ENTERPRISE INSIGHT and Proactive Analytics

PROCESS INSIGHT

ASSET PERFORMANCE INSIGHT

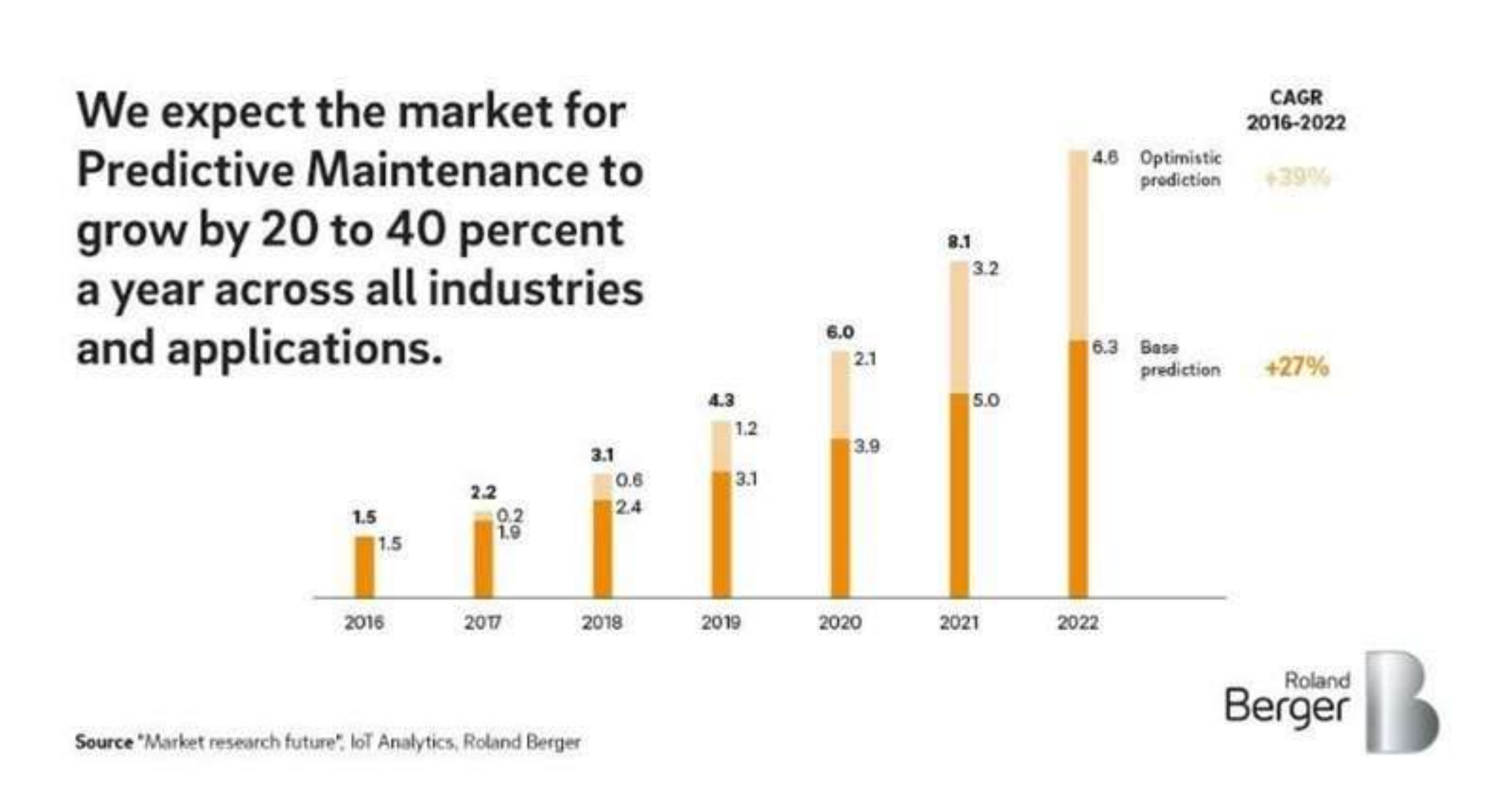
SKILLS INSIGHT

Predictive Maintenance with Machine Learning Models

Overview

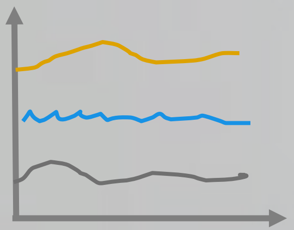
- Predictive Maintenance
  - Market trend
  - Physics-Heuristics-ML Models
  - Explanation of problem solved by Machine Learning in Predictive Maintenance (with Advanced Pattern Recognition Models)
  - Probabilistic Diagnostic Model
- Heat Exchanger Analysis through different tools

Predictive Maintenance Market Trend



Holistic Approach to Health Monitoring

Sensor Data



Assets

Maintenance Action

Physics-based Models: derived from thermodynamic or first principles

"Has the efficiency of the equipment deviated significantly from the design"

Heuristic-based Models: derived from SME or engineering insight:

"Problems happen when temperature is high and pressure is low…"

Machine Learning Models: derived from a data-driven model estimation

"Are current vibration measurements normal compared to historical normal operation?…"

