Exploratory Data Analysis for Failure Detection and Isolation in Complex Systems

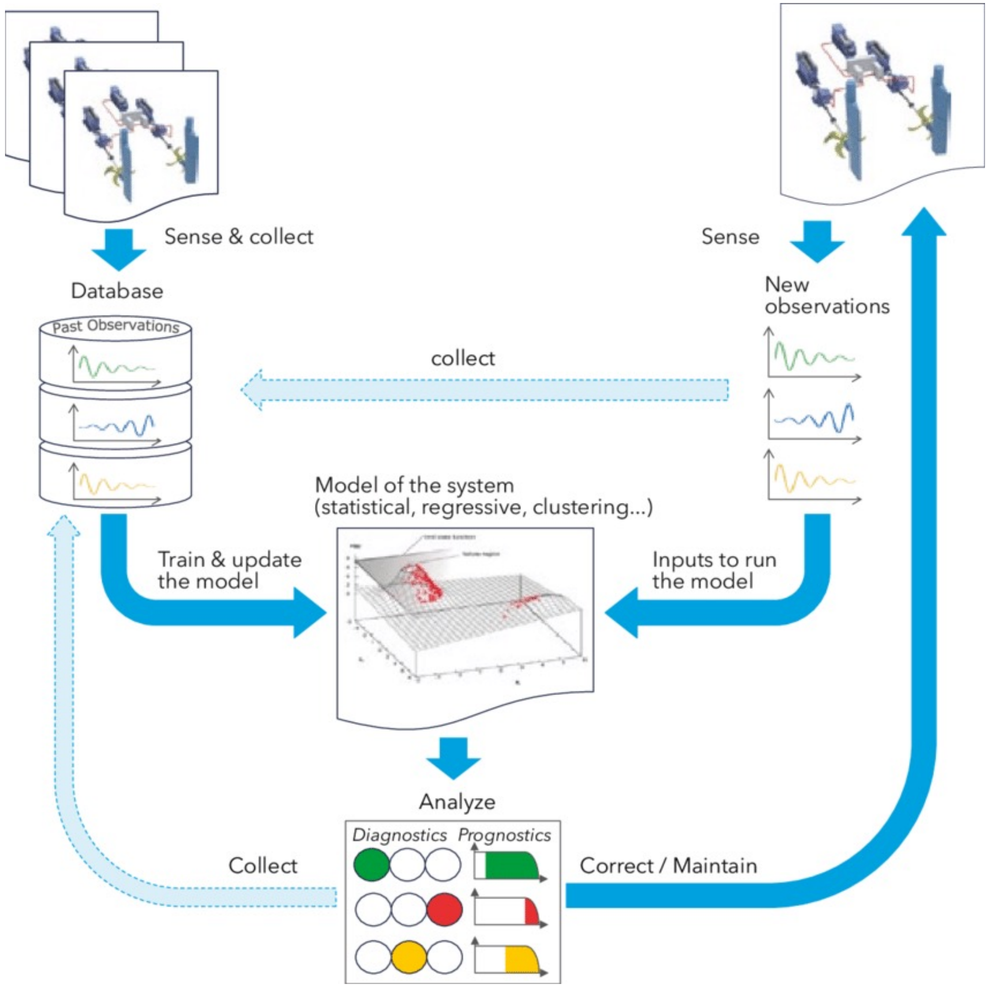
RAMS 2024

Overview and Outline

- Data in the field of RAMS and CBM
- What is EDA?
- An approach to applying EDA
- Summary

Application to RAMS and CBM

- Data-driven Condition-Based Maintenance (CBM) processes are becoming more commonplace
- The sheer amount of data means that important information will need to be extracted and summarized
- Tasks that are often required:
  - Inform and clean issues with the data
  - Visualize data patterns
  - Locate failure patterns



EDA application to CBM

- There are many areas of CBM where EDA may be useful
- Failure detection and isolation (FDI) is the focus of this paper and presentation

What is EDA?

- Exploratory Data Analysis is a series of techniques used to gain insights about the data prior to further modelling
- Both methods to extract information and presentation of findings are equally important

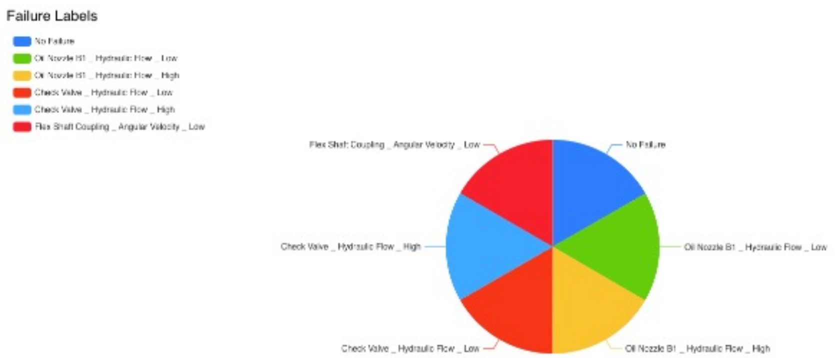
Purpose of EDA

- Here are the main reasons we use EDA:
  - Detection of mistakes
  - Checking of assumptions
  - Preliminary selection of appropriate models
  - Determining relationships among the explanatory variables, and
  - Assessing the direction and rough size of relationships between explanatory and outcome variables.
- The insights gained would inform choices in latter steps such as the type of methods or technology to train using the data or the correct features to use

