MATLAB EXPO 2019

Predictive Maintenance with MATLAB

Phil Rottier

Predictive Maintenance: addresses these questions

Is my machine operating normally?	**Anomaly Detection**	Something's not right
Why is my machine behaving abnormally?	**Condition Monitoring**	A specific thing's not right
How much longer can I operate my machine ?	**Remaining Useful Life Estimation**	A specific thing will not be right in X [days / hours / minutes / seconds] ....

Increasing value

Increasing difficulty

Predictive Maintenance: why are we interested ?

- Cost reduction
  - "Unexpected / unplanned downtime costs me a lot of money"
- Performance improvement
  - "Unexpected / unplanned downtime is not acceptable to my end-user"
- New offerings
  - "I want to provide a condition monitoring / predictive maintenance service to users of my product"

Predictive Maintenance for polymer-based production machines

Sensor Data (~1 minute)
10s-100s sensors/machine
Quality State (~40 minutes)

1 TIMESTAMP	2 PARAMETER										3 STATE
'2015-07-14 00:49:12.0'	160	160	160	160	1000	7	1000	9	33	32	1
'2015-07-14 00:50:12.0'	160	160	160	160	1000	8	1000	10	33	32	1
'2015-07-14 00:51:13.0'	160	160	160	160	1000	8	1000	10	33	32	1
'2015-07-14 00:52:12.0'	160	160	160	160	1000	8	1000	10	33	32	1
'2015-07-14 00:53:12.0'	160	160	160	160	1000	8	1000	11	33	32	2
'2015-07-14 00:54:12.0'	160	160	160	160	1000	8	1000	12	33	32	2
'2015-07-14 00:55:12.0'	160	160	160	160	1000	8	1000	10	33	32	2

Classification using Statistics, Machine Learning, and Neural Networks

Nearest Neighbor Classification | Support Vector Machines (SVMs)

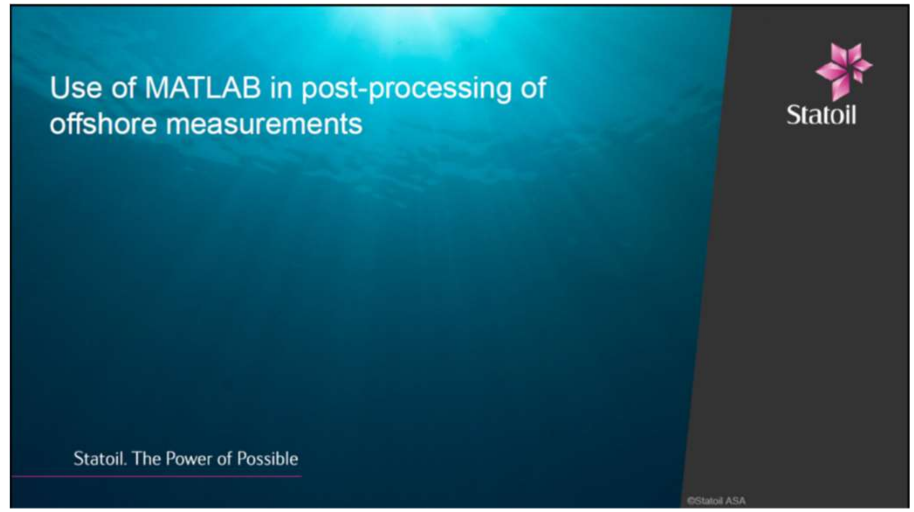
Results

- **More than 50,000 euros saved per year.** "Our financial control department determined that we are saving more than 50,000 euros per year by using MATLAB for predictive maintenance," says Dr. Kohlert. "That total is based on just eight machines. We expect that to increase at least fourfold as we analyze the data from more of our machines."
- **Prototype completed in six months.** "With many consultants, there's a great deal of discussion but no action," notes Dr. Kohlert. "MathWorks consultants started directly. We had the first tests within two months and a working prototype in six. The MATLAB code is easy to understand, so we can make changes rapidly when needed."
- **Production software run 24/7.** "There's a misconception that MATLAB is only for research or development," says Dr. Kohlert. "We operate our machines nonstop, even on Christmas, and we rely on our MATLAB based monitoring and predictive maintenance software to run continuously and reliably in production."

How are MathWorks Tools Used for Predictive Maintenance?

Link to user story

"…Subject Matter Expert Familiarity…"



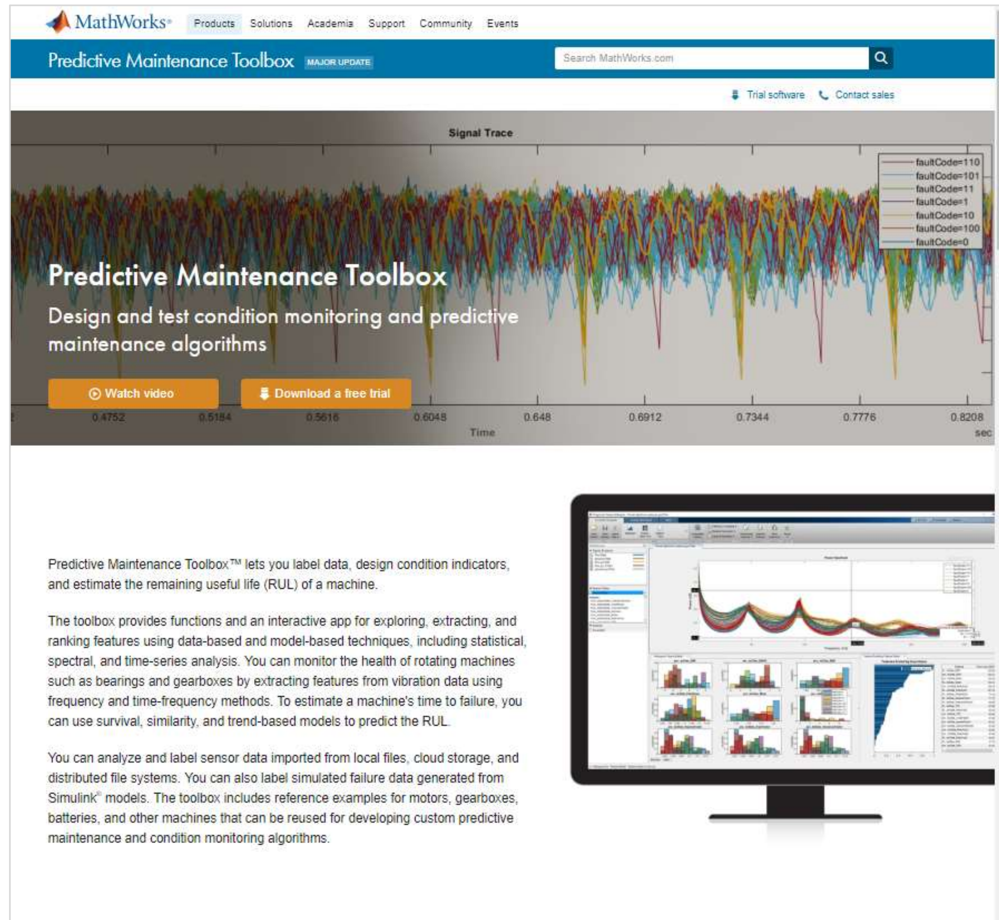
Link to user story

"… [MATLAB is] Popular across the company…"

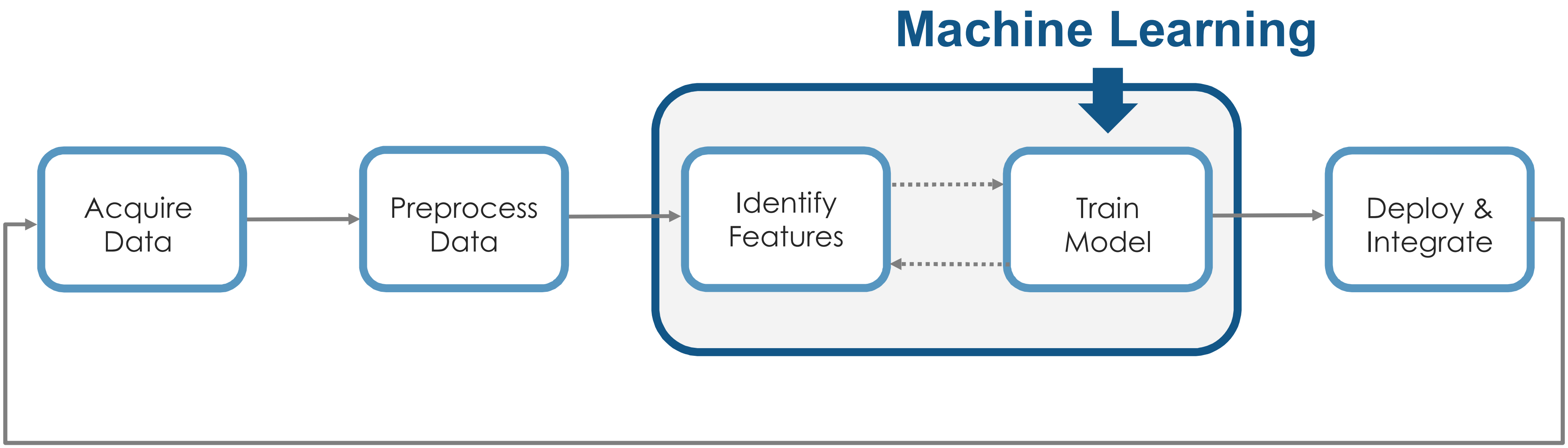
SAFRAN AEROSPACE · DEFENCE · SECURITY — mondi — SNCF — Mercedes-Benz — BOSCH

Predictive Maintenance Toolbox: for developing algorithms

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**

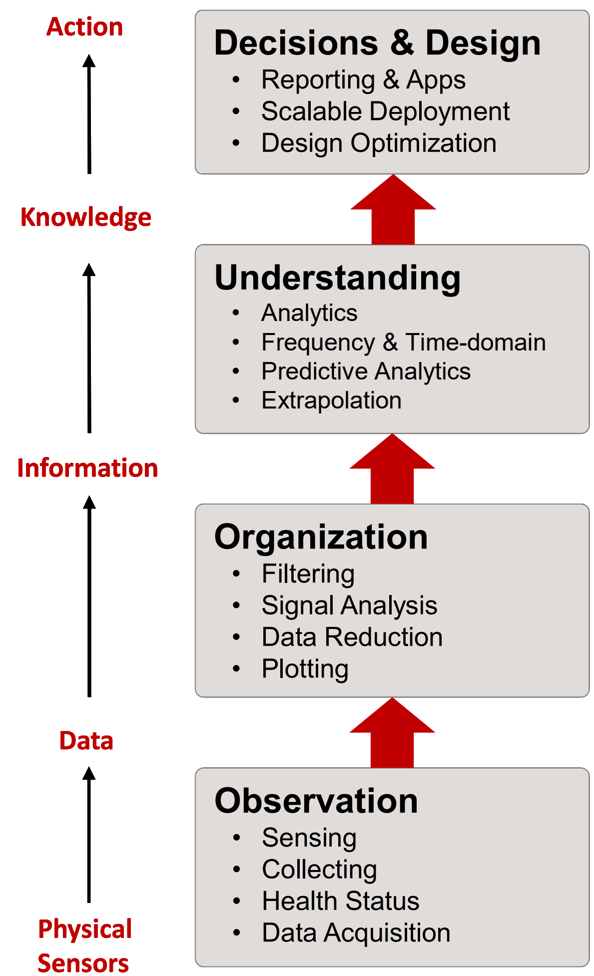


Workflow for Developing a Predictive Maintenance Algorithm



Why MATLAB & Simulink for Predictive Maintenance

- Support for all aspects of the end-to-end workflow
  - Acquire data / observations
  - Reduce the amount of data you need to store and transmit
  - Explore approaches to feature extraction and predictive modeling
  - Machine learning / predictive analytics
  - Deliver the results of your analytics based on your audience
- Get started quickly…especially if you are an engineer
  - Useful Apps such as
    - Diagnostic Feature Designer
    - Classification Learner
    - Regression Learner



