MATLAB EXPO 2019

Industrial IoT and Digital Twins

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Data Science & Enterprise Integration

Digital Twin - Mode for Digital Transformation

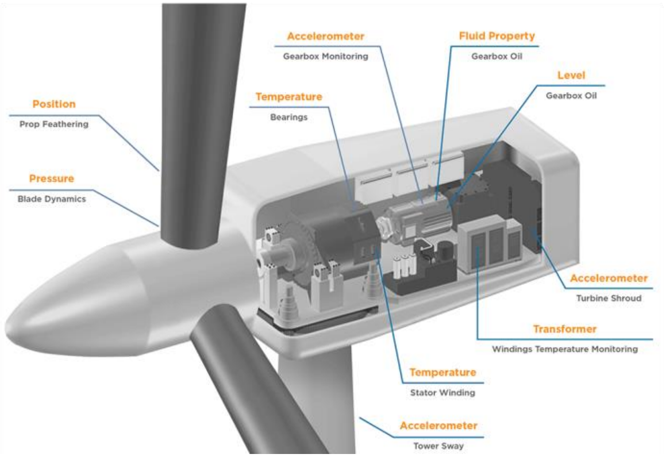
Customer Goals

By **connecting machines** in operation,

you can use **data, algorithms, and models**

to make **better decisions**, improve processes, reduce cost, improve customer experience.

- **Industrial IoT**
- **Digital Twin**
- **Industry 4.0**
- **Smart ‘XYZ’**
- **Digital Transformation**



Transpower Ensures Reliability of New Zealand National Grid with Reserve Management Tool

> "We record frequencies on the grid, inject them into our Simulink model, and compare the simulation results to the actual system response. With Simulink we can continually calibrate and improve our model, and ultimately improve the accuracy of our reserve estimates."
>
> — *Heidi Heath, Transpower*

Transmission lines near Transpower's Benmore substation.

Challenge

Calculate the amount of reserve power needed to ensure that New Zealand's national grid can continue to operate if a generator fails

Solution

Use Simulink to run simulations of the entire grid, including generators, loads, and HVDC links, every 30 minutes

Results

- Critical updates rapidly implemented
- Simulations verified using real data
- Updates made in-house

Transpower - Building Reserve Management Tool using Digital Twins

Measure data from electrical grid	→	Simulate grid models for current measurements
Predict reserve requirements Update controller setpoints	←	Analyze to update digital twin

> "We record frequencies on the grid, inject them into our Simulink model, and compare the simulation results to the actual system response. With Simulink we can continually calibrate and improve our model, and ultimately improve the accuracy of our reserve estimates."
>
> — *Heidi Heath, Transpower*

Objective: Always have enough reserve energy

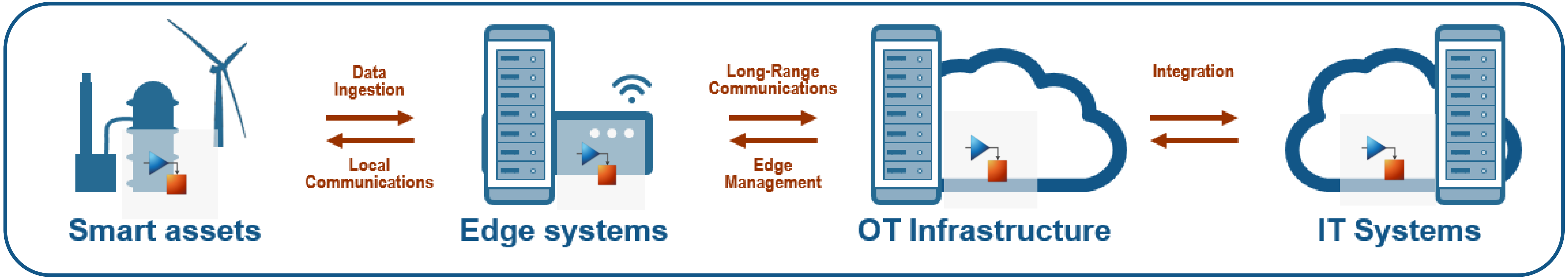
Digital Twin:
- Simulink model of entire grid and tune parameters
- Simulate 100s future scenarios to predict maximum energy needed.

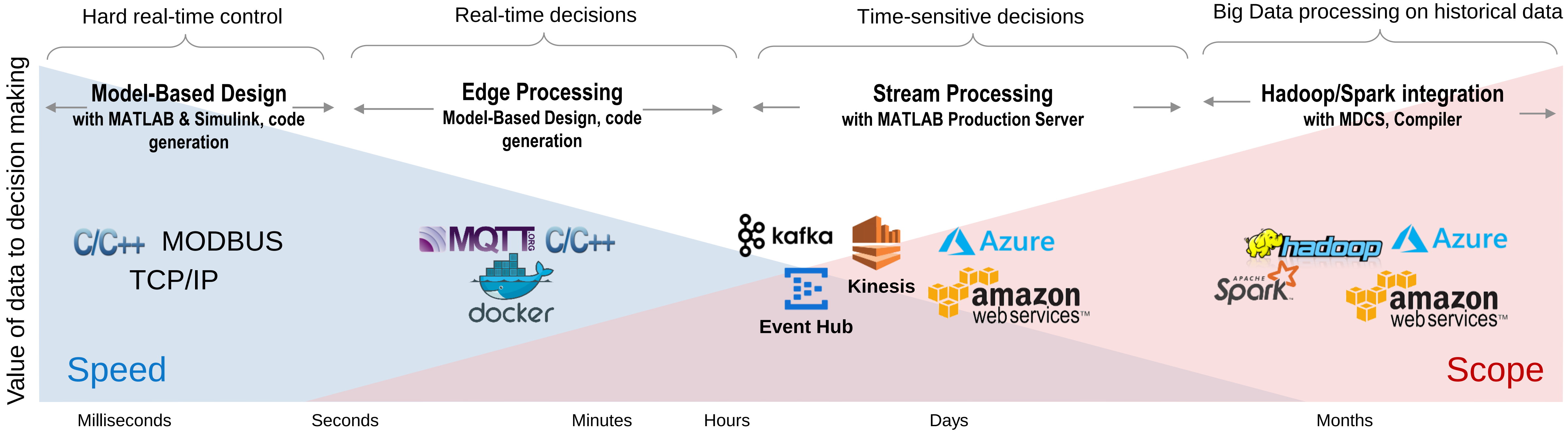
Outcome: Optimize & provided operators control setpoints for sufficient energy reserves

Monitor → Analyze & Updating → Predict → Control → Optimize

Create Digital Twin | Use Digital Twin

Operationalizing Digital Twin with Industrial IoT infrastructure





Challenges in building Digital Twins & related applications:

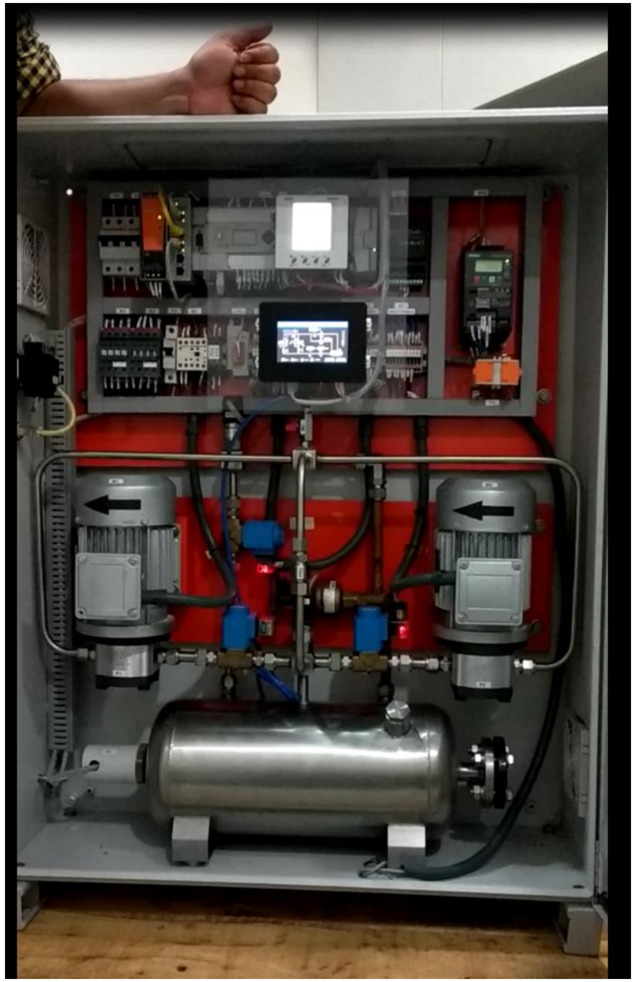
– Building Digital Twins from scratch: Physics based or Data based statistical Models

– Keeping Digital Twins Updated – Tuning Models & AI Algorithms with new data

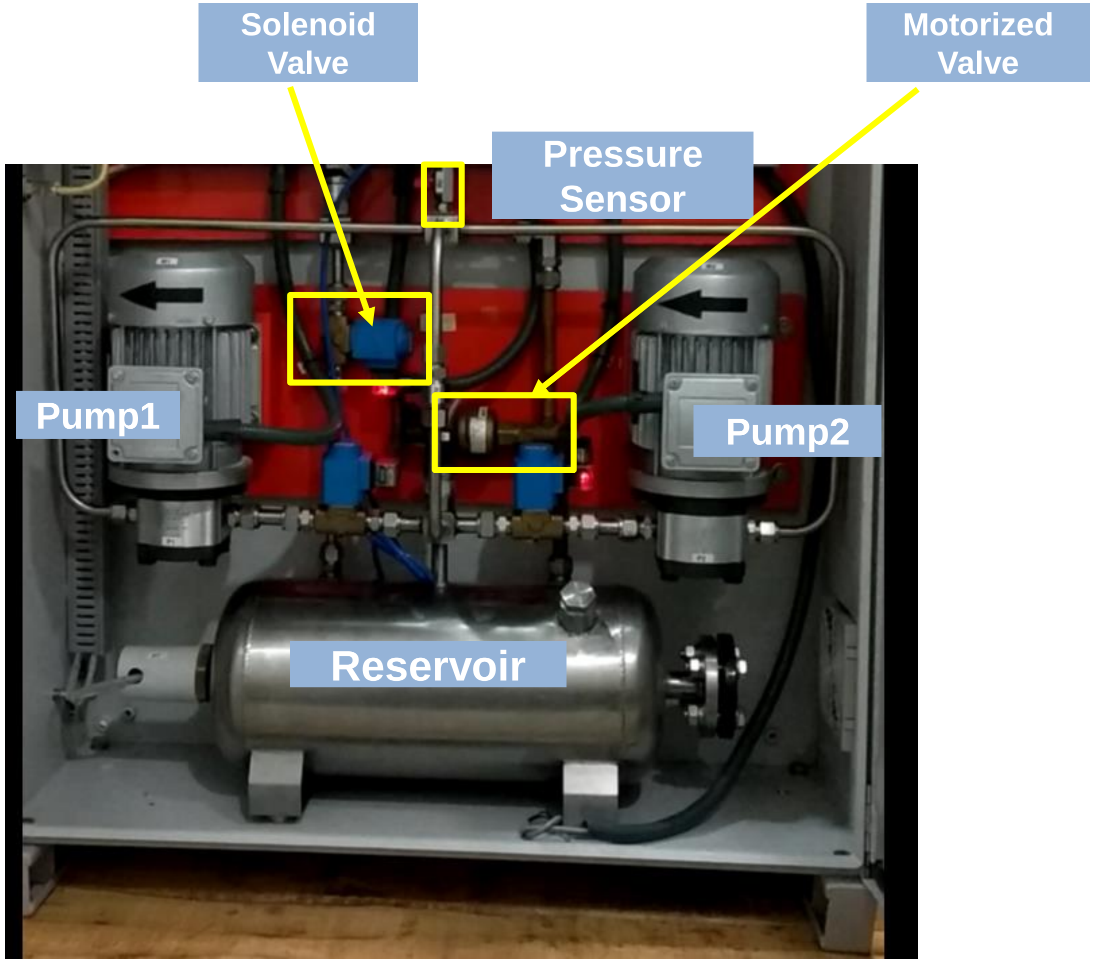
– Scaling number of Digital Twins to match the number of assets

– Deploy Digital Twin Models & Algorithms across the IIoT ecosystem

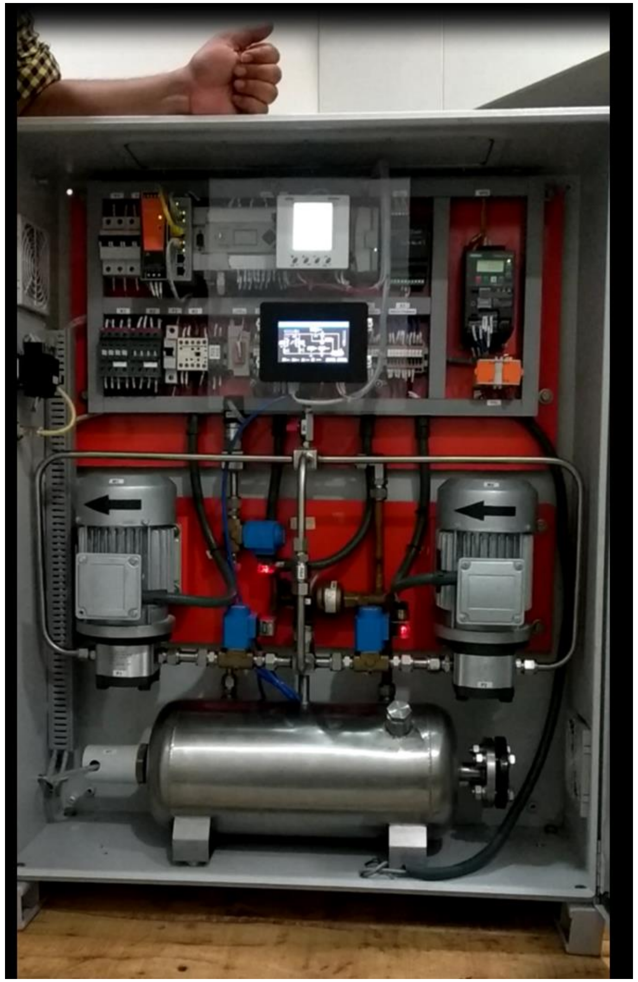
Digital Twin Example: Motorized Pump Demo Hardware



