9 On-Depot Fault Finding

Good fault finders are drawn to problems. They work with limited or imperfect data to identify symptoms and rectify the faults promptly. They are often compelled to engineer a permanent solution when the all the symptoms have been considered and the root cause has been properly identified.

This section explores good practice for **on-depot** fault finding. This section does not cover faults in service but *Section 11 – Managing the Impact of Fleet Incidents on the Railway* does. Some of the main issues with fault finding is the different ages of rolling stock and variance in reporting and recording faults across depots.

This section covers complex No Fault Found (NFF) and systemic faults that often materialise as repeat defects. To help with the diagnosis and rectification of these faults this section contains information on specifications, functional specifications and wiring diagrams. This section also explores root cause analysis and the development of a permanent solution to the fault which may be:

1. Modifications to the train design
2. Additional training and development of staff
3. Addressing supply chain quality issues

Topics covered in this section are as follows:

Other sections of the 20PP related to on-depot fault finding are:

- *Section 7 – The Depot*, which includes details on the human resources aspect of depots.
- *Section 8 – The Vehicles*, which describes good practice in data collection and analysis, repeat defects and trends.

9.1 **Standardising fault finding**

One of the most effective ways to defining a process is by a continual improvement loop. Jumping to conclusions when fault finding often leads to an incorrect diagnosis and repeat faults occurring. For example, if a driver reports that they can't get the train to move then a hastily made assumption that there is a fault with the traction could be wrong; there could be any number of reasons such as a fault with the door interlocking system.

The flow chart below shows the general, 5 high level steps needed when fault finding. The flow chart is based on two principles: DMAIC and OODA. The OODA loop (Observe, Orientate, Decide, Act) is a continuous cycle used when the correct solution to a problem needs to be found fast with several iterations and so is useful for depot maintenance. DMAIC (Define, Measure, Analyse, Improve, Control) is part of the 6 Sigma process and is more useful when time isn't a constraining factor. By combing both these principles, the flow chart gives guidance on how to arrive at the root cause of the problem in a short period whilst also creating learning points for future processes.

Step 1: Identify the features and conditions of the fault

a) At this stage, asking the right initial questions is vital to speeding up the fault-finding process. Whoever is creating the work order must give and receive the correct information.
b) What are the **symptoms**? At this stage the fault finder is looking for specific features and conditions of the fault. Collection and processing of information from sources such as OTDR, CCTV or driver's reports lead to a more accurate diagnosis of the fault.
c) At this stage fault finders are not trying to diagnose the fault. Broken components are not necessarily the root cause in themselves and may be a symptom of another fault in the system. A system based approach is best adopted whereby inputs, process and outputs are compared to specification of the component; there may be an issue between the train and the component.
d) It is important to carry out visual inspections as well as functional tests by making use of existing VMIs and VMPs.
e) Diagnosis may require working on live systems and so a safe working plan should be created to manage the risks. Safe working practises are covered in the VMI/VMPs in the initial sections covering safety conditions

Example: The quality of information from driver's reports, especially when the unit has limited telemetry, can greatly assist the collation of information on symptoms. GWR issue drivers with 'prompt cards' to use if a HST set fails in service that assists them in getting the unit moving. When the unit gets to the depot, the driver can report that they have completed certain tests to help eliminate some potential faults. The prompt cards are complimented by a guide for maintenance controllers which ensure that the right cards are used and the process followed by the driver can be verified.

