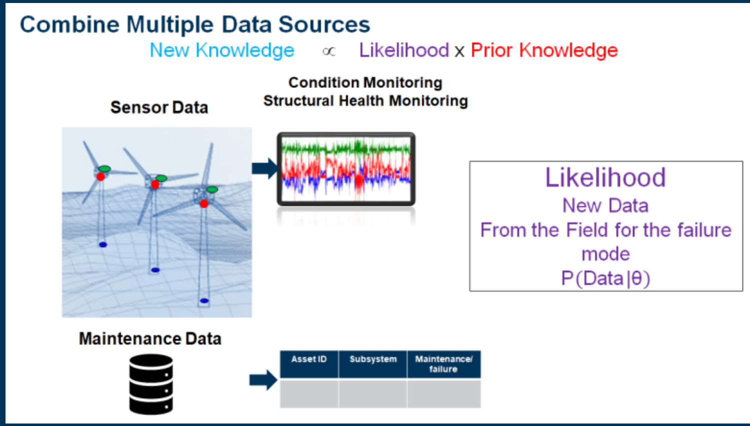
HBM Prenscia Technology Day

Virtual Seminar Series



Increase Operational Efficiency by Combining Sensor Data and Maintenance Records

Presented by Mr. Guga Gugaratshan
Head of Partner Solutions & Analytics
Prenscia Engineering Solutions

Session #6: Mathematical Modelling for Data Analytics, Durability, and Reliability #2

Increase Operational Efficiency by Combining Sensor Data and Maintenance Records

Abstract

This presentation outlines how combining multiple data sources can be used to get key information about an asset's health and to improve operational efficiency. Avoiding failure of the asset during operation is very critical especially if the asset is very hard to access by the maintenance team. Every time an asset fails, production efficiency is affected. An effective maintenance plan will help improve the efficiency. Management of effective maintenance plan requires reliable data that provides information about the asset. Getting access to such data can be very challenging. Prenscia Engineering Solutions is working with multiple industry and academic partners to provide a complete solution that can be implemented without spending years of planning and execution. The approach combines both operational, sensor, and maintenance data along with the digital twin of the asset to improve the data quality, capture and verify failure events, and perform analysis to help improve operational efficiency.

About the presenter, Mr. Guga Gugaratshan

Guga Gugaratshan is the Head of Partner Solutions & Analytics at HBM nCode Federal. Guga brings 23 years of experience in ground vehicle product development, measurement and data acquisition, data science, and machine learning development. He supports customers for the defense, transportation, oil and gas, mining, and renewable energy industries. He collaborates with worlds' leading research institutions to support his customers. He has technical expertise in engines, reliability/durability, and manufacturing operation. Guga leads multiple teams and managed an operational budget up to 20 million dollars. He received multiple innovative patents and awards on R&D processes related to product development.

Increase Operational Efficiency by Combining Sensor Data and Maintenance Records

Nov 17, 2020

Guga Gugaratshan
Head of Partner Solutions & Analytics
M: +1-248-732-9638
Guga.Gugaratshan@ncodefederal.com
HBM nCode Federal LLC
26555 Evergreen Rd Ste 700 | Southfield, MI | 48076

PUBLIC

Prenscia
Engineering Solutions

Questions from Customers

Operational Efficiency $\propto$ f(availability, reliability, maintainability)

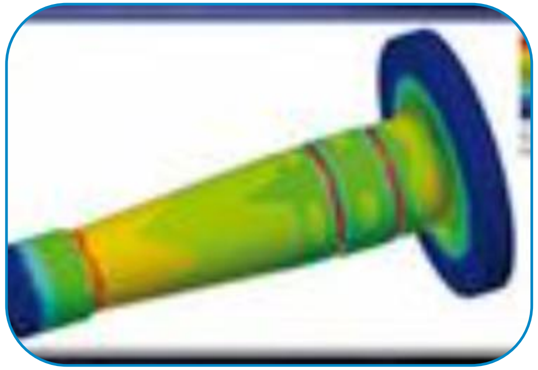
- When to
  - Repair
  - Replace
- What is
  - Remaining useful life
  - Cost of repair vs replace
- How to
  - Reduce maintenance cost
  - Reduce unplanned downtime
  - Avoid catastrophic failures
  - Plan capital investment

