Implementing Condition Based Maintenance for Rolling Stock System

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Overview of presentation

- Condition Based Maintenance and Remote Condition Monitoring Challenges in Rail

- Continuous Improvement in maintenance to reduce failures using ISOGRAPH methodology

- Engineering Optimisation principles to reduce maintenance whilst maintaining/improving performance

- The employing of Reliability Centred Maintenance modelling approach to allow a longer time between overhauls

- Stochastic model and uncertainties associated with maintenance of critical components

- Determining the probability of component failure to support decisions on maintenance

- Challenges around implementation of "true" CI

- Data visibility and predictive analytics (AI, BIG DATA, Machine Learning)

- 3D animation

- Can potential failures points, be recognised using the chosen technique and appropriate technology available to enable potential failures to be monitored?

- Is the P-F curve reasonably predictable? For Condition Monitoring/Remote Monitoring to take place there must be confidence that once the potential failure has been detected the component will fail within a known time.

- Monitoring Interval – this must be practicable to implement.

- After detecting the potential failure point the time left before failure must be sufficient to allow suitable maintenance.

Data collected need to be…

- –Accurate,
- –Repeatable, and
- –Properly analysed

It depends on…

- – Level of understanding of basic principles.
- – Skill and experience.
- – Information System.

"There is nothing quite so useless as doing that which is not needed, more efficiently." – Peter Drucker

i.e. Doing the same thing more efficiently is NOT lean maintenance. We must also consider WHAT we do, not just how we do it.

What we do is often the ignored aspect of Lean and CI – too much focus is given on improving efficiency, without challenging whether it is actually even required in the first place at all.

» **Reduce the risk of in-service failures, and to improve the reliability of railway rolling stock train fleet.**

» **Determine the state of critical systems prior to failure**

» **Customer satisfaction**
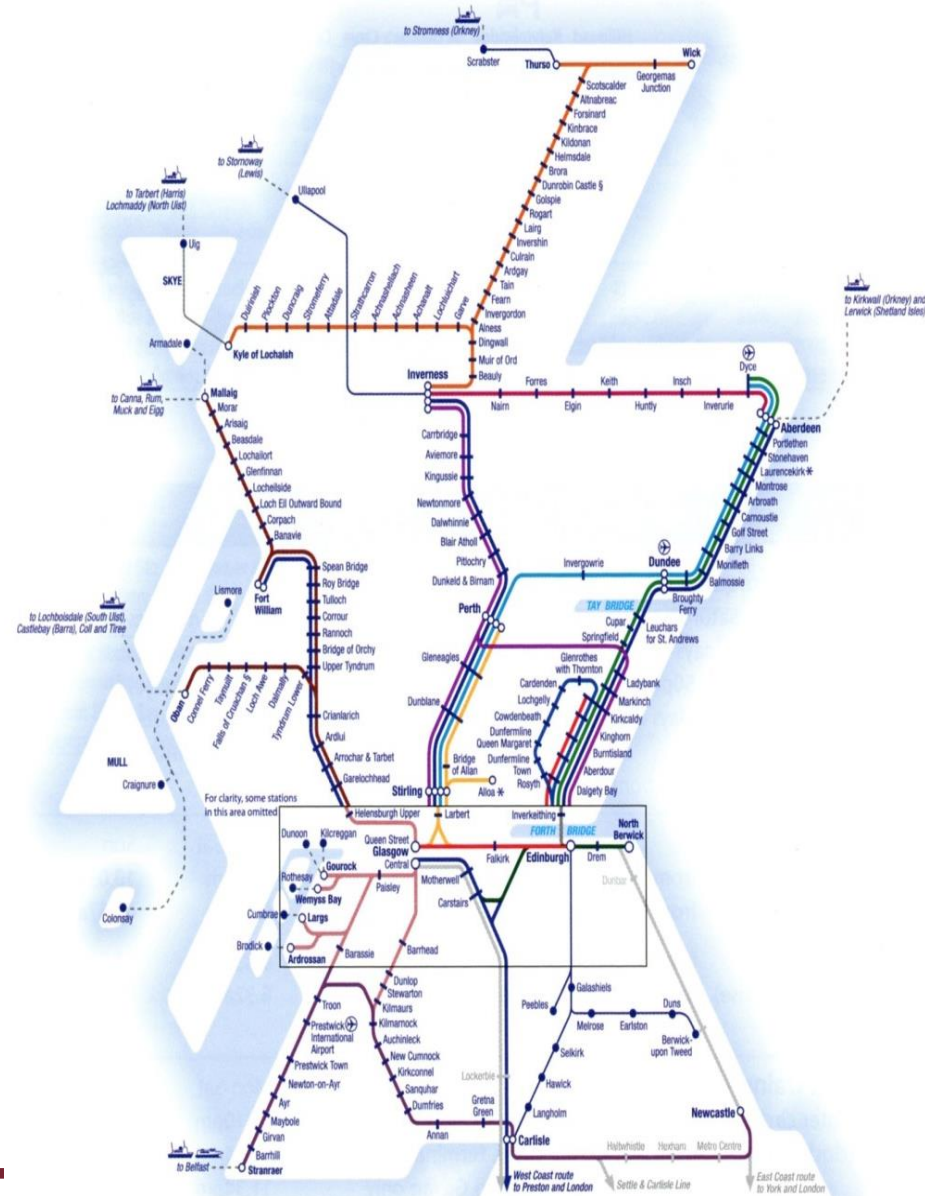
Breakdown Incident Challenges

» **Trains that fail in-service can have different degree of disruption to services for example, minute's delayed, part cancellation of a service or full cancellation of a service.**

» **In-service failure can cause disruption for example a door failure can cause a delay of 5 minutes or greater, cancellation or part cancellation.**

» **This in effect is attributable to the train maintenance procedure and thus affects the train reliability performance.**

Rolling Stock Background

- **Delays & Passenger Dissatisfaction**

- **Increased Maintenance Cost**

- **Availability & Reliability Performance**

**The 158 DMU**

- Poor performance of door systems compared to other train systems

- There are 48 units within the ScotRail 158 DMU fleet

- Each unit consists of 2 vehicles.

- Each vehicle has 4 doors, 2 on each side, each train unit has a total of 8 doors.

- Each door system consists of several functionally dependent components.

- The doors are frequently monitored at discrete time points.