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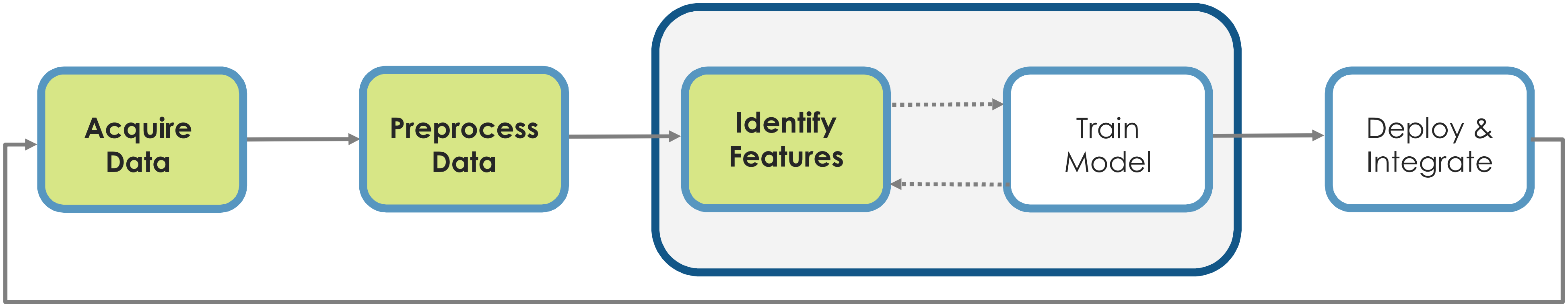

From Data to Decisions & Design

Action

Knowledge

Information

Data

Physical Sensors

Decisions & Design
- Reporting & Apps
- Scalable Deployment
- Design Optimization

Understanding
- Analytics
- Frequency & Time-domain
- Predictive Analytics
- Extrapolation

Organization
- Filtering
- Signal Analysis
- Data Reduction
- Plotting

Observation
- Sensing
- Collecting
- Health Status
- Data Acquisition

Database Access
- **Financial Data**
- **ODBC**
- **JDBC**
- **HDFS** (Hadoop)

File I/O
- **Text**
- **Spreadsheet**
- **XML**
- **CDF/HDF**
- **Image**
- **Audio**
- **Video**
- **Geospatial**
- **Web content**

Hardware Access
- **Data acquisition**
- **Image capture**
- **GPU**
- **Lab instruments**

Communication Protocols
- **CAN** (Controller Area Network)
- **DDS** (Data Distribution Service)
- **OPC** (OLE for Process Control)
- **XCP** (eXplicit Control Protocol)

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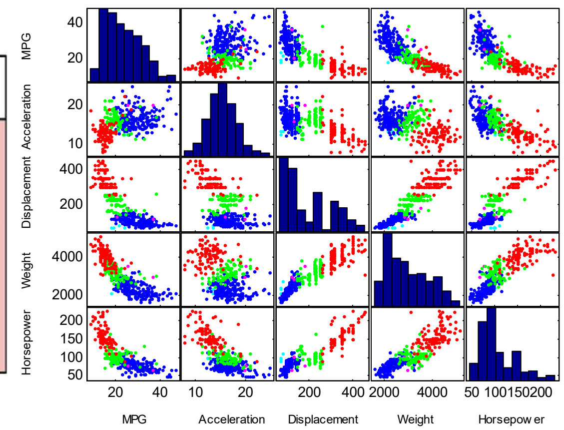
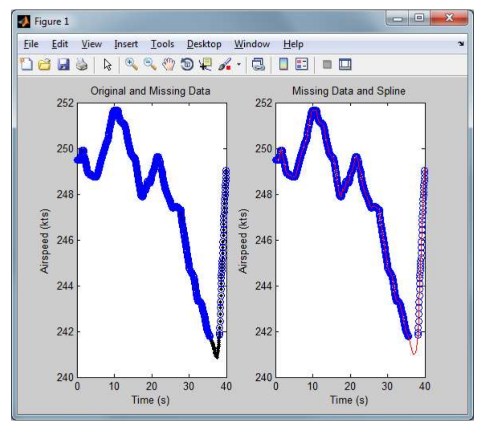
Key	B	Y	Z
1	1.1	0.1	0.2
4	1.4	NaN	NaN
7	1.7	0.7	0.8
9	1.9	NaN	NaN





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

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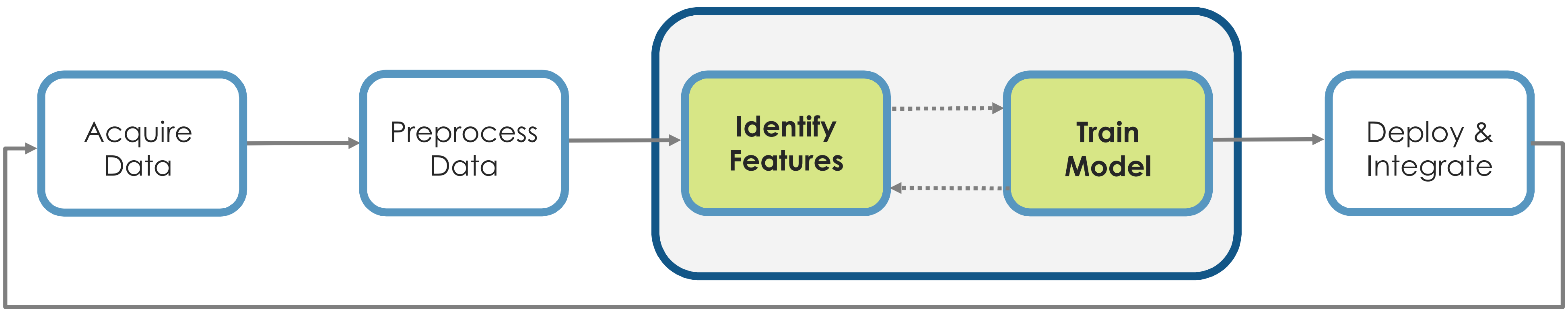

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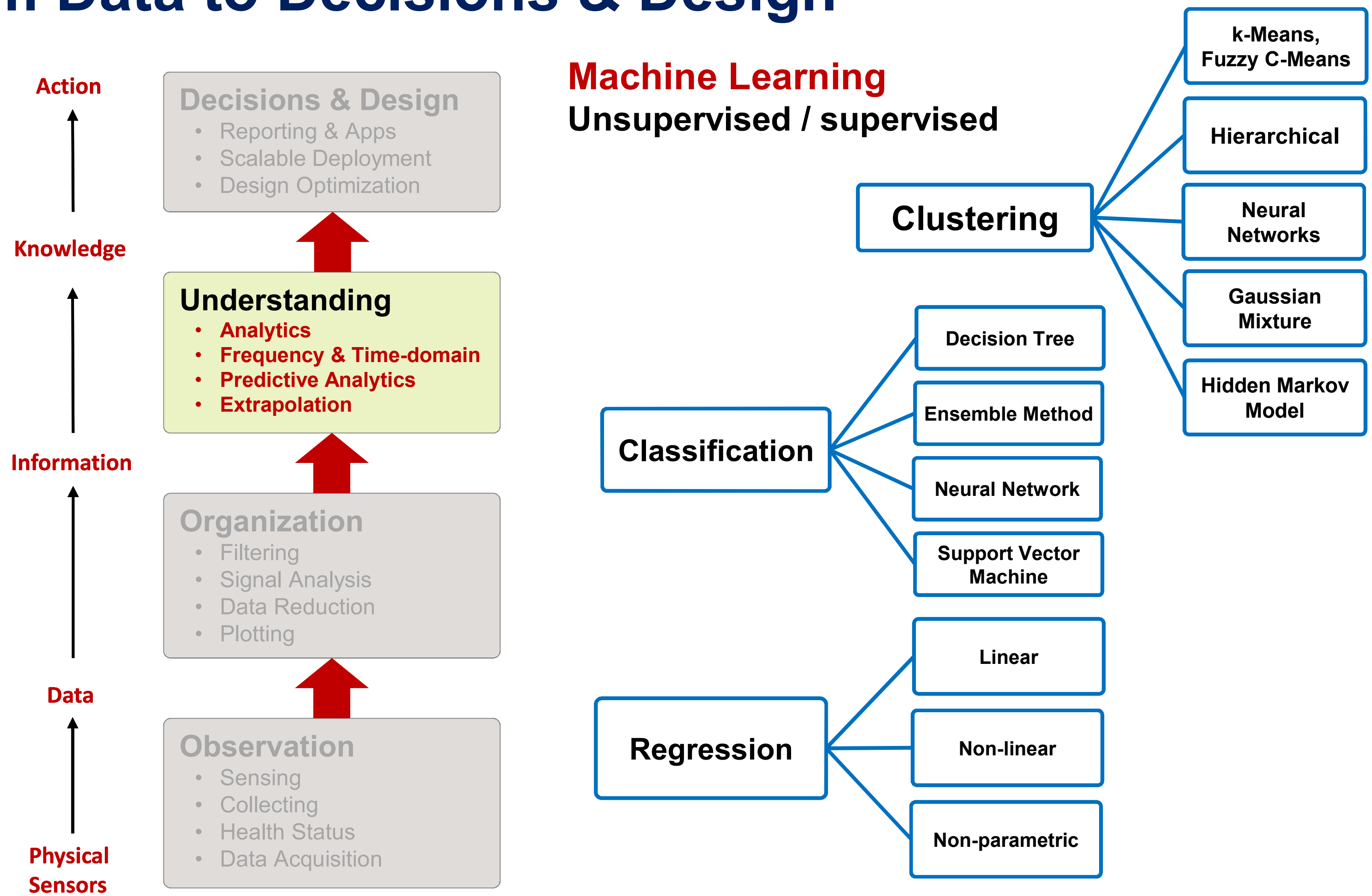
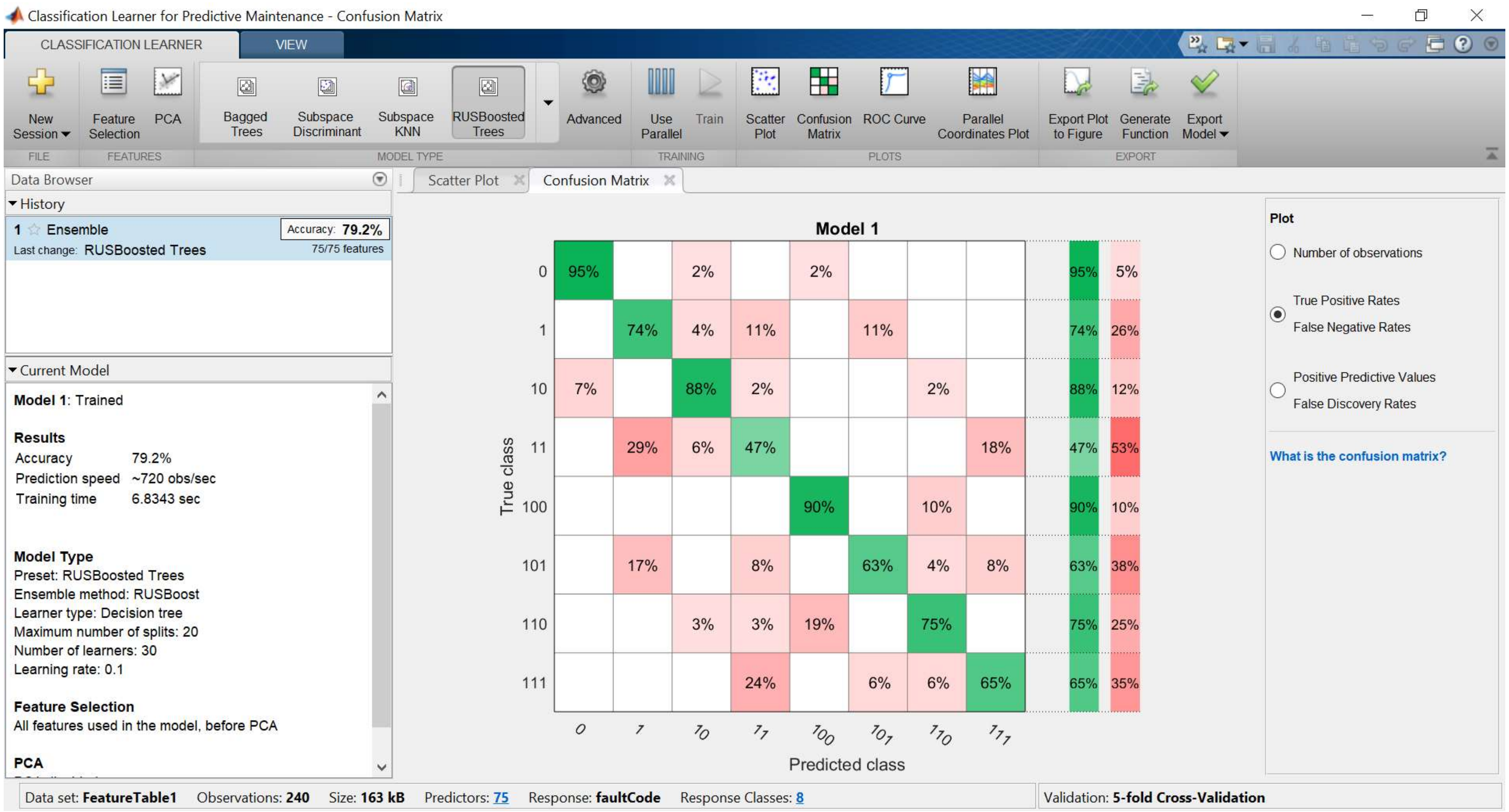