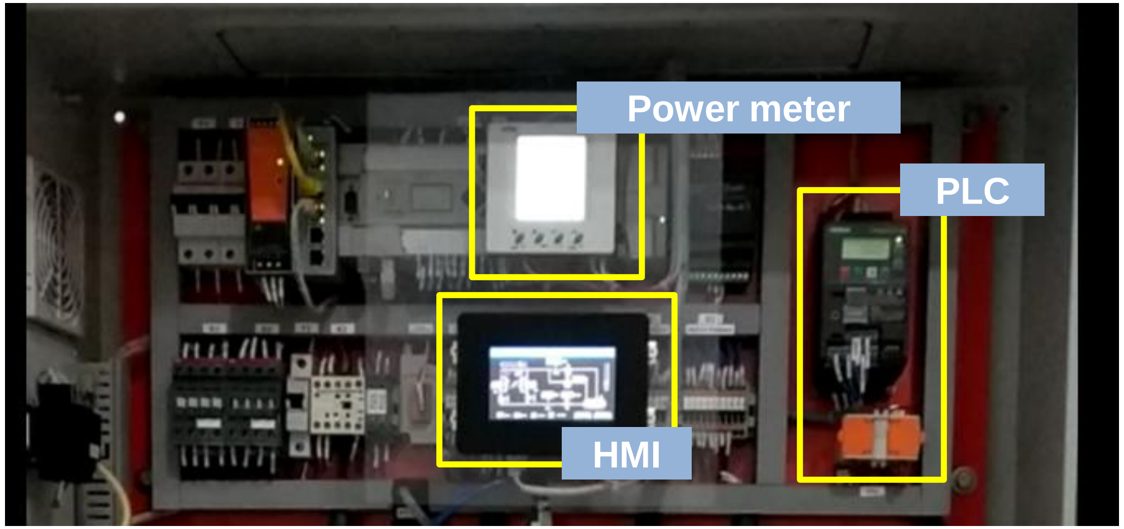
Hydraulics



Digital Twin Example: Motorized Pump Demo Hardware



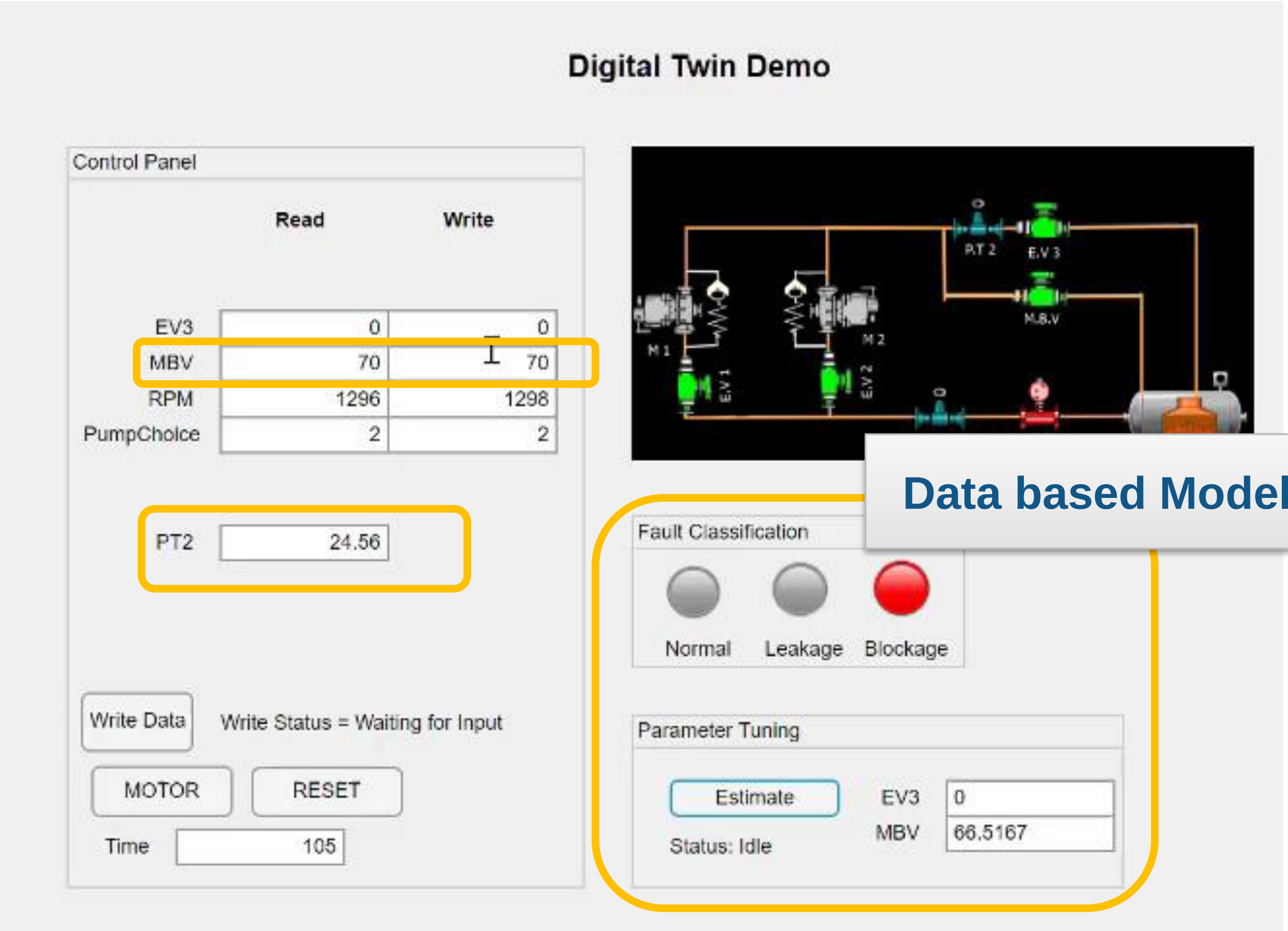
Electrical



Digital Twin Example

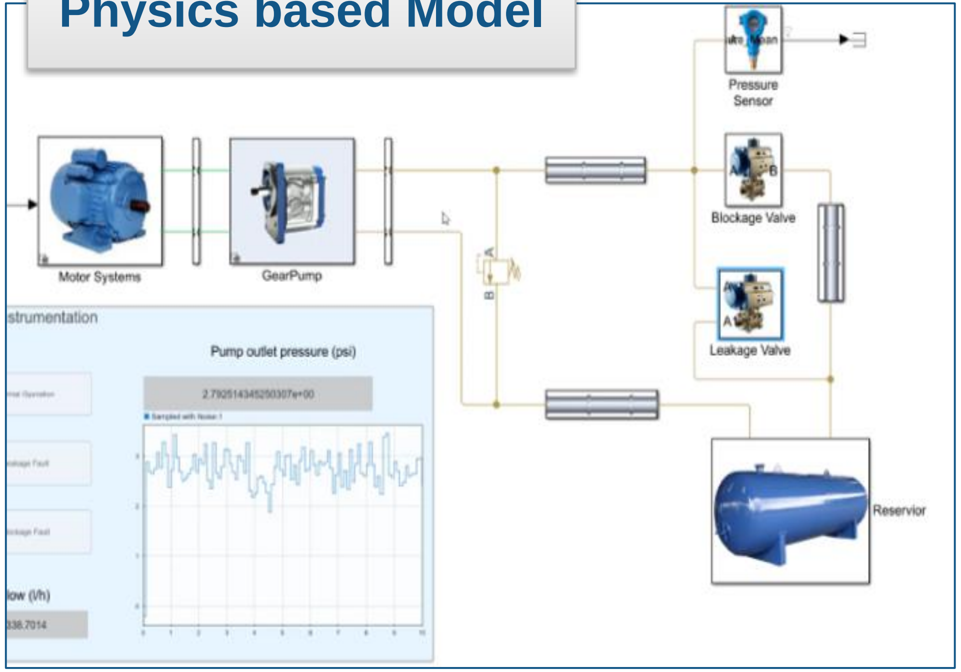
Condition Monitoring & Parameter Estimation

Monitor → Analyze → Predict → Control → Optimize



Data based Model

Physics based Model

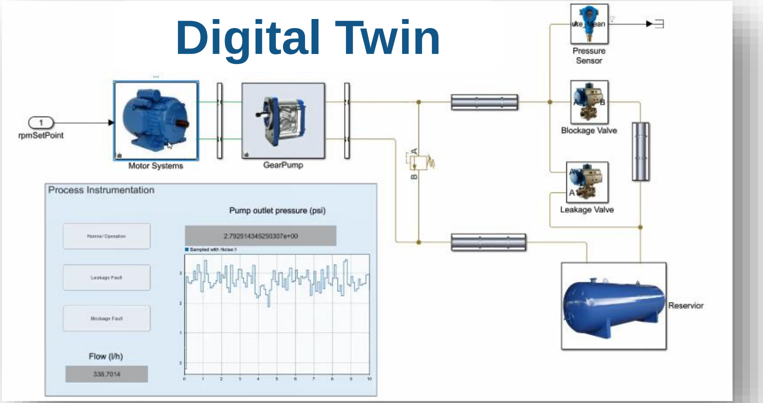


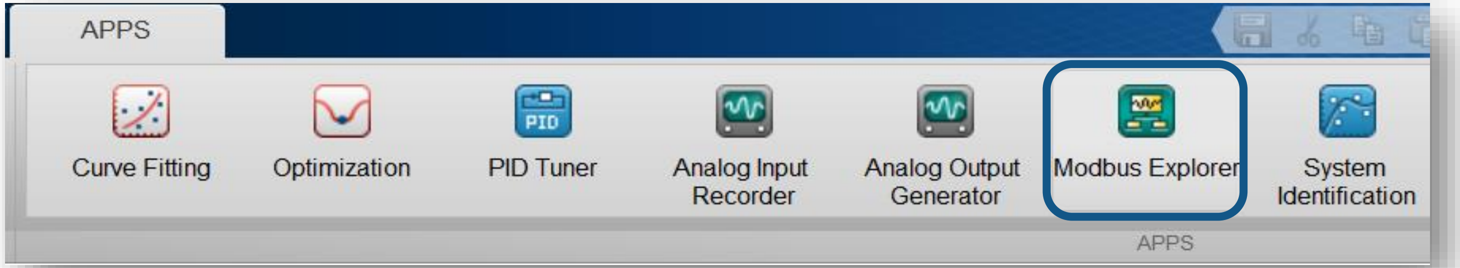
Acquire Real-Time Data for Updating Digital Twin

Monitor → Analyze & Update → Predict → Control → Optimize

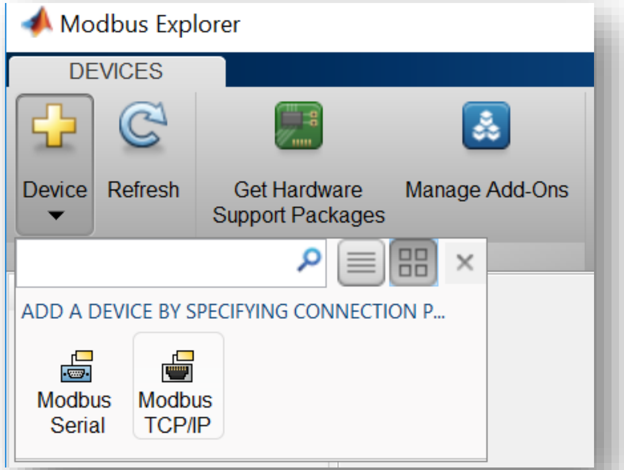
Pump Hardware

MODBUS TCPIP



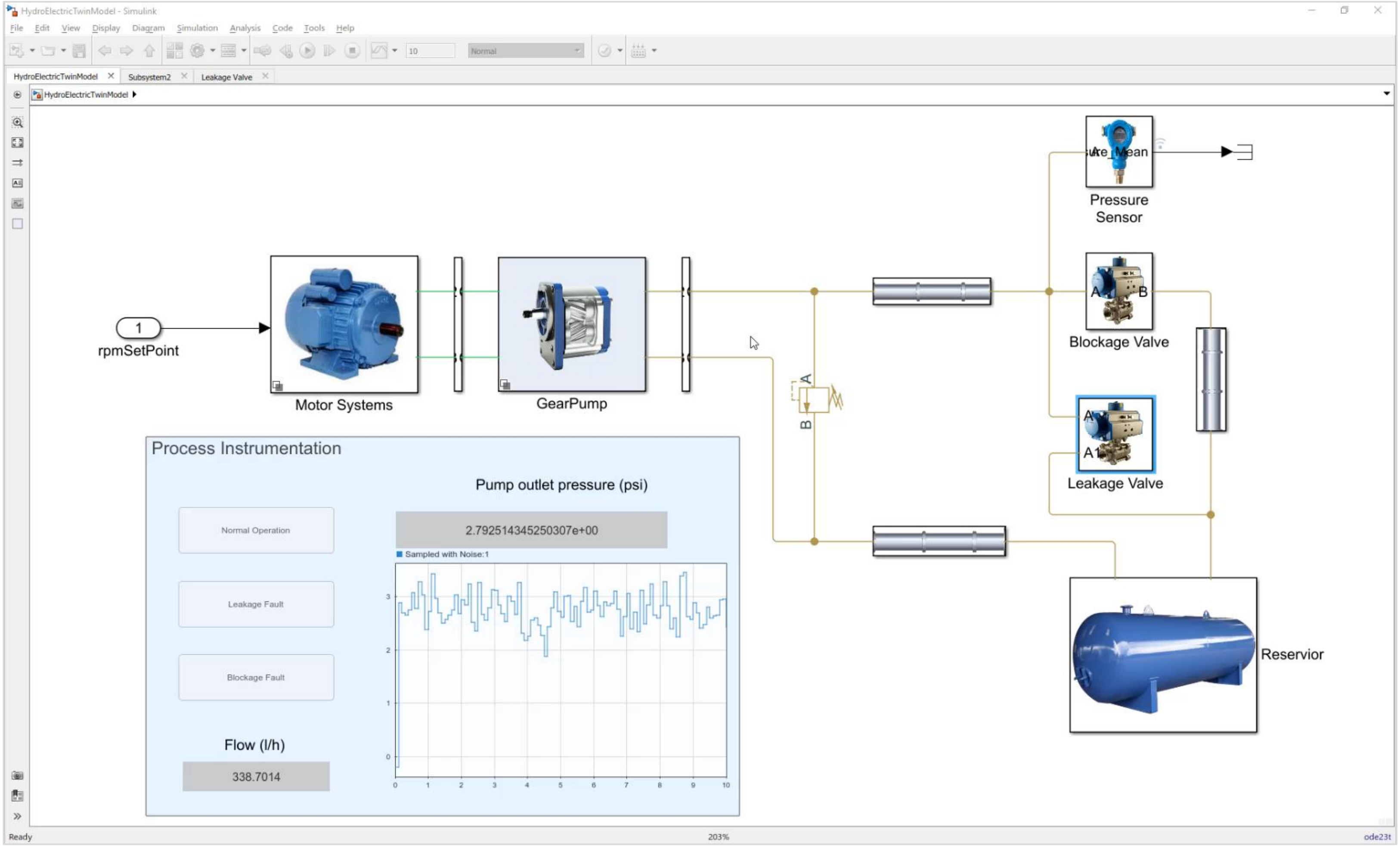



```
m = modbus('tcpip', '192.168.2.1', 308)

m =

   Modbus TCPIP with properties:

     DeviceAddress: '192.168.2.1'
              Port: 308
            Status: 'open'
        NumRetries: 1
           Timeout: 10 (seconds)
         ByteOrder: 'big-endian'
         WordOrder: 'big-endian'
```