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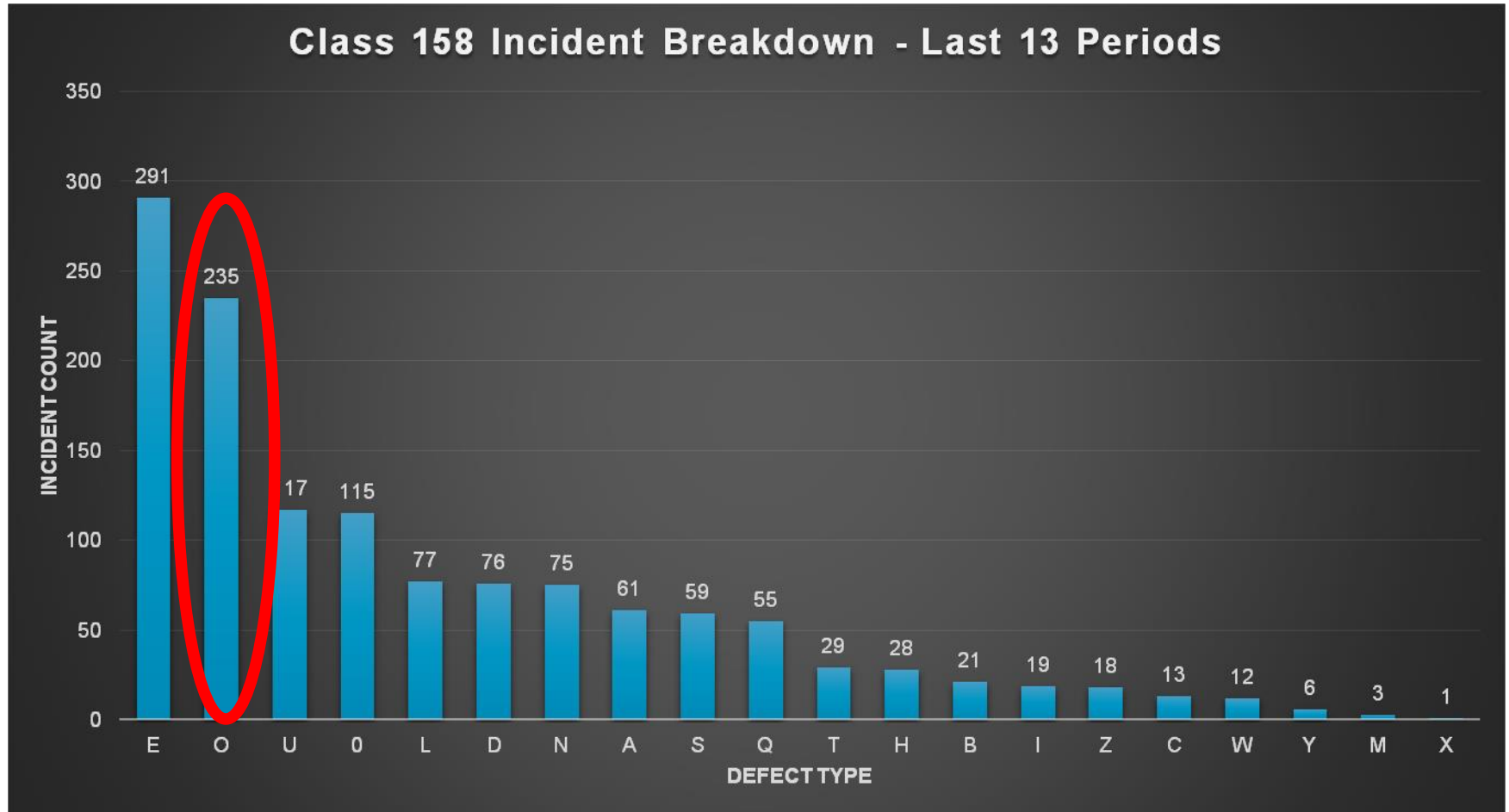# Maintenance Optimisation Case Study

- Optimise Class 158 Doors using Reliability Centred Maintenance (RCM).

- Improve asset reliability, performance and functional life.

- Gain significant cost savings via optimised maintenance and reduced penalties from delays and cancellations in-service.

- Utilise RCM methodology on other fleets and Systems.

Door Incidents/Performance

$$y = 424.4x^{0.1671}$$
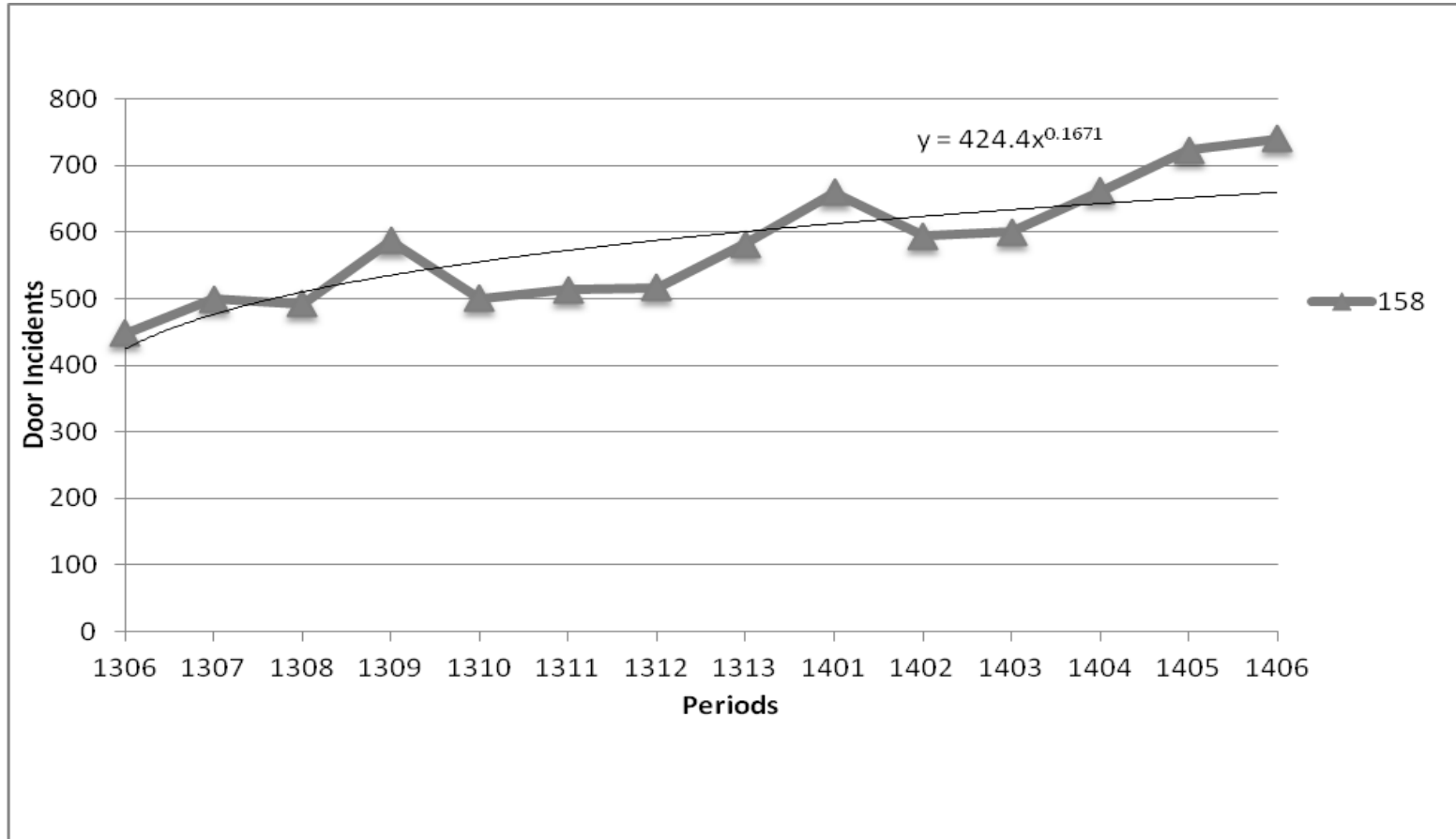
The class 158 door systems has the most technical incidents and minutes attributed to it against the other safety critical systems on the class 158 DMU fleet and this largely due to a combination of poor reliability and logistical difficulty in bringing the unit back for maintenance.