Classification Learner App

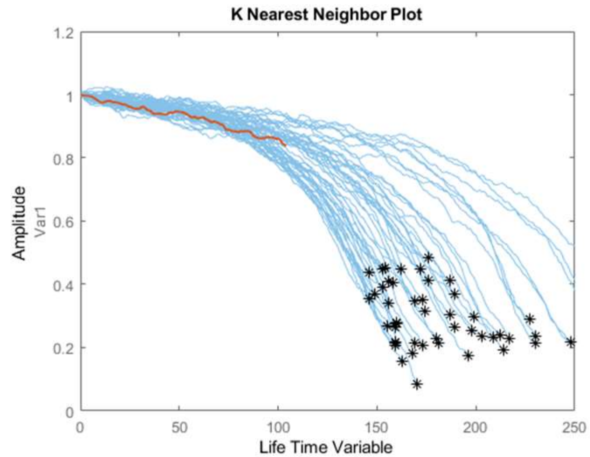
Statistics and Machine Learning toolbox

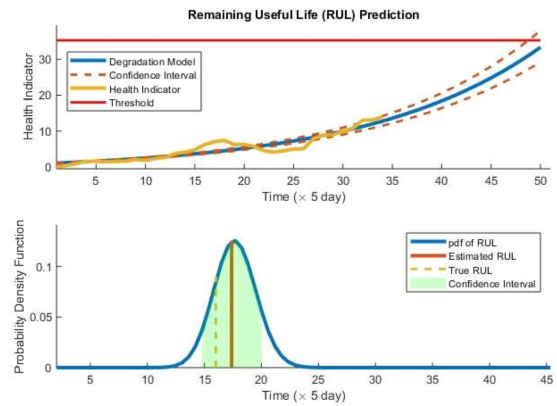


Remaining Useful Life (RUL) Estimation Methods

Predict RUL and time-to-failure using historical data and sensor data

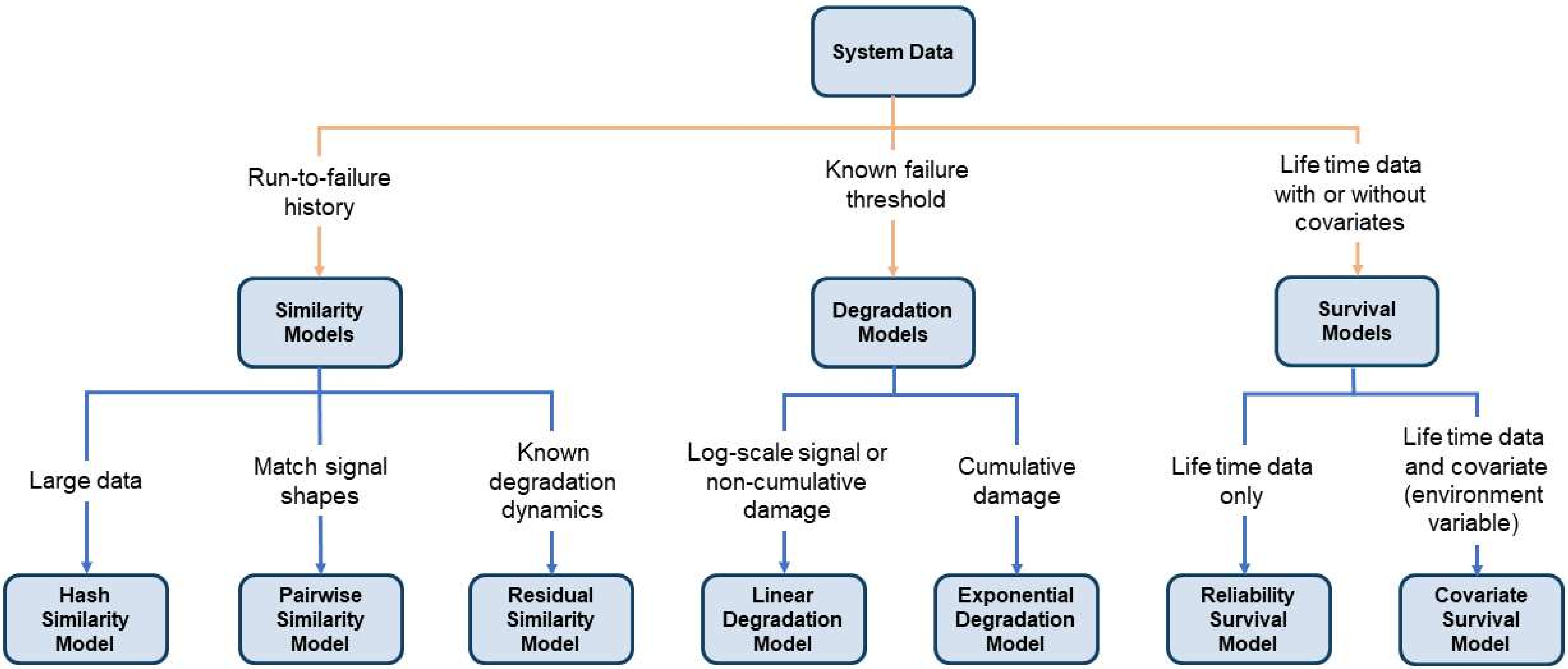
- Use Similarity-based methods if run-to-failure data is available that captures data over a machine's complete lifetime
- Use Degradation methods if there is information about critical threshold values
- Use Survival methods if the only data available corresponds to when a machine failed



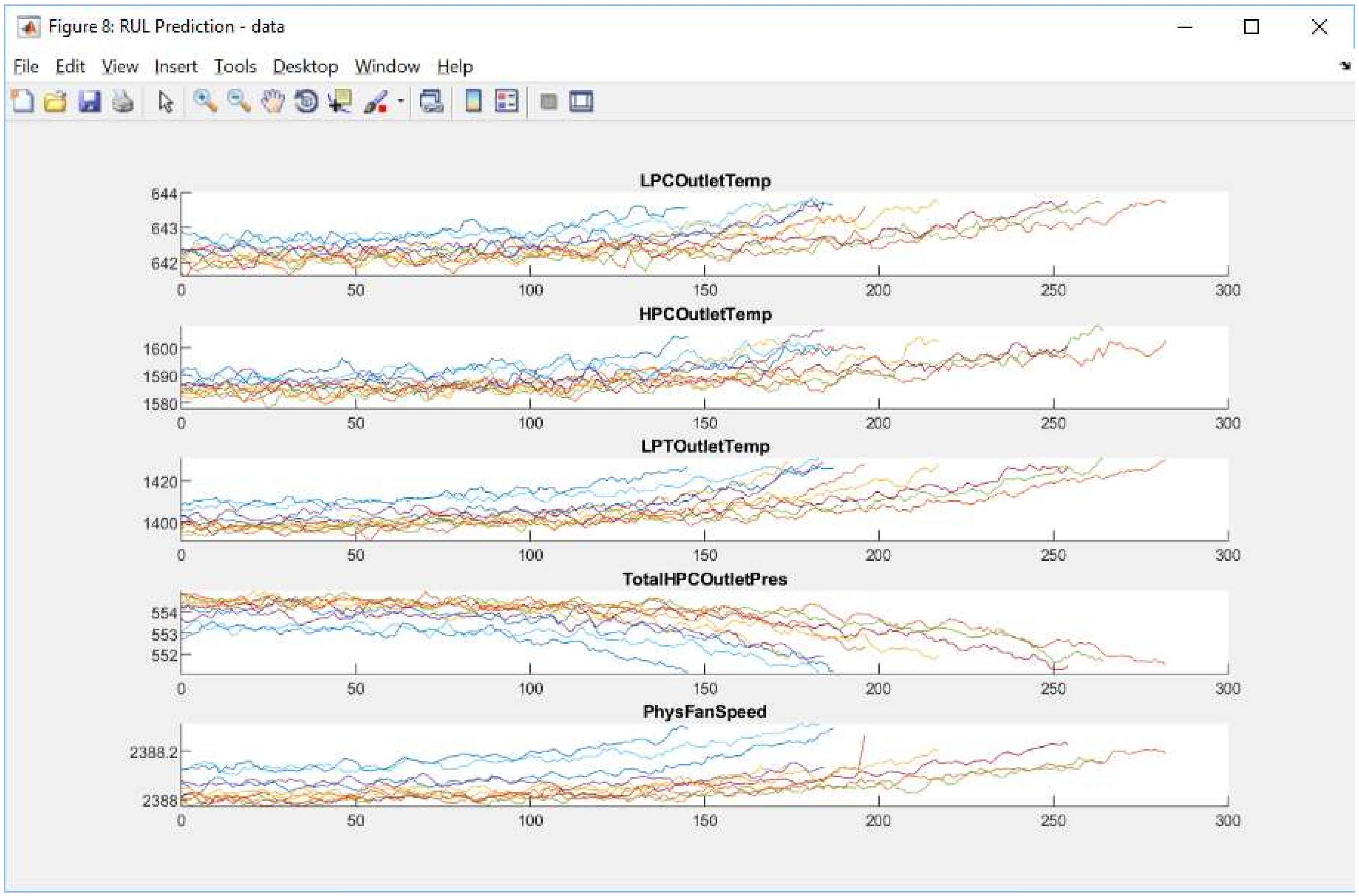


Remaining Useful Life (RUL) Estimation Methods

Requirement: Need to know what constitutes failure data



Example – Remaining Useful Life



Remaining Useful Life

- Set up model and train

Train a Residual Similarity model

```
% Create model
rmdl = residualSimilarityModel('Method', 'exp1');

% Which variable indicates the lifetime measurement ?
lifeTimeVar = 'Time';

% Which variable(s) indicate the condition ?
dataVariables = rulData{1}.Properties.VariableNames(3:end);

% Train model
fit(rmdl, rulTrain, lifeTimeVar, dataVariables)
```