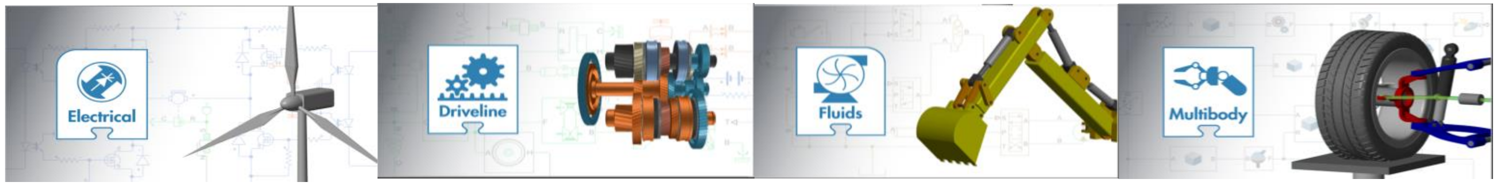
Creating Multi-Domain Physical Models using Simscape

Monitor → Analyze & Update → Predict → Control → Optimize

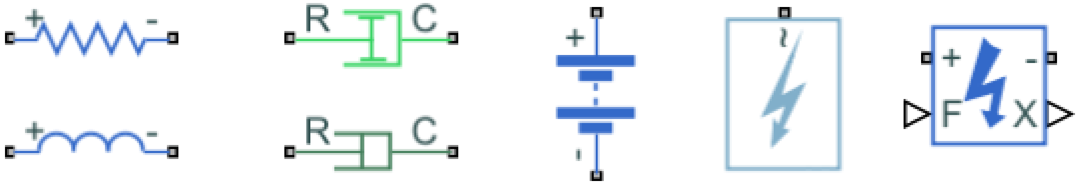


Pump Hardware

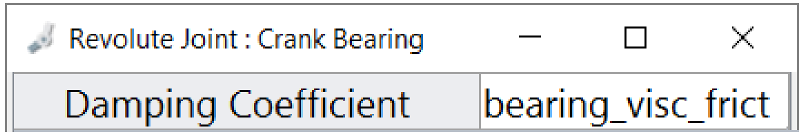
Simscape : Multidomain Modeling and Simulation platform

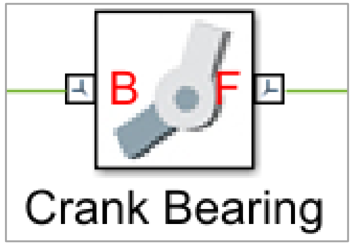


Built-in faults

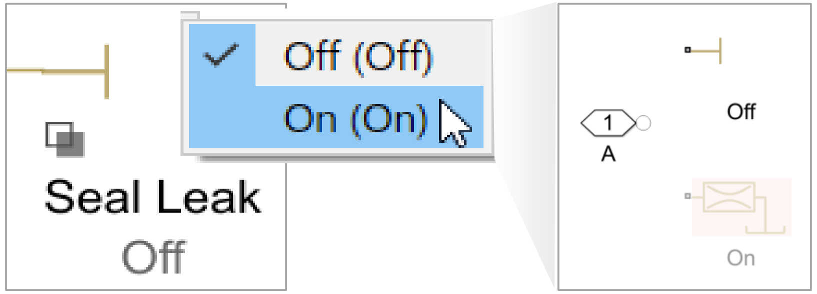


Parameters

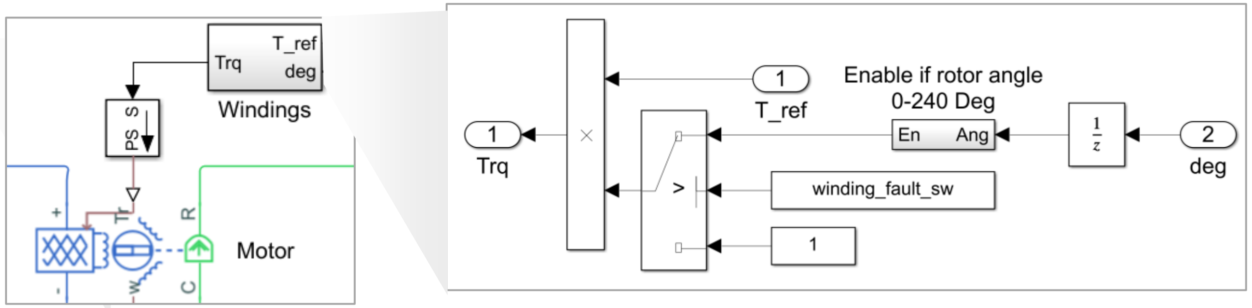




Variants

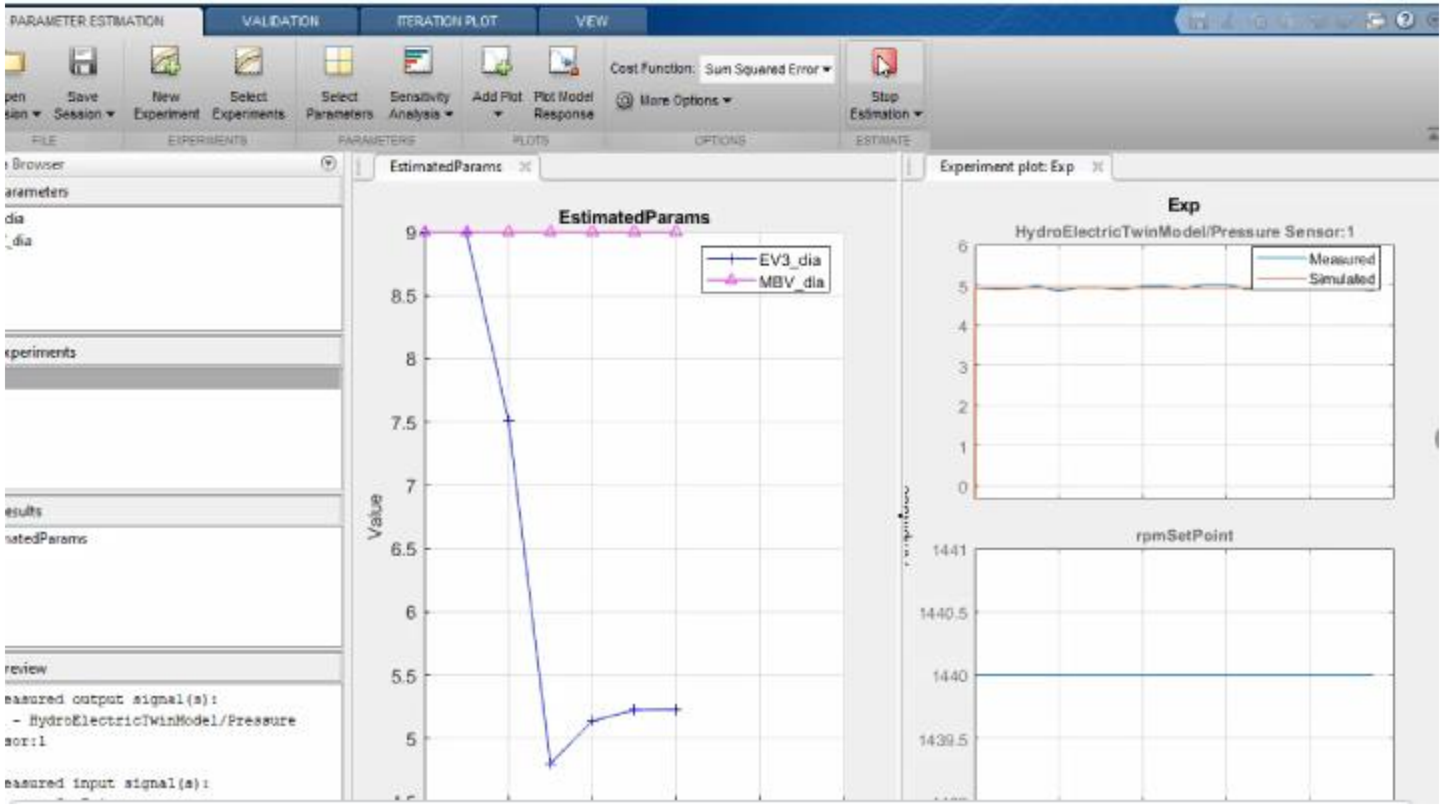


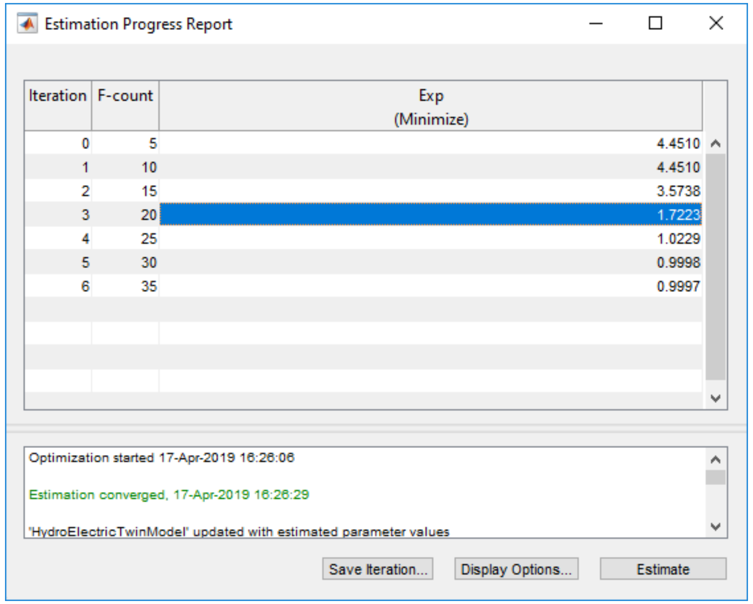
Custom



Use Simulink Design Optimizer to Parameterize Pump Model

Monitor → Model & Update → Predict → Control → Optimize





- ✓ Setup Experiments
- ✓ Parameterize
- ✓ Save Sessions
- ✓ Generate Code

Parameter Estimation – Behind the scenes

Monitor → Analyze → Predict → Control → Optimize

```
% Group the model parameters and initial states to be estimated together.
%
v = [p;s];

% Estimation Function
estFcn = @(v) sdoPumpEstimation_Objective(v, Simulator, Exp);


% Optimization options
opt = sdo.OptimizeOptions;
opt.Method = 'lsqnonlin';

% Estimate the Parameters
vOpt = sdo.optimize(estFcn, v, opt)
```