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Class 158 Incident Breakdown - Last 13 Periods

Overview of Door System

Four external bi-parting swing doors per vehicle for both passenger and crew access

Doors are electrically controlled and pneumatically operated

The torque cylinder operates linkages attached to each door leaf, operating the door

The door closes and is mechanically locked over centre
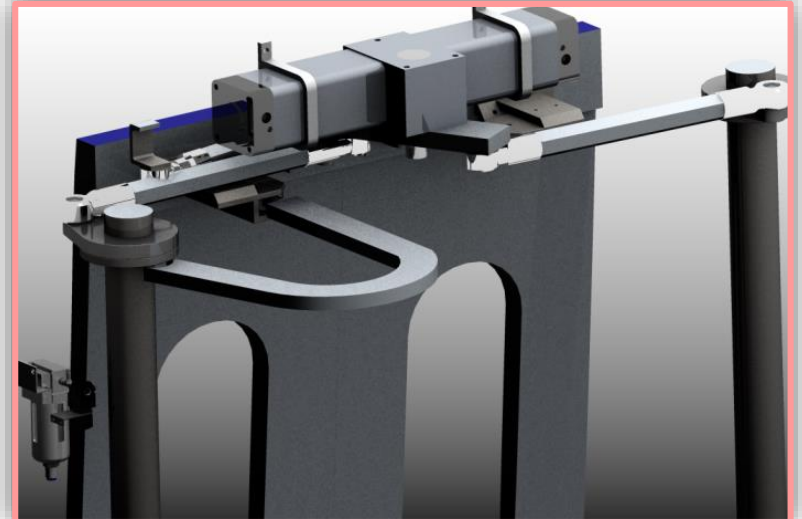
RCM Analysis of Door System

Over 100 inter-dependant components

Over 345 Failure Modes.

- Function.
- Functional Failure.
- Failure Mode.
- Effect

Failure Consequences:

- Hidden.
- Safety.
- Environmental.
- Operational.

Table 1. Top 3 Failure modes technical incidents

Year	Failure model 1	Failure mode 2	Failure mode 3
2012	DKS defective	DIS adjusted	DIS defective
2013	DKS defective	DIS adjusted	DIS defective
2014	DIS adjusted	DIS adjusted	DIS short circuit

Table 2. Top 3 % technical incidents & delays

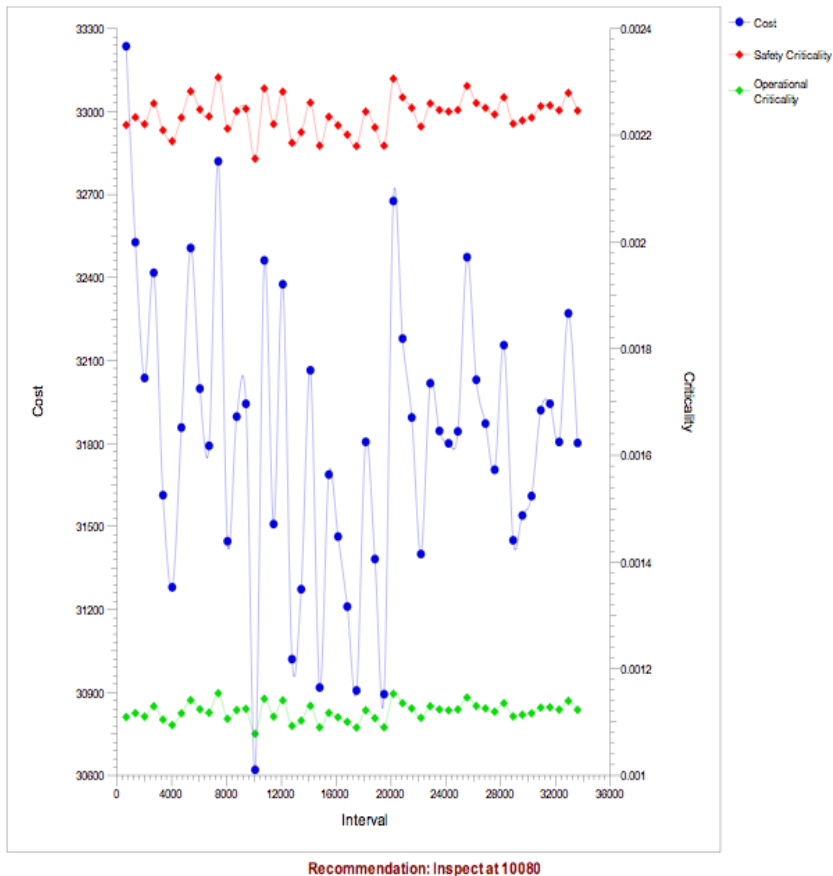| Year	Maintenance	% of incidents	% of delays
2012	7k miles	66%	75%
2013	7k miles	43%	35%
2014	10k miles	38%	16%

- Proposed Condition Monitoring on the following:
  - **Door Key Switch.**
  - **Door Interlock Switch**.
  - Door Operating Pressure.
  - Door Opening Pressure.
  - Door Closing Pressure.
  - Emergency Passenger Relay.

- Preventive Maintenance Strategy:
  - Schedule Maintenance Prior to Degradation.
  - Incident Investigation.
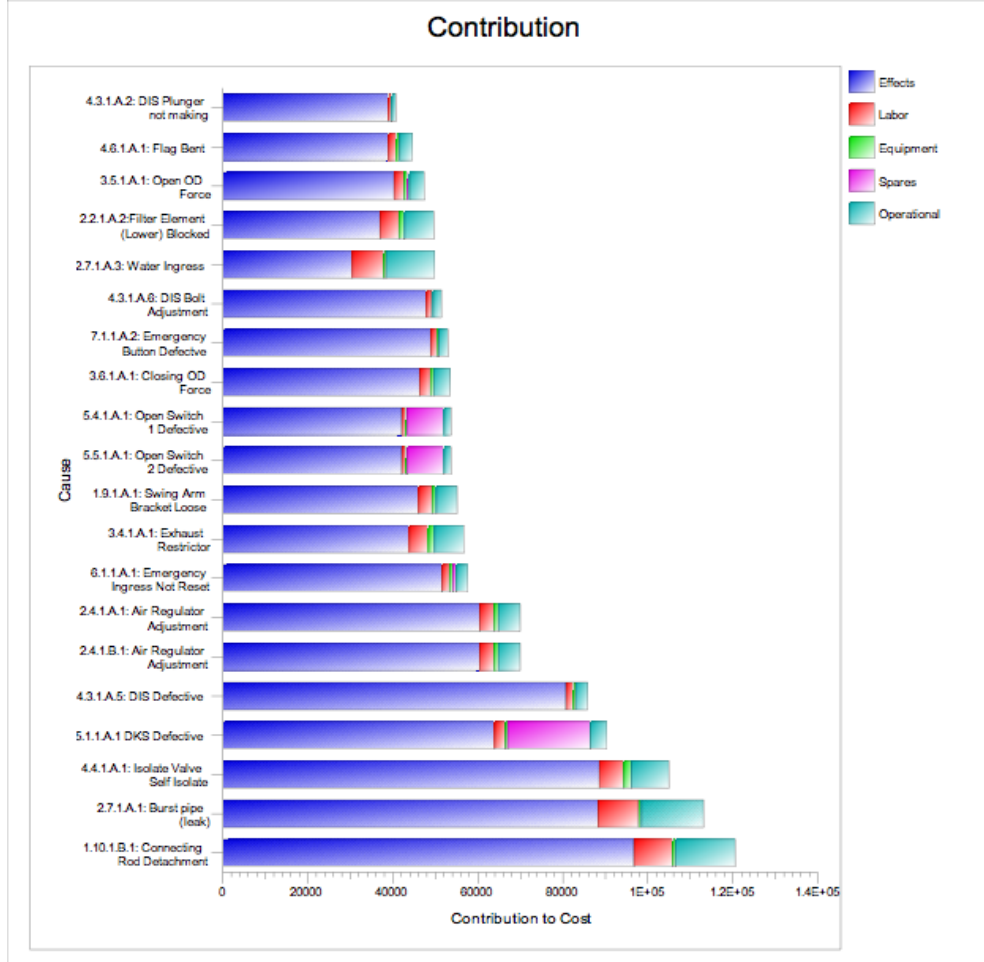 - Determine if Maintenance is necessary.