Identify: Reduction in performance or failures

Sources of Answers

Asset

- Operational data, Failures, Functionality loss

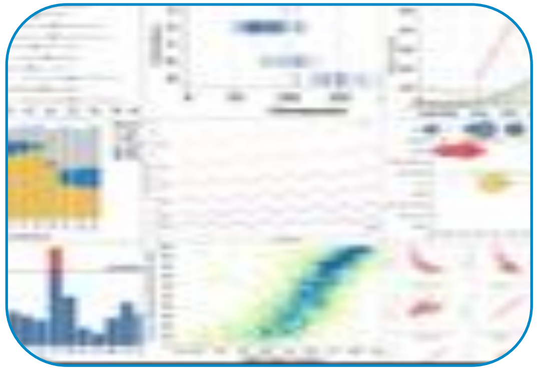


Modeling and Simulation

- FEA, Failure modeling

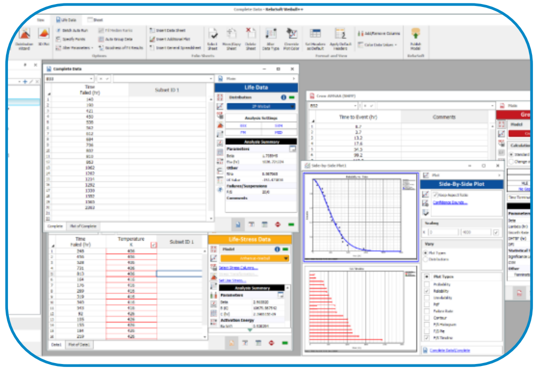
Sensing / Instrumentation

- Operational / Special



Data Interrogation / Management

- Feature extraction,



Decision sciences

- Statistical modeling, Uncertainty, Economics

Life cycle requirement

- RUL, Expected life, Regulatory, Extending life

Supporting Activities

- Operational Evaluation
- Data acquisition, normalization and cleansing
- Feature extraction and information condensation
- Statistical model development

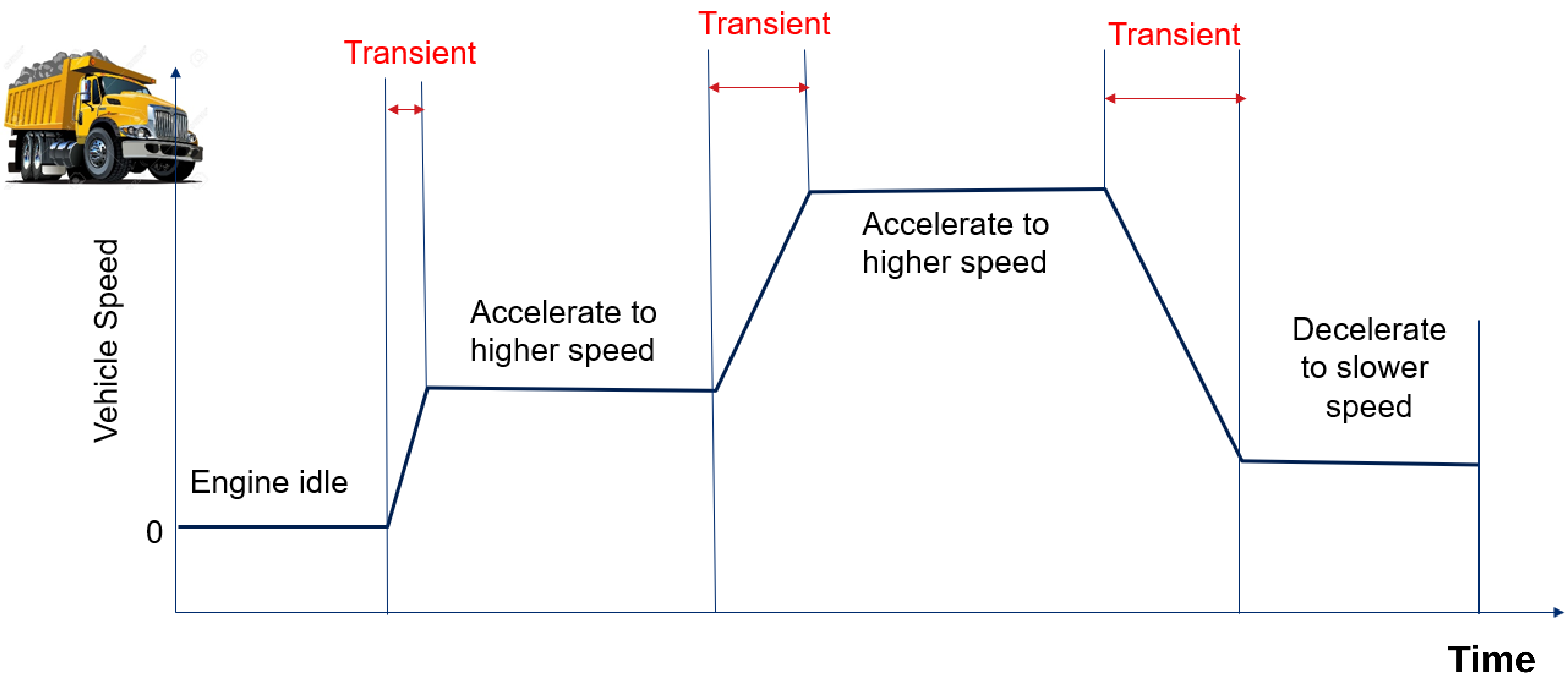
Refer:
Chuck Farrar & Keith Worden, An introduction to structural health monitoring, 2005

Prenscia
Engineering Solutions

HBK
HOTTINGER BRÜEL & KJÆR

Operational Data

- **Transient** –is not equal to zero
- **Steady state** – rate of change is equal to zerorate of change