Initialize

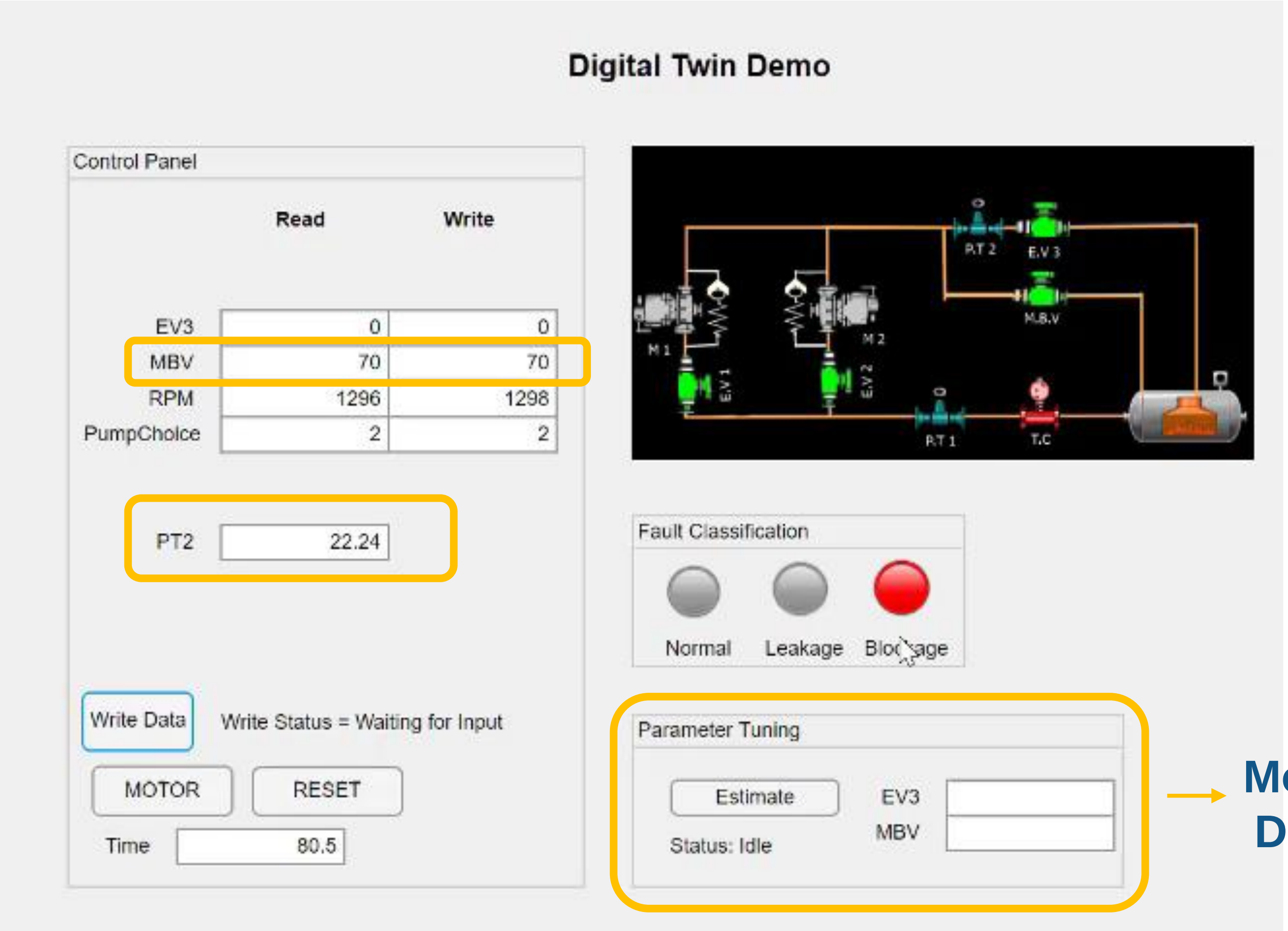
Set Objective

Select solver

Estimate

Digital Twin Example: Estimate Model Parameters to match System

Monitor → Analyze & Update → Predict → Control → Optimize



MATLAB Standalone App

1. **Communicating with Hardware**
2. **Reading Pressure Values**
3. **Writing Valve Setting**
4. **Identify Fault conditions**
5. **Estimating Model Parameters to match the System**

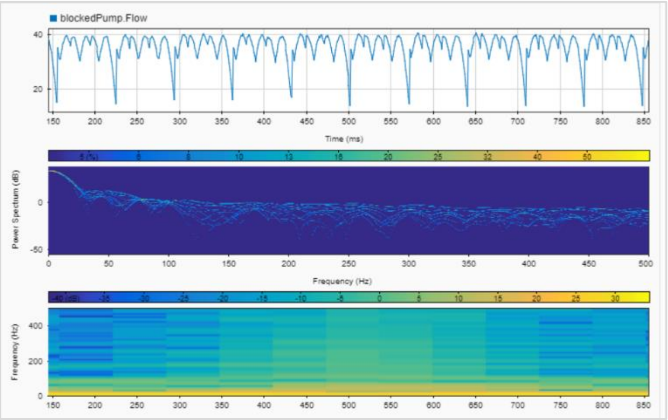
→ **Model based Digital Twin**

Workflow for developing data & AI based digital twins

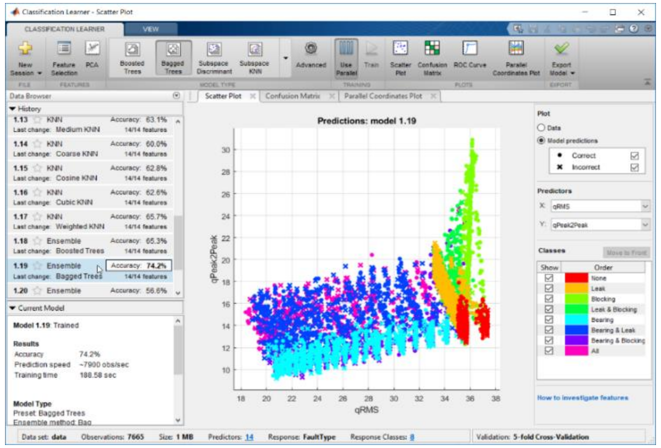
Monitor → Analyze & Update → Predict → Control → Optimize

	Time	1 LeakFault	2 BlockingFault	3 BearingFault	4 FaultType
1	0 sec	2.8472	-0.1477	1.8000	All
2	0.001 sec	-0.1498	-0.4207	1.3103	Bearing & Blocking
3	0.002 sec	0.6511	1.6521	-0.5557	Leak
4	0.003 sec	0.1469	-0.2775	1.0074	All
5	0.004 sec	-0.6480	0.7065	-0.8878	Blocking
6	0.005 sec	-0.8165	-0.5434	-0.3079	Blocking
7	0.006 sec	-1.0061	1.2083	0.0661	Bearing
8	0.007 sec	1.0125	-1.9098	-0.7027	Leak & Blocking

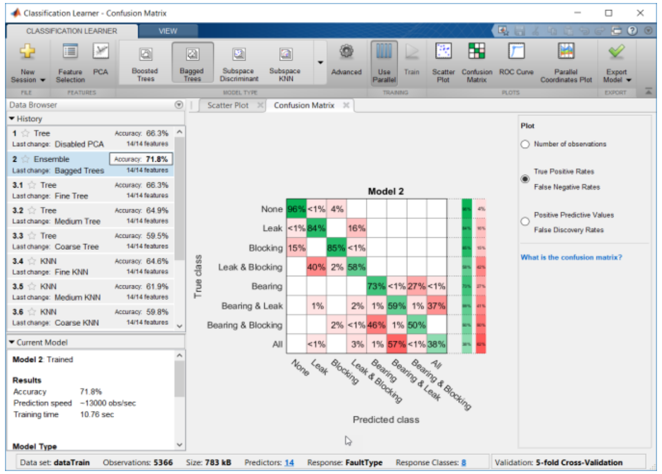
Label Faults



Represent Signals



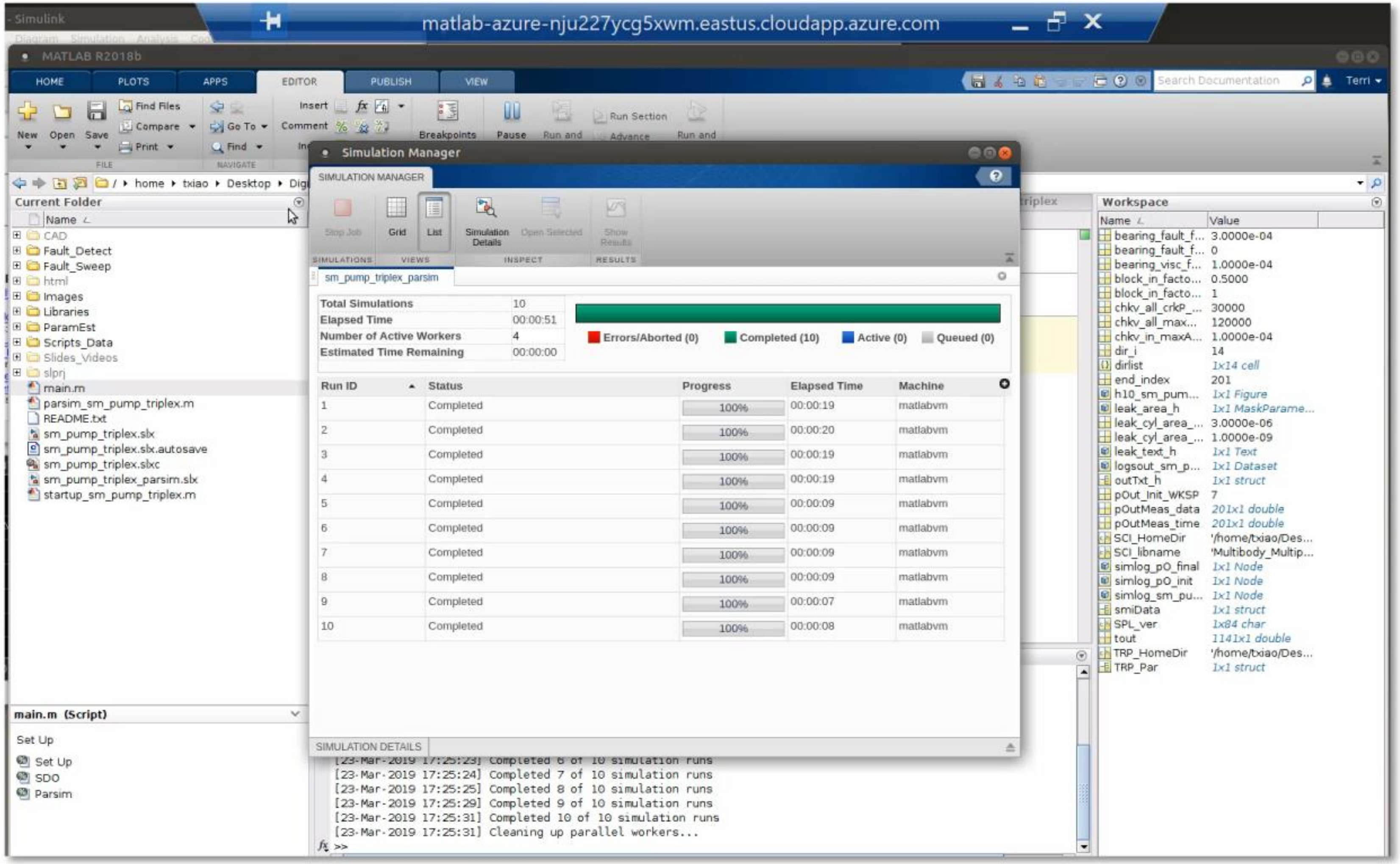
Train Model

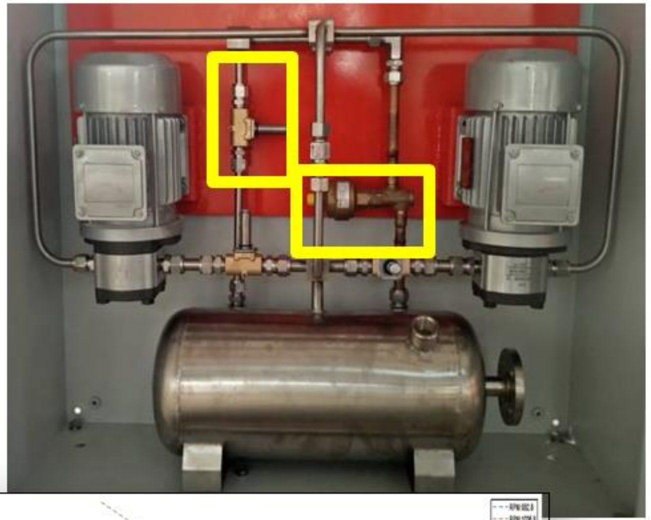


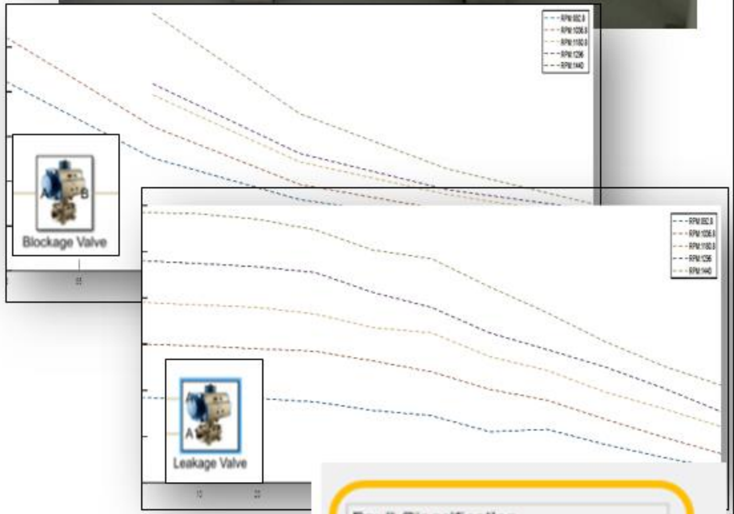
Validate Model

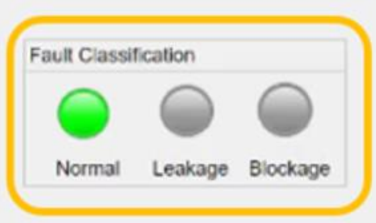
Failure Scenario Generation - Run Parallel Simulations to scale up