RCM Cost Analysis (ISOGRAPH)

- Utilises information gathered from RCM Analysis and proposes cost effective maintenance and intervals.

- The data sets taken into consideration are the:
  - Historical Failure Data.
  - Mean Time to Failure.
  - Cost of Delays & Cancellations.
  - Current Maintenance Practices.
  - Tools, Equipment & Labour.
  - Corrective Maintenance Times.
  - Performance & Safety Targets.

Door Maintenance Optimisation and Cost

Speed Interlock

Inspection optimization plot for 5.10.1.A.1: LSR2 Defective ORS 0001

Recommendation: Inspect at 10080

Cost Contributions

Contribution

Optimization plot for ORS 0001

Simulation graph states that labour costs decrease due to decreased maintenance periodicity.

The simulation shows that the decreased maintenance periodicity does not affect safety/ operational criticality.
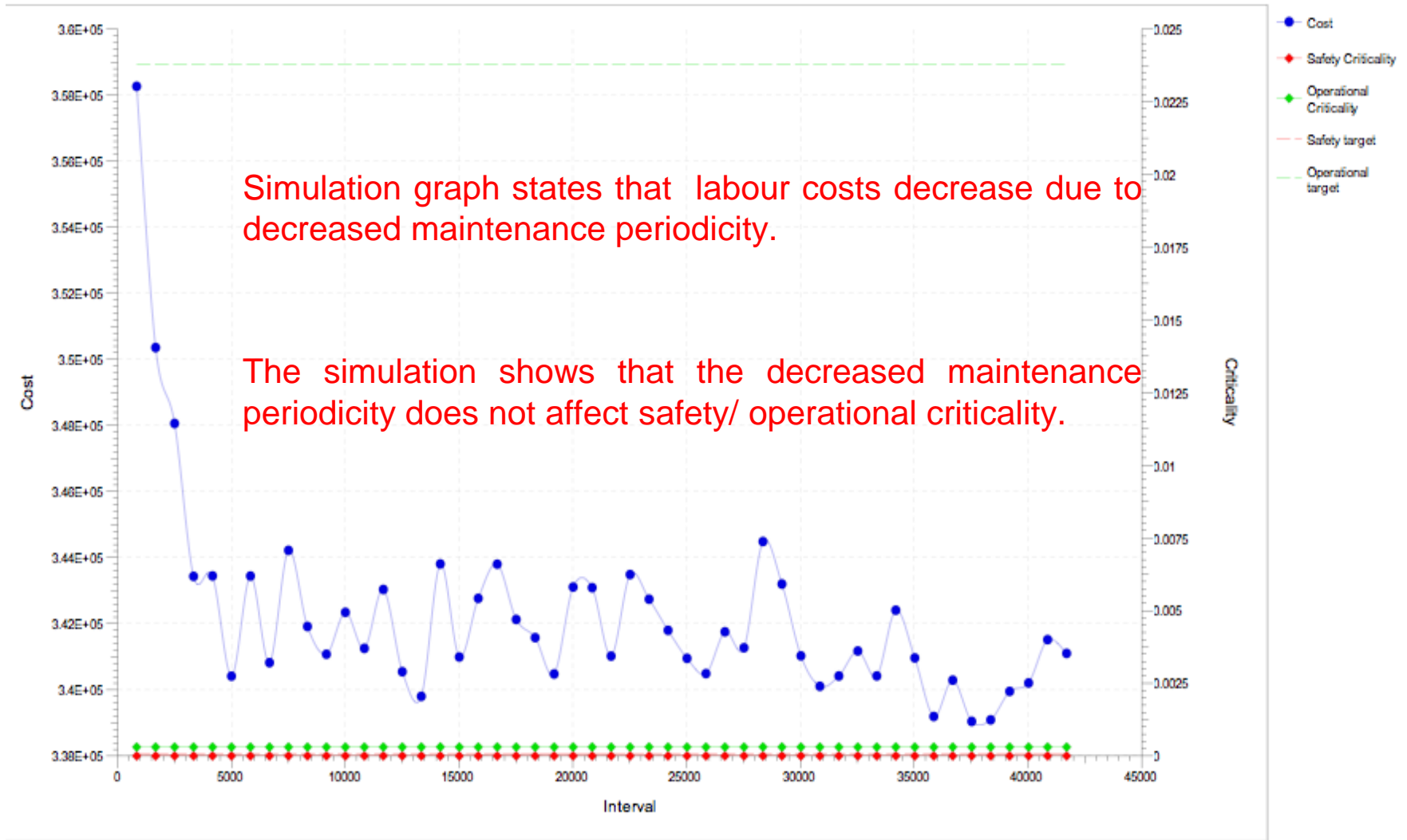
Recommendation: Task group not cost effective

- Maintenance Optimisation Cost Savings:
  - ✦ 40% - 75% Cost Savings/ Year.

- Increased Reliability Savings:
  - ✦ 10% - 20% Reduced Failures/ Year.
  - ✦ Increased Performance & Functional Life.

- Projected Cost Savings for Class 158 Doors:
  - ✦ £61,000 - £116,000 Cost Savings/ Year.
  - ✦ £200,000 Investment (2 Years), 3.2 Year Break Even.

- Projected Cost Savings for 8% of ScotRail Assets:
  - ✦ £400,000 - £685,000 Cost Savings/ Year.