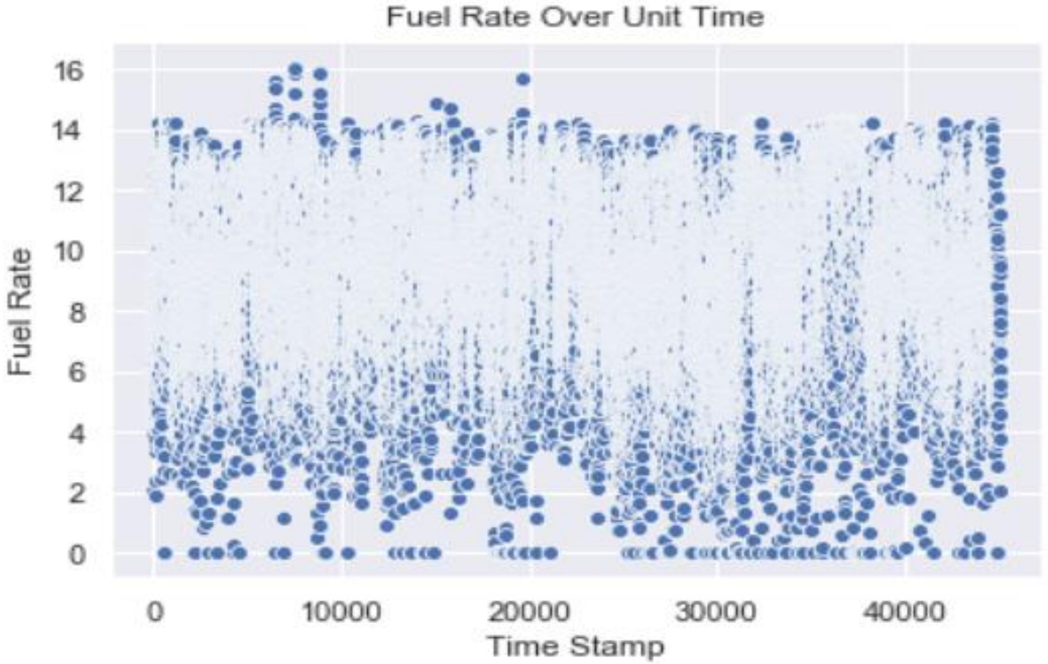
Speed, Load, Weight, Location, Road condition, Driver, Weather, Fuel Variation, Maintenance

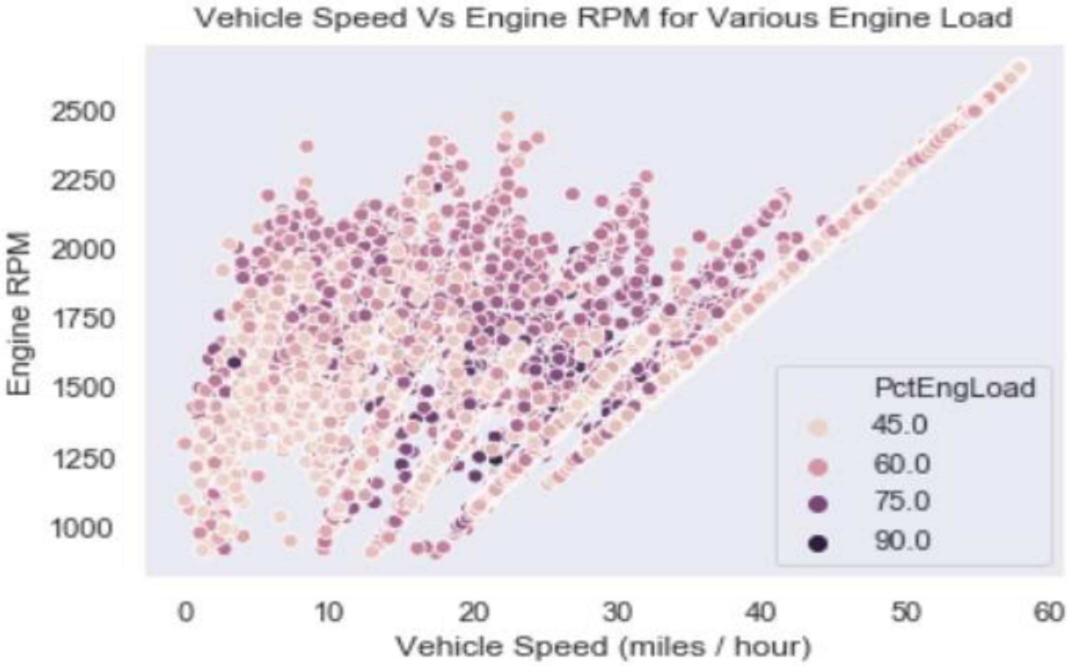
Map all variation using machine learning

Challenges in Operational Data

TransOilTemp = Transmission Oil Temperature
InstFuelEco = Instantaneous fuel Economy
VehSpeedEng = Vehicle Speed (miles per hour)
AccelPedalPos = Accelerated Pedal Position (%)
BoostPres = Turbo Boost Pressure (psi)
InjCtrlPres = Injector Control Pressure (psi)
PctEngLoad = Percent Engine Load (%)
EngSpeed = Engine Speed (engine revolution per minute)
Fuel Rate = Fuel Rate or fuel consumption rate (lb per hour)
EngCoolantTemp = Engine Coolant Temperature (Degree F)

Medium Duty Diesel Engine





- Challenge
  - Large operating range
  - Not enough data to train models
- Solution
  - Identify signals unique for each operating range
  - Large range