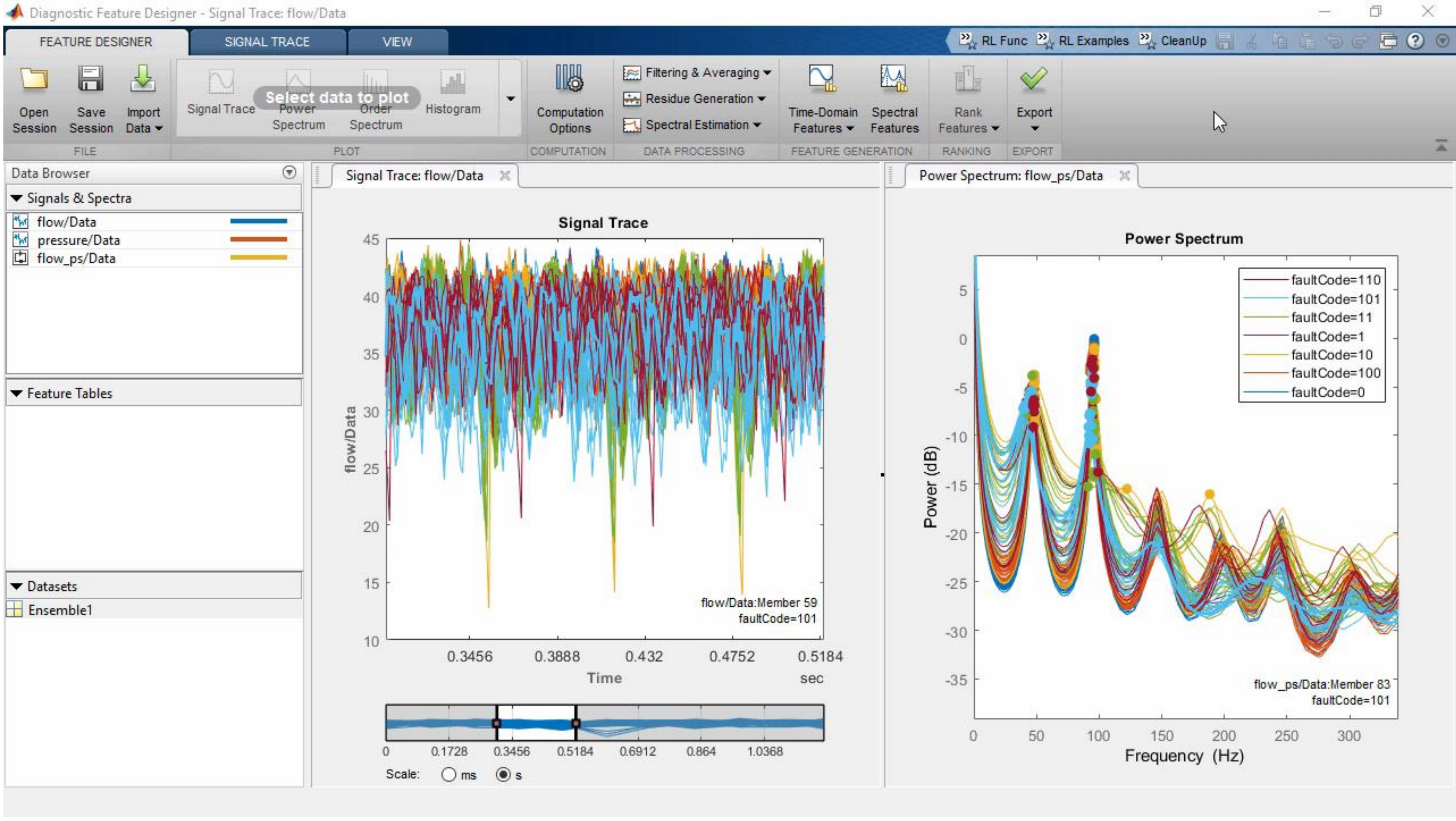
Monitor → Analyze & Update → Predict → Control → Optimize



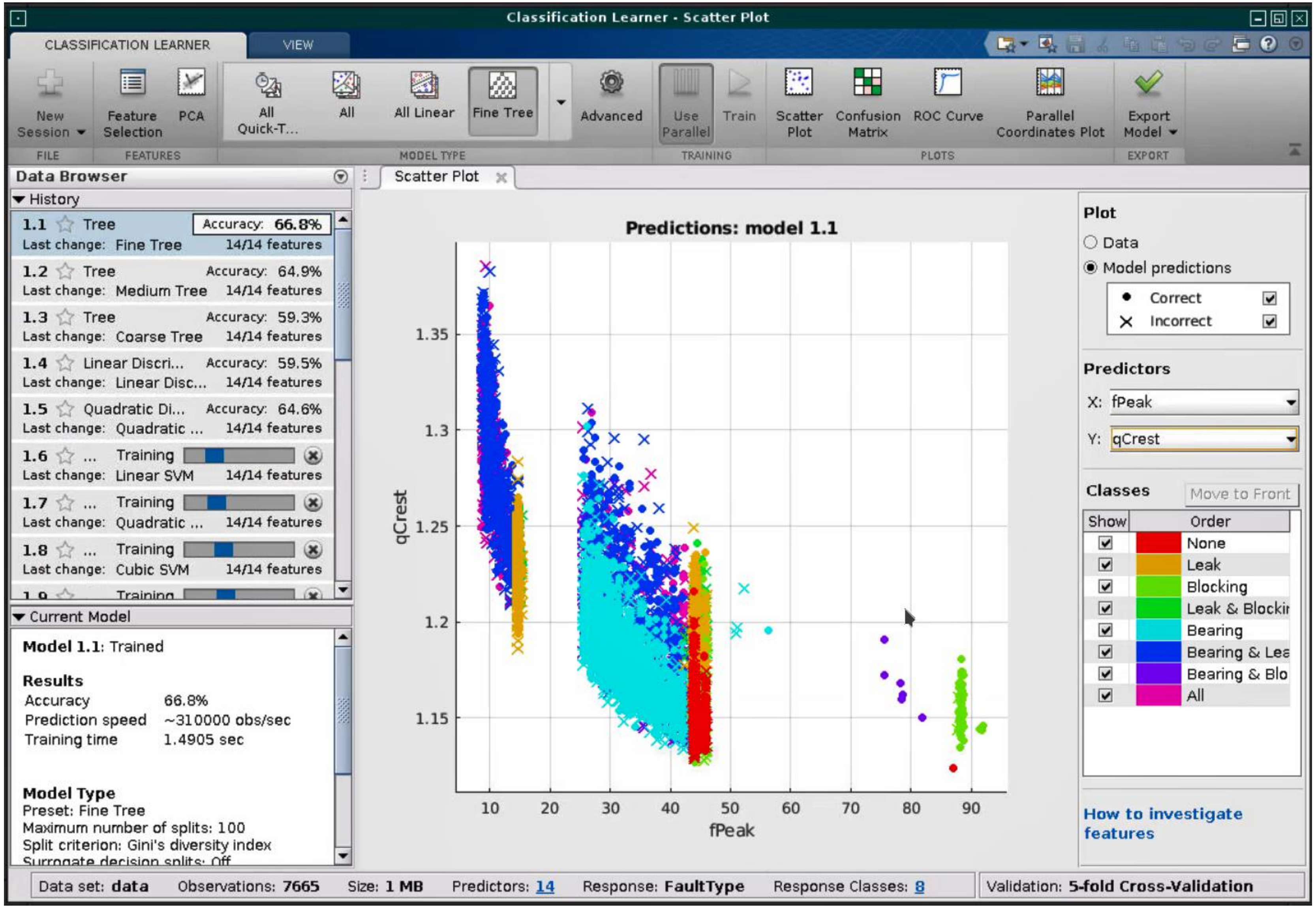


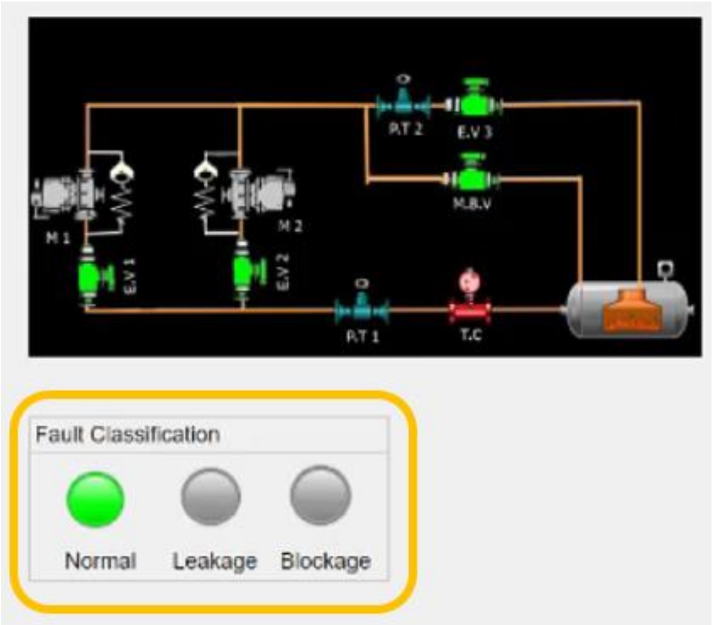




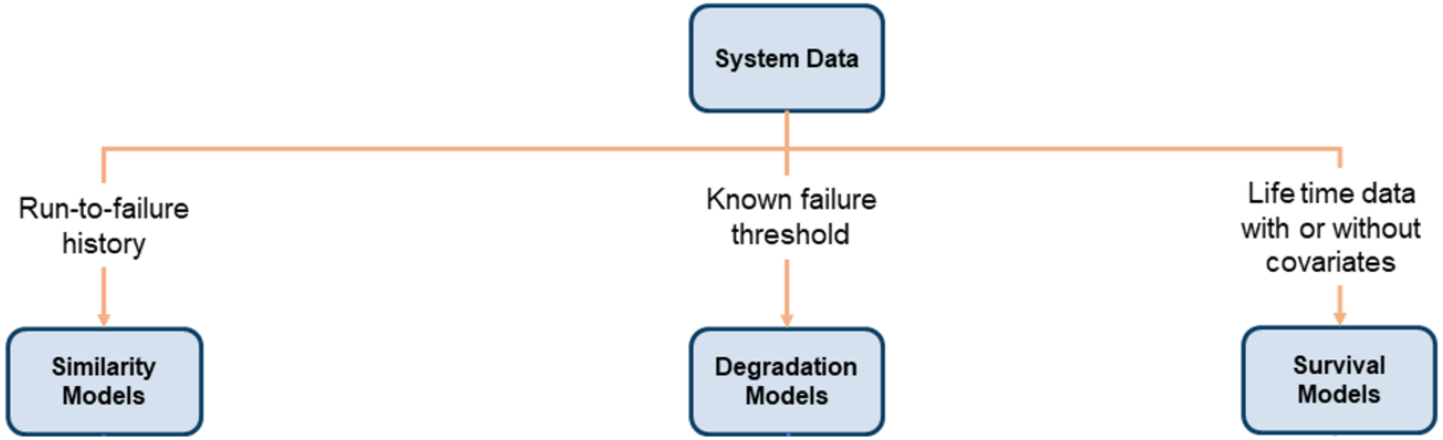

Diagnostic Feature Designer - Signal Trace: flow/Data
FEATURE DESIGNER
SIGNAL TRACE
VIEW
RL Func
RL Examples
CleanUp
Open Session
Save Session
Import Data
Signal Trace
Select data to plot
Power Spectrum
Order Spectrum
Histogram
Computation Options
Filtering & Averaging
Residue Generation
Spectral Estimation
Time-Domain Features
Spectral Features
Rank Features
Export
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
Signal Trace
flow/Data
Time
sec
flow/Data:Member 59
faultCode=101
Scale:
ms
s
Power Spectrum: flow_ps/Data
Power Spectrum
Power (dB)
Frequency (Hz)
faultCode=110
faultCode=101
faultCode=11
faultCode=1
faultCode=10
faultCode=100
faultCode=0
flow_ps/Data:Member 83
faultCode=101

Condition Monitoring: Develop AI based models

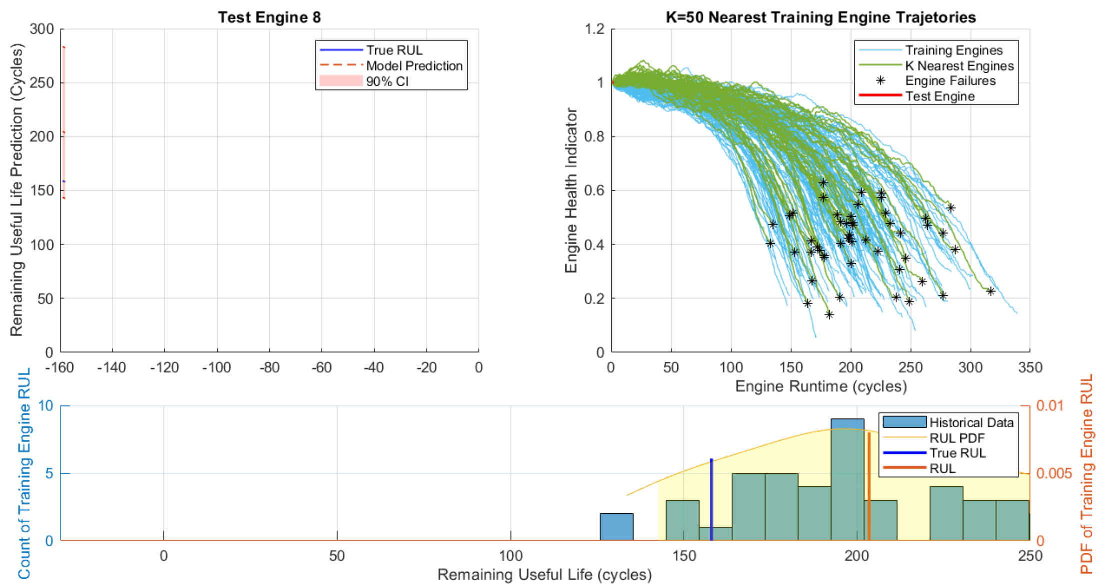




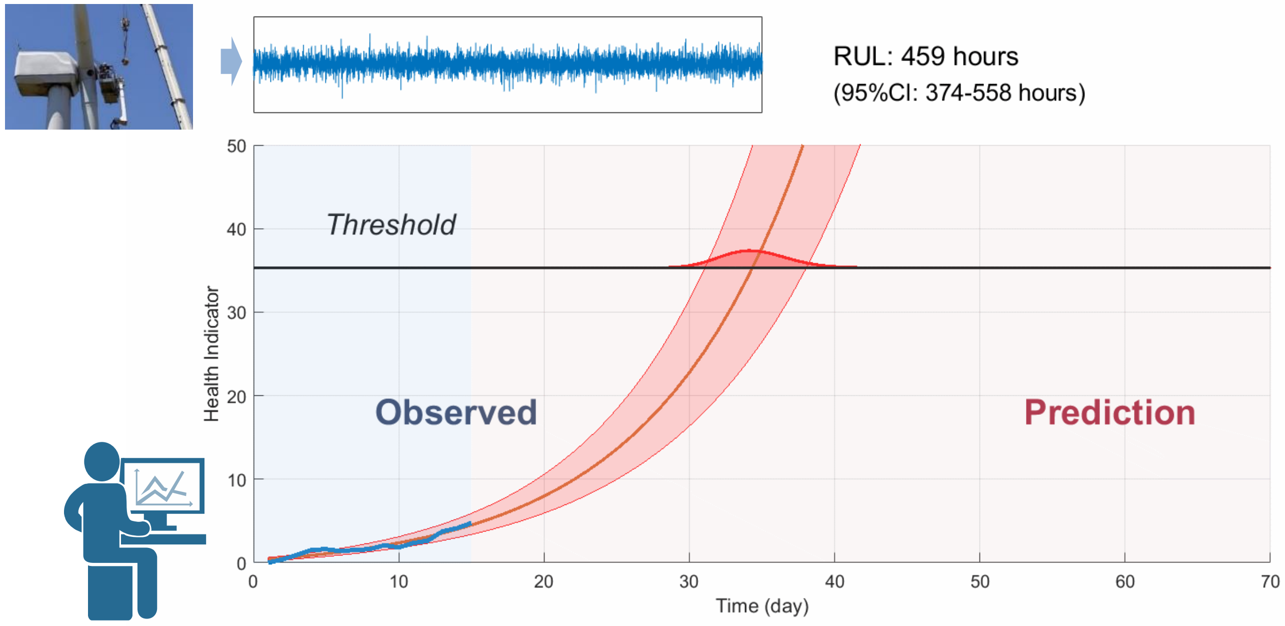
Off-the-shelf Remaining Useful Life (RUL) estimators



