Managing Streamed Sensor Data for Mobile Equipment Prognostics

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Project Motivation

- 125M connected cars on our roads by 2022[1]
- Streamed sensor data on mining trucks and excavators now
- Equipment manufacturers' predictive maintenance solutions immature
- Asset operators
  - Raw data difficult to access and process
  - Are not getting **data-driven** insights for maintenance actions

1: CounterPoint Research [1] Image source: Tesla [2], Komatsu [3]

Data Sources

Dataset of 13 excavators measured over 9 months totalling ~300M rows in 19.9GB

58 numeric sensors and 40 binary indicators

(per excavator)

Fleet management database

Operator entered machine status codes

CMMS work orders describing maintenance events

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Image source: Hitachi [4]

Raw Data State – normal transformation

Long form sensor data

Time	Sensor	Value
0:33:24	57	4.176
0:33:24	1	24
0:33:24	58	30537.4
0:33:24	3	59
0:33:54	1	24
0:33:54	58	30537.4
0:33:55	3	59
0:33:55	57	4.128
0:34:24	1	23
0:34:24	58	30537.4
0:34:24	57	3.792
0:34:25	3	60

An example of raw data for three sensors with varying timestamps.

Pivoted sensor data

Time	Sensor	Value
T	1	X
T+0.5	1	Y
T+0.3	2	A
T+1.3	2	B

Fleet management data

Start Time	End Time	Status
T	T+1.3	Loading
T+1.3	T+2.7	Hydraulic fault

CMMS data

Start Time	Work order short text
T +12.2	Repair hydraulic system

Wide form data (for data analysis)

Time	Sensor 1	Sensor 2	Loading	Hydraulic fault	CMMS
T	X	NA	1	0	0
T+0.3	NA	A	1	0	0
T+0.5	Y	NA	1	0	0
T+1.3	NA	B	0	1	0
…	…	…	…	…	…
T+12.2	Z	C	NA	0	1

3.1 GB

17 GB

Size of the Data

Hydraulic Oil Tank Temperature

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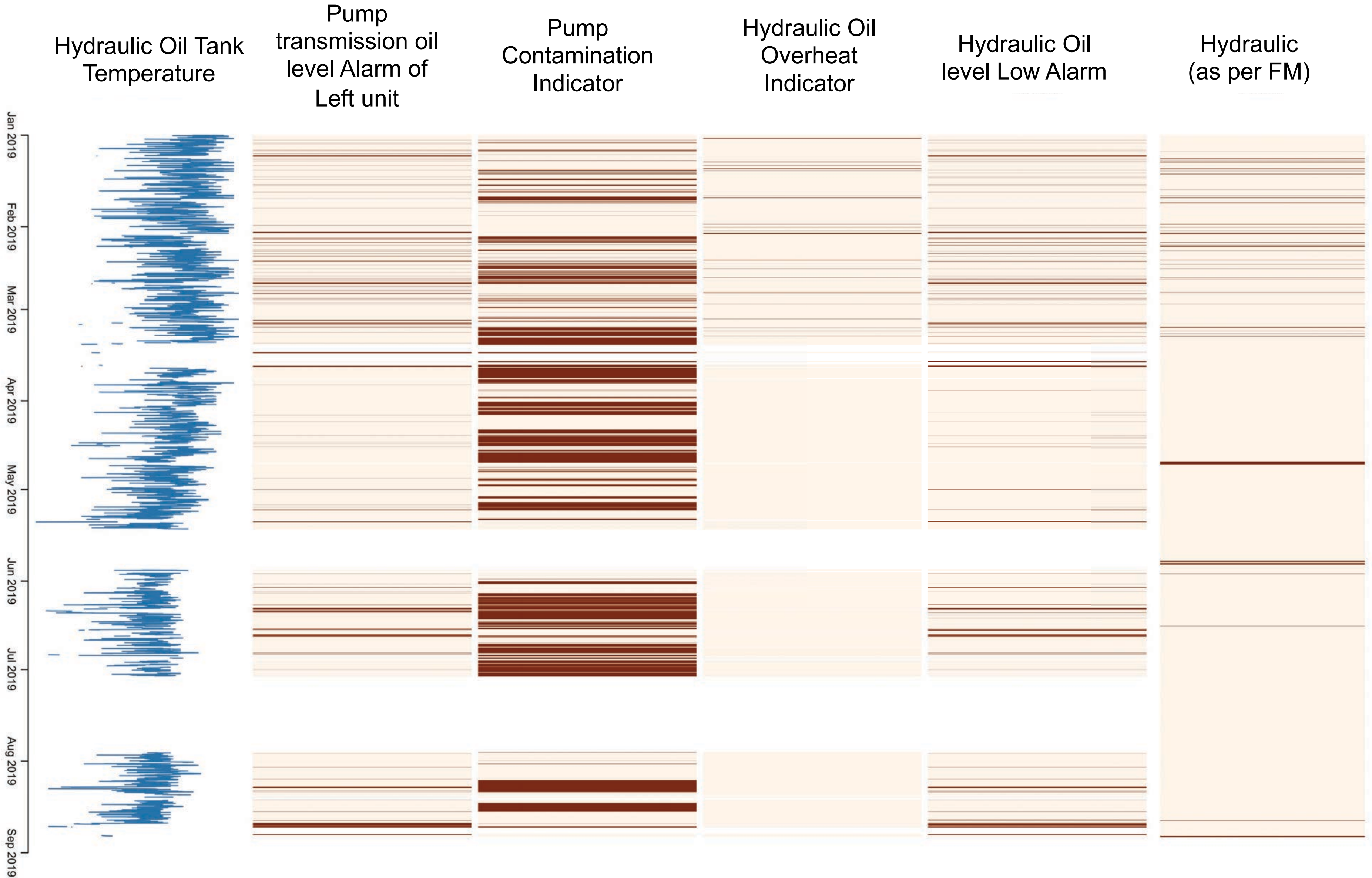
- This example spans **four days**, showing data for one sensor on one excavator
- The complete dataset encompasses 58 numeric sensors and 40 binary indicators across 272 days for 13 excavators
- This extract can be considered **0.001%** of the data
- Impossible for engineers to monitor this volume of data visually

