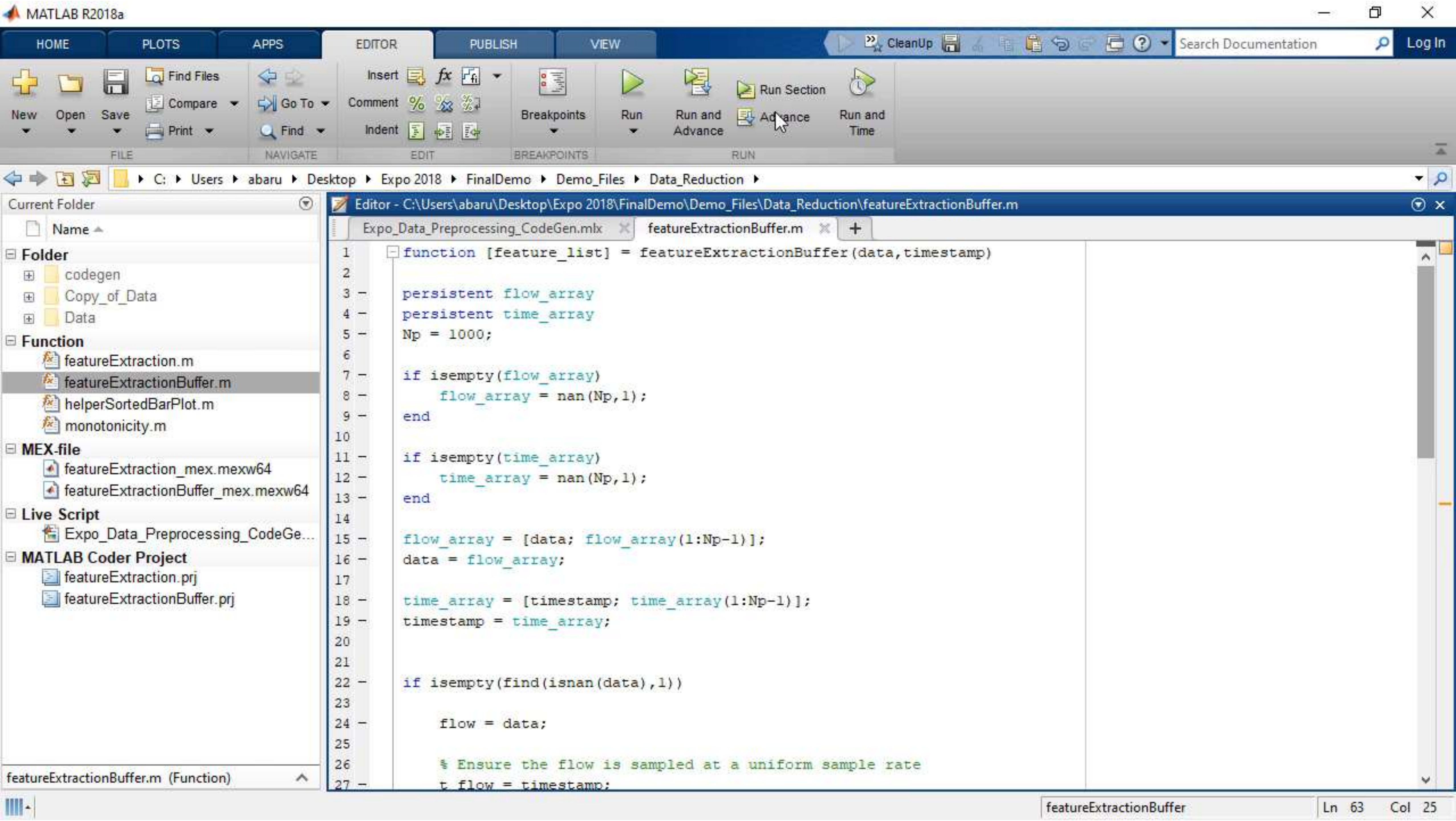
Go To
Find
NAVIGATE
Insert
Comment
Indent
EDIT
Breakpoints
BREAKPOINTS
Run
Run and Advance
Run Section
Advance
Run and Time
RUN
C: ▸ Users ▸ abaru ▸ Desktop ▸ Expo 2018 ▸ FinalDemo ▸ Demo_Files ▸ Data_Reduction ▸
Current Folder
Name
Folder
codegen
Copy_of_Data
Data
Function
featureExtraction.m
featureExtractionBuffer.m
helperSortedBarPlot.m
monotonicity.m
MEX-file
featureExtraction_mex.mexw64
featureExtractionBuffer_mex.mexw64
Live Script
Expo_Data_Preprocessing_CodeGe...
MATLAB Coder Project
featureExtraction.prj
featureExtractionBuffer.prj
featureExtractionBuffer.m (Function)
Editor - C:\Users\abaru\Desktop\Expo 2018\FinalDemo\Demo_Files\Data_Reduction\featureExtractionBuffer.m
Expo_Data_Preprocessing_CodeGen.mlx
featureExtractionBuffer.m
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;
featureExtractionBuffer
Ln 5
Col 11