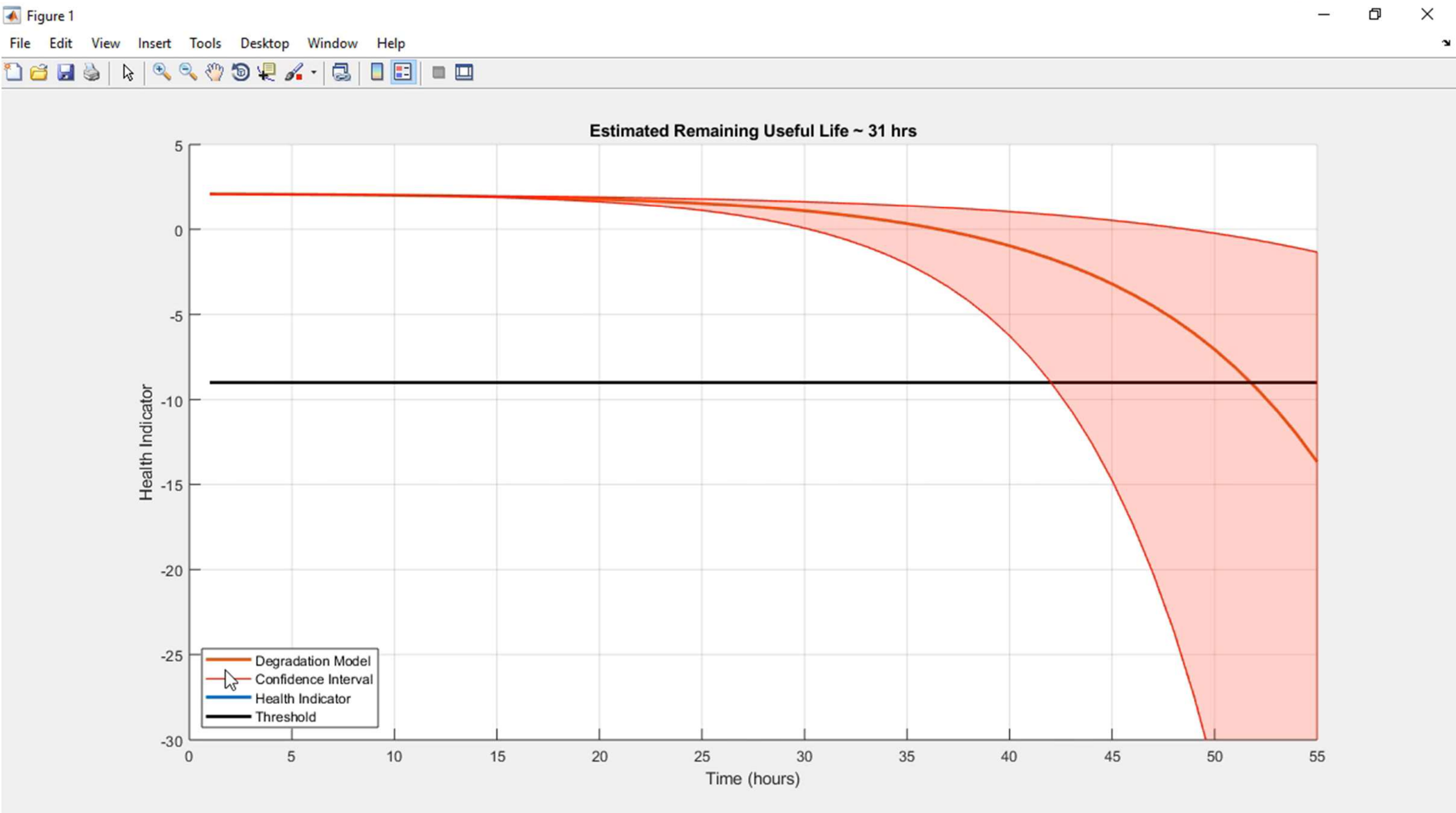
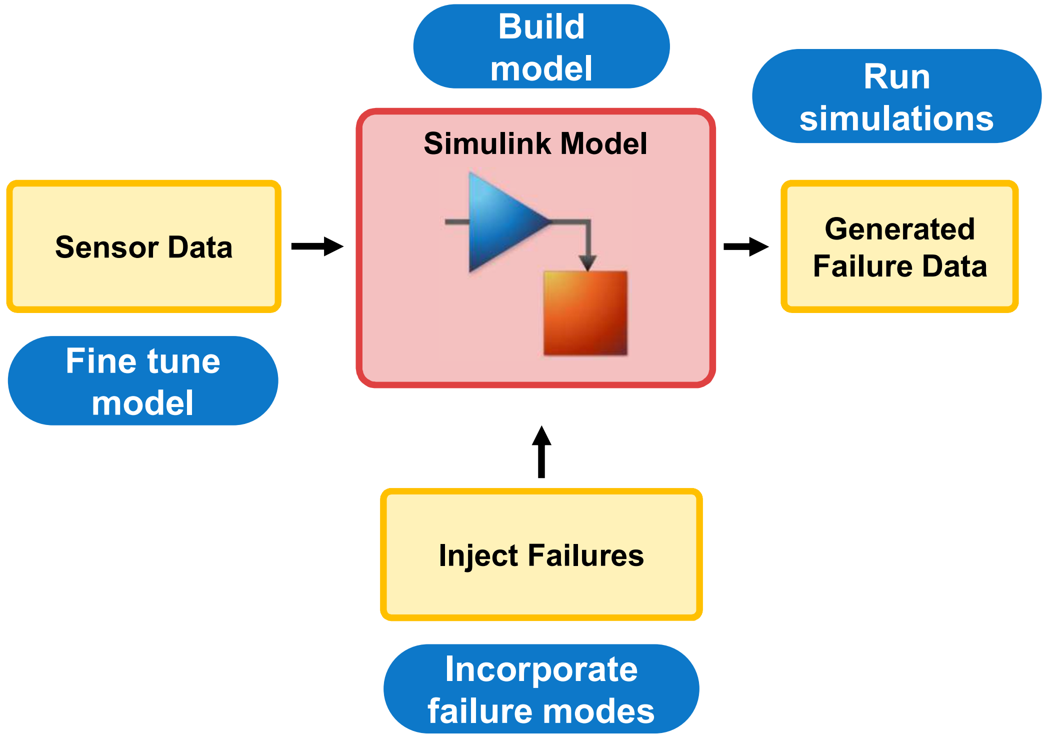


Figure 1
File
Edit
View
Insert
Tools
Desktop
Window
Help
Estimated Remaining Useful Life ~ 31 hrs
Health Indicator
Time (hours)
5
0
-5
-10
-15
-20
-25
-30
0
5
10
15
20
25
30
35
40
45
50
55
Degradation Model
Confidence Interval
Health Indicator
Threshold

If Real Failure Data is Unavailable ? Simulate it

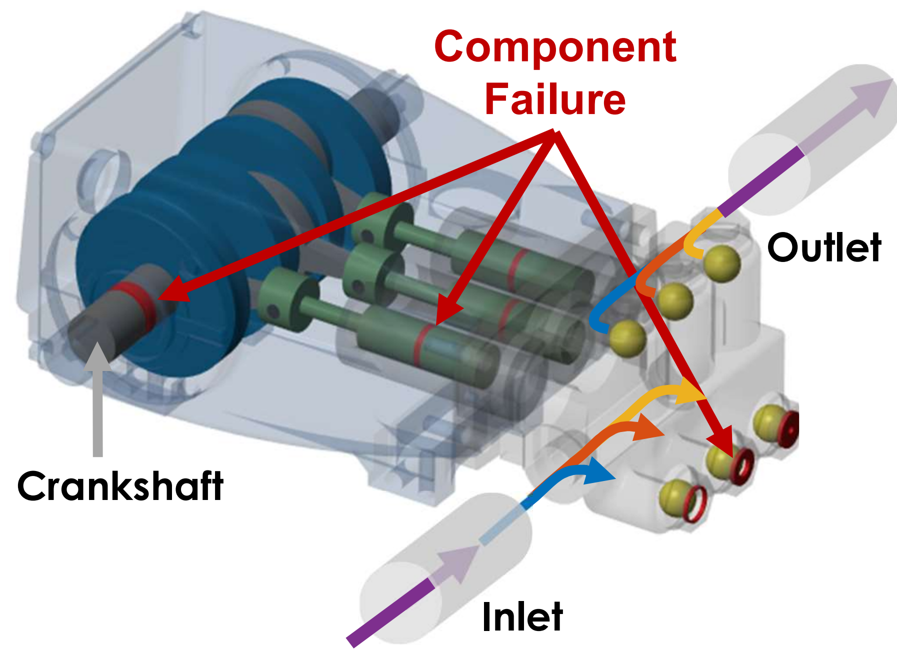
- Model failure modes
  - Work with domain experts and the data available
  - Vary model parameters or components
- Customize a generic model to a specific machine
  - Fine tune models based on real data
  - Validate performance of tuned model