Failure signature?



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Question

How can streamed sensor data be efficiently transformed and compressed and then used to inform maintenance on mobile equipment?

Data Cleaning Pipeline

Transform

- Extract timestamps and values to separate files
- Pivot each separately

Compress

- OHLC (Open High Low Close) data representation

Model

- Engineering based dimension reduction
- Log-linear mean regression model

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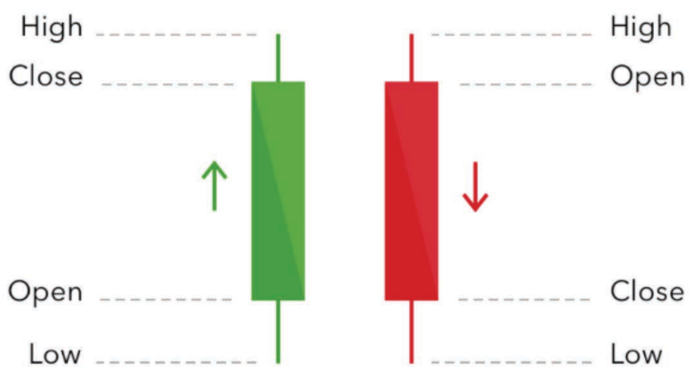
Data per sensor + CMMS data + Fleet Management data

Clean and separate into 146 files, one for each sensor, alarm, fleet management status and CMMS data

30 MB as opposed to 17GB

OHLC Data Transformation



- Original data has **14402** entries.
- OHLC data has **600** entries.
- Retains key trends of the original data.