Similarity Models



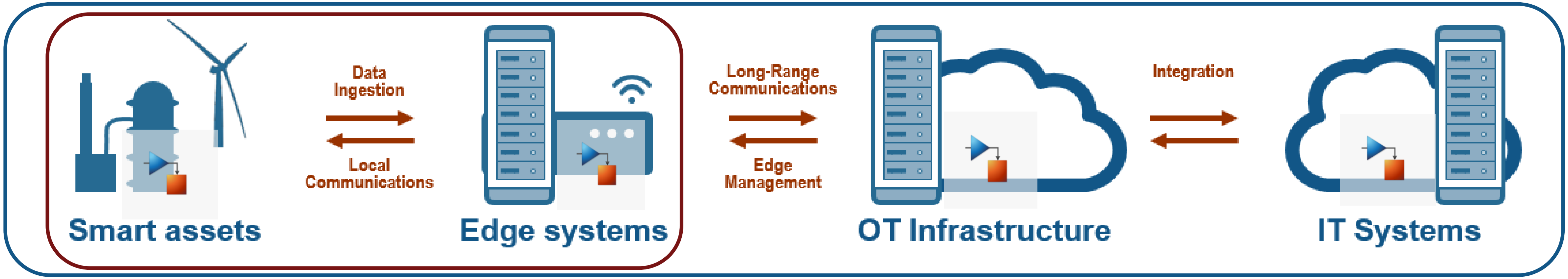
Degradation Models

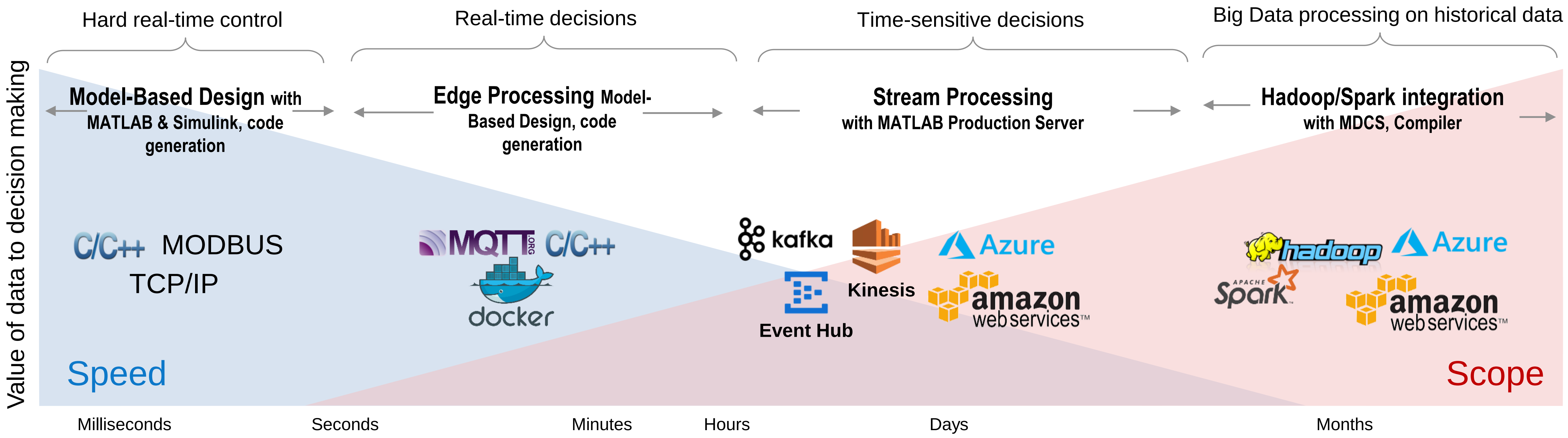


Challenges in building Digital Twins & related applications:

- ✓ Building Digital Twins from scratch: Physics based or Data based statistical Models
- ✓ Keeping Digital Twins Updated – Tuning Models & AI Algorithms with new data
- ➢ Deploy Digital Twin Models & Algorithms across the IIoT ecosystem
- ➢ Scaling number of Digital Twins to match the number of assets