Consumption Model

Consumption as an indicator

Energy consumption
Power consumption
Fuel consumption
Current consumption

Engineering → Data Science

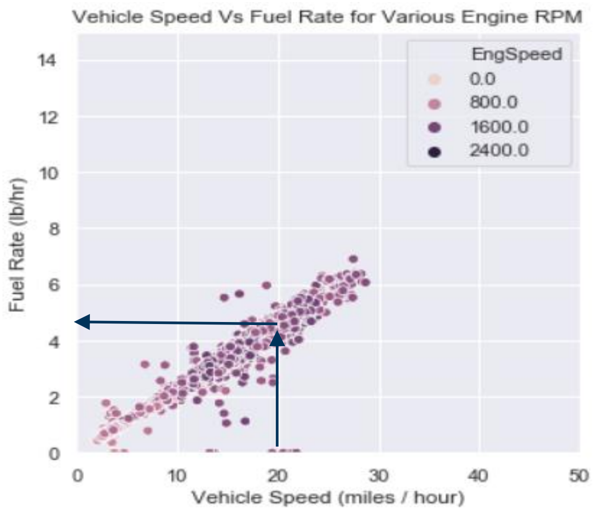
Driving Speed	RPM	Coolant Temp	Fuel Consumption	Injection Pressure	Turbo Pressure	Intake Pressure
Transmission Oil Temperature	Oil consumption	Oil Temperature	Intake Air Temp	Exhaust Temp	Transmission Gear	Injection Pressure

Operational Data - Vehicle Data

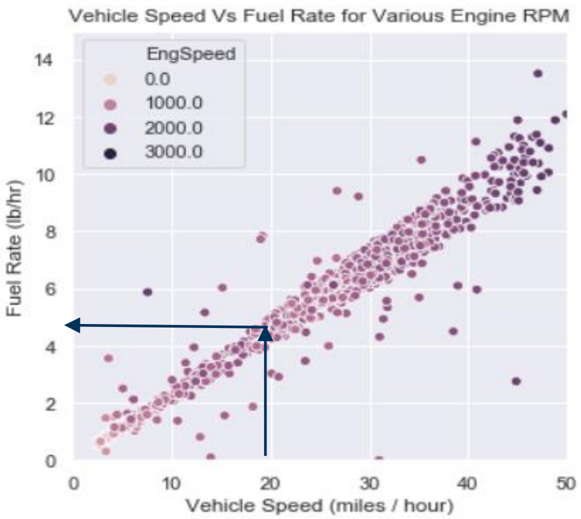
Driving Speed	RPM	Coolant Temp	Fuel Consumption	Injection Pressure	Turbo Pressure	Intake Pressure
Transmission Oil Temperature	Oil consumption	Oil Temperature	Intake Air Temp	Exhaust Temp	Transmission Gear	Injection Pressure