Example of DIS and DKS Duty Cycles – monitored via Nexala

Cycles

	A	B	D	C
	291	149	1925	2773
	84	12	181	653

158738 | | 52738 | | 57738 | | 158738

CAB ... CAB

	45	19	117	1169
	314	209	1846	2972
	C	D	B	A

DKS Cycles
DIS Cycles
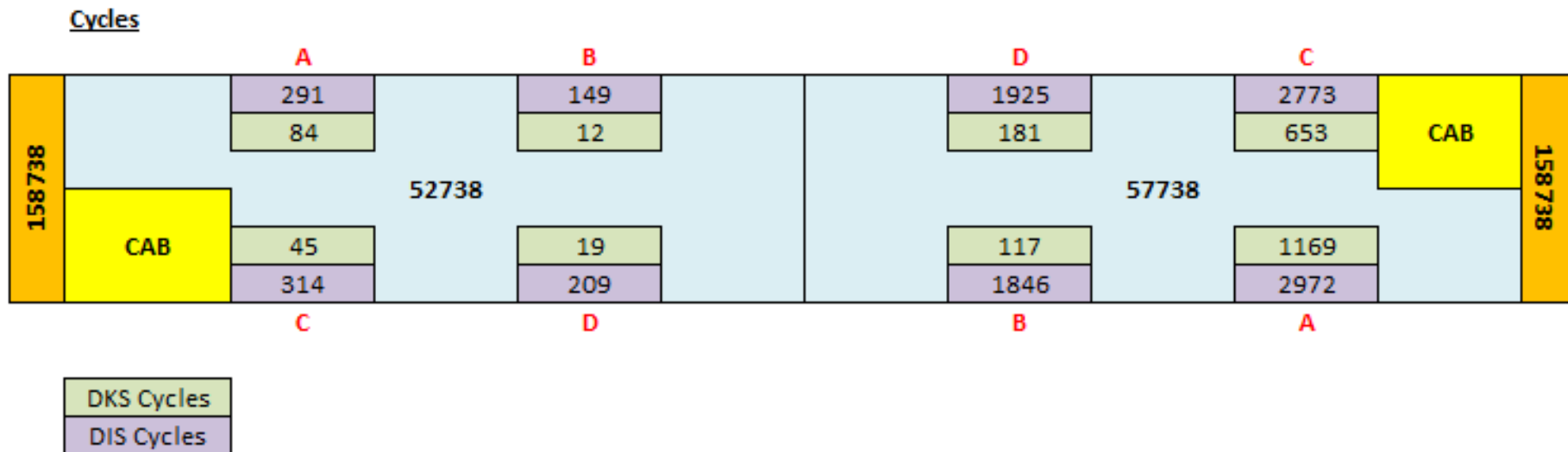
- Identify which doors and door control operated in-service to aid corrective maintenance planning.
- Records station, route and time.
- Provides interesting insight for other areas of the business – loading patterns, human factors, crew habits etc.

- Most common causes of incidents were attributed to the DKS and DIS systems.

- The door slow to close alert generated if more than door takes more than 8 seconds to achieve interlock after pressing the door close button on the DKS Panel.

- Once the door close command is initiated the door release triggers, the hustle alarm sounds for 3 seconds before the doors start to close.

- It takes about 4 to 4.5 seconds for the door to close.

- Initially configured to alert if 4s rule breached, then refined to 4.5 s to account for differences between manual and electrical measurements during maintenance vs Real Time
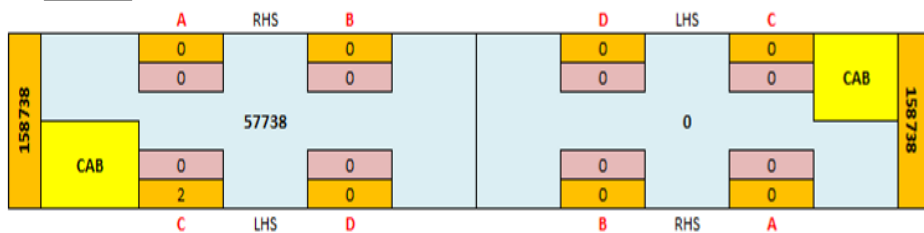
Number of Slow to Close on the Door C is 32
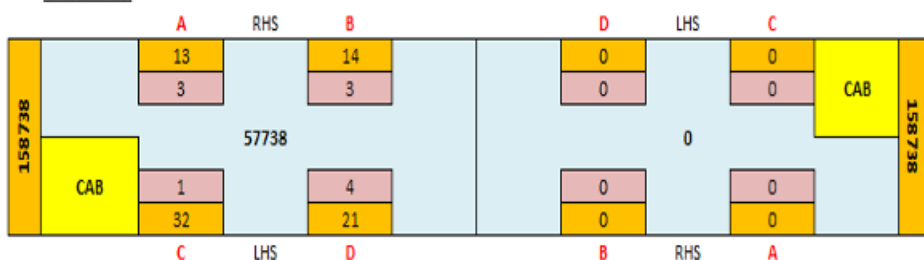
**93.75% Decrease in False Reports**

Failure Identification Alerts

- New "slow to close" alert, to identify performance issues in-service.

- Specific doors showing signs of deterioration and repeat failures (C door) can be recalled for performance improvements.
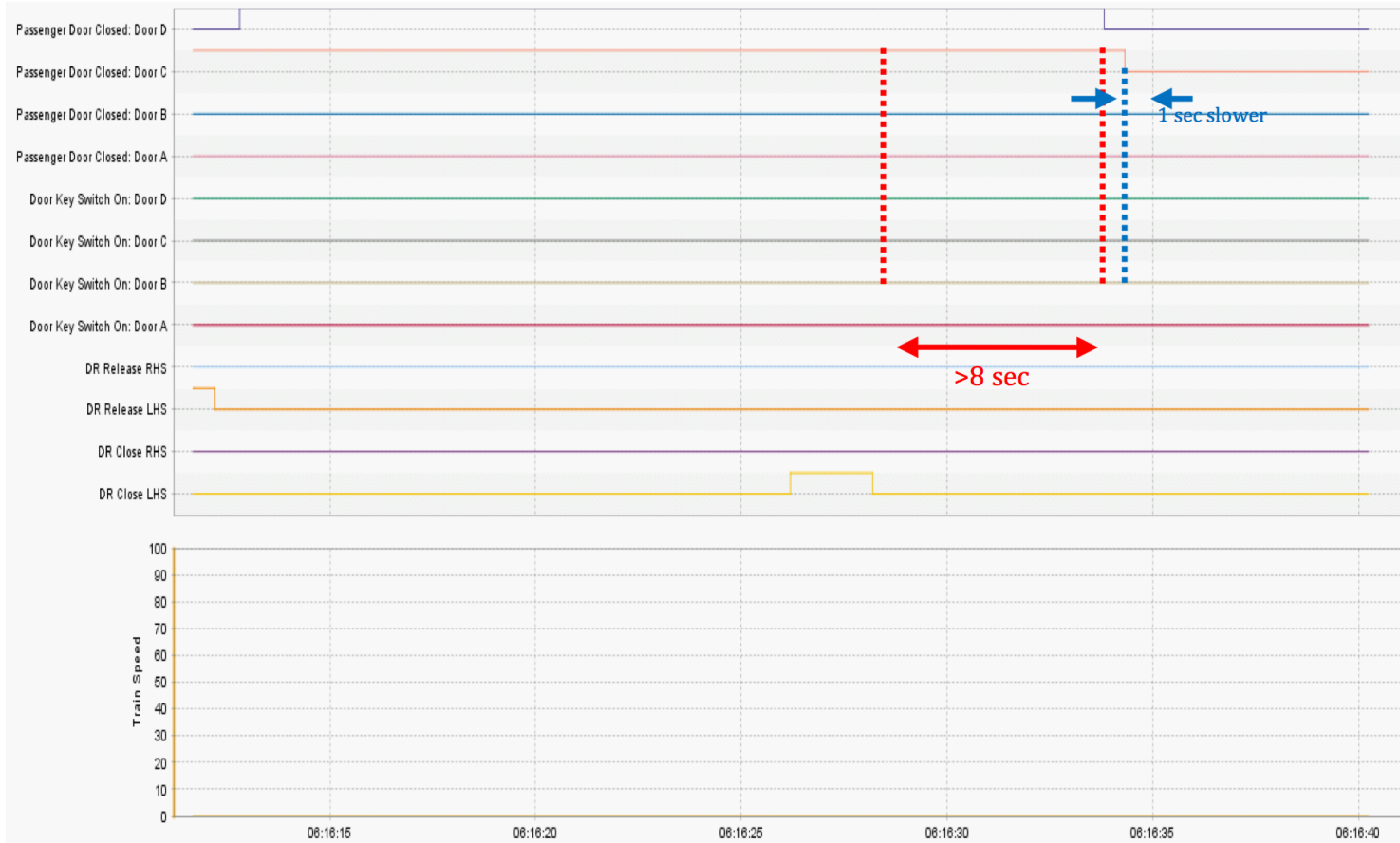
Failure Identification Alerts