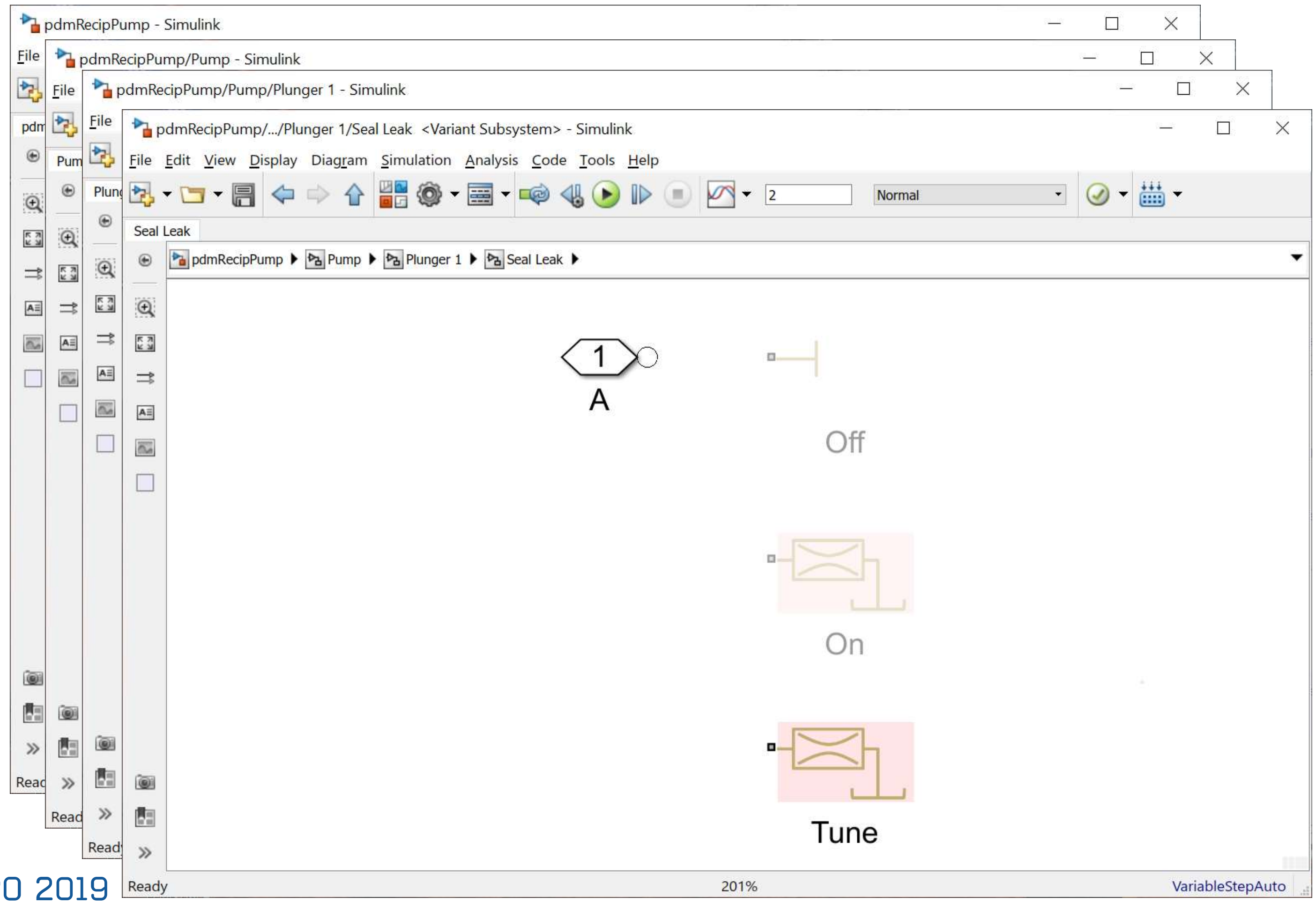
Simulating the behavior of a faulted system

- 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



Simulink and Simscape to model the system



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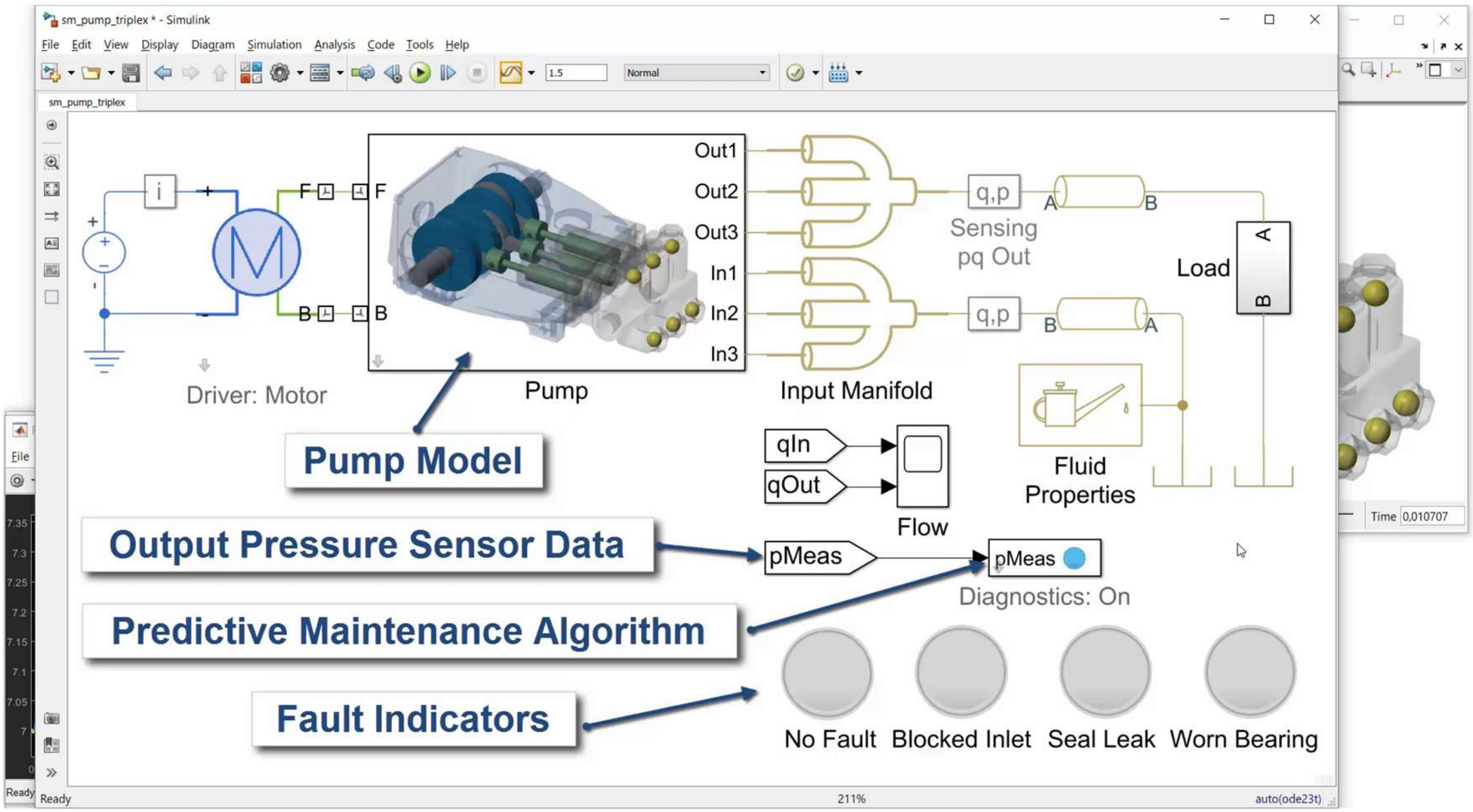
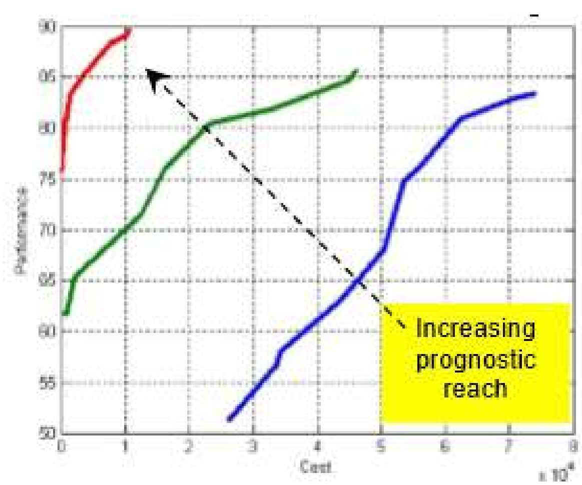


How do you know if a predictive maintenance solution is likely to be worthwhile ? Simulate it

- Simulate delivery of service(s)
  – Allow for failures triggering need for support services to be delivered
  – Model consumption of support resources, and their flow through the supply chain
    - Spare parts (consumables, reusables)
    - Human resources
  – Measure performance (uptime, downtime, asset availability, etc)
  – Measure cost of delivering that level of performance
    - Monetise the consumption of resources
- Simulate delivery of service(s) with a predictive capability
  – Preposition required resources based on "prognostic reach"
  – Measure cost of delivering same level of performance



Simulating delivery of services

SimEvents for Operations Research

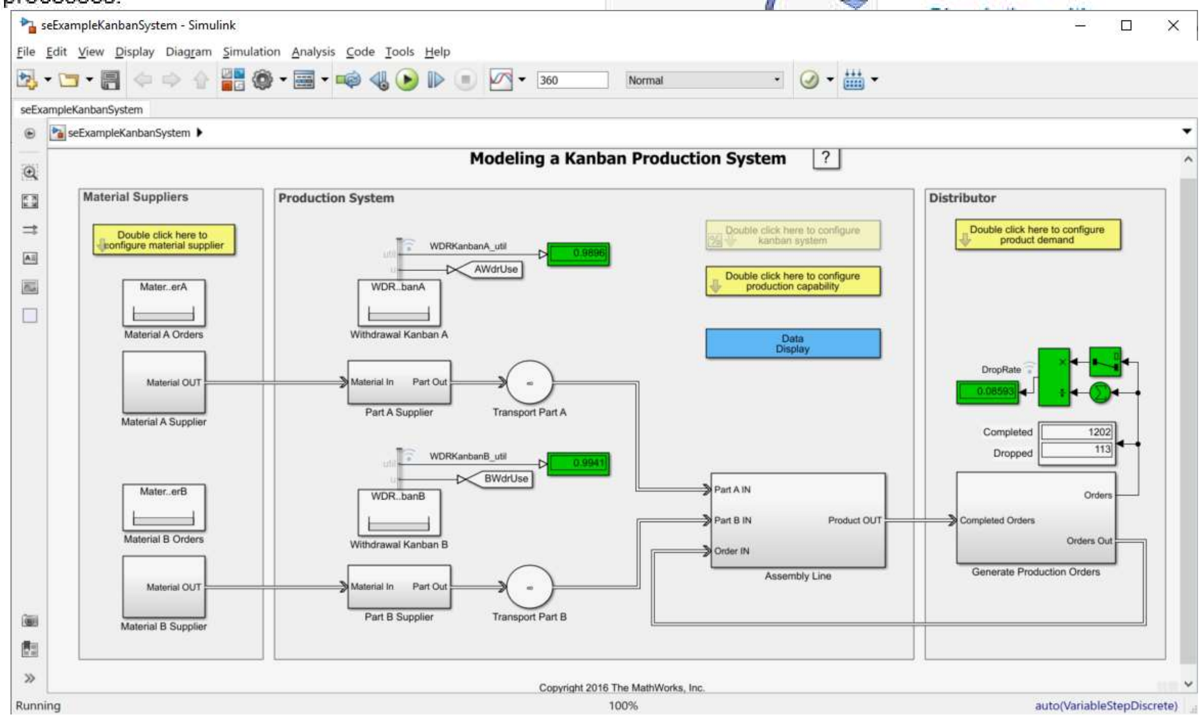
Teresa Hubscher-Younger, MathWorks

SimEvents® can help you model, analyze, and optimize various operational processes, including mining operations, semiconductor manufacturing, or batch production processes.