Steady State Speed - Medium load

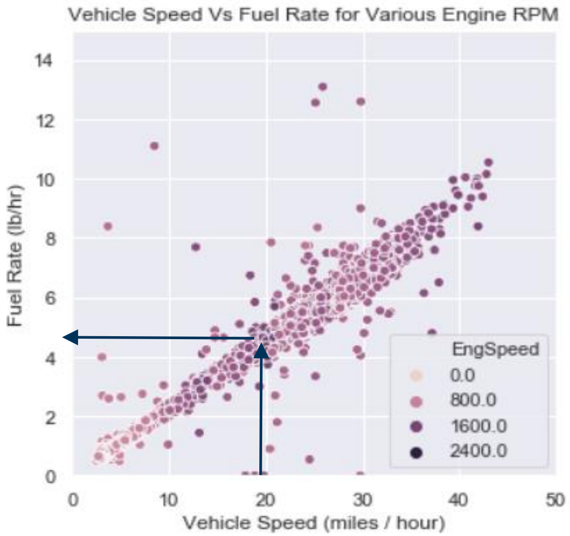
Vehicle 1



Vehicle 2



Vehicle 3



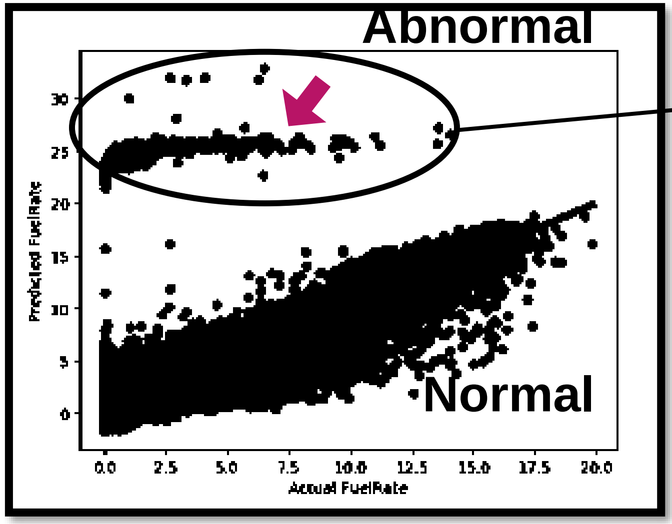
Identifying Turbo Boost Performance

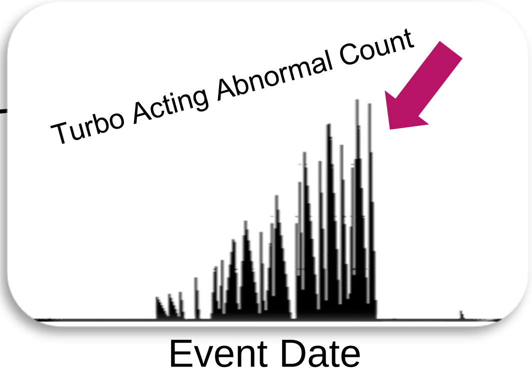
Problem

Identify abnormal vehicle behavior using only the available CAN bus data

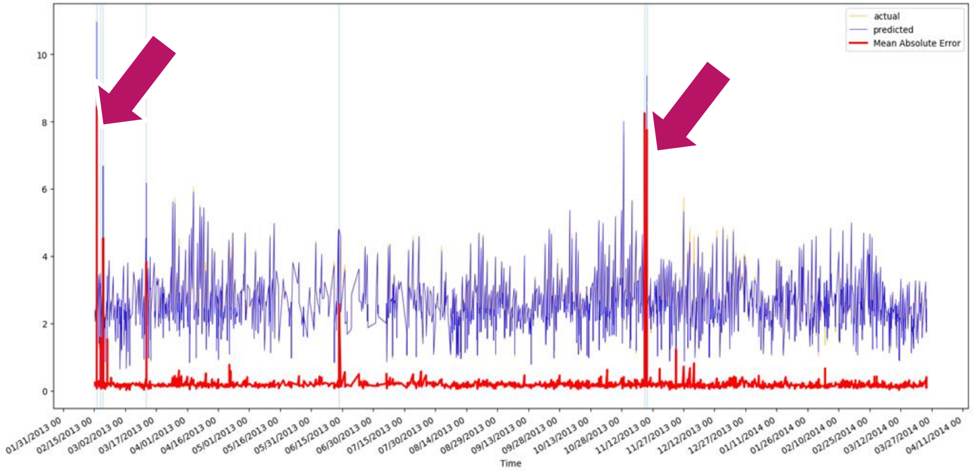
Results

Failure Mode: **Turbo Boost Pressure Failing**





Verify using number of failures obtained from CMMS



Peaks correspond to abnormal behavior (vs time)

Prenscia
Engineering Solutions

HBK
HOTTINGER BRÜEL & KJÆR

Combine Multiple Data Sources

New Knowledge $\propto$ Likelihood x Prior Knowledge

- Past data: Operational, measurement
- Past field experience
  - Legacy design experience
  - Learn from hot spots of the current design
  - Experts knowledge
- Simulation
  - Computer Models
  - Statistical models

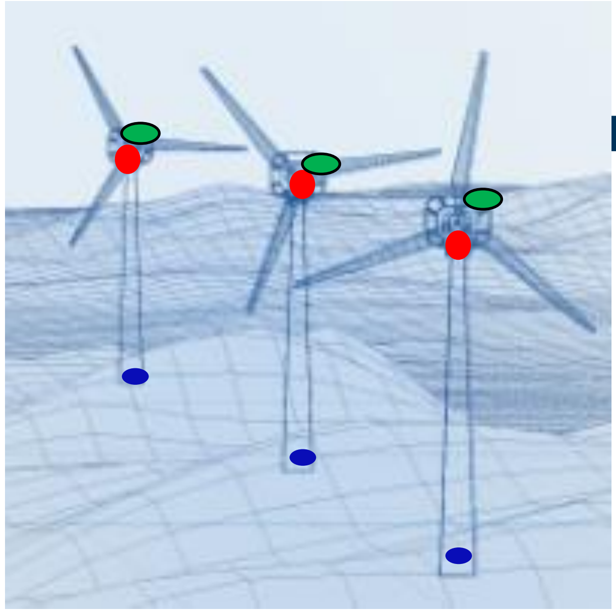
Prior Knowledge
About a specific failure mode
$P(\theta)$

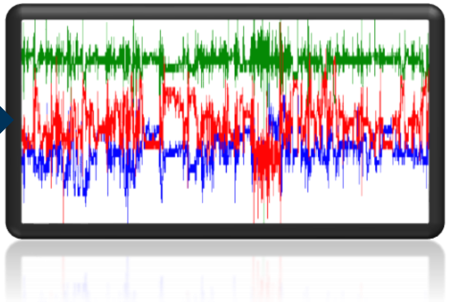
Combine Multiple Data Sources

New Knowledge $\propto$ Likelihood x Prior Knowledge

Condition Monitoring
Structural Health Monitoring

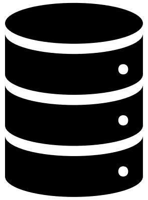
Sensor Data





Likelihood
New Data
From the Field for the failure mode
P(Data|θ)