- "Signal Pulse" monitors if the sensor signal from the DKS or DIS is active for less than a second (0ms – 1000ms)

- Highlights via alert if any intermittent failures during service which would not be noticed through maintenance or by train crew
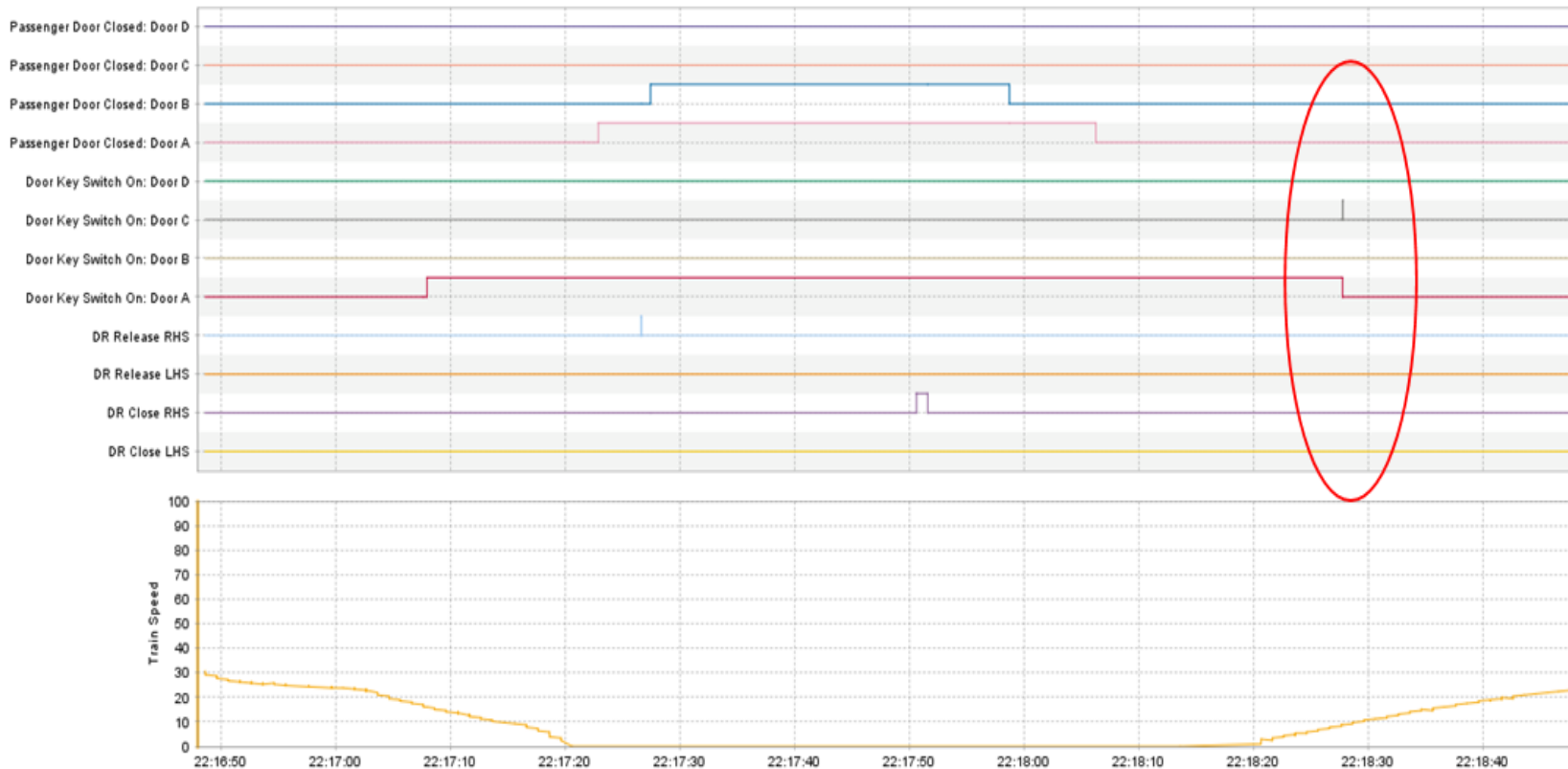
$T_1, T_2, T_3,...$ ⟹ **Times to successive intermittent failures of the door system**

$S_i = T_i \quad T_{i-1}$ ⟹ **Time of the signal pulse between failures $i \quad 1$ & i.**

T_i & S_i ⟹ ***R*andom variables**

$$exp\left(- \int_0^{S_i - S_{i-1}} \lambda_j (t)dt \right)$$

$$F(t \mid S_1, S_2,......, S_n) = 1 - e^{-t\sum_{i=1}^{j-1}(S_{i+1}-S_i)\lambda_i + (t-S_j)\lambda_j}.$$

✖ **Where λ_i is the failure rate of the doors and S_j is the largest signal pulse time less than t.**

- The idea in this model is that discrete event occur that change the underlying failure rate (events such as signal pulse)

- The model requires us to define the failure time distribution through a process rather than through the more conventional survival function approach

- We define an increasing sequence of signal times $(S_{i-1}, S_i]$ and for each period between signals $S_0 = 0, S_1, S_2, ...,$ a failure rate $\lambda_i(t), t \in (0, S_i - S_{i-1}]$