An Approach to applying EDA to FDI

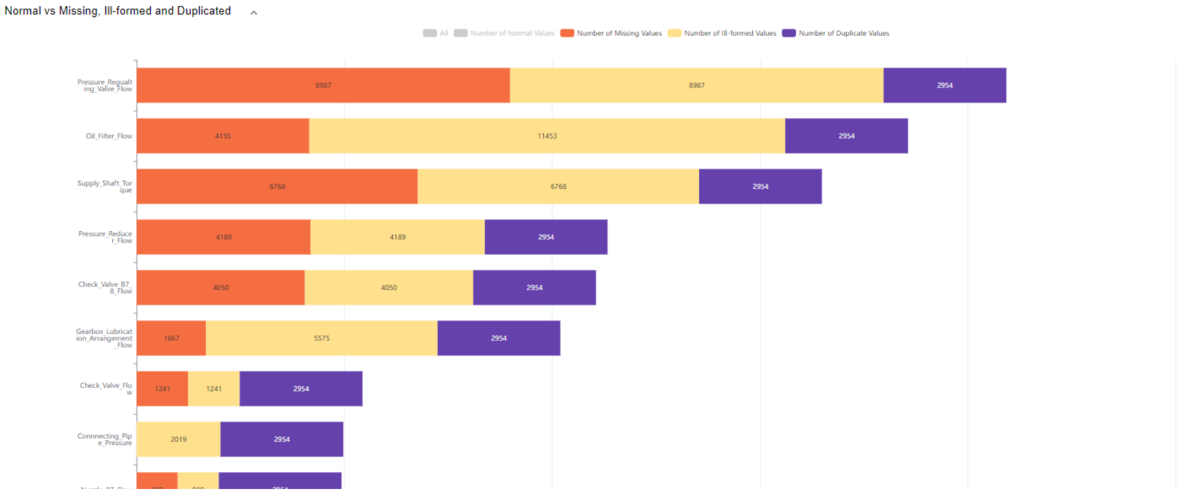
- Use of a causation tool to model domain knowledge – MADE
- Data is then analyzed correspondingly
- Correlation-based analysis:
  - Number of failure events
  - Missing, duplicate and ill-formed values
- Causation-based analysis:
  - Detectability of failures
  - Distinguishability of labels