Step 2: Check the vehicle history and documentation

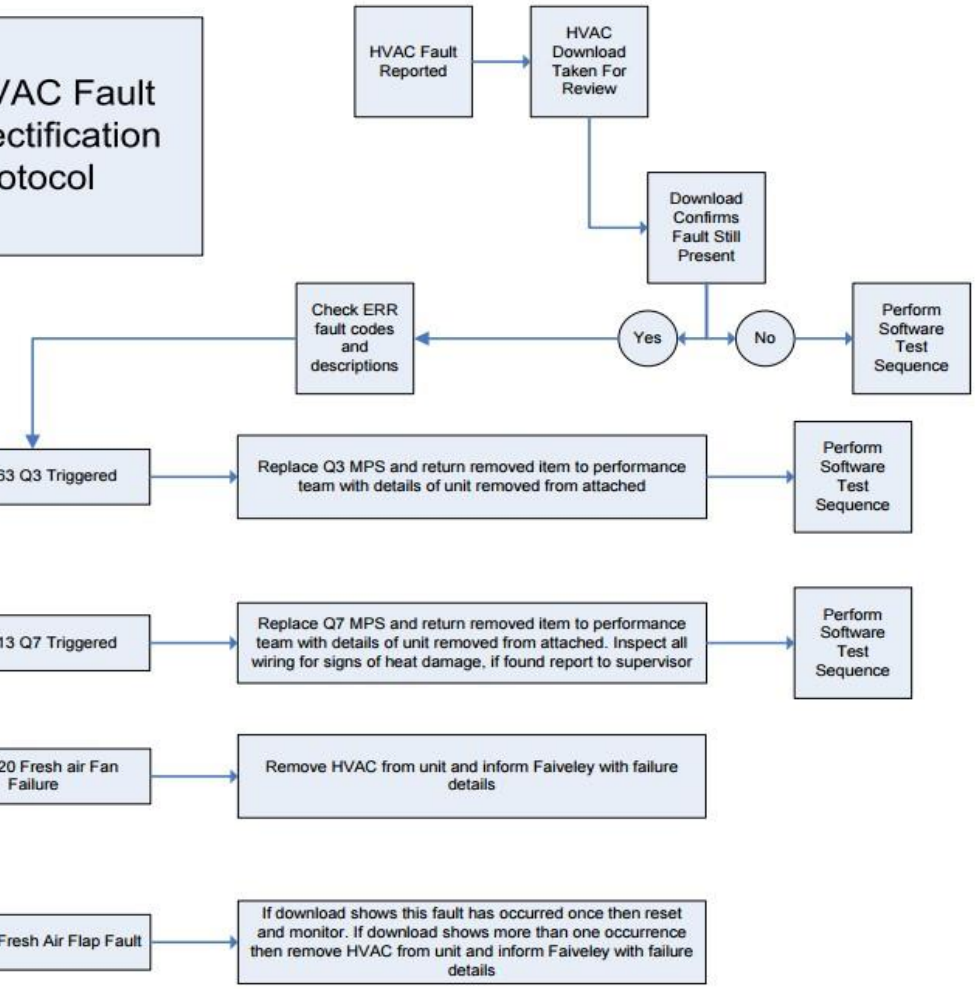
a) Using the vehicle history faults can be identified as intermittent, repeat or hard; this will determine how to proceed and whether the fault is active.
b) When dealing with a repeat faults any previous work carried out should be reviewed to avoid repeating procedures. This relies heavily on the reporting process, which is covered in a later step. For intermittent faults, the process followed should be accurately logged so that it can be referenced if the fault occurs again and save time by not repeating fault finding work that has already been completed.
c) Historical data of the fault should be reviewed as well as the vehicle history. This includes change control, modification levels, drawings, etc. It would also be good to review the Failure Mode and Effect Analysis (FMEA) for the vehicle.
d) As a minimum, fault finders need wiring diagrams, all system schematic diagrams, functional specifications and interface specifications for the systems they are working on. Some operators have fault finding procedures within the VMI.

e) Use industry groups, such as fleet comparison user groups, to compare fleet issues. However, information obtained from these sources should be treated with caution and should not replace any existing industry processes (such as raising an NIR).