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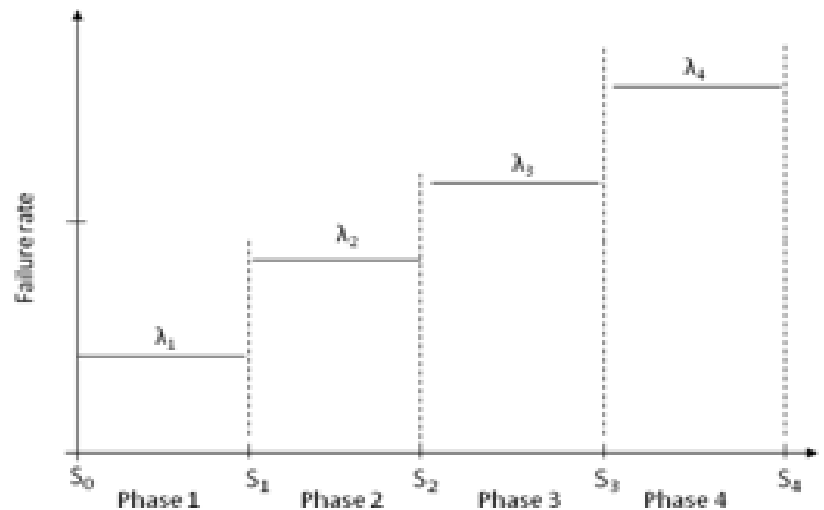
Signal pulse are assumed to occur according to a Poisson process with mean 1.2. To provide a cut-off we also assume that the equipment is replaced at time 10 in any case. Based on a simulation of 1000 events, the underlying survivor function for X
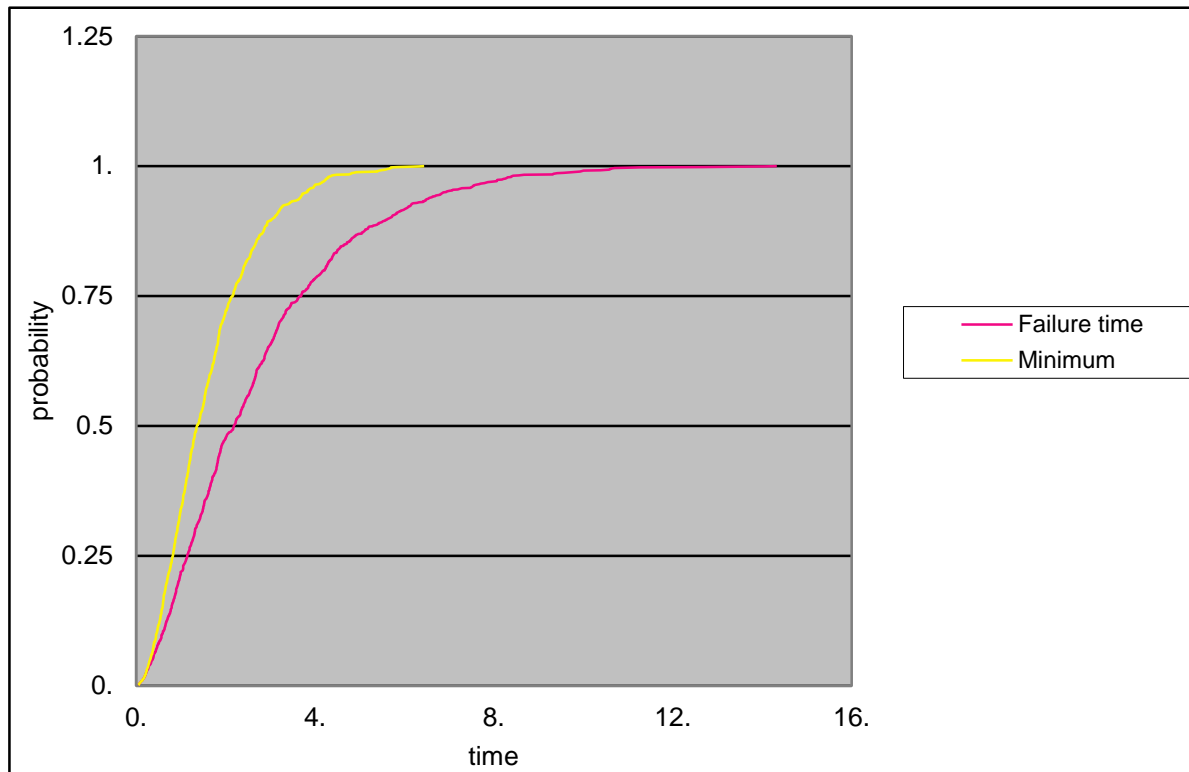
Remote Condition Monitoring is seen as the "Holy Grail" – but it has its challenges and runs the risk of being deemed a failure if not implemented with due concern and consideration.

Questions to ask yourself if you are thinking of developing a CI/Lean/Remote Monitoring based approach to maintenance:

- Do you already use the existing data effectively? If not, can you realistically use the additional abundance of data?

- Do you have the capacity and the capability to a) sort the data and prioritise work to be undertaken and b) actually then undertake the work required with all the other work streams still progressing?

- Do you have a CI culture of wanting to find problems proactively to solve them? Or is the culture around constant fire fighting?

- Is there a mismatch in priorities and agendas for those driving the change (generally management) and those most impacted by it (generally front line staff)

- Is your CI solution people led or technology led?

- Is there an appreciation of Ongoing Costs to continue providing the benefits expected?

Sensor data

Fault Recognition
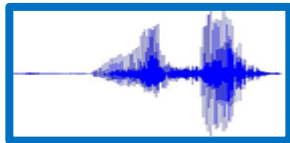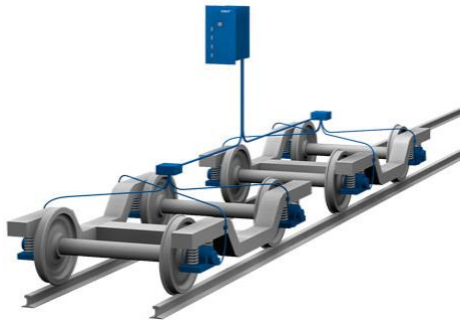
Fault Type

Neural Network

Neural Network

The term Big Data, Artificial Intelligence and Machine Learning are sometimes use interchangeably however they have subtle differences

What do we mean by Big Data?

"high-volume, high-velocity and high-variety information that demand cost-effective, innovative forms of information integration, processing, analysis for enhanced insight and decision making" https://www.gartner.com/it-glossary/big-data

Deep Neural Networks

Learning by technical information

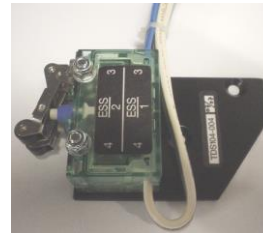

Door Header Gear Image

Door Control Plate Image

Push button

Stroke Switch

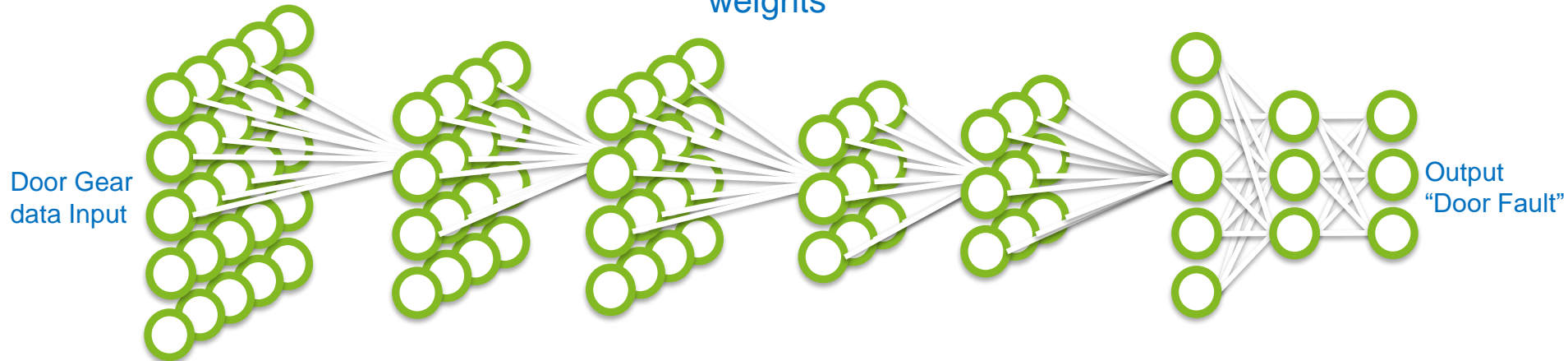Isolator Shut-off

Air Filter & Regulator

weights

Door Gear data Input

Output "Door Fault"