Operationalizing Analytics across IIoT infrastructure

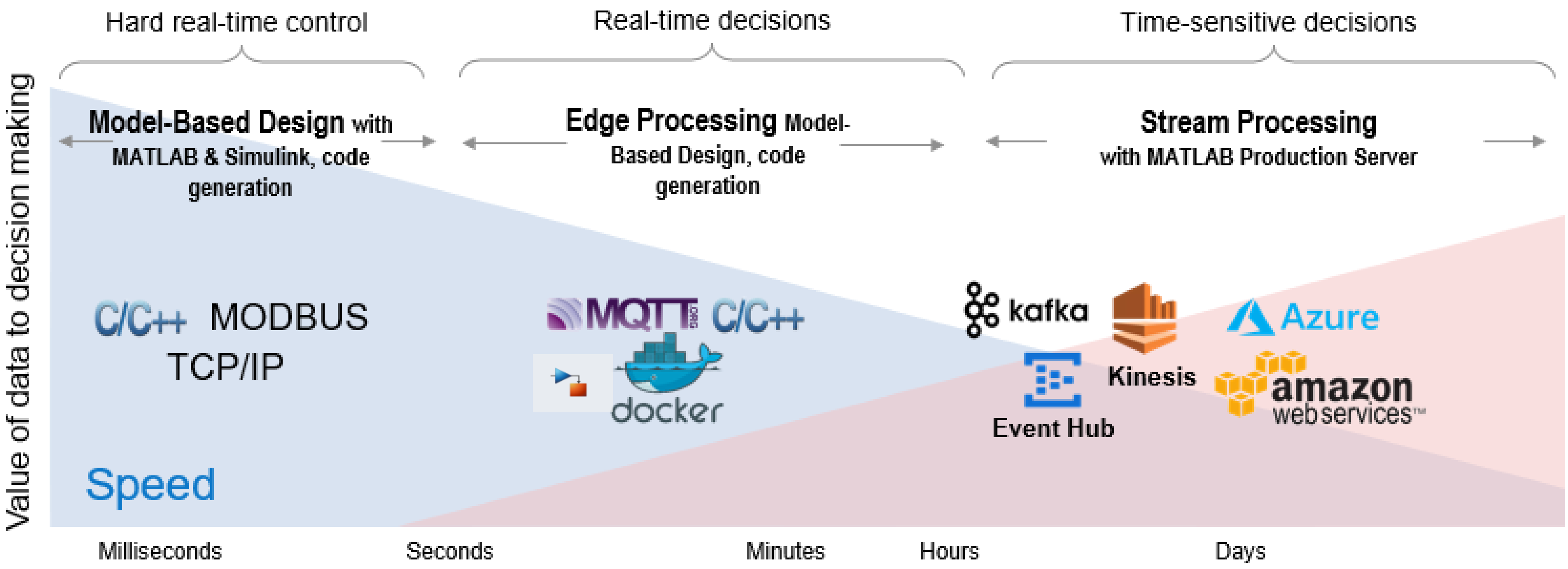




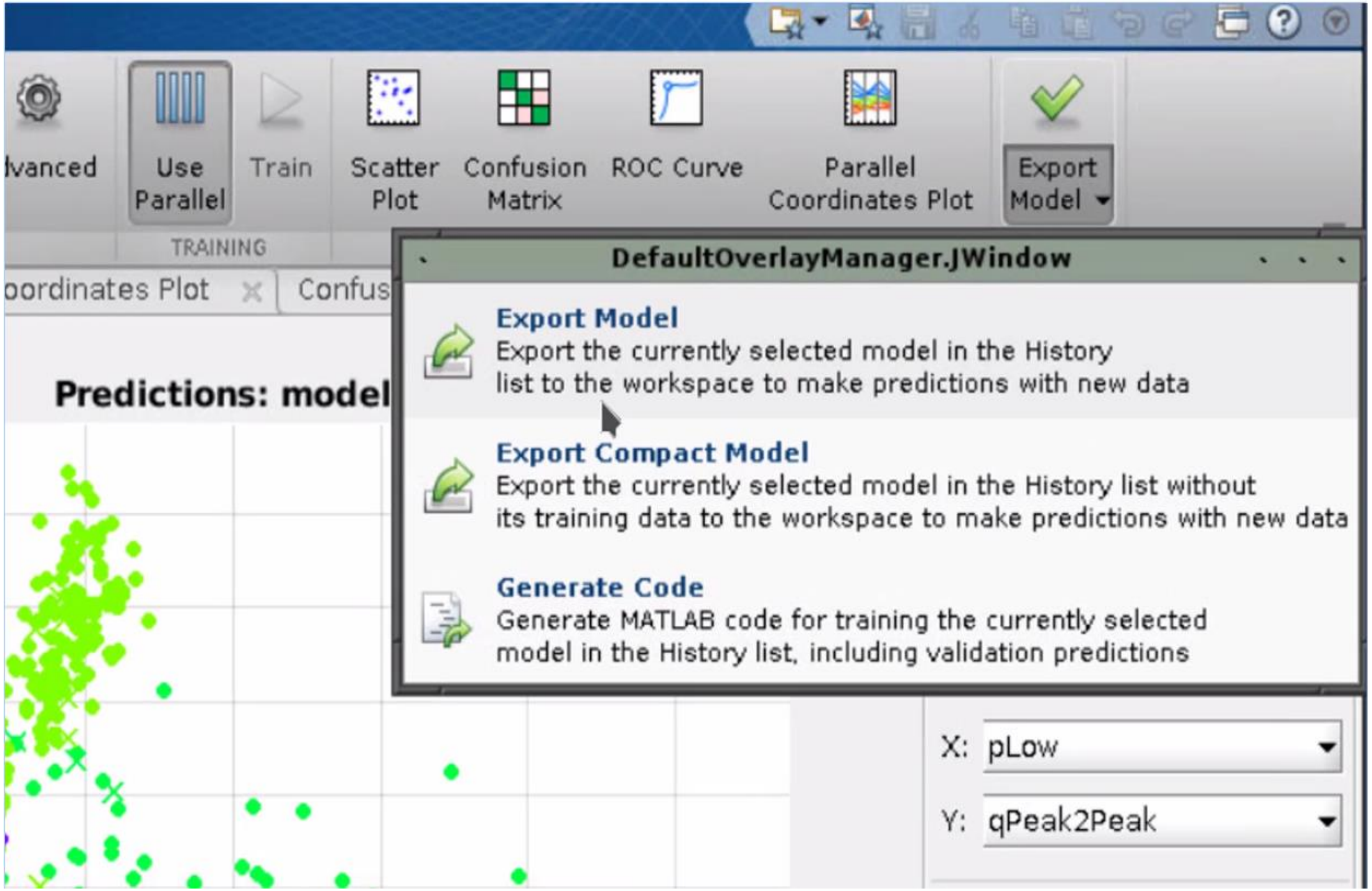
Operationalizing on Edge

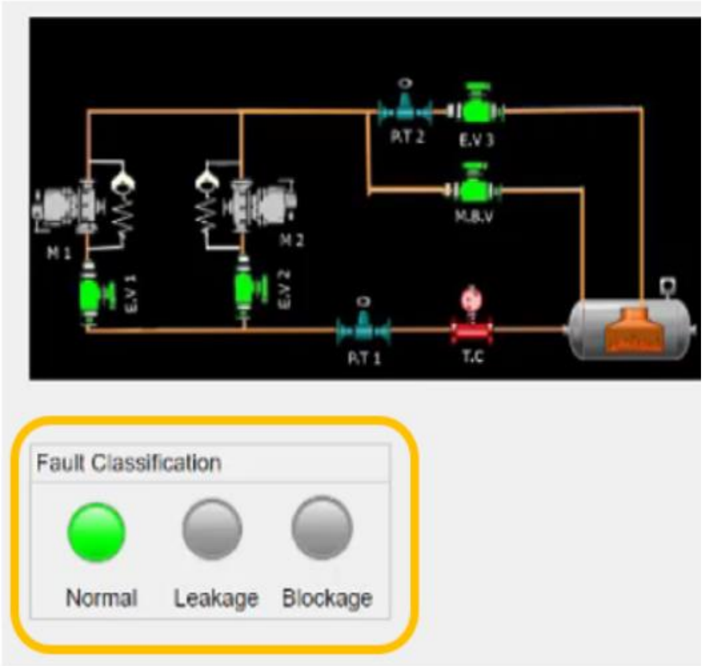
Low Compute
Near range Communication

Higher Compute
Both Near & Far Communication

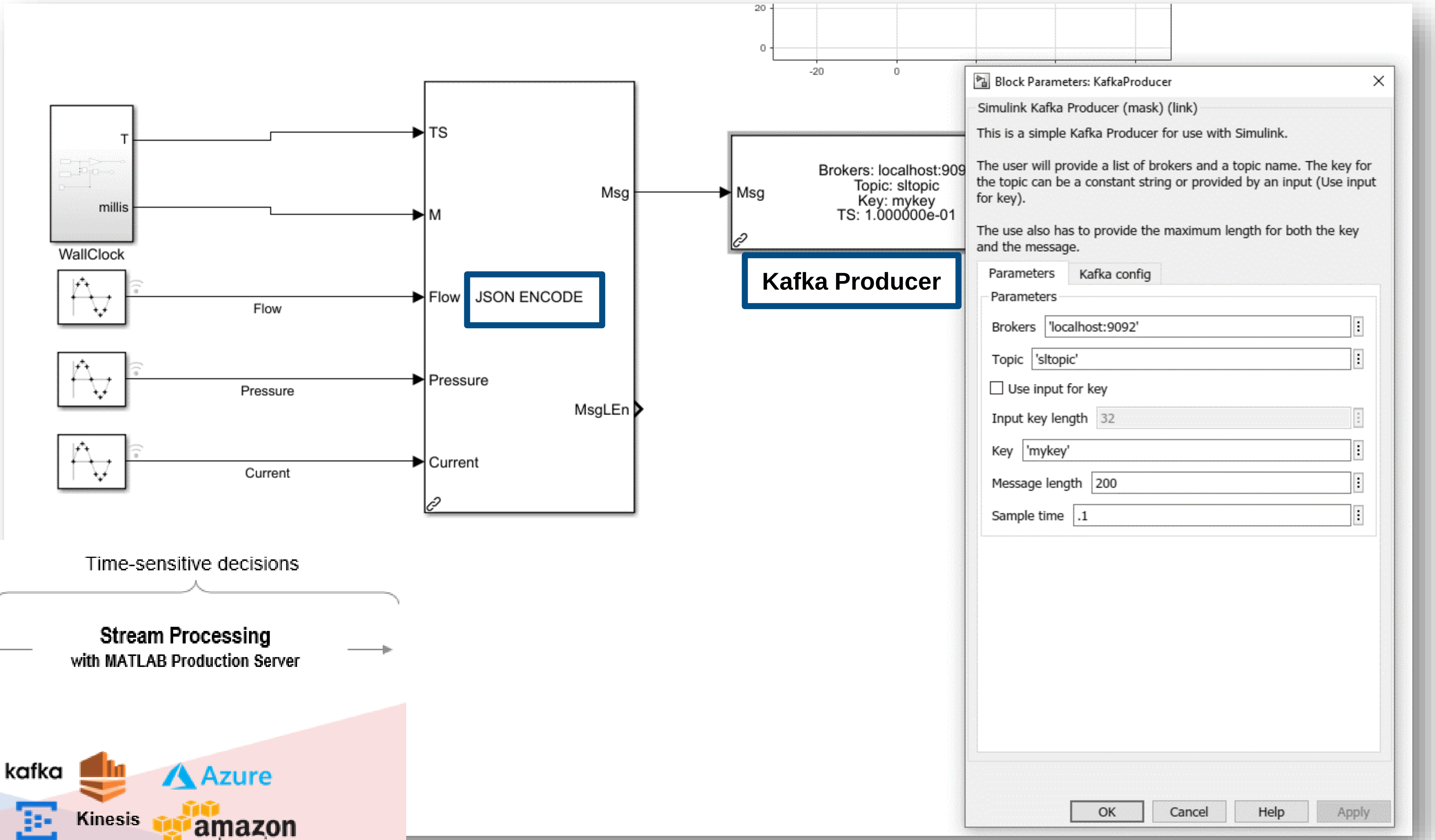


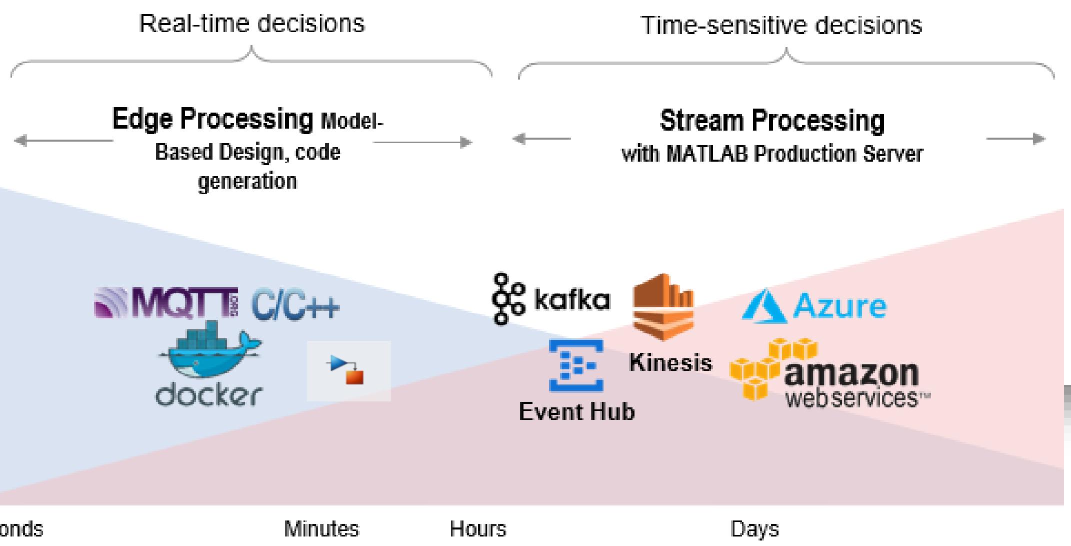
Deploying An Use MATLAB Coder to generate C code





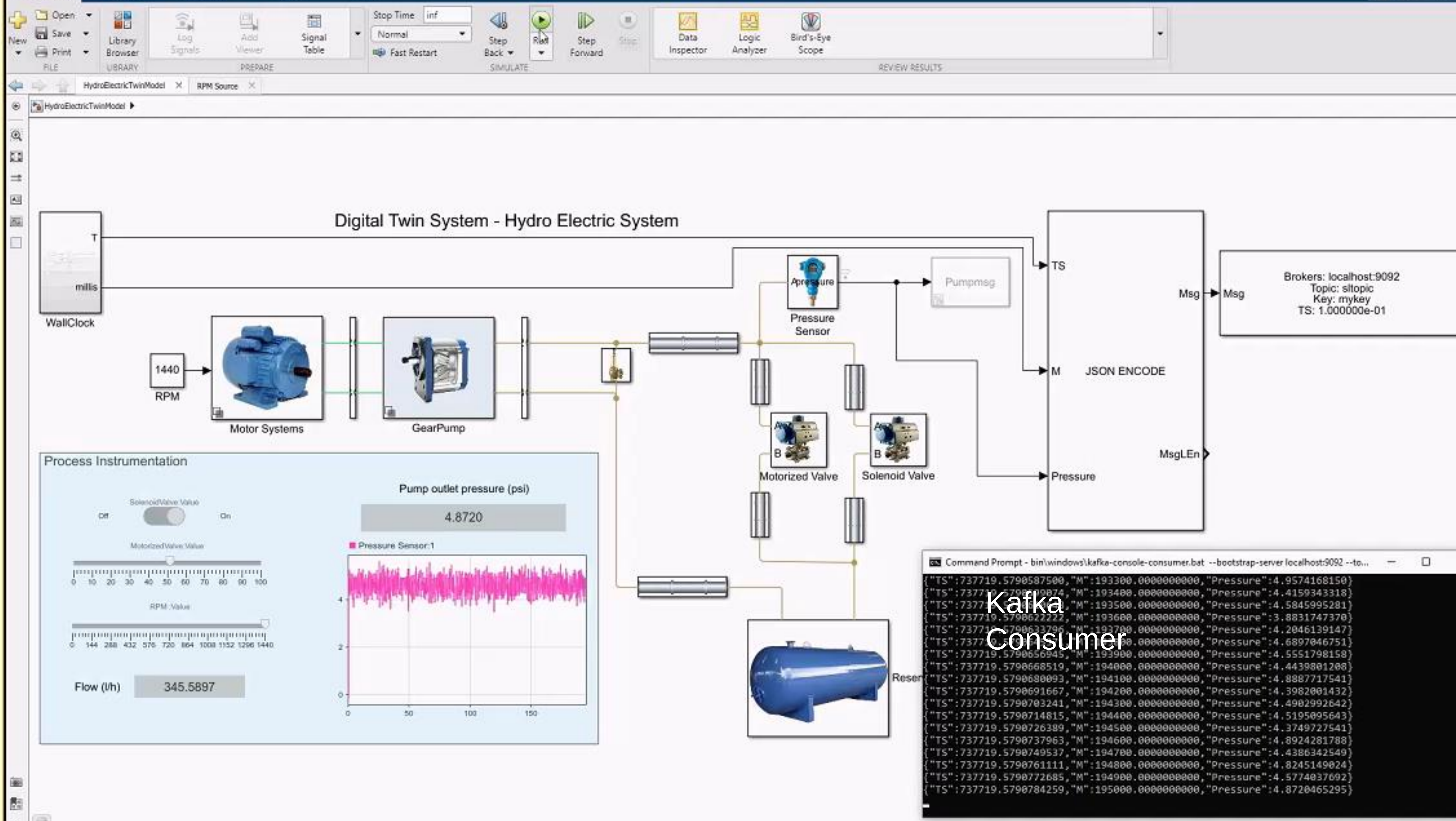
Running MATLAB on Edge and streaming processed data





librdkafka : https://github.com/edenhill/librdkafka

jansson : http://www.digip.org/jansson/


Digital Twin System - Hydro Electric System
WallClock
T
millis
1440
RPM
Motor Systems
GearPump
Pressure Sensor
Pumpmsg
Motorized Valve
Solenoid Valve
TS
M
JSON ENCODE
Pressure
Msg
MsgLEn
Brokers: localhost:9092
Topic: sltopic
Key: mykey
TS: 1.000000e-01
Process Instrumentation
Pump outlet pressure (psi)
4.8720
Pressure Sensor:1
Flow (l/h)
345.5897
Command Prompt - bin\windows\kafka-console-consumer.bat --bootstrap-server localhost:9092 --to...
Kafka
Consumer
{"TS":737719.5790587500,"M":193300.0000000000,"Pressure":4.9574168150}
{"TS":737719.5790656945,"M":193900.0000000000,"Pressure":4.5551798158}
{"TS":737719.5790668519,"M":194000.0000000000,"Pressure":4.4439801208}
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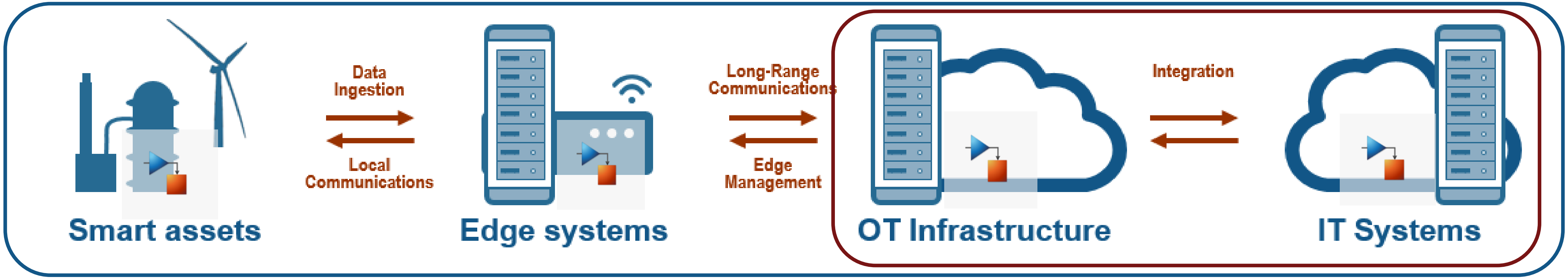
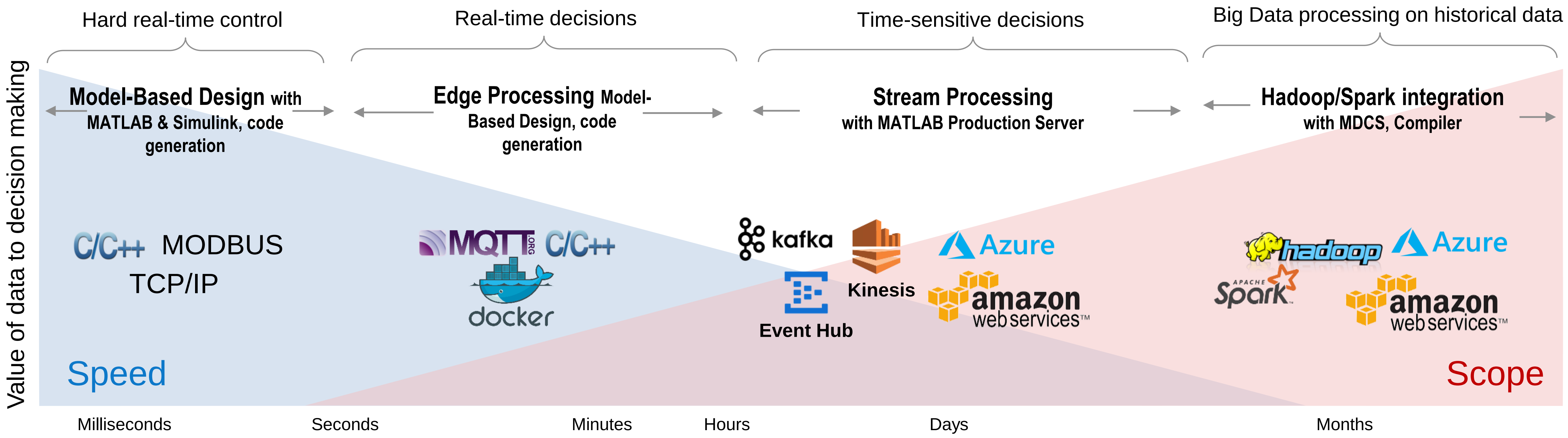
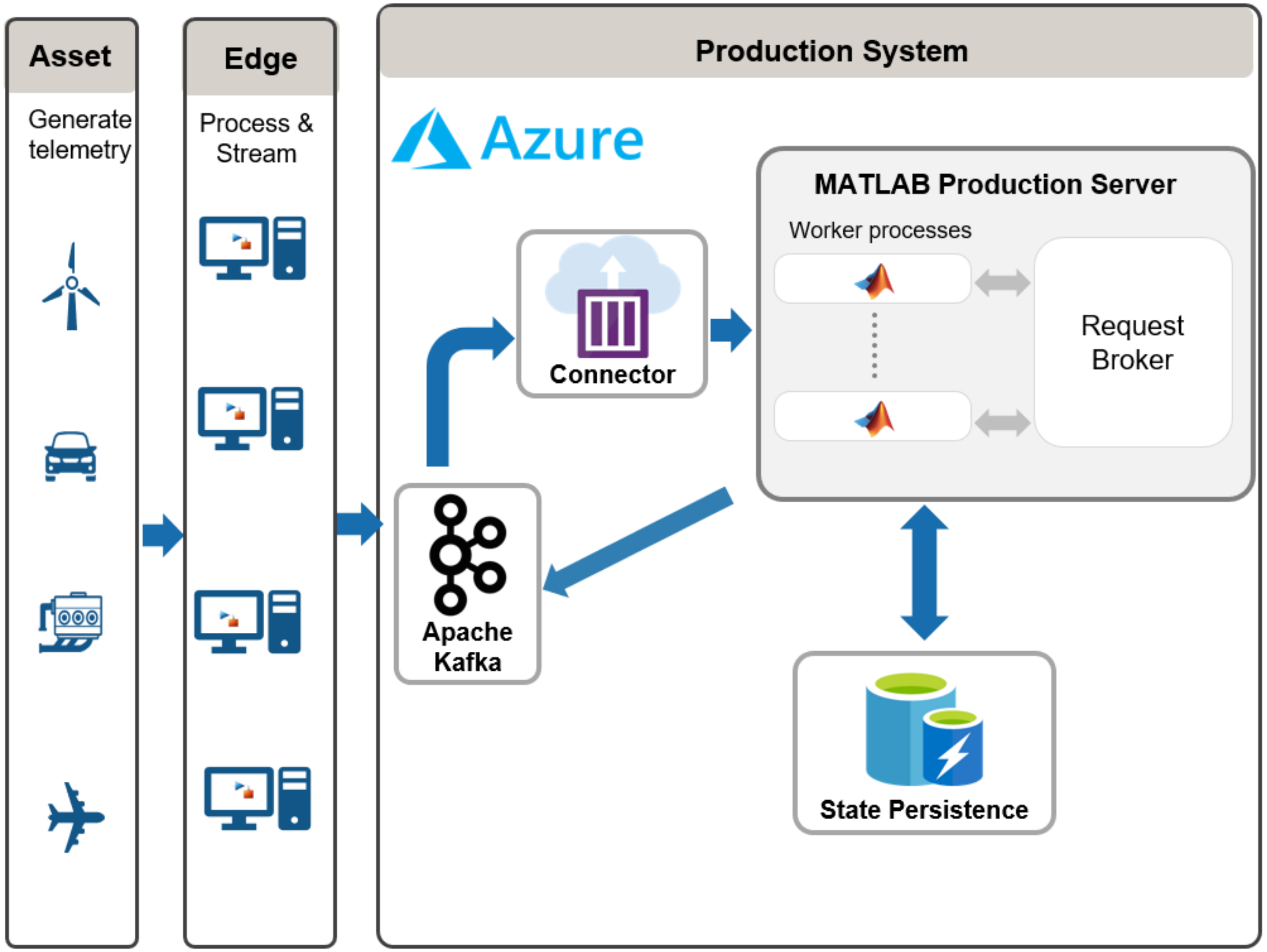
Operationalizing Analytics across IIoT infrastructure