Alerts

E.g. Compressor efficiency < 90%

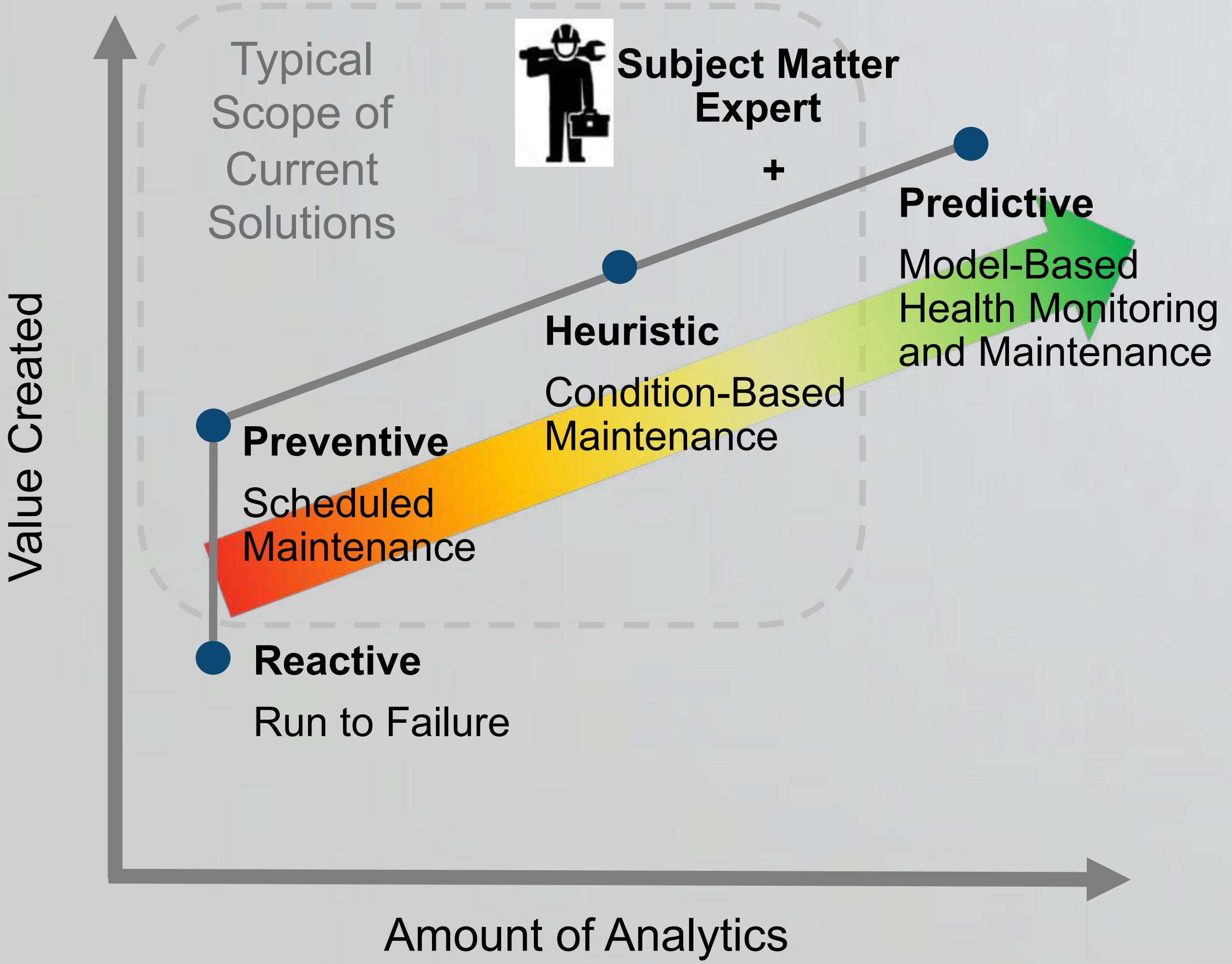
E.g. Temp. > Temp. MAX
Press. ≤ Press. MIN

E.g. Historical Vibration → Data-driven model → Expected Vibration

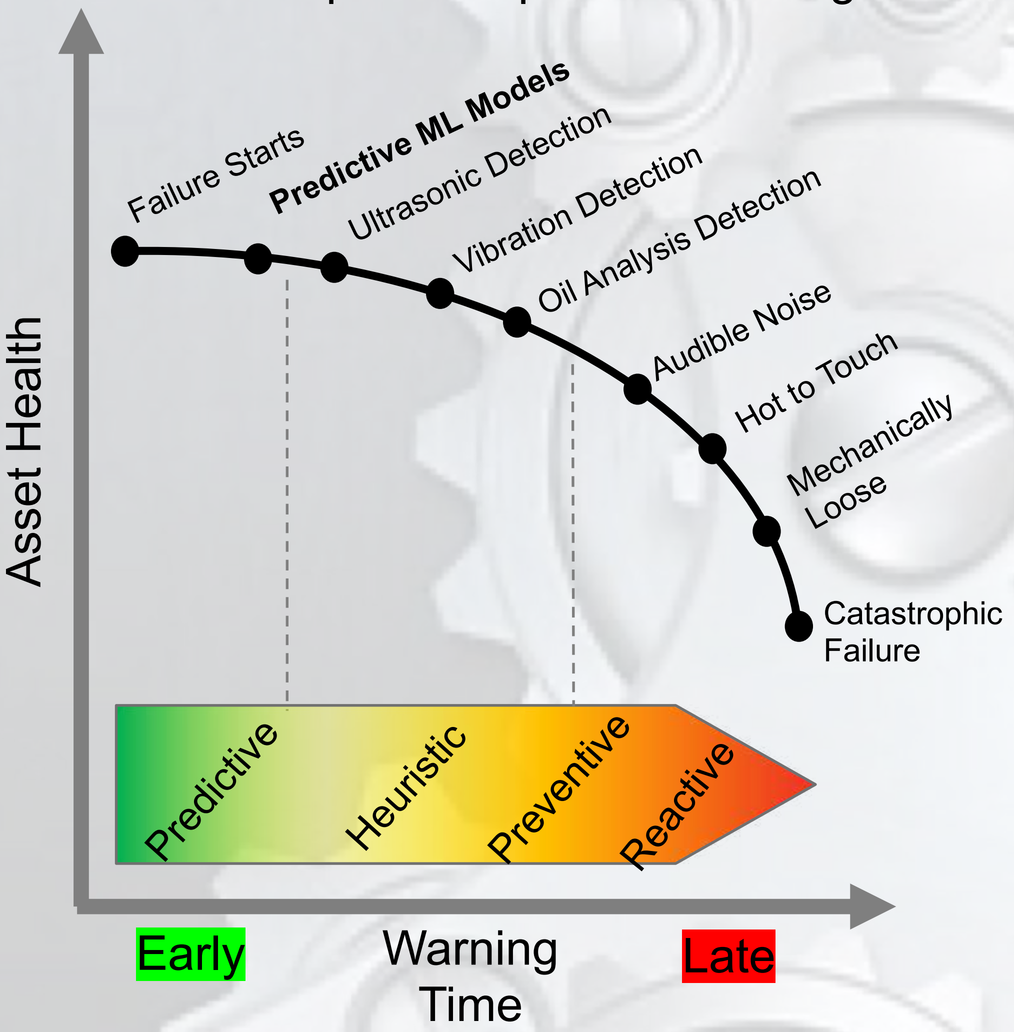
(Measured – Expected) > Limit

Alert Management Analysis

ASSET HEALTH MONITORING AND DATA ANALYTICS



Example: Compressor Bearing



Machine Learning Enables Predictive Health Monitoring

ASSET HEALTH MONITORING

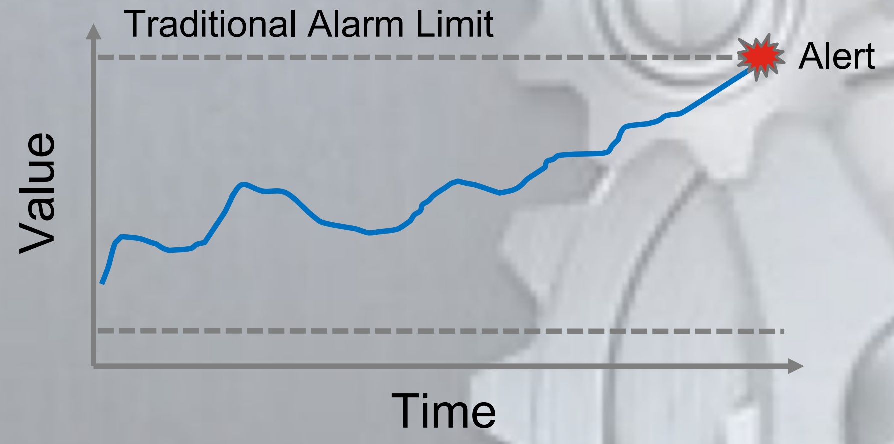
Heuristic Rules:

- Sensor Alarm limits must be set outside of normal operating range to cover all possible conditions

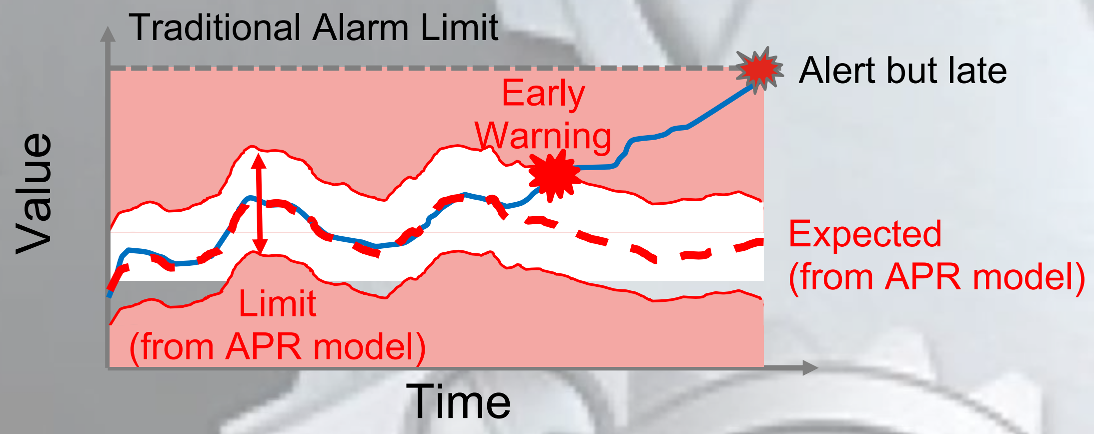
Predictive Asset Health Monitoring:

- Advanced Pattern Recognition (APR) Machine Learning (ML) trained models
- Compares observed behavior to expected behavior
- Provides early warning of sensor issues and equipment degradation
  - Can determine very subtle condition changes to identify anomalies
- Makes SME aware of abnormal conditions and supports the decision making process

Typical with Heuristic Rules:

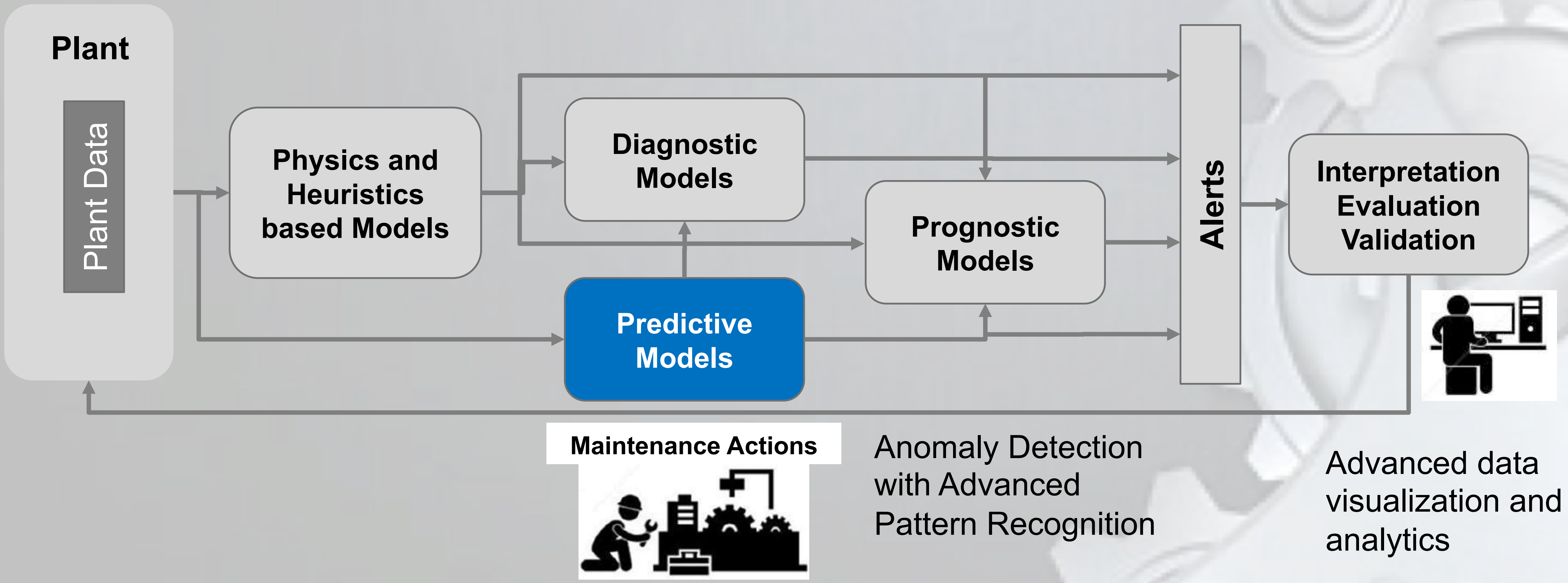


Predictive Asset Health Monitoring:



Early Warning Moves from Reactive\Heuristics to Predictive

Holistic Approach to Health Monitoring



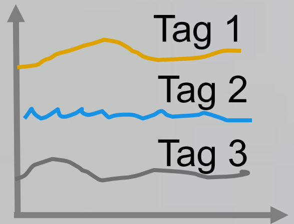
Asset Health Monitoring with APR Machine Learning

Typical Case

		Low	High
Tag 1	10	0	100
Tag 2	2	0	100
Tag 3	1.2	0	100

Is this normal?

Historical Data

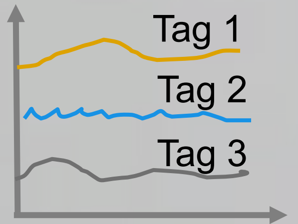


Assets

Process Historian

Asset Health Monitoring with APR Machine Learning

Historical Data



Assets

Process Historian

Typical Case

Is this normal?

		Low	High
Tag 1	10	0	100
Tag 2	2	0	100
Tag 3	1.2	0	100

With Machine Learning*

		Low	High	Exp.	Resid.
Tag 1	10	0	100	9.7	0.3
Tag 2	2	0	100	0.1	**1.9**
Tag 3	1.2	0	100	1.3	0.1

Current values compared against historical normal

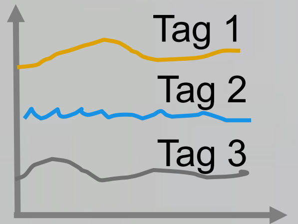
Expected from Normal Operation

Deviation

*with Advanced Pattern Recognition (APR)

Asset Health Monitoring with APR Machine Learning

Historical Data



Assets

Process Historian

Typical Case

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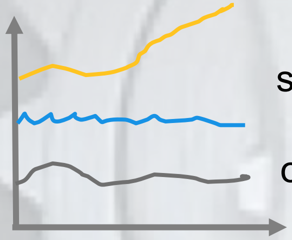
Current values compared against historical normal

Expected from Normal Operation

Deviation

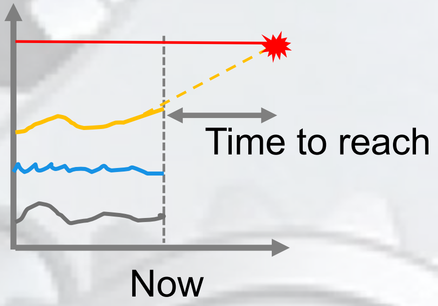
Are the current patterns normal?