Step 3: Make an informed hypothesis as to what the fault is, create a work order and repair the fault

a) By now the fault finder should have a starting point for further investigation. They should broadly know the scale of investigation for maintenance planning and the resource requirements. The key now is to work in a systematic way and record all relevant information as they proceed towards the root cause.
b) When testing the failed component, the VMI and fault finding guides should be followed; experience can sometimes be a hindrance. The root cause can be overlooked if fault finders are too hasty in diagnosing the fault without considering the symptoms especially where line replaceable units are suspected.
c) There should be a feedback loop in place for situations when drawings don't match what is in the vehicle. Any modifications or changes must be approved by all relevant parties (such as maintainer, owner, and operator), recorded and added to keep drawings up to date.
d) It's vital that the fault can be simulated and recreated to confirm the diagnosis. It's worth noting this may require the development of special test equipment which is discussed later in this section.
e) If the fault cannot be found, consider using the warranty team and the supply chain to get a subject matter expert opinion; whichever party overhauled the system should be consulted at the first instance where possible.
f) By now the fault finder should have identified the nature and cause of a certain fault. Once the failure mode is known a plan can be created to decommission the train, make a repair and then recommission it.

Example: Below is an example of a fault finding procedure used by Angel Trains when the HVAC equipment fails. Following a flowchart such as the one below ensures that all the correct procedure is followed and fault finders don't jump to conclusions, ensuring the root cause is identified.



This flow tree is intended to cover the most common faults and actions required for them. Any other faults and fault codes found during fault diagnosis require investigation as per instruction given by Faiveley in accordance with training course.

Step 4: Testing and Reporting

a) The repair needs to be tested thoroughly to ensure it has been rectified but also that other new fault modes have not been introduced as part of the investigation.

b) A functional test should be carried out to confirm that the system is now functioning correctly in accordance with the VMI as this is the certified maintenance plan supporting the safety case.

c) Where a component is continually showing NFF use asset tagging to find rogue offenders. Components can be tracked several ways, including asset tags, bar codes and recording the component serial number. Monitoring equipment such as data loggers or temperature indicator strips can also be used for monitoring specific equipment.

d) Reports should as a minimum replicate each phase of this process and the key findings.

i. Test data and parameters should be included in electronic format for further analysis. Scanned copies of written reports are acceptable providing they are filed correctly.

ii. Where fault finding has been limited by testing equipment then a process to allow recommendations on how to improve test equipment should be made. iii. The report should focus not only on the technical aspects of the job but also softer elements such as team work and listening to feedback from operations.

Example: Lockheed Martin have developed their own test rig, the LM-STAR. The test rig is adaptable and can easily integrate new testing capabilities as they come to the market. The benefit of the LM-STAR is that all components from the supply chain are tested on the same rig, so if there are any quality issues Lockheed Martin can address them and won't accept an NFF.

Example: London Midland use the computer based system Equinox to report and record faults. Technicians populate the system with their repair notes and all defects are coded and grouped so they are easier to spot for future reference. The repeat defects are then monitored using screens connected to the network; these screens display data from the last 28 days in places critical to the business. This means that all the data is readily available to technicians. In order to make this effective, technicians should be given guidance on the level of detail needed in the system. The MMS needs to be managed to ensure the information is captured and the work report cannot be closed without sufficient information.

Example: Alstom have a test rig set up (shown below) that can simulate a train being in service in order to test the traffic management systems. The use of this simulator means that the root cause can be identified through trial and error without the unit failing in service. The test rig has tested over 500 TMS components and over 350 CCTV components of which only 24% and 35% respectively were assessed as NFF. All of these items were returned to stores for train use and no repair costs were incurred.