Maintenance Data



Asset ID	Subsystem	Maintenance/ failure

Combine Multiple Data Sources

$$P(\theta|Data) = \frac{P(Data|\theta)P(\theta)}{P(Data)}$$

Bayes Theorem

New Knowledge $\propto$ Likelihood x Prior Knowledge

Likelihood

New Field Information
Knowledge
Sensor Data
$P(Data|\theta)$

Prior

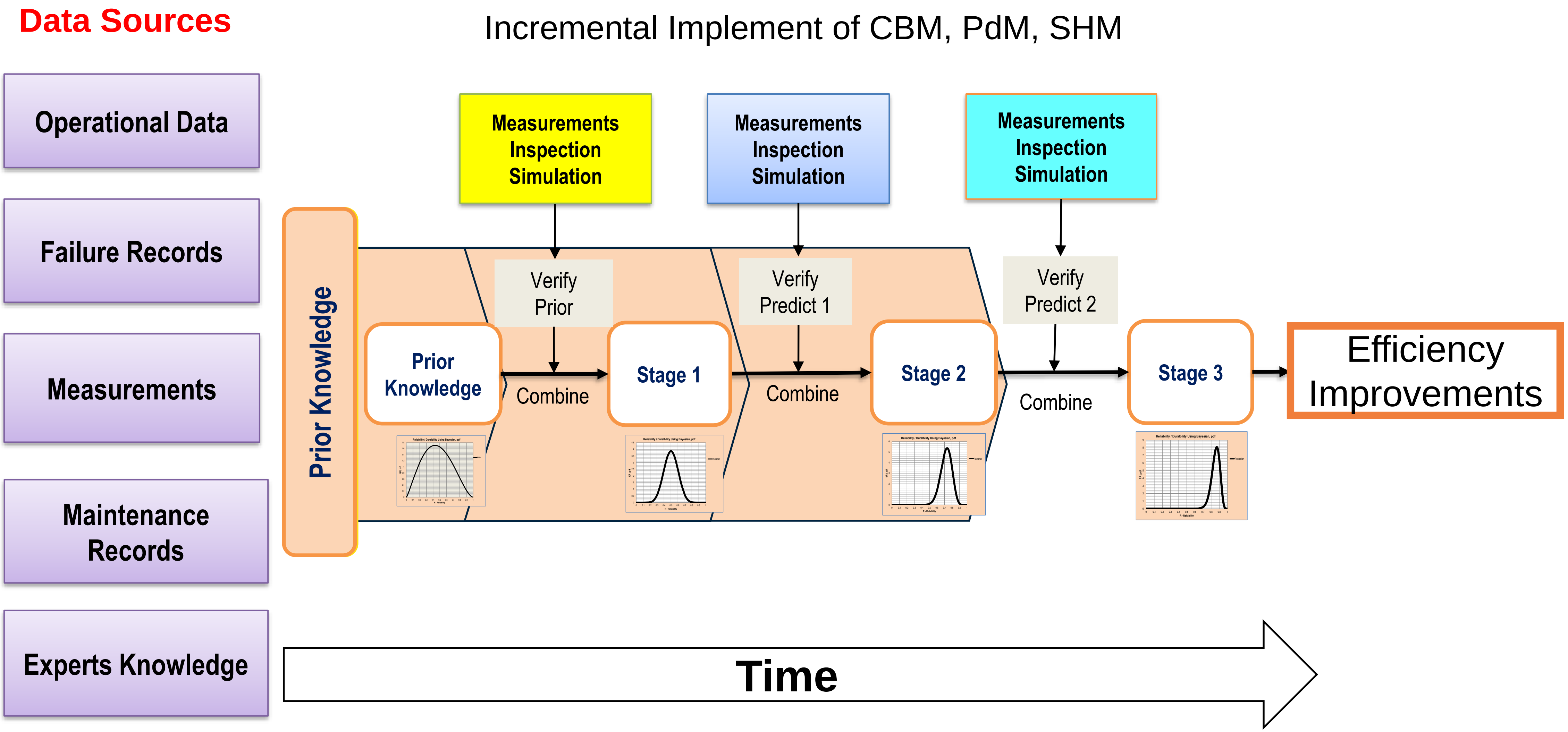
Prior Knowledge
$P(\theta)$

New Knowledge =
Prior Knowledge x
Likelihood

Posterior

New Knowledge
$P(\theta|Data)$

Incremental Benefit Overtime



Example: River Lock – Existing Assets

Maintenance Data

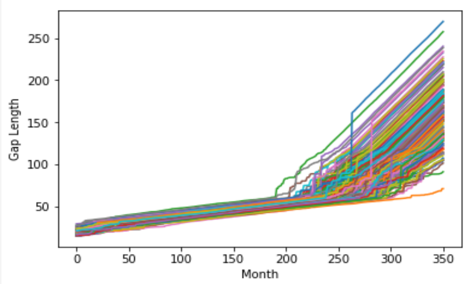
(CMMS)

Inspections

	A	B	C	D
A	0.7756	0.2126	0.0052	0.0021
B	0	0.9847	0.0093	0.0036
C	0	0	0.8698	0.1187
D	0	0	0	0.9402

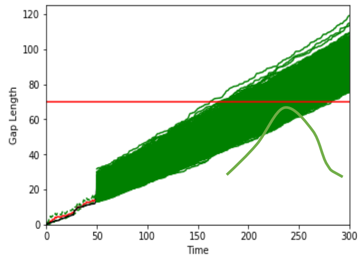
Failures

Asset Deterioration Model

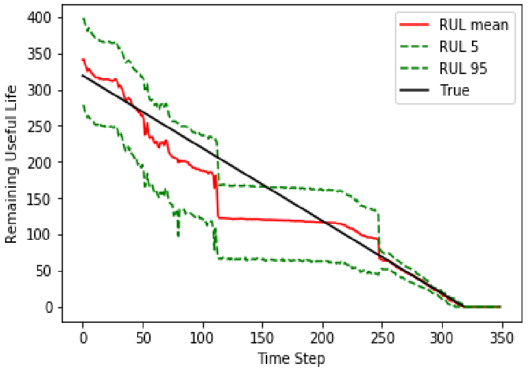


"Average Asset Behavior"
(consider maintenance data of all similar assets)