Does the pattern indicate a specific failure [Diagnostics]?



E.g. Only one signal abnormal? High probability of a sensor fault

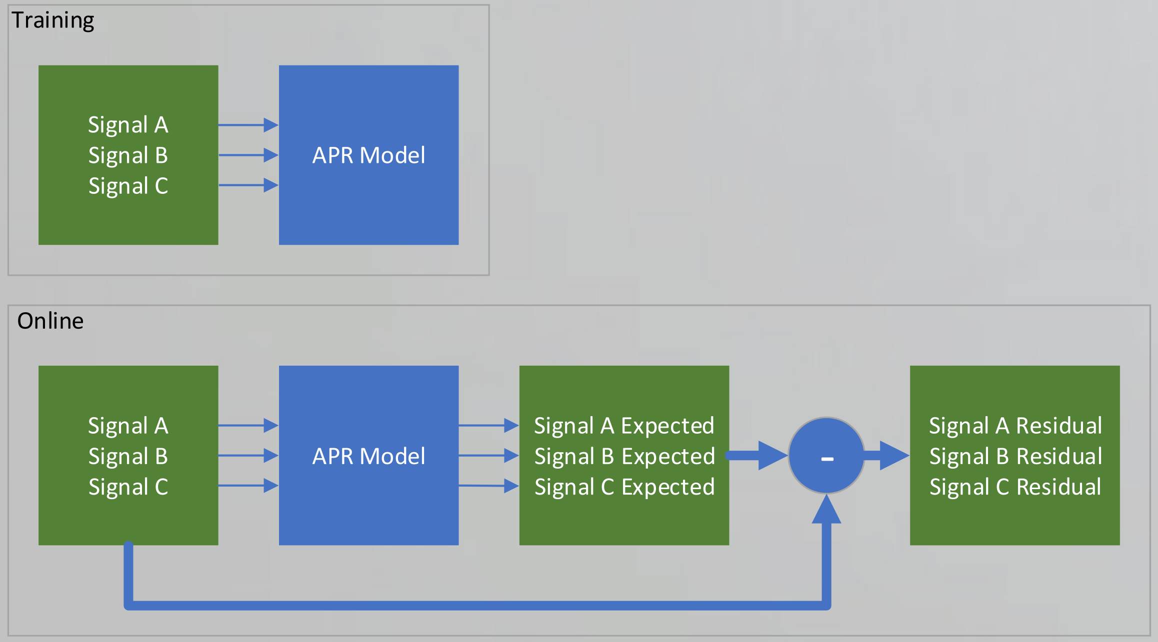
How long before reaches critical limits [Prognostics]?

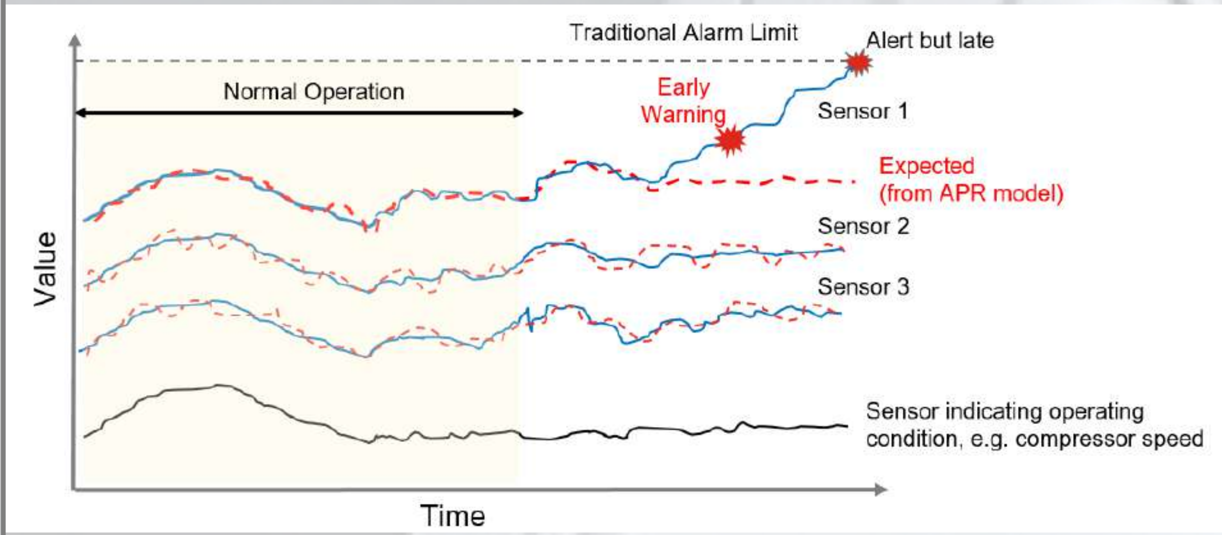


*with Advanced Pattern Recognition (APR)