Discrete Event

Product Focus

- SimEvents
- Global Optimization Toolbox
- Optimization Toolbox
- Parallel Computing Toolbox
- Simulink



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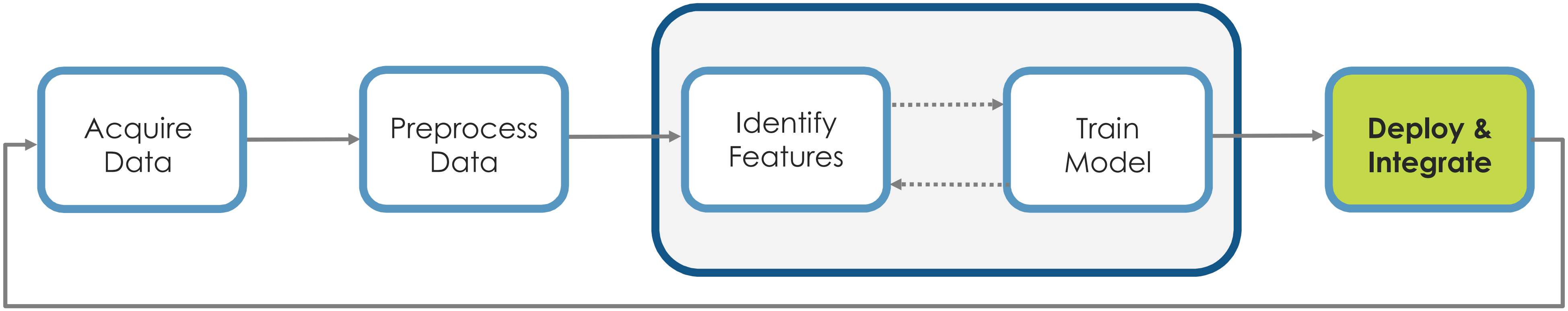
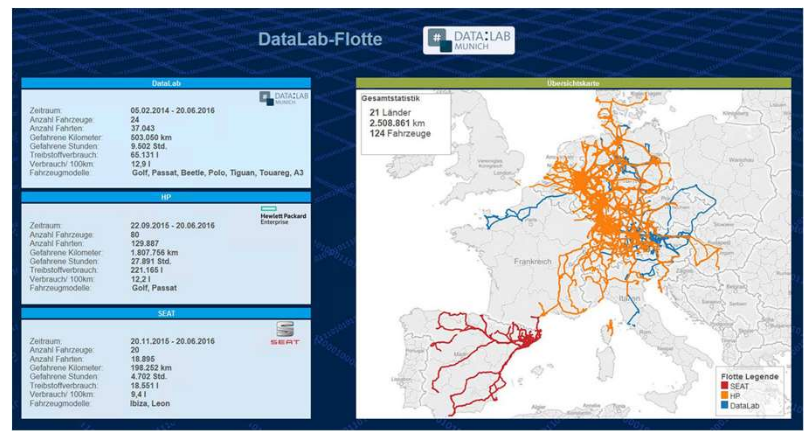


Challenges: Delivering results to your end users

- 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

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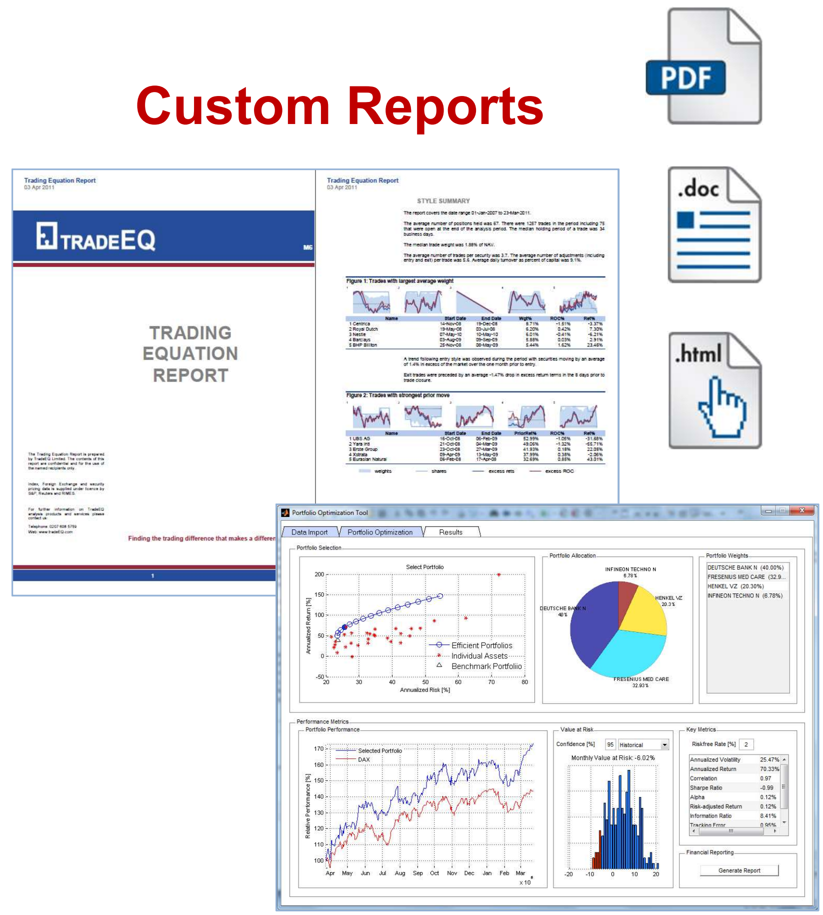
Custom Reports



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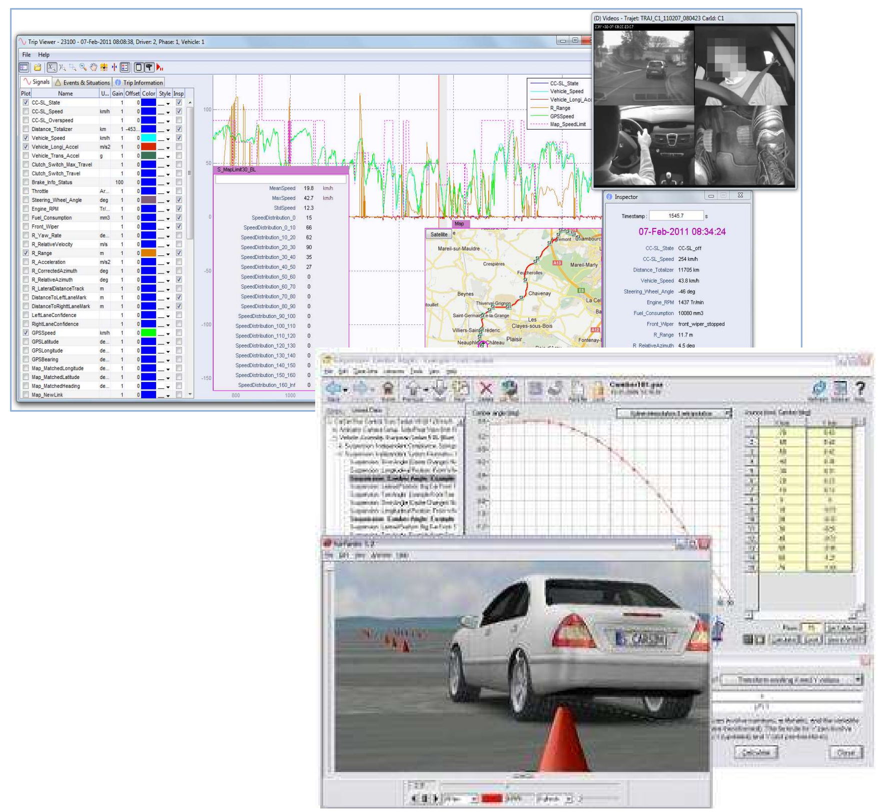
MATLAB Apps



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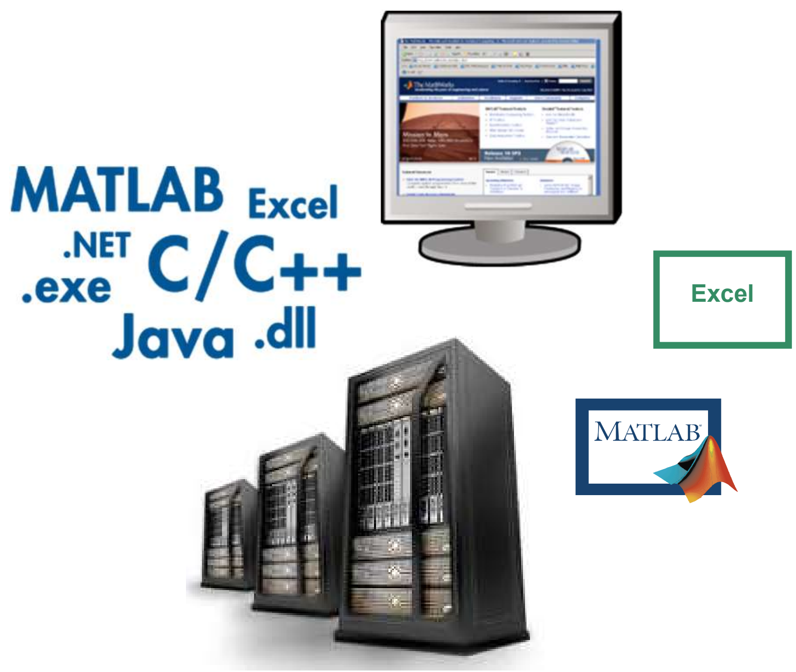
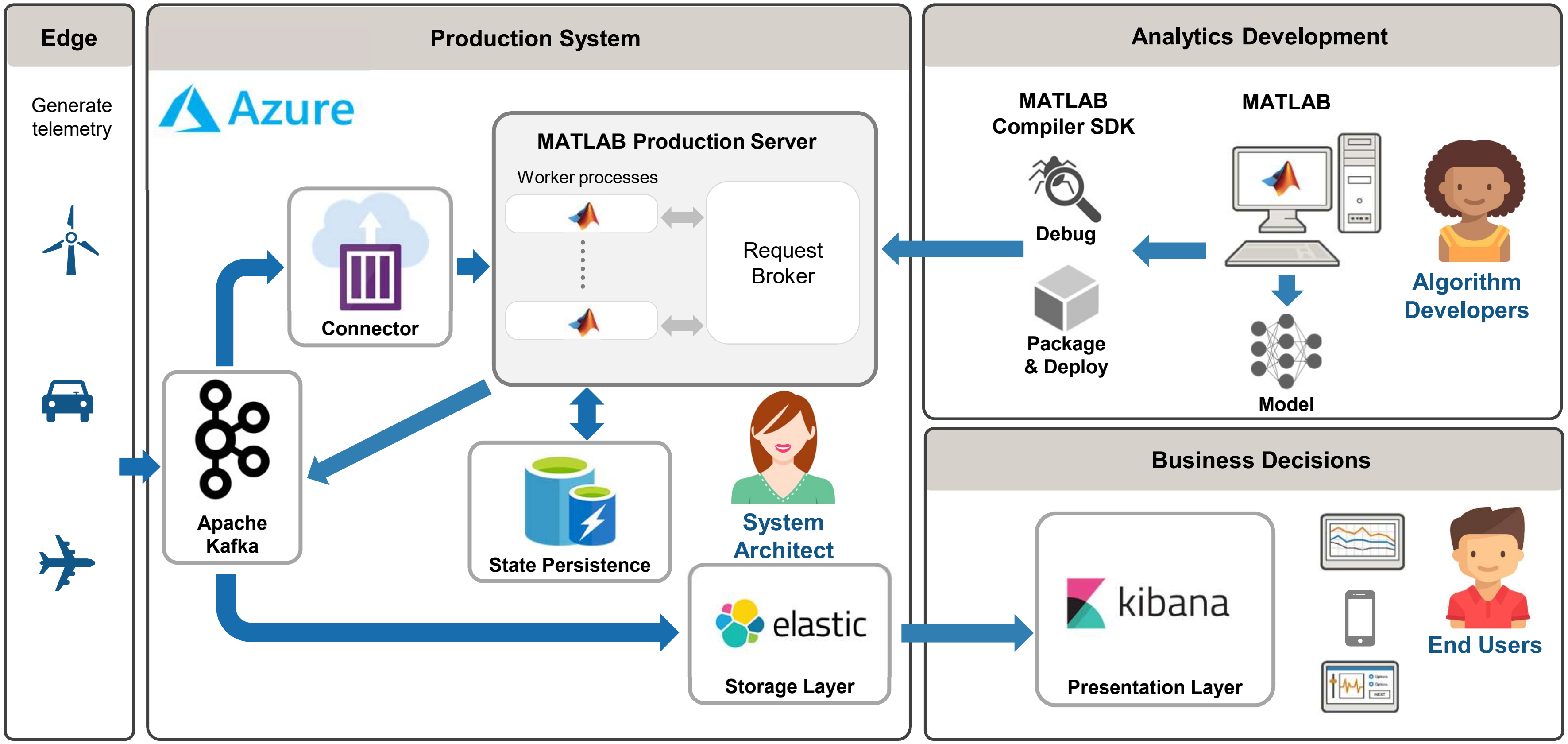
Integration