Hydraulic Oil Tank Temperature

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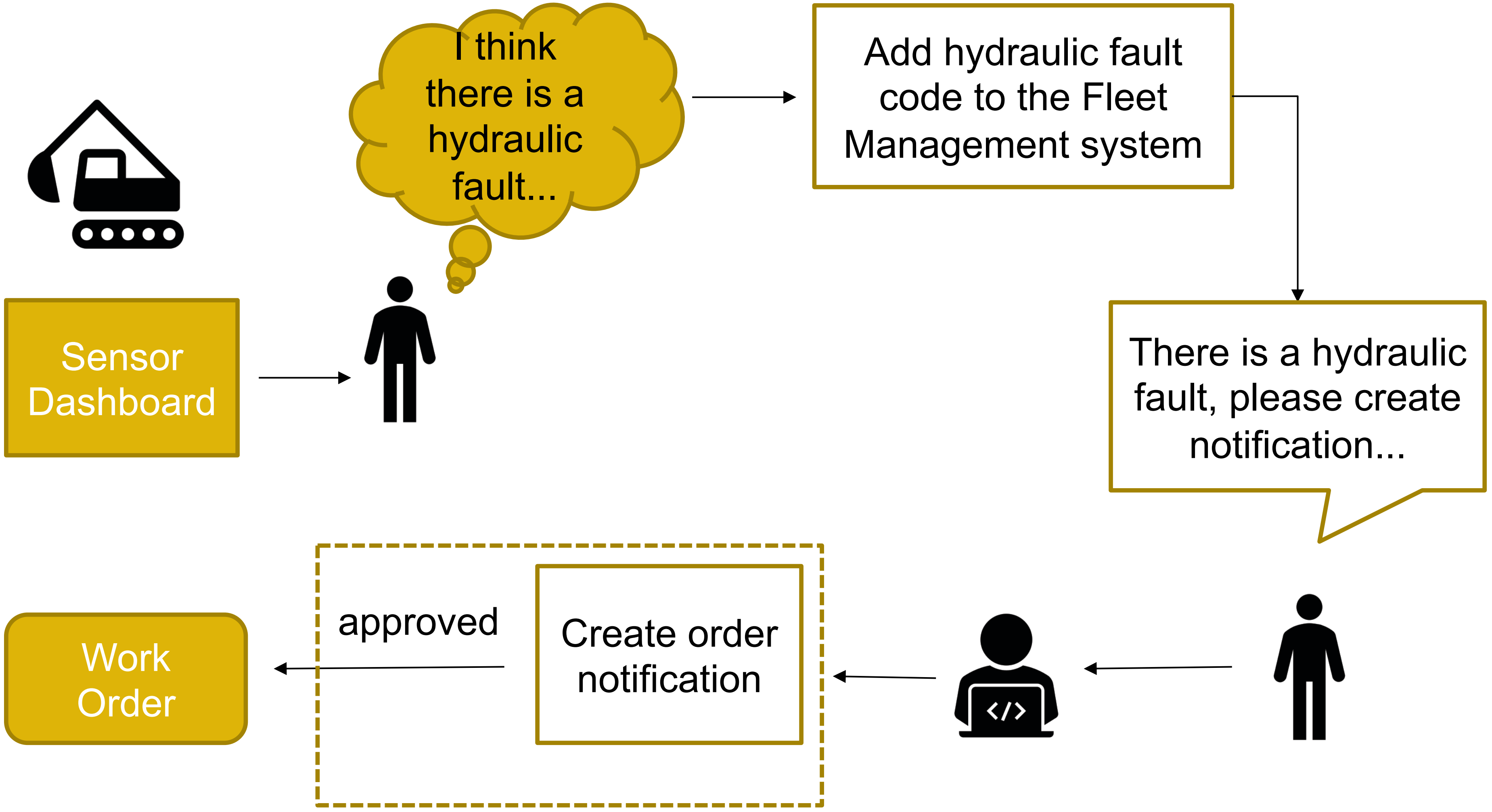
Human in the loop