Swing door
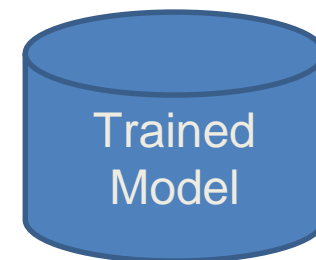
Control

Header Gear

Deep Learning Framework

Forward Propagation

Signal

Repeat

Backward Propagation

Update the weights to nudge from "Signal" towards "Gear"
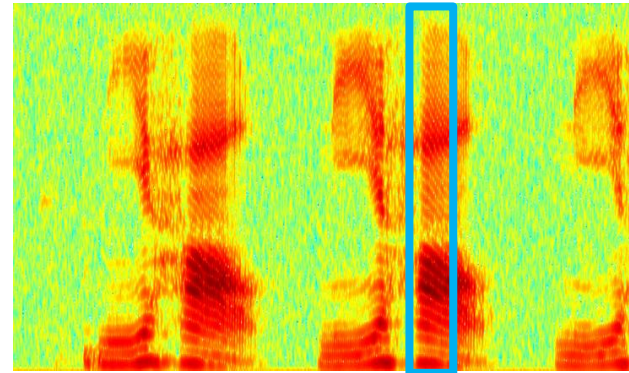
Trained Model

Door
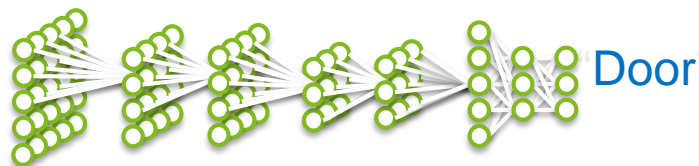
From sensor data to NN

spectrogram

Waveform

DFT
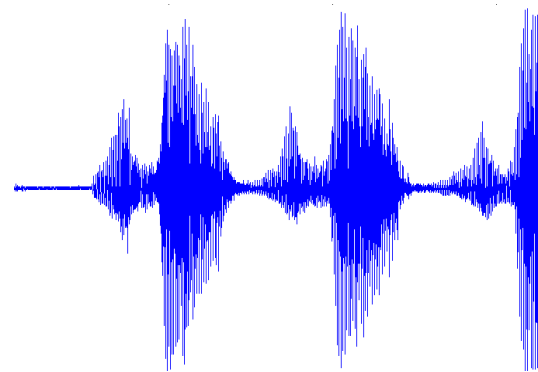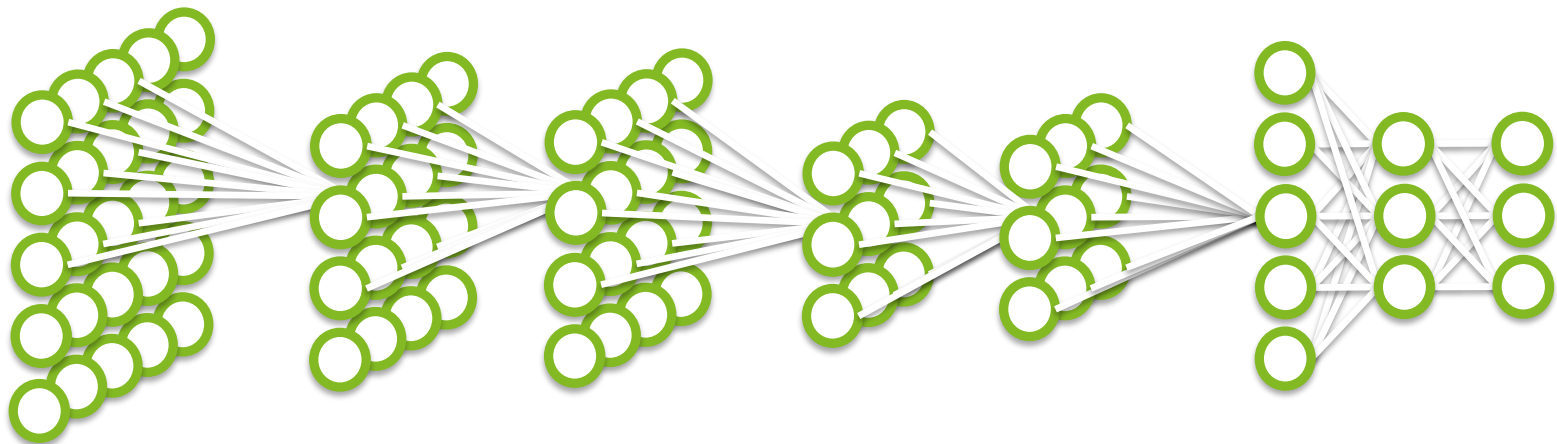
Input of DNN

Data Input

"Output"

Conclusions

The study and results presented highlight critical system failure distribution and allow Engineers to identify maintenance improvement in planned routine maintenance and overhaul specifications to achieve higher operational safety, performance and reliability.

This new knowledge would enhance maintenance procedures to improve maintenance effectiveness and reduce the amount of technical failures in-service.

RCM helps organisations to:

- Select the most appropriate technique for the component/system
- Deal with each type of failure process including hidden and linked failures
- Maximise usable life of the asset
- Choose the most cost-effective and enduring maintenance approach

Future Research

- Effective utilisation of Condition Monitoring and Remote Condition monitoring data

- Using DNN (AI) coupled with Reliability modelling towards maintenance optimisation

- Data Visualisation using 3D Virtual Reality

- Simulation of the proposed signal pulse model to predict the time to failure of the door system is envisaged. This work is still ongoing and will be presented in future publications.

Alkali B, Dinmohammadi F, and Raman A., (2017). **Towards Implementing Condition Based Maintenance Policy For Rolling Stock Critical System. IMechE The Stephenson Conference: Research for Railway. 25-27 April, One Birdcage Walk London UK.**

Dinmohammadi F, Alkali B, Shafiee M, Bérenguer C, & Labib A. (2016). **Risk Evaluation of Railway Rolling Stock Failures Using FMECA Technique: A Case Study of Passenger Door System.** Urban Rail Transit **December 2016, Volume 2,** Issue 3**, pp 128–145**

F. Dinmohammadi, B. Alkali, M. Shafiee, C. Bérenguer, A. Labib, (2016). **"Failure Mode, Effects and Criticality Analysis of Railway Rolling Stock Assets", in J. Pombo, (Editor), "Proceedings of the Third International Conference on Railway Technology: Research, Development and Maintenance", Civil-Comp Press, Stirlingshire, UK, Paper 256, 2016. doi:10.4203/ccp.110.256**

B.M. Alkali, V. Orsi, (2016) **"Diesel Multiple Unit Trains Wheel Set Maintenance Modelling, Simulation and Optimisation", in J. Pombo, (Editor), "Proceedings of the Third International Conference on Railway Technology: Research, Development and Maintenance", Civil-Comp Press, Stirlingshire, UK, Paper 284, 2016. doi:10.4203/ccp.110.284**

B.M. Alkali, V. Orsi, A. Ramani, (2016). **"Rolling Stock Door System Reliability Improvement using Maintenance Optimisation", in J. Pombo, (Editor), "Proceedings of the Third International Conference on Railway Technology: Research, Development and Maintenance", Civil-Comp Press, Stirlingshire, UK, Paper 281, 2016. doi:10.4203/ccp.110.281.**