MATLAB R2018a
HOME
PLOTS
APPS
EDITOR
PUBLISH
VIEW
CleanUp
Search Documentation
Log In
New
Open
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Find Files
Compare
Print
FILE
Go To
Find
NAVIGATE
Insert
Comment
Indent
EDIT
Breakpoints
BREAKPOINTS
Run
Run and Advance
Run Section
Advance
Run and Time
RUN
C: ▸ Users ▸ abaru ▸ Desktop ▸ Expo 2018 ▸ FinalDemo ▸ Demo_Files ▸ Data_Reduction ▸
Current Folder
Name
Folder
codegen
Copy_of_Data
Data
Function
featureExtraction.m
featureExtractionBuffer.m
helperSortedBarPlot.m
monotonicity.m
MEX-file
featureExtraction_mex.mexw64
featureExtractionBuffer_mex.mexw64
Live Script
Expo_Data_Preprocessing_CodeGe...
MATLAB Coder Project
featureExtraction.prj
featureExtractionBuffer.prj
featureExtractionBuffer.m (Function)
Editor - C:\Users\abaru\Desktop\Expo 2018\FinalDemo\Demo_Files\Data_Reduction\featureExtractionBuffer.m
Expo_Data_Preprocessing_CodeGen.mlx
featureExtractionBuffer.m
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end
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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;
featureExtractionBuffer
Ln 63
Col 25

Code Deployment for Machine Learning

Deploy trained models as standalone C/C++ code

Release	Models
R2016b	SVM Classification Linear Classification
R2017a	Linear Regression Generalized Linear Regr. Decision trees Ensembles for Class.
R2017b	Ensembles for Regr. SVM Regression KNN Classification Gaussian Process Regr. Discriminant Analysis
R2018a	Non-tree Ensembles KNN with kd-tree

MATLAB code

```
function label = classifyIonosphere(X) %#codegen
%classifyIonosphere   Classify Ionosphere based on pre-trained SVM model
mdl = loadCompactModel( 'SVMIonosphere' );
label = predict( mdl, X );
end
```

saveCompactModel   loadCompactModel

C code

```
/* Variable Definitions */
static emlrtRSInfo emlrtRSI = { 4,      /* lineNo */
  "classifyIonosphere",                 /* fcnNam
  "C:\\Users\\jcherrie\\Sandbox\\temp\\feature-
};

/* Function Definitions */
void classifyIonosphere(classifyIonosphereStack
  const real_T X[11934], cell_wrap_0 label[351]
{
  real_T t0_Alpha[90];
  real_T expl_temp[34];
```