Updated deterioration model



RUL over time

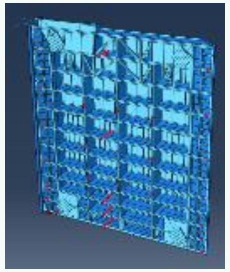


Decision making

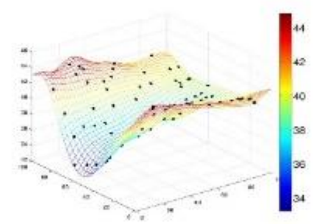
Operational Data

Time series from sensors

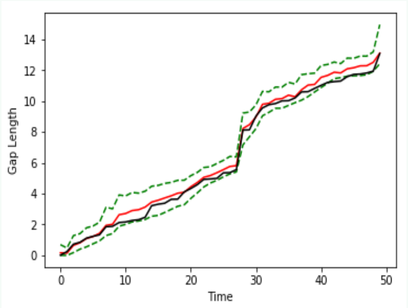
Physics Model



Surrogate Model (ML)



Asset Deterioration Model



"Specific Asset Behavior"
(consider operational data of the specific asset being monitored)

Example: Wind Farm – New Asset

1

Design
CBM, PdM,
SHM

Operational data
Failure Mode
Sensor location
Sensor count
Feature extraction

2

Sensors

Instruments

3

Data

influxdata

mongoDB

kafka
A distributed streaming platform

PostgreSQL

Analysis

nCode

Engineering & Data Science:

- FEA, Vibrations, Fatigue, Physics
- Machine Learning, Pattern Recognition, Outlier Detection

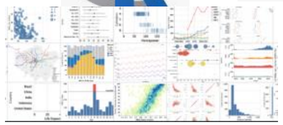
ReliaSoft

Reliability Strategy and Analysis:
FMEA, RCM, LDA, RAM, Asset Criticality, Incident Tracking, Root Cause Analysis

python

R

TensorFlow



4

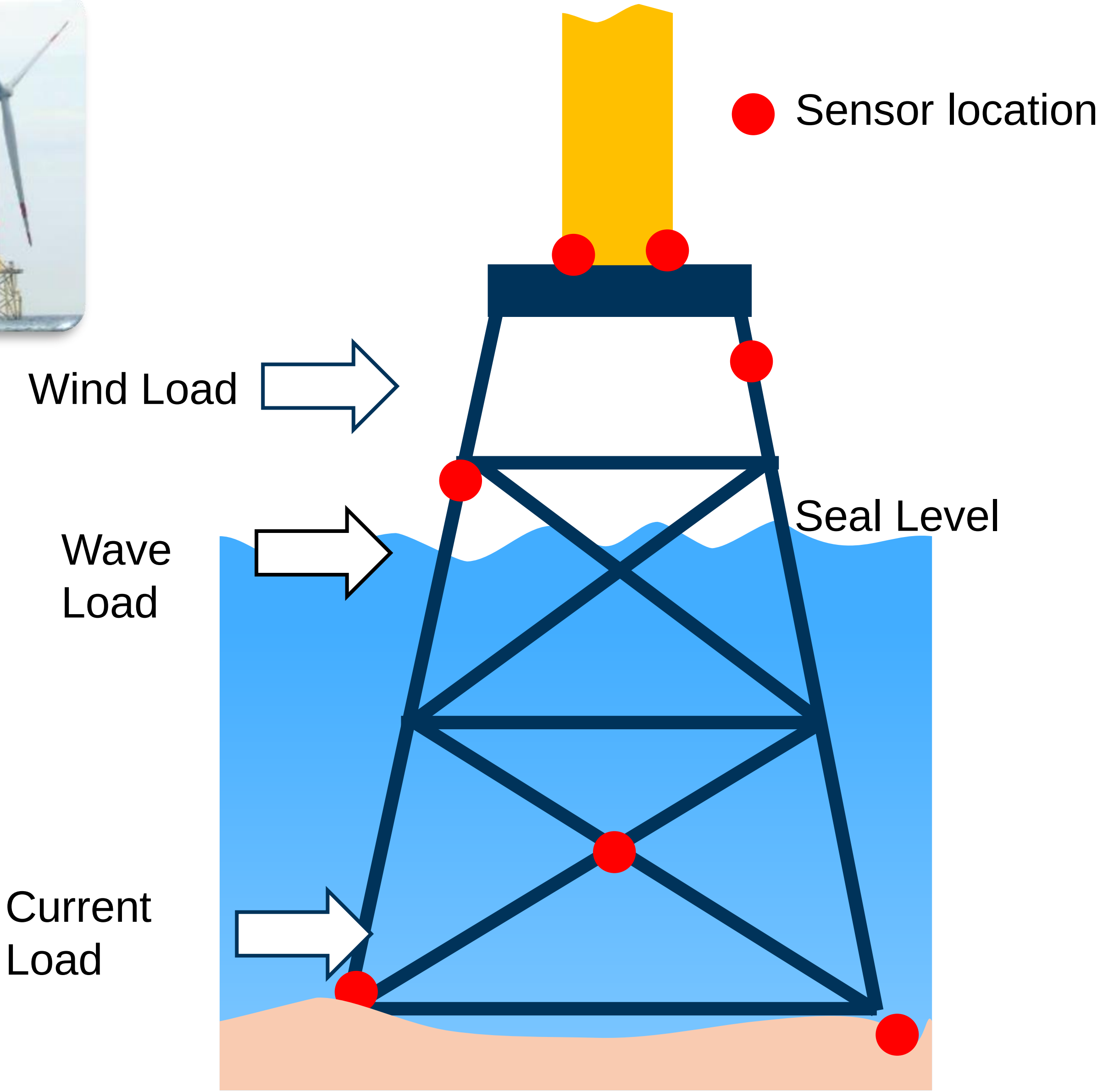
Customer
Dashboard

Power
Generation

Maintenance

Operation &
Maintenance

Optimal Sensors and Sensor Location



- Identify optimal Sensors
- Type sensors
  - Structural movement
  - Structural accelerations
  - Structural strains
  - Corrosion protection system
  - Local environmental conditions
  - Scour protection system
- Count of sensors
- Location of sensors