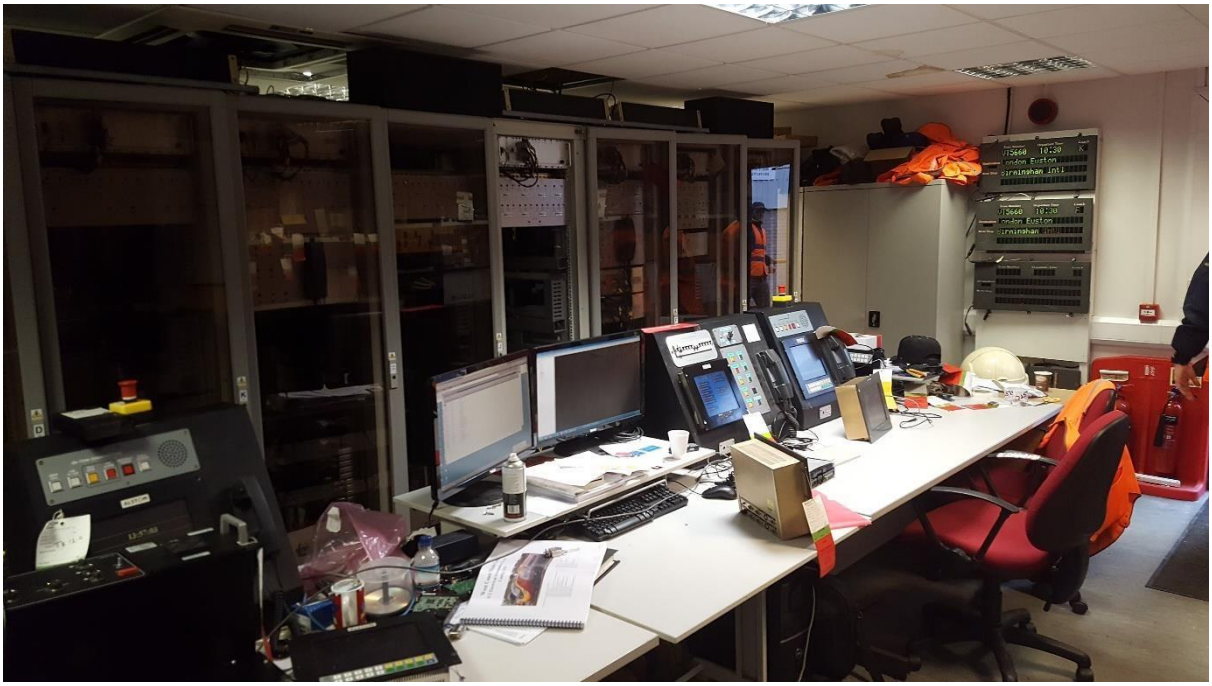


Figure 1: Alstom's TMS simulator at Oxley Depot

Example: GWR carry out in-house overhaul and repair on certain components (for example, load regulator electronic modules). All work, including defects, is recorded in a database maintained by the ride inspector team. This enables repeat defects to be highlighted and monitored for trends. The Electrical Test Room (ETR) at GWR also has a test rig that allows prolonged testing of any effected modules which can be used to find intermittent faults that may not be obvious under normal testing conditions. The test rig also allows for live testing of high voltage electrical equipment under controlled conditions away from the vehicle allowing the vehicle to stay in service while defective components can be fault found.

Step 5: Review, rectifications and training

Step 5: Review, rectifications and training

a) Fault finders need to own the problem and commit to finding a permanent solution.
b) VMIs and fault finding guides should be regularly updated and reviewed in hindsight of work carried out, especially where the fault could have been identified as part of routine maintenance.

c) The vehicles FMEA may also need updating to include any new failure modes identified as part of fault finding.
d) Return of experience - any lessons learned in the process should be recorded and added to future training regimes.
e) Training and competence needs to be assessed to ensure that lessons have been learnt.
f) Information on any of the above changes needs to be briefed to all relevant personnel, including fleet operations as maintenance may have affected the way guards and drivers interface with the equipment. There may be an issue with the way the defective equipment is being operated that has potential to become a training issue for the whole industry.
g) The use of public advertisement, such as the stickers that are used on Virgin Trains West Coast's toilets, can help to reduce the likelihood of a fault from the public
h) Skills availability across teams and shifts needs to be balanced to ensure there are always adequately skilled staff for fault finding work. A skills matrix to manage skill shortages/deficiencies across shifts is one way of managing skill availability.
i) Fault finders should consider if a technical enquiry is appropriate to address the problem and ensure that any modifications to a unit or fleet are recorded for future reference. Fault finders cannot make any modifications without the correct Engineering Change approval.