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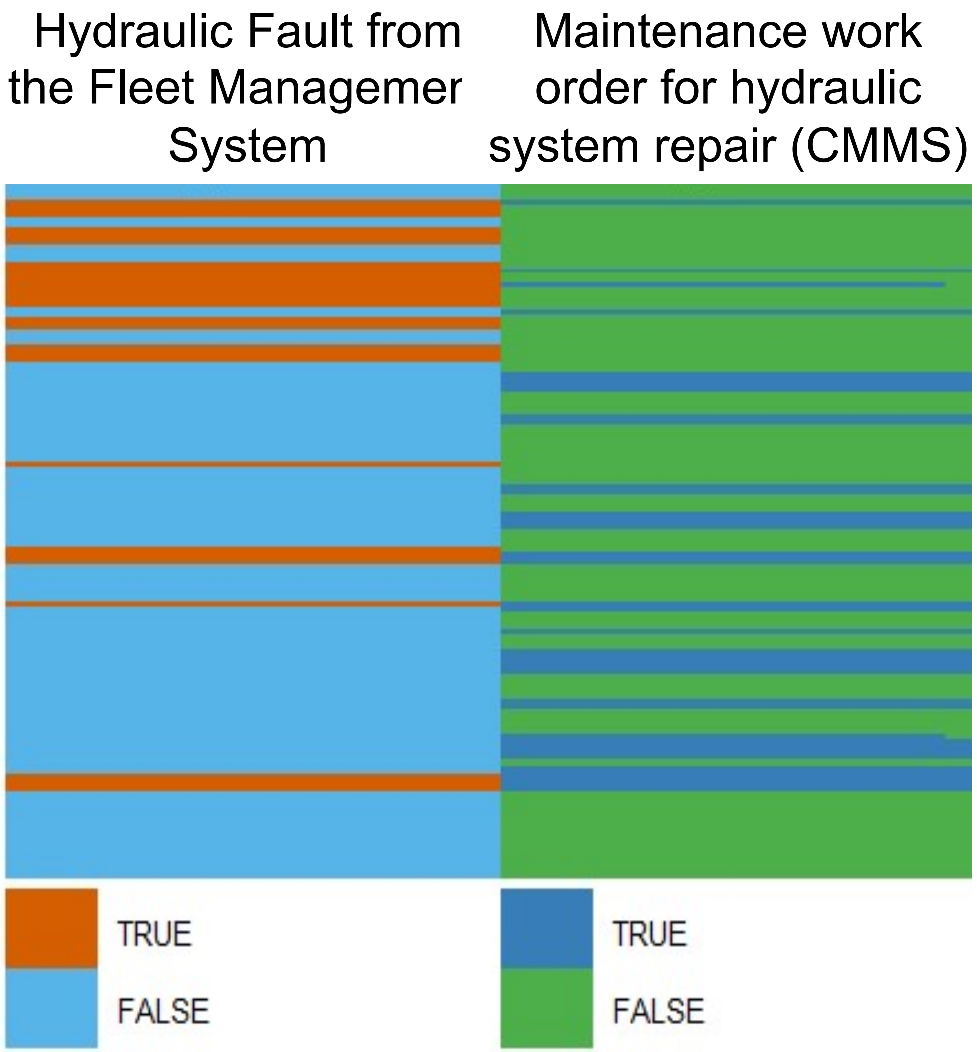
Response Variable