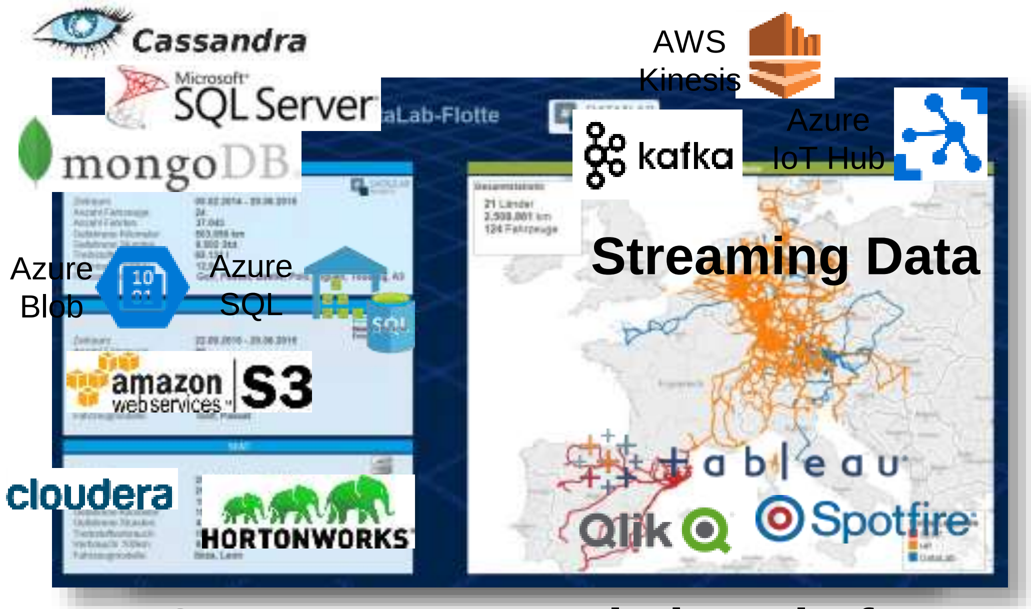
What do your end users want?

Flexible Deployment

- 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



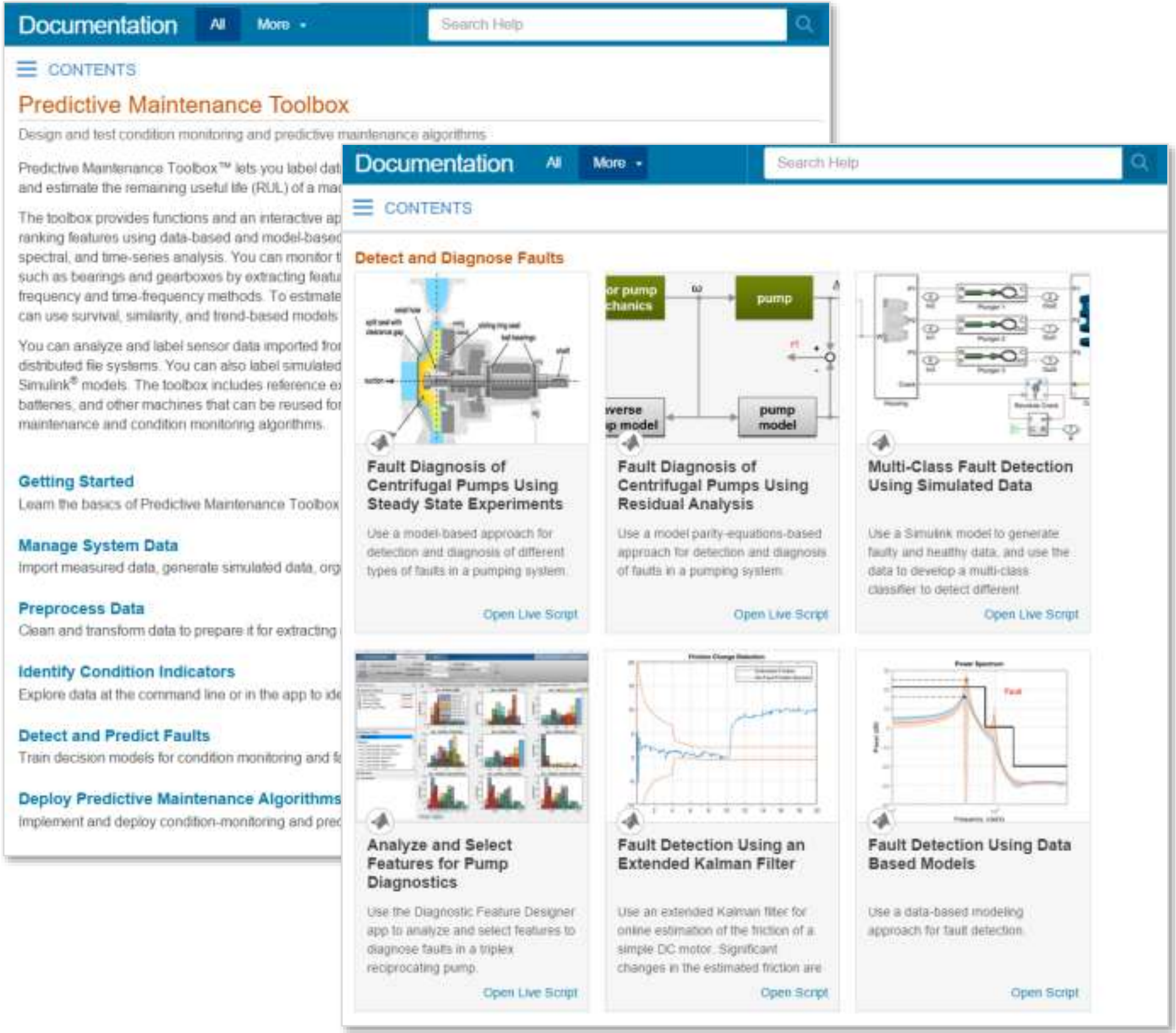
Data Sources Analytics Platforms
Fleet & Inventory Analysis
Hand held Devices