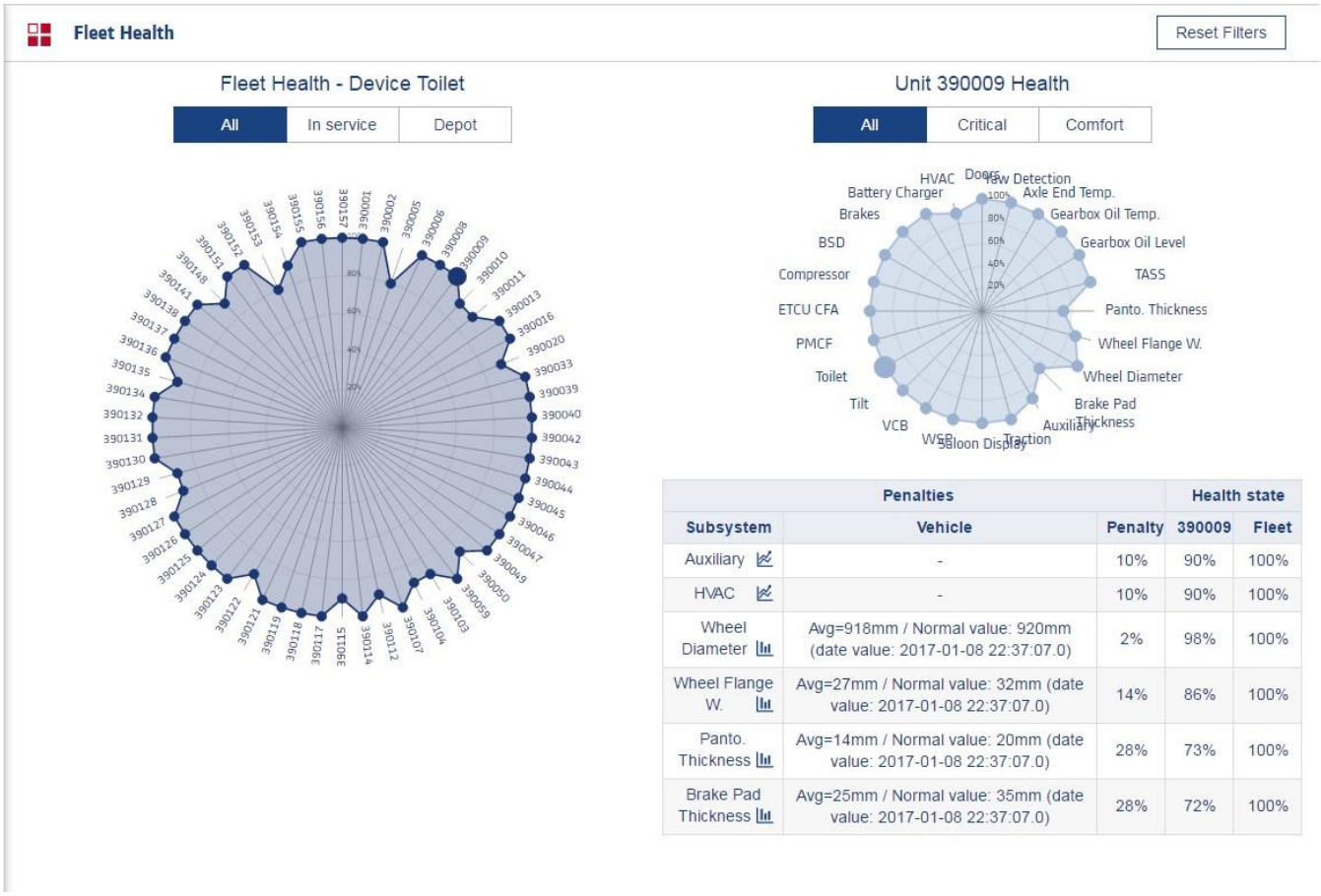
Example: Alstom use a Root Cause Analysis (RCA) as part of their review process. If a unit fails in service and the fault is a suspected repeat failure, or found to be due to previous incorrect intervention actions, an RCA should be raised against the relevant department or site. This is so the business can understand the root cause and put in place preventative actions so that the events of the repeat failure do not occur again.