Both response variables are generated by an operator



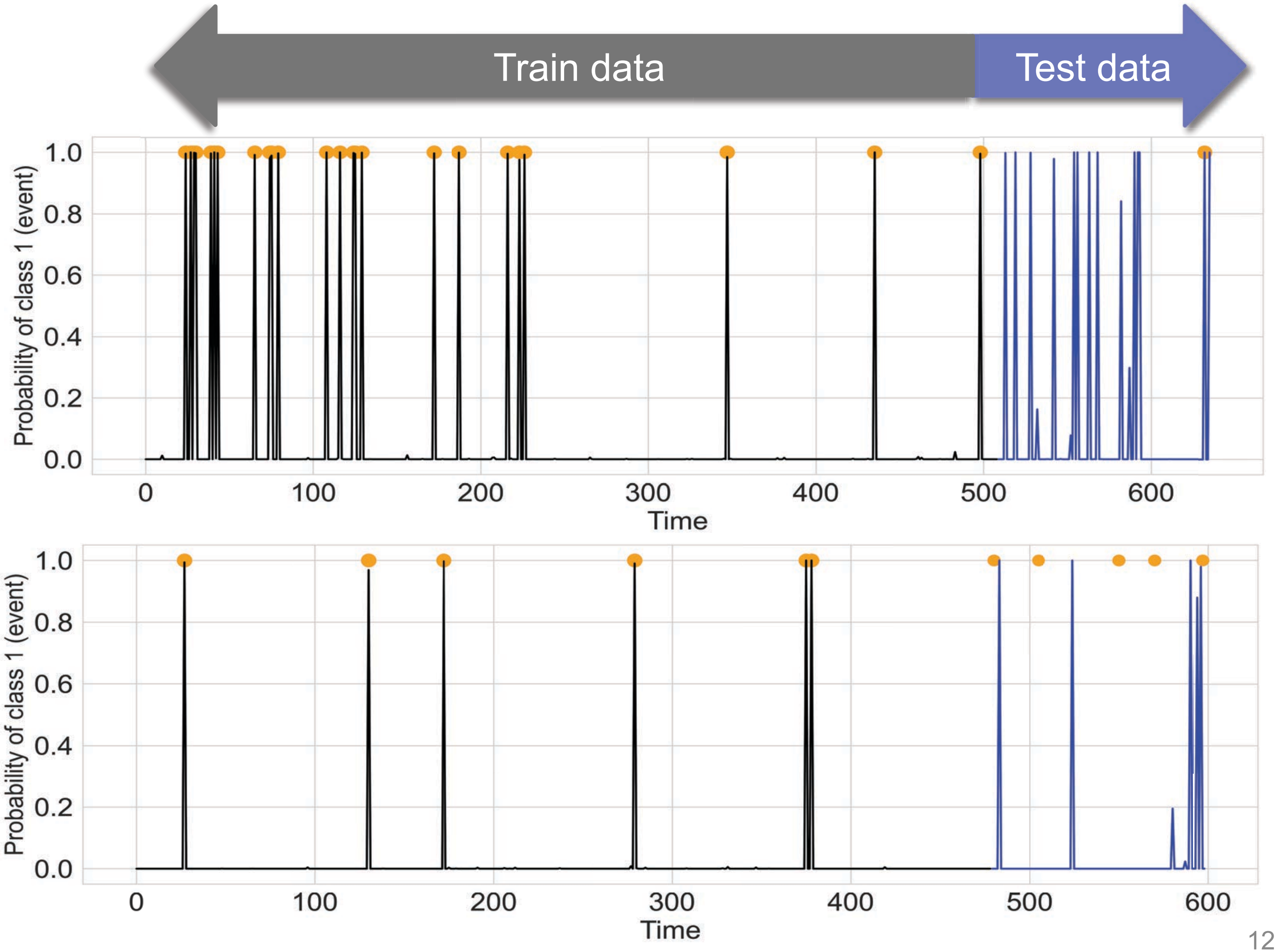
Comparison of two response variables

Modelling event occurrence

event

Fleet Management

CMMS



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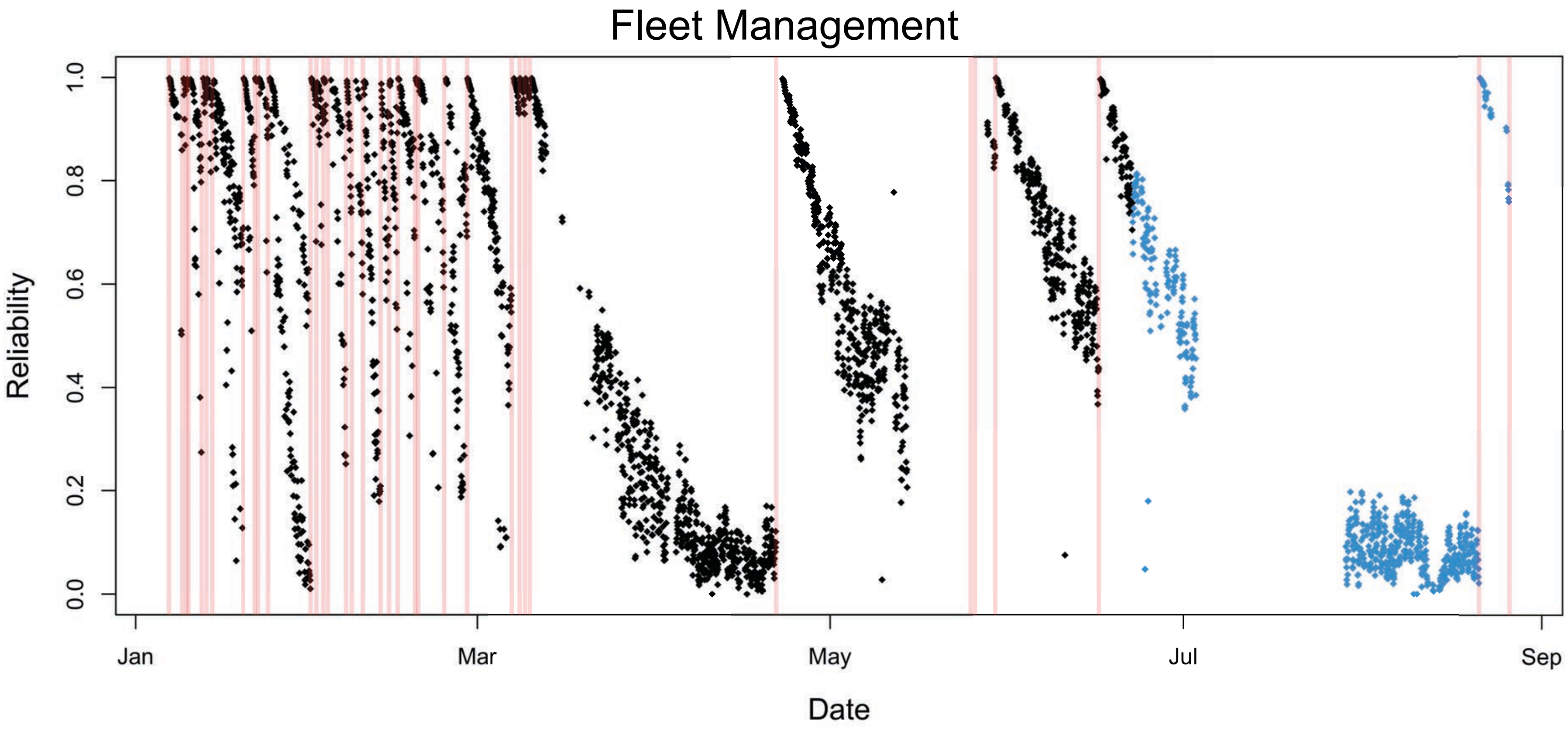
Time to event modelling