Agenda:

1. What is Predictive Maintenance? Who is benefiting by doing it?
2. How can you develop a predictive maintenance algorithm using MATLAB?
3. How can you get started quickly?

MathWorks can help you get started TODAY

- Examples
- Documentation
- Tutorials & Workshops
- Consulting
- Tech Talk Series



Training Services

Exploit the full potential of MathWorks products

Flexible delivery options:

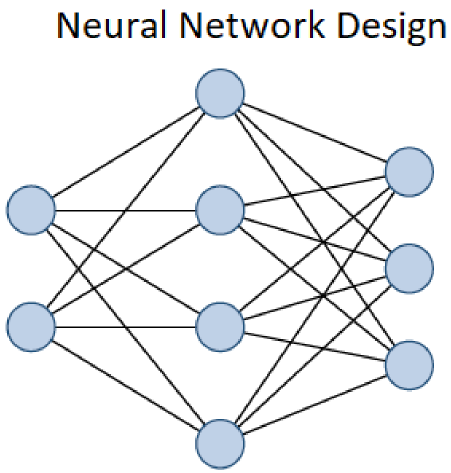
- Public training available in several cities
- Onsite training with standard or customized courses
- Web-based training with live, interactive instructor-led courses

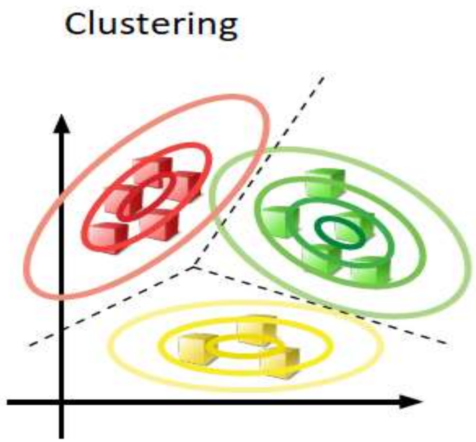
More than 48 course offerings:

- Introductory and intermediate training on MATLAB, Simulink, Stateflow, code generation, and Polyspace products
- Specialized courses in control design, signal processing, parallel computing, code generation, communications, financial analysis, and other areas