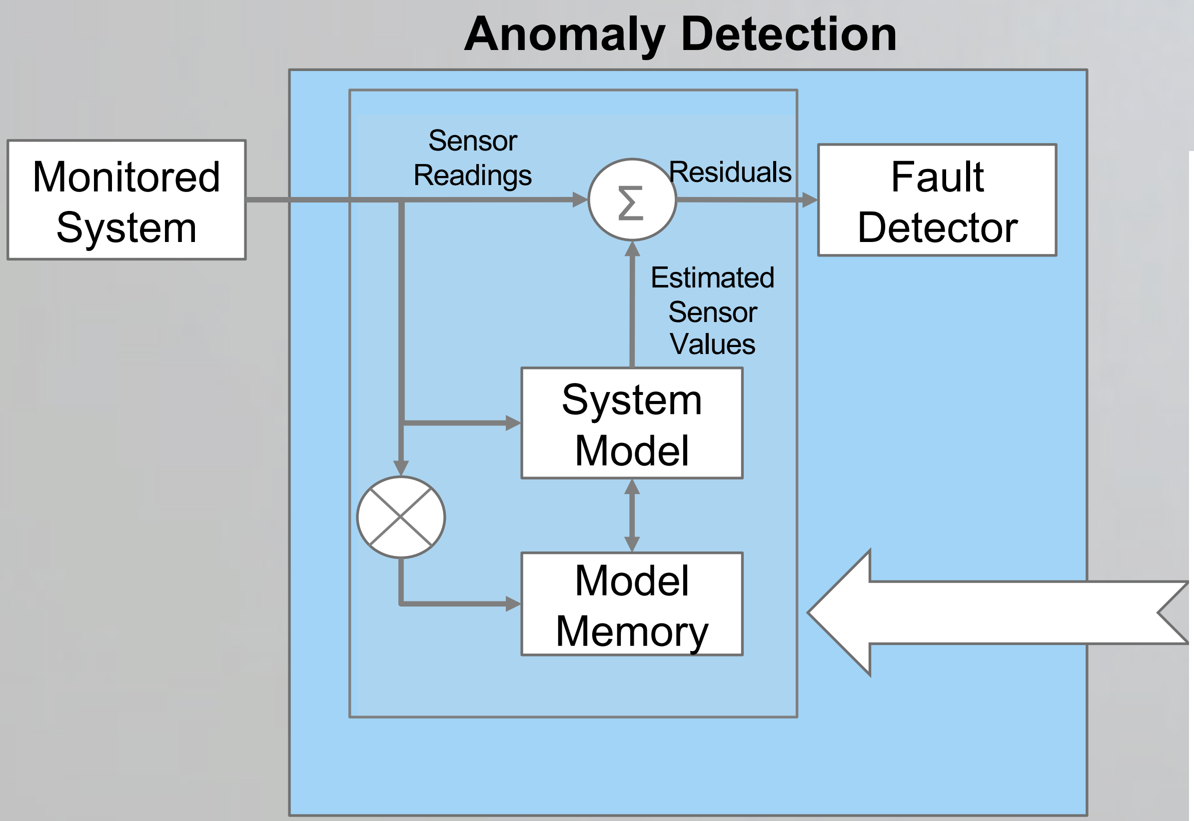
APR Modeling: Basic Concepts

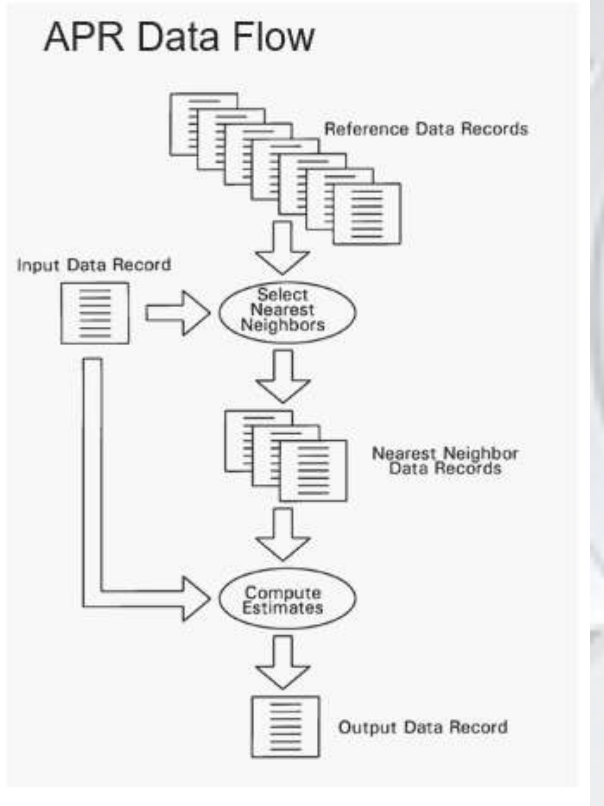
- APR models learn patterns from multiple signals from normal (historical) operation
- Learned patterns include correlation among sensor signals, historical max/min values, correlation with operating conditions





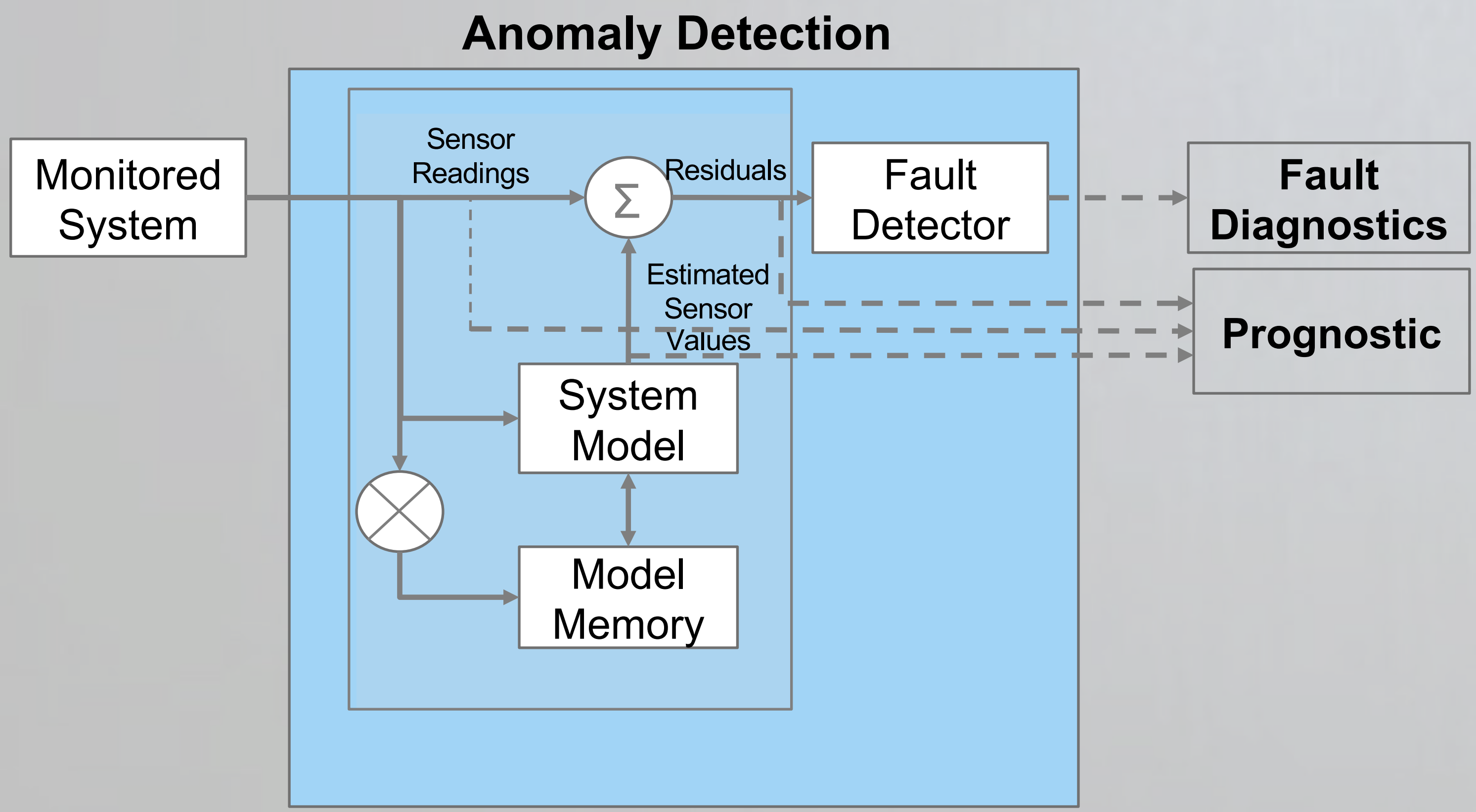
Asset Health Monitoring with APR Models: Data Flow