After the RCA has been completed and the root cause found the report is added to a tracker which is distributed to Head of Operations and the Fleet Engineer.

9.2 **Novel testing and inspection equipment**

As a minimum to support a systematic based approach to fault finding fault finders need equipment to break into all the trains wiring to test for inputs and outputs and monitor functions. Train wiring schematics/diagrams can help a fault finder locate a feed from the relay panel but actual test looms may require fabrication to 'break' into train wiring. Where PLCs and control units are used specialist diagnostic equipment will be required to test processes and fault finders may need specific IT training to support these specialist diagnostic tools.

Example: Alstom use a Health Hub scanner in conjunction with a Fleet Health application to monitor fleet performance. After the unit has passed through the scanner information on wheels profiles, brake pads, pantographs and component position is collated into the health checker (as seen in Figure X). This allows them to monitor defects and build an accurate data base of faults and where they occur on the network. The monitoring software also allows TMS events to be recorded in real time.



Penalties			Health state	
Subsystem	Vehicle	Penalty	390009	Fleet
Auxiliary	-	10%	90%	100%
HVAC	-	10%	90%	100%
Wheel Diameter	Avg=918mm / Normal value: 920mm (date value: 2017-01-08 22:37:07.0)	2%	98%	100%
Wheel Flange W.	Avg=27mm / Normal value: 32mm (date value: 2017-01-08 22:37:07.0)	14%	86%	100%
Panto. Thickness	Avg=14mm / Normal value: 20mm (date value: 2017-01-08 22:37:07.0)	28%	73%	100%
Brake Pad Thickness	Avg=25mm / Normal value: 35mm (date value: 2017-01-08 22:37:07.0)	28%	72%	100%

Figure X: Alstom Train Management tool

9.3 **Developing the establishment of fault finding within your organisation**

9.3.1 **Establishment of Fault Finders**

When beginning to establish fault finders the following should be considered:

a) What are the volume, nature and type of faults experienced?
b) What type of fault finders are required; fleet or systems?
c) How many fleets or systems will each fault finder be accountable for?
d) How long is it expected to rectify a fault?
e) Have training courses/days been planned for and is there adequate cover for these periods?

By considering these points, depots can properly plan how many fault finders they are looking to recruit or development from existing maintenance technicians. Once that has been decided, technicians need to be incentivised to become fault finders. There needs to be enticements such as career progression, increased responsibility and rewards.

Once the potential fault finders are identified (desirable skill sets are detailed later in this section) then a clear training and development programme needs to be set out that progresses their skills and

allows them to understand the role properly. Succession planning is a vital element of this so that there is continuous flow of experienced fault finders available for new talented fault finders to work alongside and eventually succeed. The new apprentice levy is an excellent opportunity.

9.3.2 **Features of a Fault Finder – Soft Skills**

Soft skills are important as often fault finders must work as part of or support a maintenance team and be able to clearly explain faults to their peers to rectify it. Fault finders also need to explain the fault to non-technical staff in a way they will be able to understand. They need to be confident in their competence so they are also able to challenge design elements of the system they are fault finding; evidencing facts using data is a good technique. There may also be a need to converse with the supply chain if there is a NFF component that needs further analysis.

They also need an inquisitive nature. Fault finders should be able to self-reflect on their performance and can identify their own strengths and weaknesses. A fault finder should be disciplined, organised and methodical with the ability to confidently express their ideas on a problem. Fault finders should be able to apply a methodical approach to a problem and take accurate notes through out.