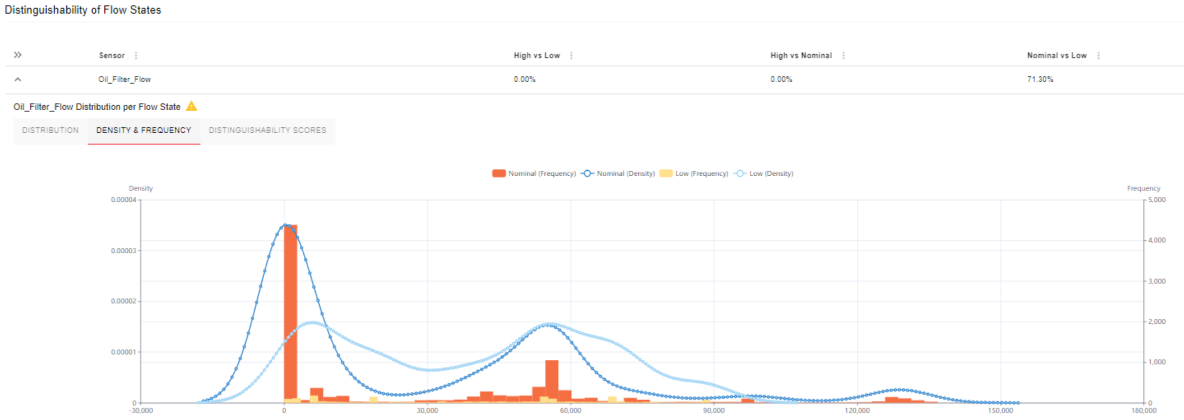
MAINTENANCE AWARE DESIGN ECOSYSTEM



Sensor analysis

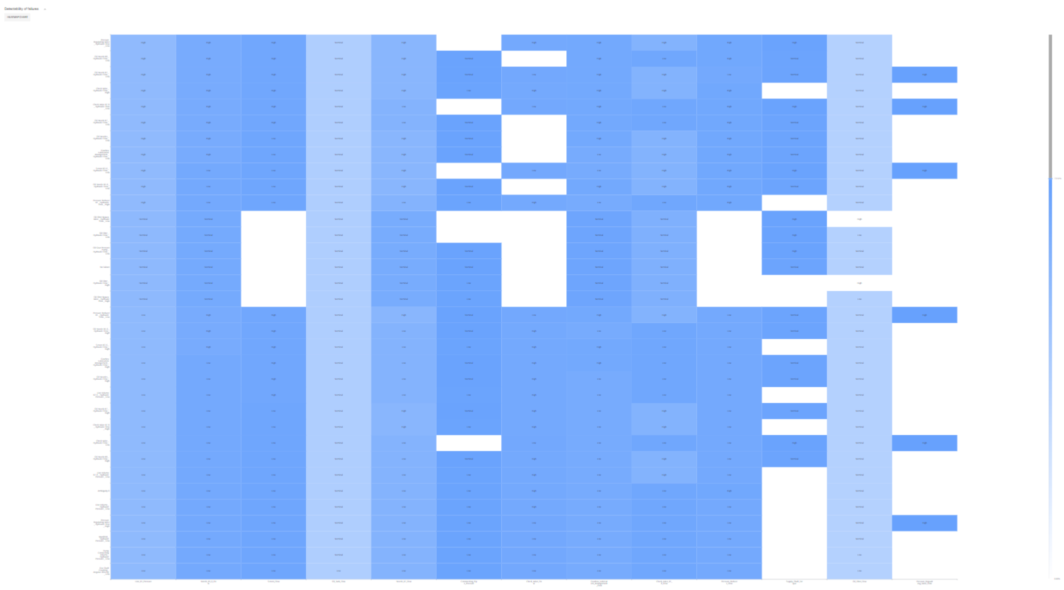
- Sensors readings serve as inputs to predict failures
- Data may be missing, ill formed or duplicated and thus require cleaning
- The effect of a failure on a sensor can be quantified as higher or lower than what is nominal
- A univariate analysis on each sensor and their corresponding flow states can provide insight into the sensors' characteristics

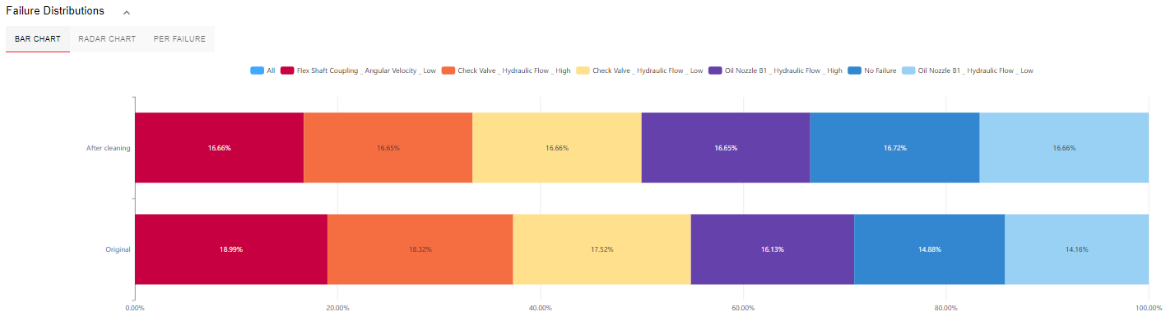




Failure analysis

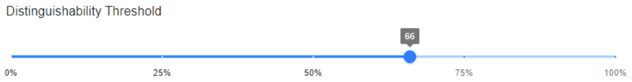
- Failure events are the labels that are output from an FDI tool
- Each failure has a unique pattern of flow states that define the system behavior when it occurs
- A multivariate analysis of sensors and failures provides an understanding of the relationship of input to output





Distinguishability and detectability

- Using the causation model alongside analysis of event data, an estimate may be made of FDI performance
- Distinguishability provides an estimate of which and by how much failures may be misclassified
- Detectability is how likely a failure may be identified when data is missing



Sensor	High vs Low	High vs Nominal	Nominal vs Low
Oil_Filter_Flow	0.00%	0.00%	71.30%
Oil_Tank_Flow	0.00%	0.00%	76.38%
Line_B1_Pressure	52.91%	53.77%	54.30%
Check_Valve_B7_8_Flow	66.26%	52.00%	70.74%
Nozzle_B7_Flow	50.63%	62.11%	67.12%
Nozzle_B5_6_Flow	65.05%	64.46%	67.63%
Gearbox_Lubrication_Arrangement_Flow	62.73%	71.27%	67.82%
Supply_Shaft_Torque	79.40%	63.46%	77.01%
Connnecting_Pipe_Pressure	75.35%	76.57%	66.17%
Check_Valve_Flow	58.90%	73.99%	75.49%

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Summary & Conclusions

- CBM involves increasingly more data-driven processes
- To take full advantage of this data, tools from EDA may be used to gain insights for FDI to estimate performances and inform next steps
- Use of a causation-based model provides domain context to EDA techniques, enriching a pure-correlation analysis