Decision Science – Cost, Risk, Safety

- **Detection:** Should I inspect?
- **Localization:** Where should I inspect?
- **Design**: What sensors or operational data should be used or where should I place sensors for optimal performance?

Cost:

Cost of SHM, CBM, PdM
Cost of economic loss

Risk and safety:

Loss of life
Loss of reputation

Reference: Mike Todd, University of California, San Diego

Conclusion

- Operational Efficiency depends on availability, reliability, maintainability
- Balance between cost, risk, and safety
- Sources (operational, modeling/simulation, data analytics, decision science, lifecycle expectation)
- Combining multiple data sources – advance techniques, computing power
  - Data science
  - Engineering
- Existing assets – Start with existing data sources
- New assets – plan CBM, PdM, SHM, cost, risk, reward

Questions

Q&A

- Muhammad Afzal (Omnicell, USA)
  - Where does machine learning fit?
    - *As we saw from Prof. Cross presentation previously there are many variations of Machine Learning, using black, white and grey-box models, and from Dr. Gardner in Session 5, where "Transfer Learning" is a subset of Machine Learning to develop transfer functions from a training dataset for use with target or operational data.*
    - *Machine Learning fits where existing sensor data does not provide the direct information required, so appropriate machine learning models are used to estimate this desired information.*

- Zul Yusuf (Cummins, USA)
  - Can you talk a bit more on using Prior data with new design? - How do you balance that to other inputs?
    - *For a new design, the prior data comes from engineering analysis, simulation, FEA analysis, past experience on similar design, bench test, field test etc. You can significantly cut down your validation cost or test cost if you apply this concept of combining all available data sources. Depending on level of confidence in your engineering analysis, FEA analysis, or past experience, you can balance the input.*
    - *Bayesian framework provides a platform to combine many data sources and the result is a distribution instead of one number. Bayesian methods are used in many fields nowadays.*

Q&A

- Ganeshan Reddy (Mahindra and Mahindra, India)
  - SHM - is also done on Leaning tower of Pisa ? am I correct and how is it? any idea?
    - *Yes, you are correct, you can find many papers using search terms: leaning tower of pisa structural health monitoring*

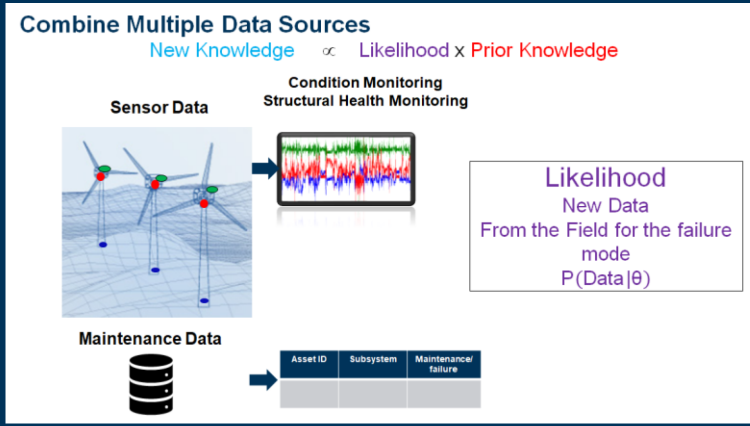
- Mathew Thomas (CNH Industrial, USA)
  - Good presentation of integrating approaches. However, do you have a complete example of how all these have been integrated? - I have only seen partial integration in these examples.
    - *Yes, we have complete examples, however they are confidential, and we cannot share their details in a public presentation like this. If you are interested, please contact us and we can provide you some more details.*

- Ovidiu Moraru (Mahindra NATC, USA)
  - It seems like the bolts and nuts of a "machine learning" concept - how relevant to this generic name is your data analysis?
    - *Yes, Machine learning provides a set of tools and it is up to us how we formulate the solution and how we use it.*

- Krzysztof Siczek (Lodz University of Technology, Poland)
  - What kind of isolation is used for in-sea water placed current sensors? - invalid isolation can affect the data stream
    - *Are you referring to “Current Load” in the “Optimal Sensors and Sensor Location” slide? – with the off-shore wind turbine foundation?*
      This is referring to the load/force on the structure from “tidal/ocean currents”.
      Yes, any in-water sensors need to be carefully electrically isolated to avoid measurement errors.

HBM Prenscia Technology Day

Virtual Seminar Series



Increase Operational Efficiency by Combining Sensor Data and Maintenance Records

Presented by Mr. Guga Gugaratshan
Head of Partner Solutions & Analytics
Prenscia Engineering Solutions

Session #6: Mathematical Modelling for Data Analytics, Durability, and Reliability #2