into Existing Systems
& Product Deployment



Predictive Maintenance Architecture on Azure



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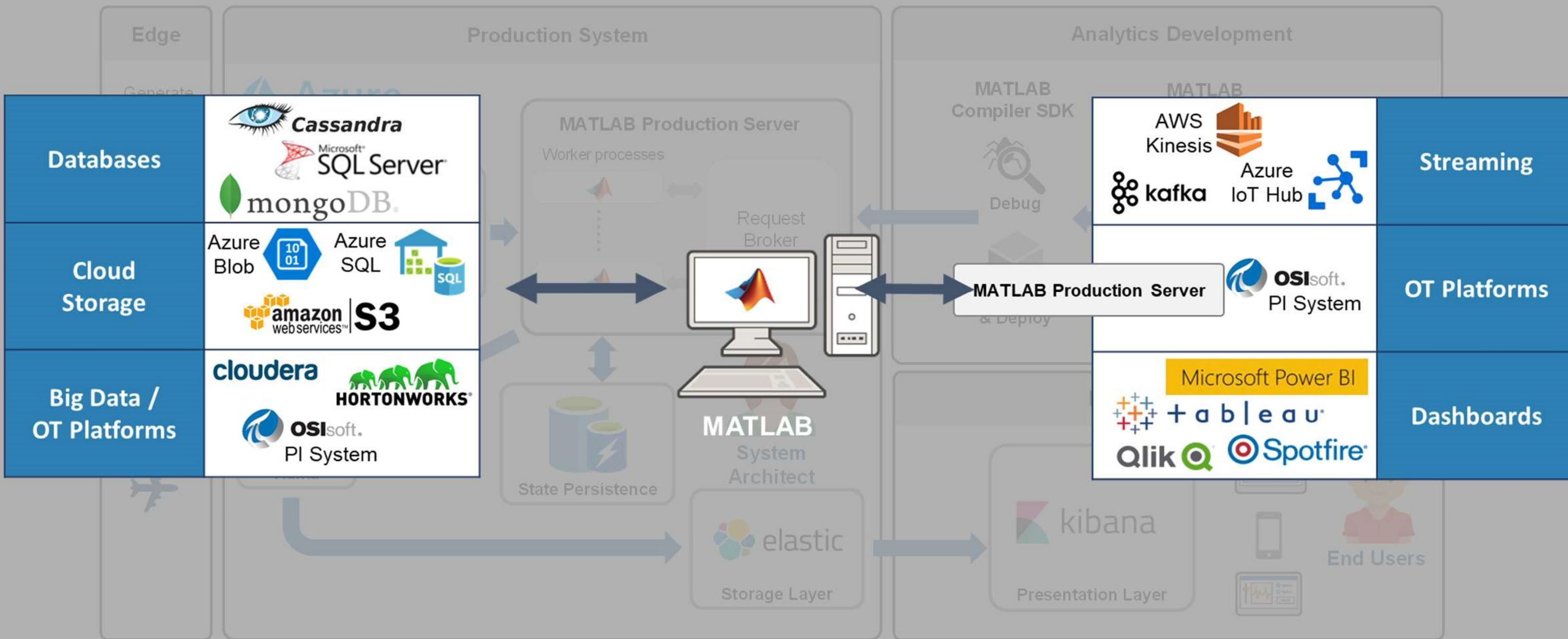
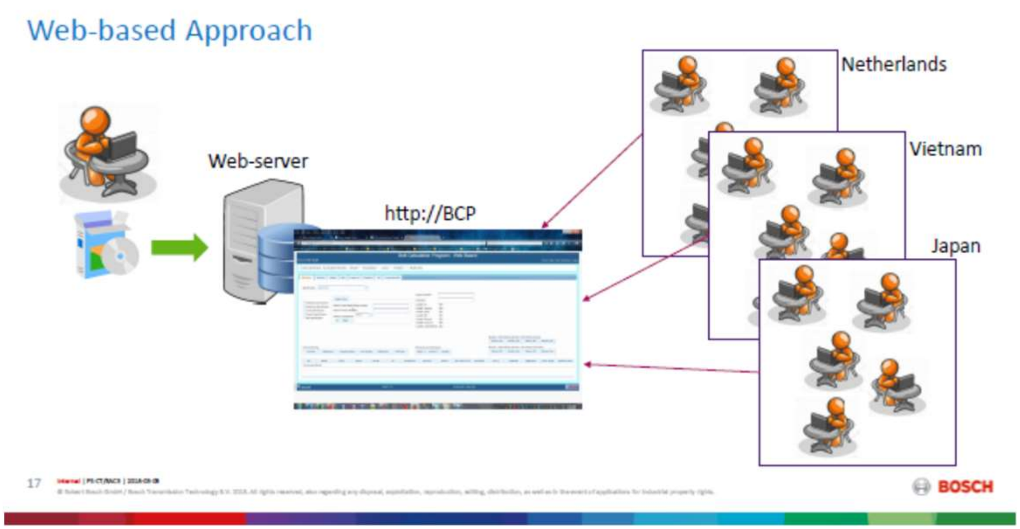
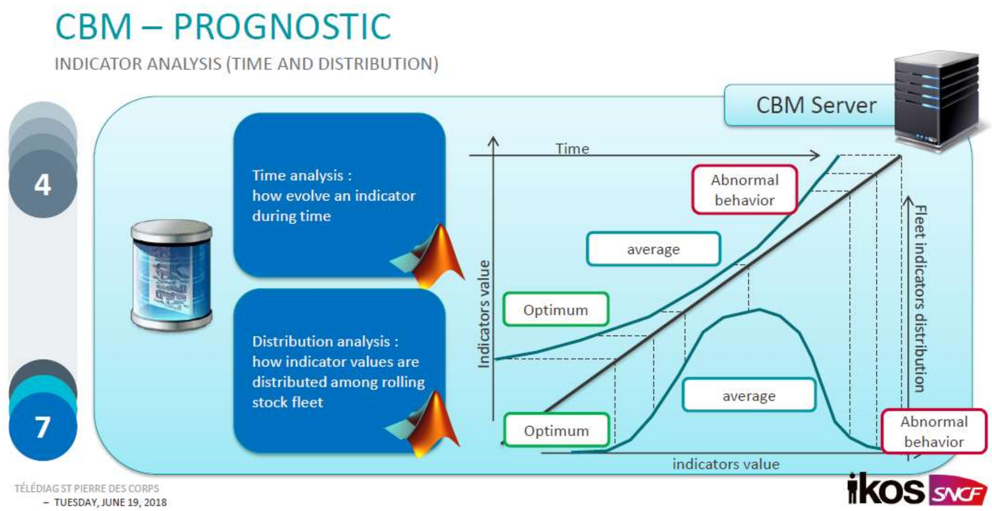


Bosch and SNCF Have Implemented Production Systems Running Today



Link to user story



Link to user story

"Updating software is required only at 1 location…Maximum of 1 hour downtime for major updates…"

"…[Our solution] optimizes the whole maintenance process without breaking the existing process…"