Machine Learning with MATLAB

- This two-day course focuses on data analytics and machine learning techniques in MATLAB. The course demonstrates the use of unsupervised learning to discover features in large data sets and supervised learning to build predictive models. Topics include:
- Organizing and preprocessing data
- Clustering data
- Creating classification and regression models
- Interpreting and evaluating models
- Simplifying data sets
- Using ensembles to improve model performance





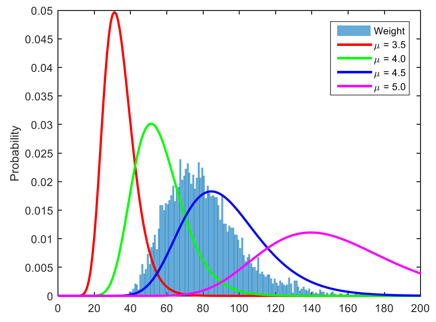
MathWorks | Training Services

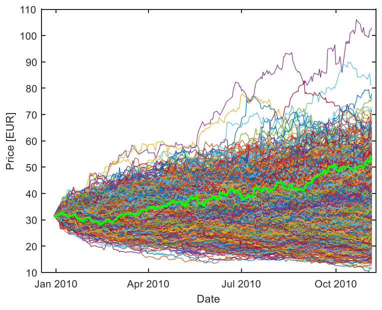
Statistical Methods in MATLAB

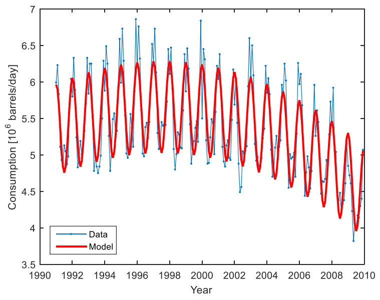
After this 2-day course you will be able to:

Import, visualize, explore, and model data

- Fit probability distributions to data, and perform hypothesis tests
- Develop and fit regression models to data
- Generate random numbers and perform simulations

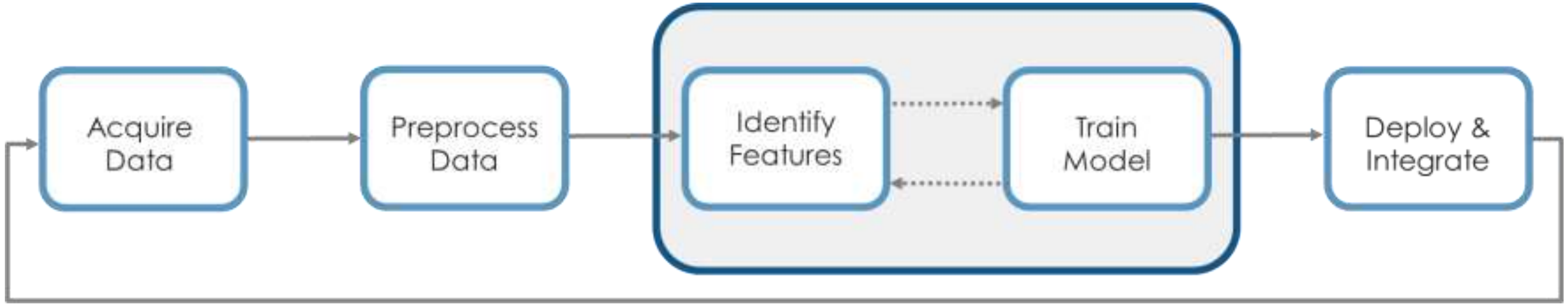






Summary: Why MATLAB for Predictive Maintenance?

- Dedicated toolbox for data preprocessing and feature extraction and developing predictive models
- Apps to make the task simple
- Support for taking these algorithm to edge and enterprise
- Get started quickly…examples, training and consulting



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- Scan this QR Code or log onto link below

  (link also sent to your phone and email)

- http://bit.ly/expo19-feedback
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MATLAB EXPO 2019

Speaker Details:

Email: adoshi@mathworks.com

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