- Developed a predictive survival model using time varying covariates
- Log linear regression model



What did we learn from the modelling?

- Traditional models for event prediction were overfitted and had poor predictive power
- For our log linear regression model the most influential covariates for predicting hydraulic faults based on response variables from a) fleet management and b) CMMS data are **not**
  - Hydraulic Oil Tank Temperatures
  - Pilot Pump Pressure
  - Hydraulic Oil Level Low Alarm
  - Hydraulic Oil Overheat Indicator
  - Pump Contamination Indicator

- This is less surprising than you might first think. There is no pattern in the data as the response variable is about a human (the operator) perception about an event that has not happened yet.

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Conclusions

- Messy data – most of our time was devoted to transforming and compressing the dataset
- If you don't have an actual failure, what are you using as your response variable? Is a human involved?
- Both fleet management and CMMS data are based on operators:
  - perceptions (what they consider *potential* failures), and
  - actions (when they report them)
- Human data are not consistent for prediction purpose
- Data analysts may not realise that the fleet management entry is human generated
- Lots of time is being wasted in trying to build predictive models on asset data sets with poorly defined response variables
- Asset owners should consider having Data Engineers to ensure consistent pre-processing of their data and selection of 'good' response variables

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Thank you!

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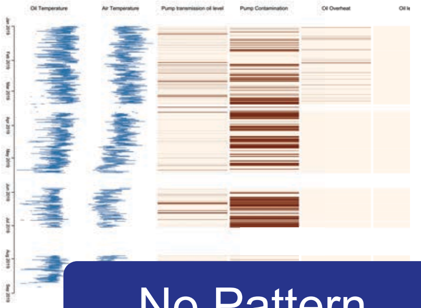
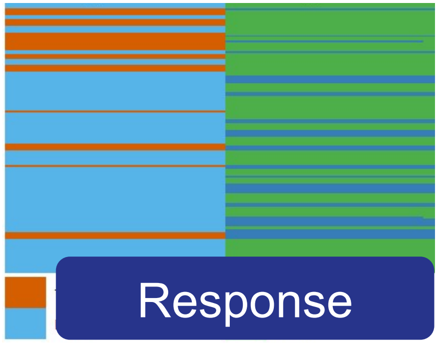
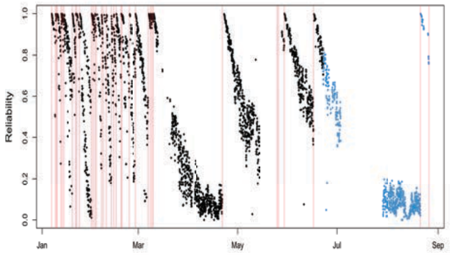


No Pattern

OHLC



Response



Reliability

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