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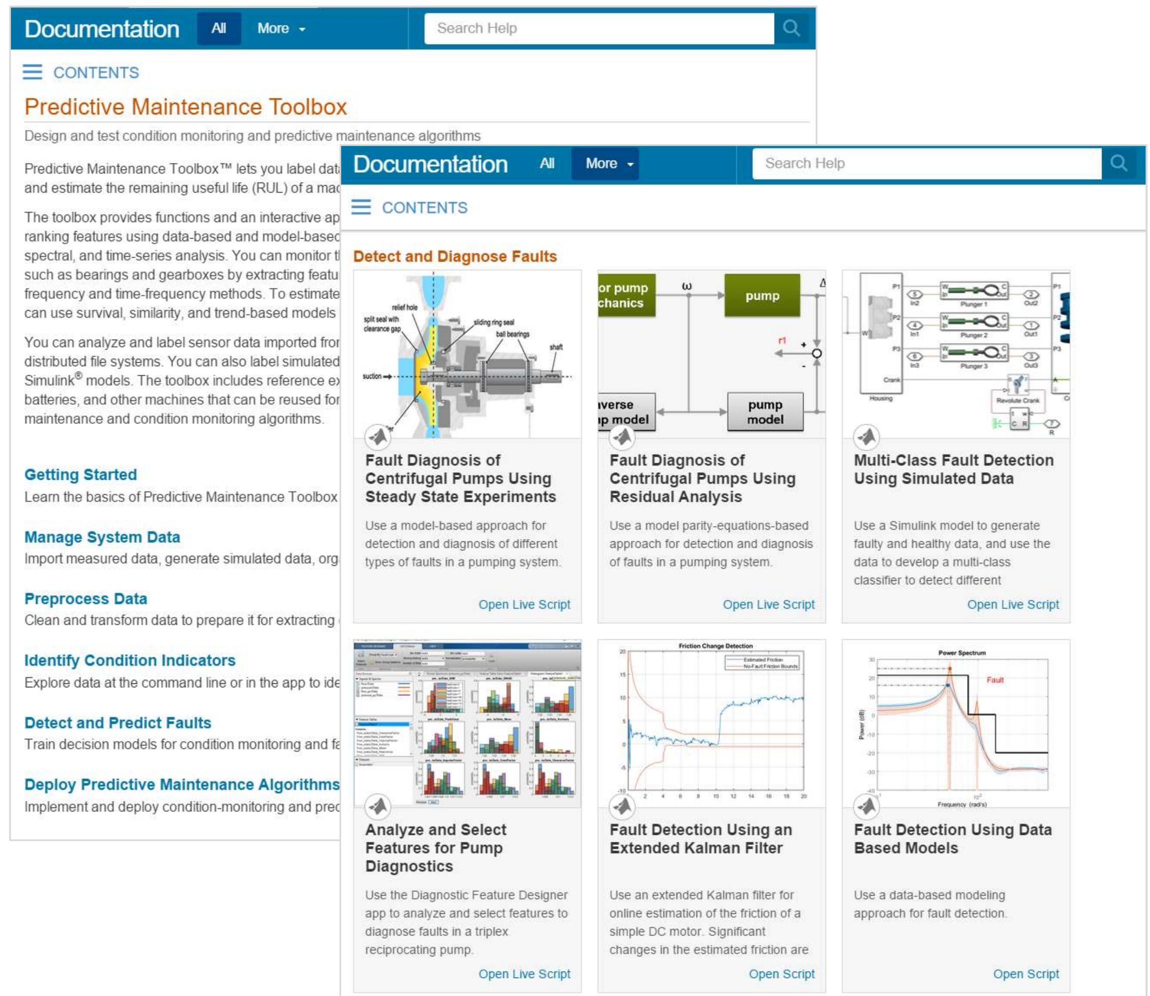
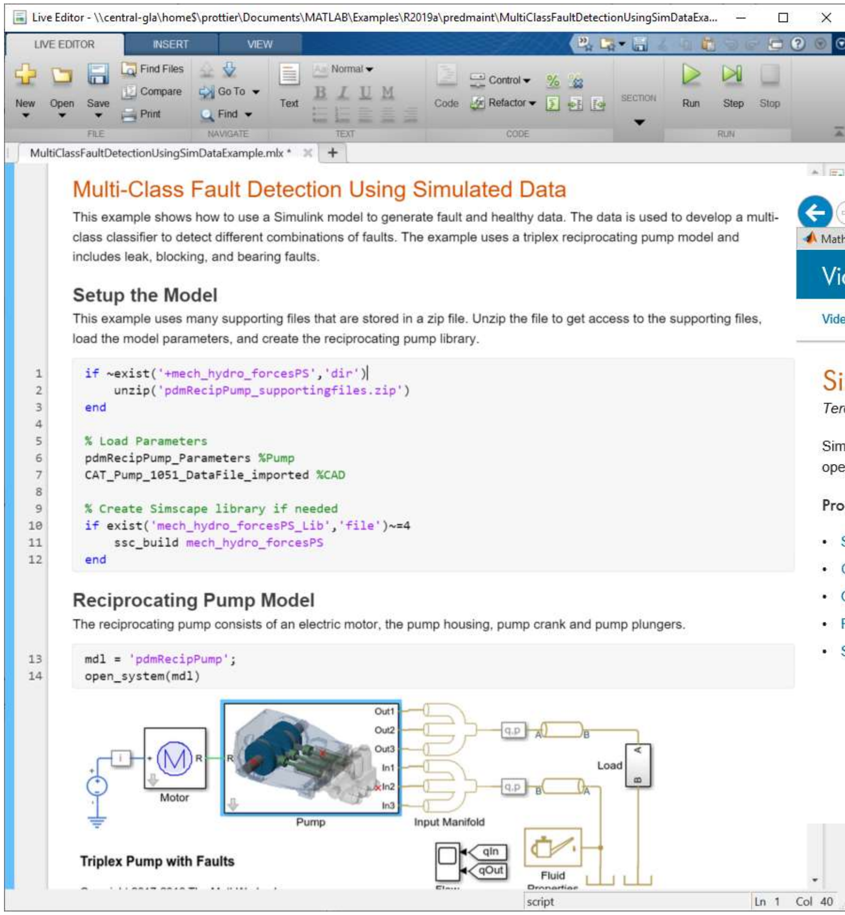
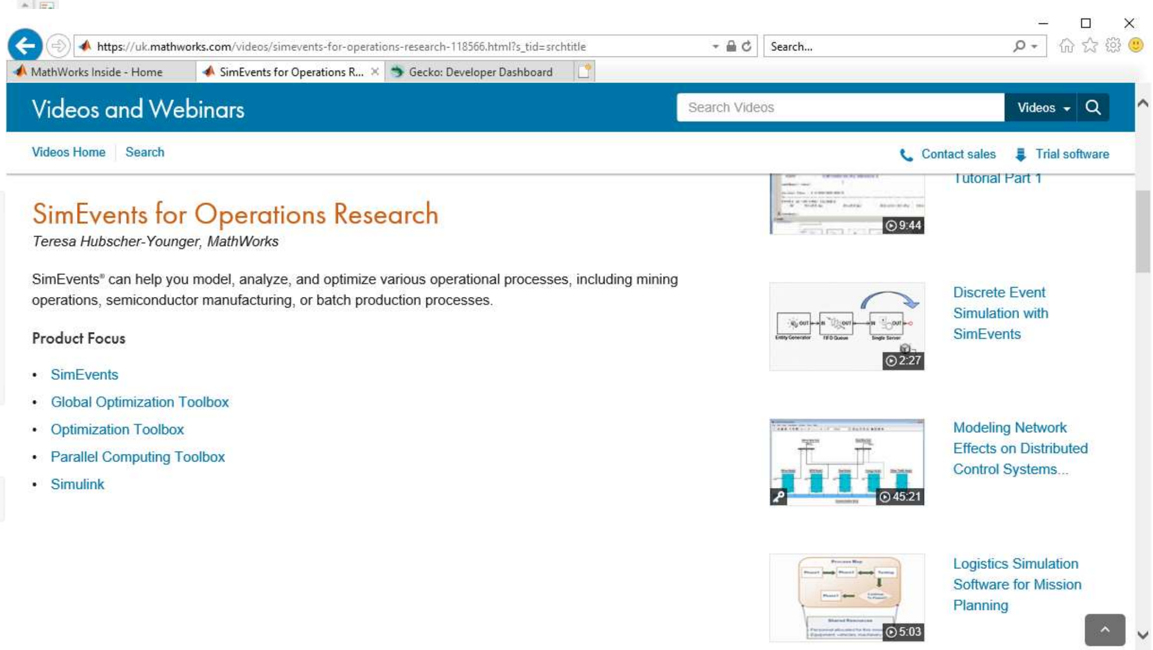
MathWorks can help you get started TODAY

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



Off-the-shelf demos and webinars





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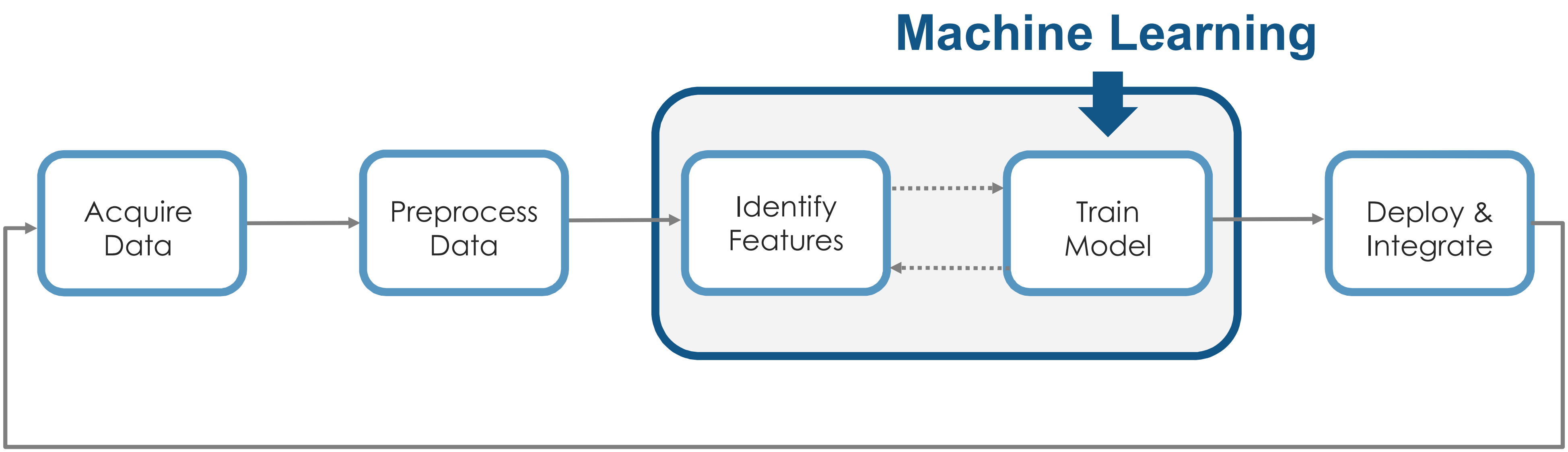
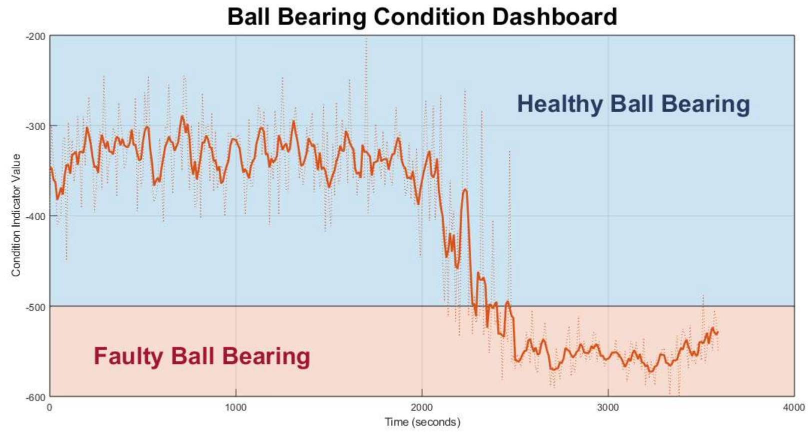
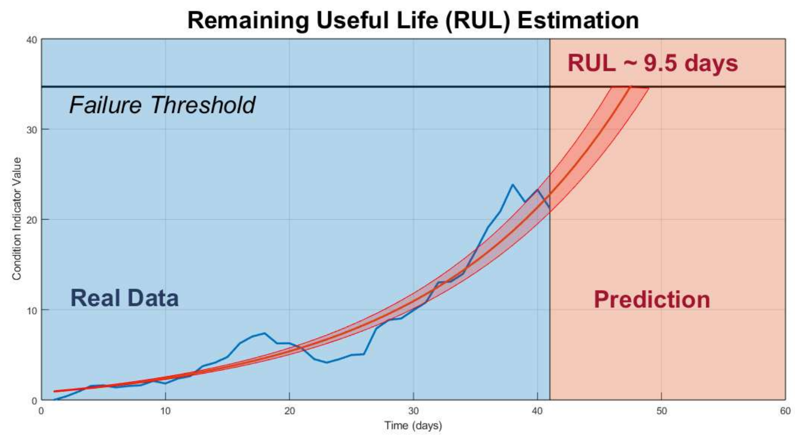


Predictive Maintenance Toolbox

- Remaining Useful Life estimation
- Condition indicator design using time, frequency, and time-frequency methods
- Interactively design and select condition indicators
- Generate and manage predictive maintenance data
- Examples for motors, gearboxes, batteries, and other machines





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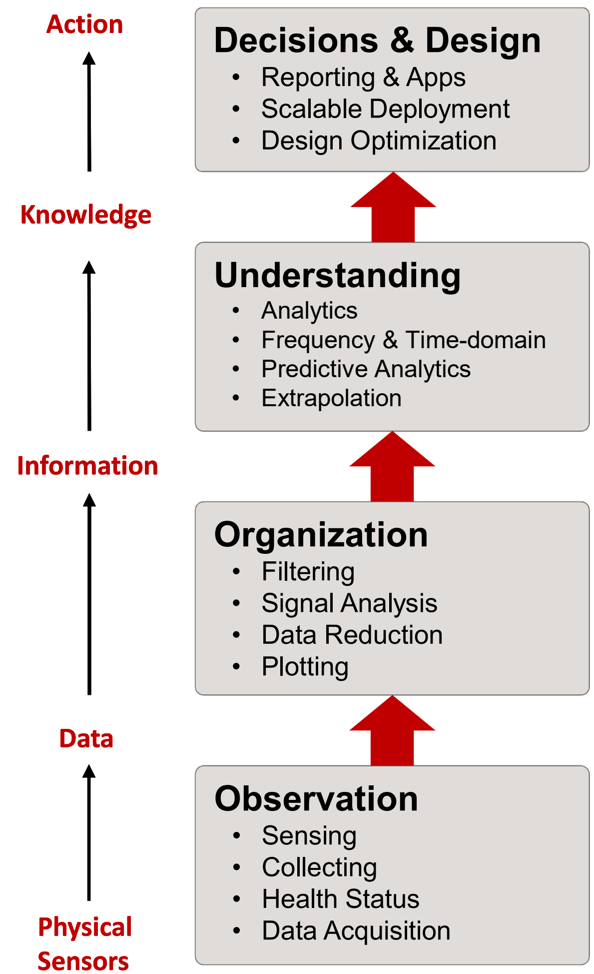

Thankyou – any questions ?