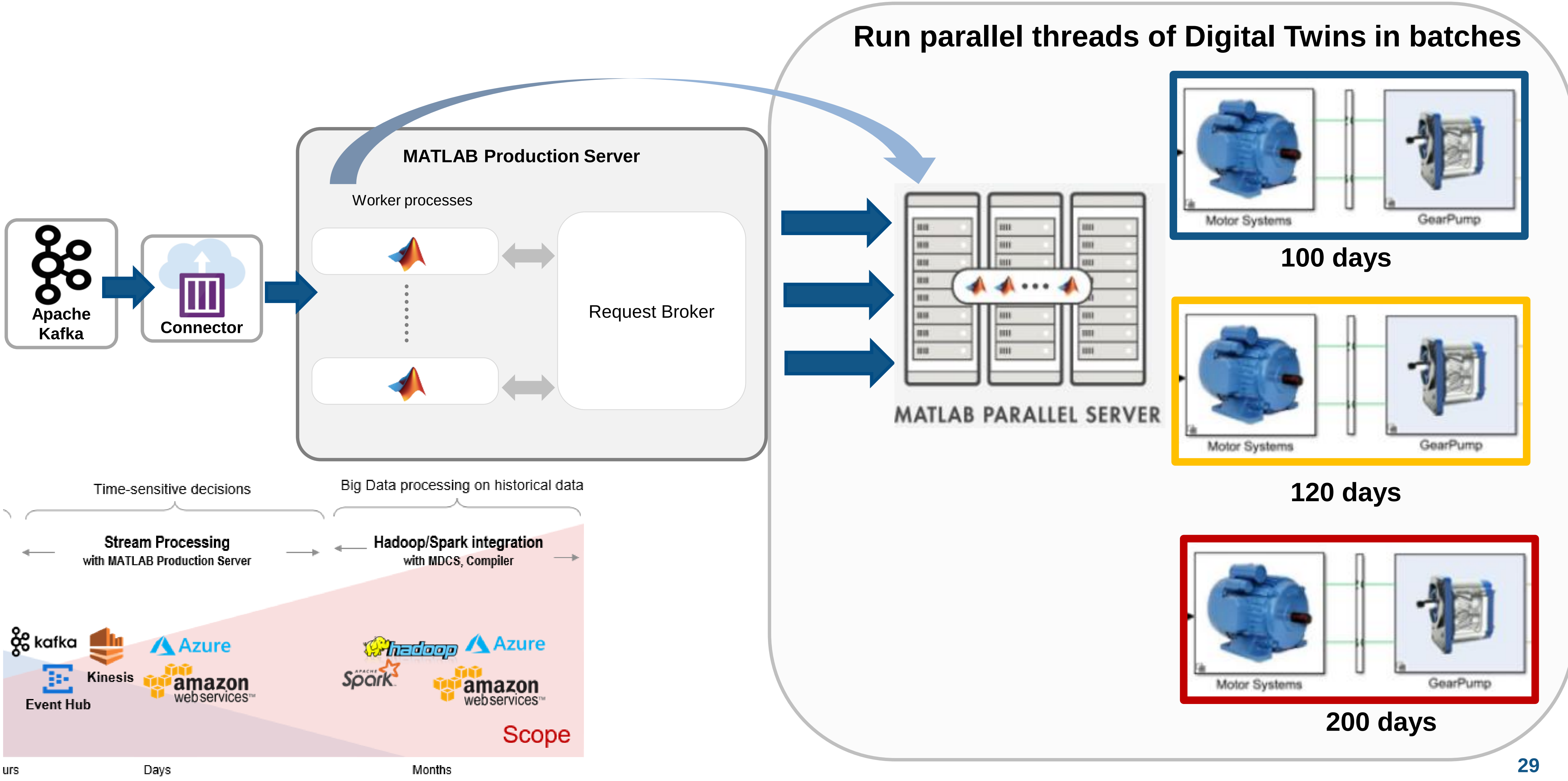




Stream based Analytics deployed using MATLAB Production Server



Scaling batch operations with MATLAB Parallel Server



MathWorks Reference Architectures

mathworks.github.io

https://mathworks.com/cloud Verified

matlab-aws-s3

MATLAB interface for AWS S3.

MATLAB Updated 26 days ago

matlab-azure-blob

MATLAB interface for Windows Azure Blob Storage.

MATLAB Updated on Feb 21

matlab-parquet

MATLAB Interface for Apache Parquet

MATLAB ★ 1 Updated on Dec 20, 2018

matlab-azure-data-lake

MATLAB Interface for Azure Data Lake.

MATLAB Updated on Feb 21

matlab-aws-common

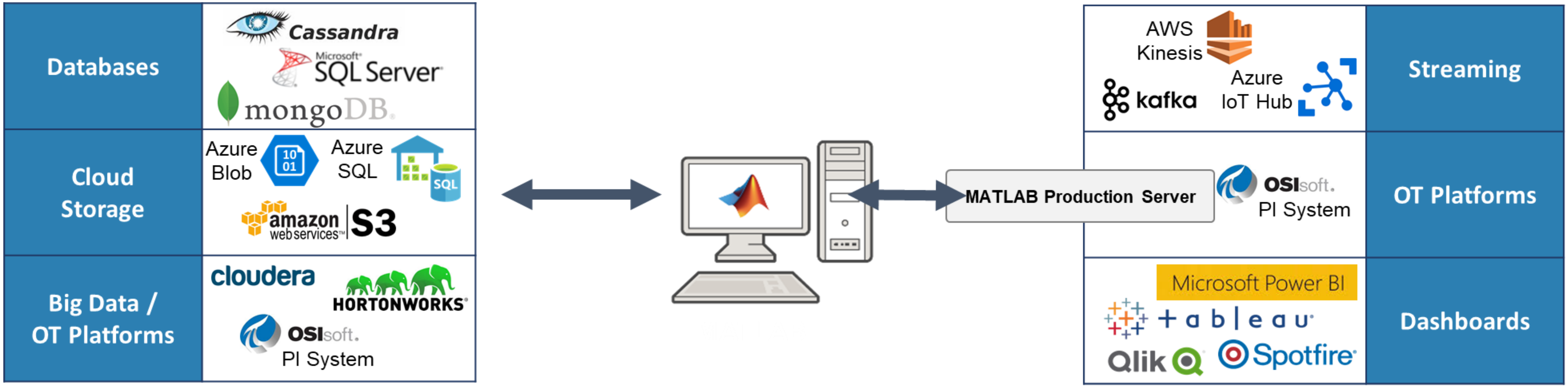
Code common to MATLAB interfaces. Code in this repository is used as a dependency for other projects such as matlab-aws-s3.

MATLAB Updated on Feb 21

matlab-avro

MATLAB interface for Apache Avro files.

MATLAB Updated on Feb 9

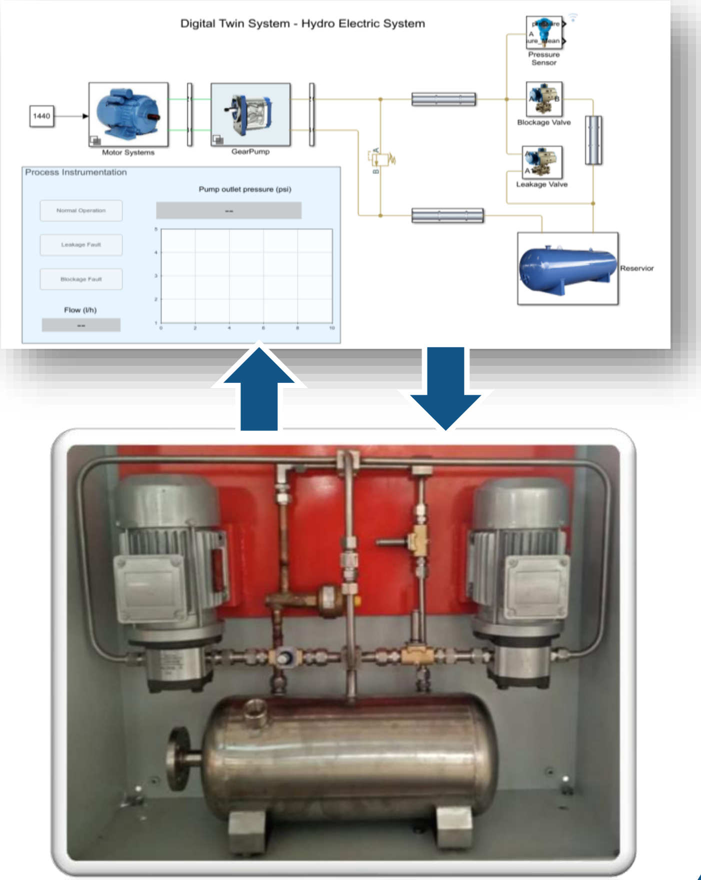


Summary

- With MATLAB you can **read hardware data** over various protocols & DAQ systems
- With **Physical Modeling blocks & AI libraries** in MATLAB you can now build Digital Representations of your asset
- You can **tune physical models** using Simulink design optimization & **RUL models with update methods**
- With **deployment** abilities in MATLAB you can **operationalize across edge and IT/OT** infrastructure

Call to Action

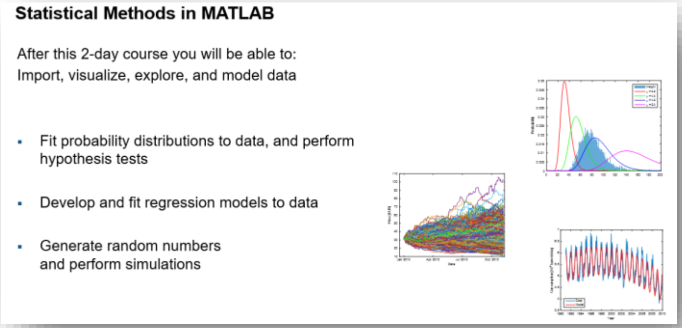
Digital Twin & Streaming Analytics



References

- [Building IoT solutions]
- [Developing and Deploying on Cloud]
- [Build Digital Twins with Physical Modeling workflow]
- [Learn: How to build Predictive Maintenance Applications?]
- [Learn Data Science with MATLAB]

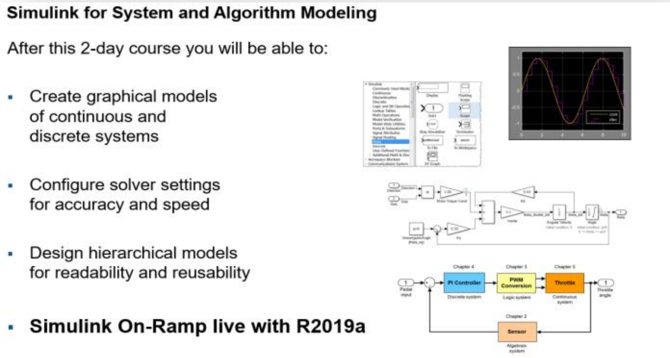
Attend Trainings



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



Simulink for System and Algorithm Modeling

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

- Create graphical models of continuous and discrete systems
- Configure solver settings for accuracy and speed
- Design hierarchical models for readability and reusability
- **Simulink On-Ramp live with R2019a**

Q&A

MATLAB EXPO 2019

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