For more information, see Section 7.1 – Human Resources (skills).

Examples: Southern use a core group of people to do fault finding, 'team technicians' who support each maintenance team.

9.3.3 **Features of a Fault Finder – Technical Skills**

Fault finders should aspire to always complete a task to the highest standard using their analytical skills to get to the root cause, and not just go through the motions of a VMI; their ability to see the bigger picture and understand the consequence of a poor or late job should motivate them. Another motivation for fault finders should be their ability and desire to learn skills and progress in their career. Fault finders need experience with complex systems engineering; commissioning experience is a good background. A good basic knowledge of how electricity works and how mechanical systems work combined with a basic knowledge of computing is essential as core skills. Along with knowledge of train systems fault finders should have some operational knowledge so they can judge the standard of an acceptable train in service and understand the reason for their work. Naturally fault finders will eventually start to become more specialised in a certain area due to over exposure to a specific system. When this becomes the case, it is important that they:

a) Can pass their knowledge onto other people using their strong communication skills.
b) Still retain their knowledge of the entire train; due to staffing numbers and the depot they may be required to work on any part of the train. Knowledge is best retained through recording work done and running refresher courses on the different sub systems on board.
c) Consider how the work they are doing can be broken down into chunks (train/subsystem for fleet/systems engineers).

With the retirement of a lot of legacy rolling stock and the introduction of new trains there is an increasing need for fault finders to have a solid understanding of IT and software information for

trains with advanced telemetry. It is increasingly vital for fault finders to be able to support and maintain their own diagnostic equipment as IT departments do not have the skillset to do so.

9.3.4 **Training and Development**

Once fault finders have been selected their skills need to be developed. They need to use a systems approach of inputs and outputs to confirm or demonstrate a repeatable fault in one or more parts of the subsystem.

Depots should make use of all available training methods such as simulators like Alstom's TMS test rig, and Interactive Virtual Training such as 5lamps (shown below). Using different mediums of training allows for subject specific training that still allows fault finders to appreciate the whole system. As an extra incentive for training and development, some depots offer technicians the opportunity to get recognised qualifications in engineering and maintenance. These training courses increase the depth of knowledge as well as recognising the level of skill that fault finders have achieved.

Example: GWR have an in-house testing facility for central door locking equipment, electrical converters, HVAC and some catering equipment. As well as providing a controlled test environment for fault finding, these facilities also provide an ideal training facility for new starters and apprentices as well as enhancing fault finding skills for depot staff.

Example: Alstom provide their technicians with a Level 3 training programme for Trains Systems (Traction, AWS, HVAC etc.). The training programme is based around PowerPoint presentations and is supported by a question paper. Technicians have to successfully complete the question paper prior to commencing the competence assessment process.

Figure 2: 5lamps software simulation

The above simulation was made for East Midlands Trains. The short video shows the location of the onboard fire extinguishers, the different types of extinguishers on board and when to use them. This video is used by train drivers and on-board staff for training. Using simulations is a powerful tool as components can be disassembled and analysed quicker in a virtual environment than in real life. There are simulations for different operators, Network Rail and other industries available at: http://www.5lamps.com/

Training doesn't have to only be delivered on depot. Groups such as:

a) OEMs
b) Supply Chain
c) Over haulers
d) Consultancies
e) Rail Research UK Association

can be used for subject matter expert training and collaboration on research projects to increase fault finders depth of understanding. There may be issues with companies not wanting to disclose commercially sensitive information so compromise may be necessary.

The use of bespoke testing equipment for verifying a NFF diagnosis (as mentioned earlier in this section) can also benefit training as well as lowering the cost of sending components back to the supplier for fault diagnosing.

Finally, a feedback loop with periodical reviews is needed to assess the quality of training. Fault finders should be encouraged to be honest with their reviews and all feedback should be taken in consideration when reviewing the training material and programme. The information gathered needs to be shared with the appropriate people so that change can happen if needed to ensure that fault finders are receiving the best level of training possible.