APR estimates are based on the similarity of a new observation with each of the reference patterns ("Model Memory")
An estimate of each input is computed using multi-variate kernel regression over the reference patterns

Asset Health Monitoring with APR Models: Data Flow



APR estimates are based on the similarity of a new observation with each of the reference patterns ("Model Memory")
An estimate of each input is computed using multi-variate kernel regression over the reference patterns

APR Modeling: Simple Example

Historical Data

Time	Signal 1	Signal 2	Signal 3	Signal 4
0	5	10	7.7	1
1	5.5	10.6	8.5	1.2
2	6.3	10.6	8.7	0.8
3	7.3	10.9	9.2	0.7
4	8.6	11.4	9.9	0.8
5	9.8	12.2	10.9	1.2
6	11.5	12.9	11.8	1.5
7	12.45	14.1	13.2	2.3
8	13.45	14.55	13.85	2.35
9	14.55	15.05	14.55	2.45
10	16.15	15.65	15.35	2.65
11	17.15	16.75	16.65	3.35
12	18.15	17.25	17.35	3.45

Difference Data				Sum
Signal 1	Signal 2	Signal 3	Signal 4	Sum(||)
-4.8	-3	-1.3	-0.9	10
-4.3	-2.4	-0.5	-0.7	7.9
-3.5	-2.4	-0.3	-1.1	7.3
-2.5	-2.1	0.2	-1.2	6
-1.2	-1.6	0.9	-1.1	4.8
0	-0.8	1.9	-0.7	3.4
1.7	-0.1	2.8	-0.4	5
2.65	1.1	4.2	0.4	8.35
3.65	1.55	4.85	0.45	10.5
4.75	2.05	5.55	0.55	12.9
6.35	2.65	6.35	0.75	16.1
7.35	3.75	7.65	1.45	20.2
8.35	4.25	8.35	1.55	22.5

Minimum Difference

Measurement

Signal 1	Signal 2	Signal 3	Signal 4
9.8	13	9	1.9

Expected

Signal 1	Signal 2	Signal 3	Signal 4
9.8	12.2	10.9	1.2

This is a simple version of a similarity-based APR algorithm

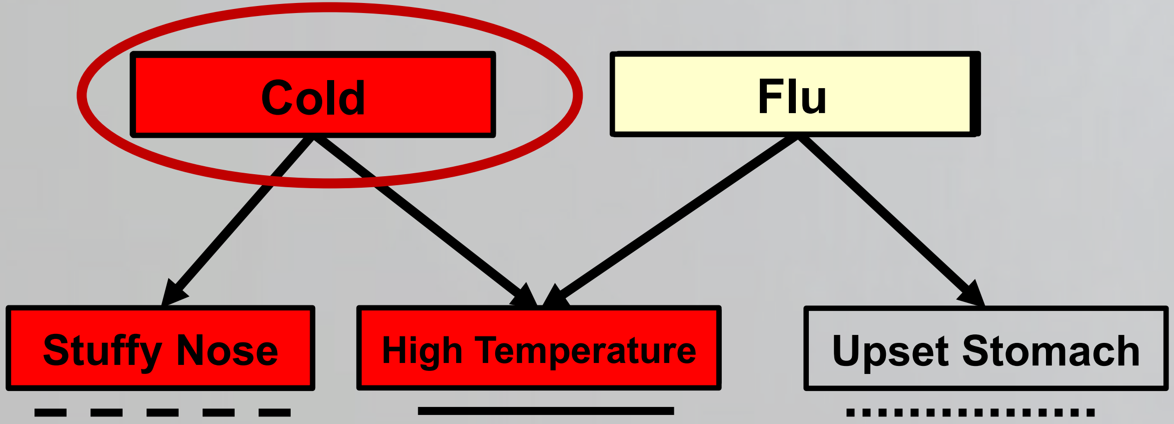
Probabilistic Diagnostic Model: Introduction

- Diagnostic models capture asset operating expertise
  - Brings expertise online
  - Combines results from multiple detection models

- Diagnostics model use a Bayesian belief network (BBN) driven from fault detector events
  - Best approach for complex failure modes with overlapping symptoms

- Diagnostic model helps to determine the likehood of a sensor, asset, or model problem.
  - Alternatives are rule-based models or SME experience to understand individual or groups of alerts

Example of Probabilistic Diagnostic Model

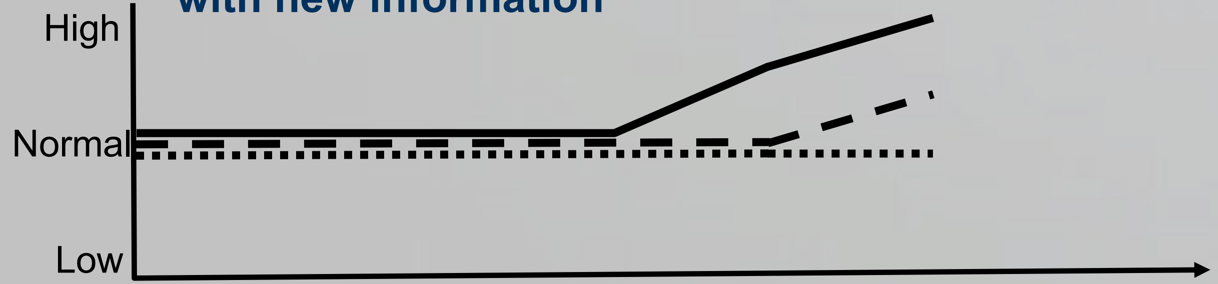


Monitored Symptoms

Diagnosis automatically updates with new information

High Temp
Cold 50%
Flu 35%

High Temp +
Stuffy Nose
Cold 90%
Flu 9%

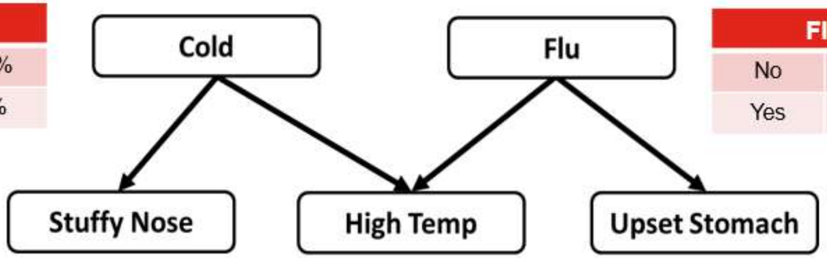


Configuration:

Prior Probability

Cold	
No	97%
Yes	3%

Flu	
No	98%
Yes	2%



Conditional Probability

	Stuffy Nose	
Cold	No	Yes
No	90%	10%
Yes	10%	90%

		High Temperature	
Cold	Flu	No	Yes
No	No	99%	1%
Yes	No	10%	90%
No	Yes	5%	95%
Yes	Yes	99%	1%

	Upset Stomach	
Flu	No	Yes
No	90%	10%
Yes	10%	90%

ASSET DESCRIPTIVE MODEL (Heat Exchanger)

➢Descriptive analytics: Observed relationships and trends among different variables identifying several patterns

- Flow Mode
- Shutdown Mode

Blue: Delta Water Temperature

Brown: Air In Flow

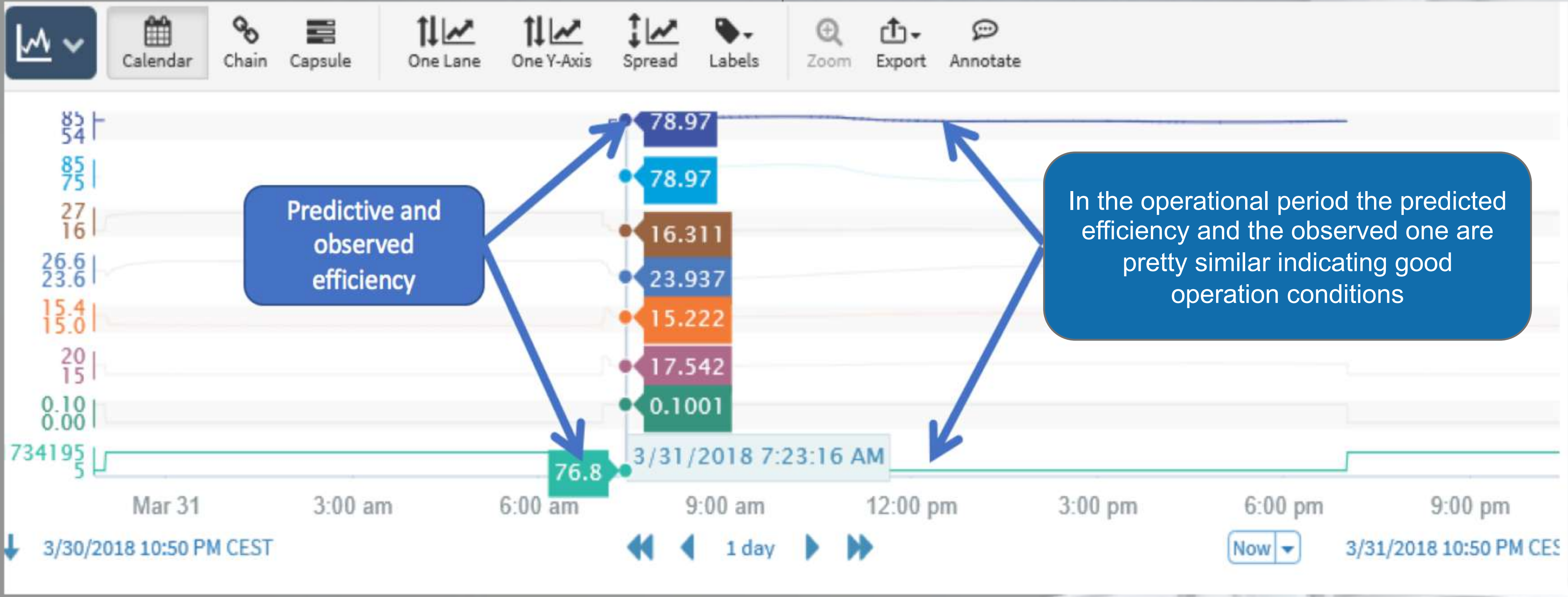
Green: Delta Air

Violet: Water Inlet Flow

Pink: Efficiency

ASSET PREDICTIVE MODEL (Heat Exchanger)

- Predictive analytics: Create basic regression models to compare the observed operation with the predictive operation which is generated through regressions models taking “efficiency” as dependent attribute



HEAT EXCHANGER

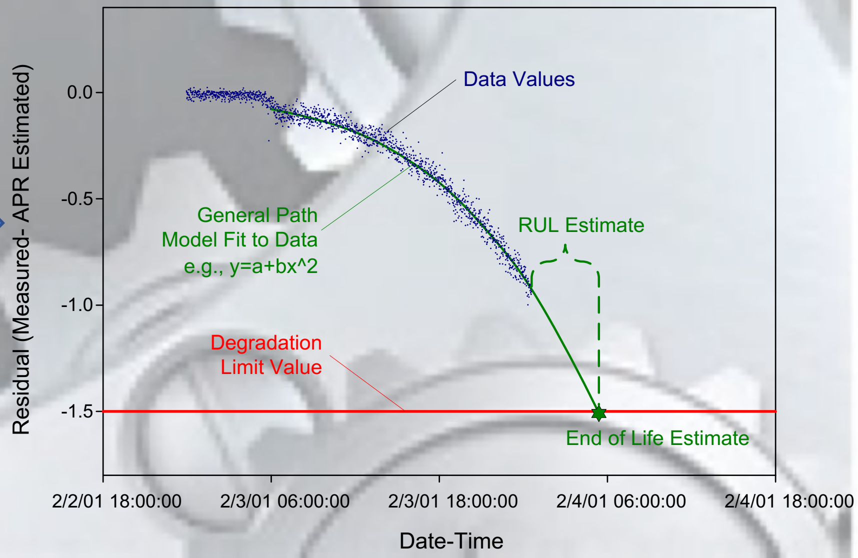
It has been simulated through 3 modeling methods:

- **Prediction Step:** Involve the use of models describing the asset when it is operating correctly to estimate the expected values of the observed data from the asset. (APR Modeling)

- **Diagnosis Step:** Correlates this pattern of agreement or disagreement with the most likely problem cause or abnormal state of the asset. Bayesian Belief Network (BBN) run it

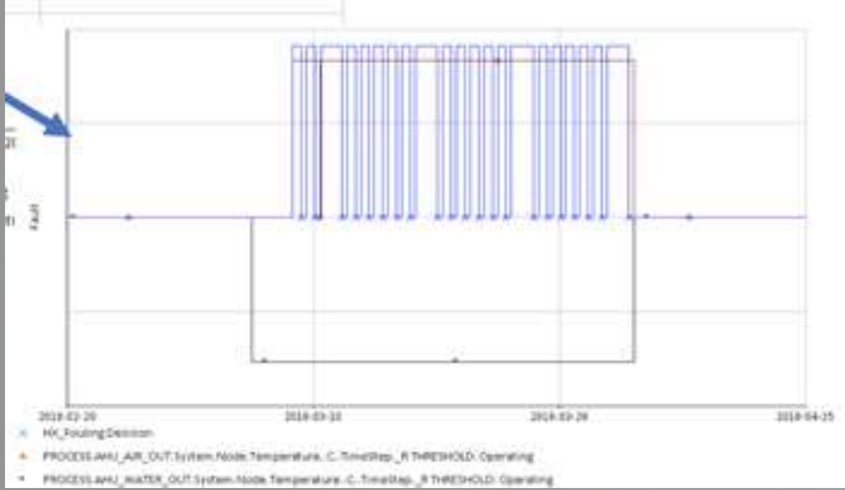
- **Prognosis Step:** Finally, the evolving diagnosis and condition data to determine the residual use life (RUL) to act before a service interruption happen using a quadratic function $a+bx^2$ modeled with 100 points being the degradation limit selected 2ºC for the Air Temperature out

Efficiency



EXAMPLE HEAT EXCHANGER DIAGNOSIS AND PROGNOSIS

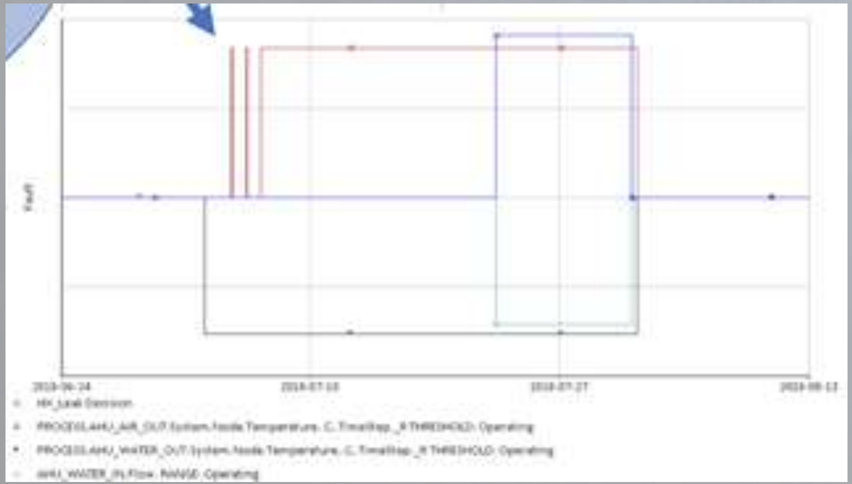
Diagnosis Fouling scenario



- ✓ Air Out Temperature ⬆
- ✓ Water Out Temperature ⬇

Conclusion: Fouling starts with the combination of both conditions

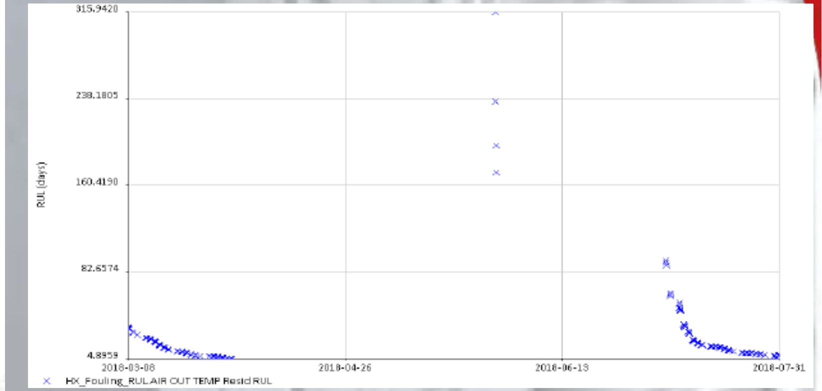
Diagnosis Leaking scenario



- ✓ Air Out Temperature ⬆
- ✓ Water Out Temperature ⬇
- ✓ Water In flow ⬇

Conclusion: Leakage starts when the Water in flow fall down

Prognostic Fouling scenario

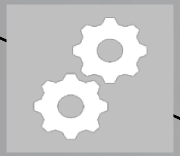


- ✓ Air Out Temperature ⬆
- ✓ Water Out Temperature ⬇

Conclusion: RUL is pretty similar in the two fouling scenarios simulated in March 18 and July 2018

Plant Data

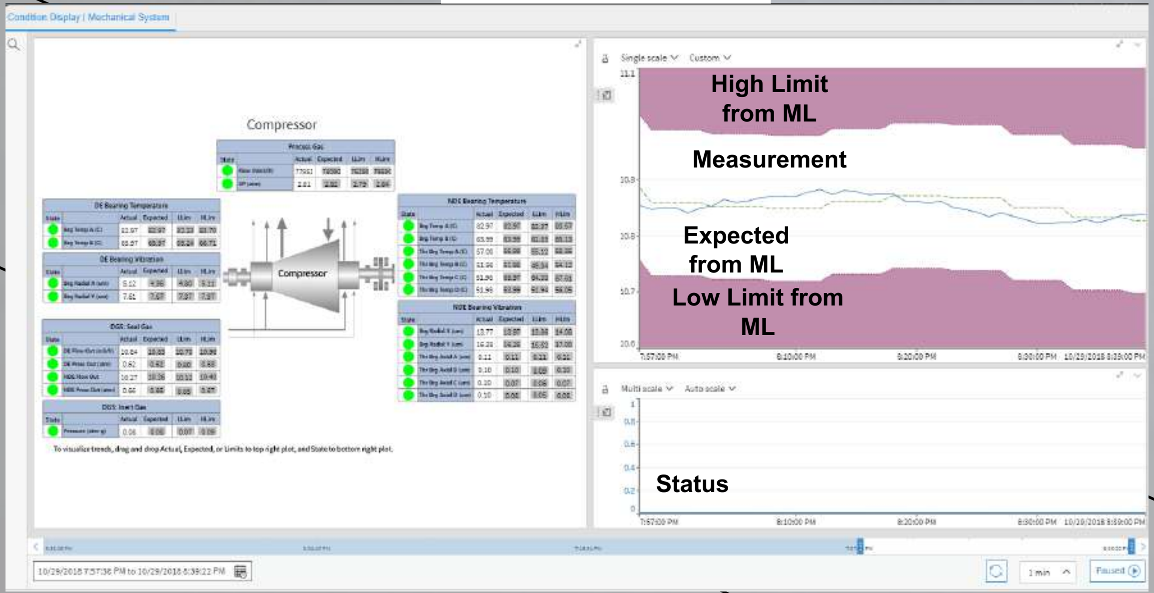
Data Cleansing
& Preprocessing



Event
Management

Dashboard for ML Model Outputs

Compressor Condition
Monitoring



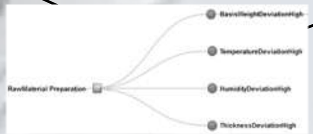
Real-Time Analytics

Graphics & Trends

Integrated Modeling Solution:

- User-Defined Calc.
- Heuristic Rules
- 1st Principle Models
- ML Models

Fault Modeling
& Event Detection



Notifications

Integrated Solution for Performance\Health Monitoring and Engineering Decision Support

Q&A