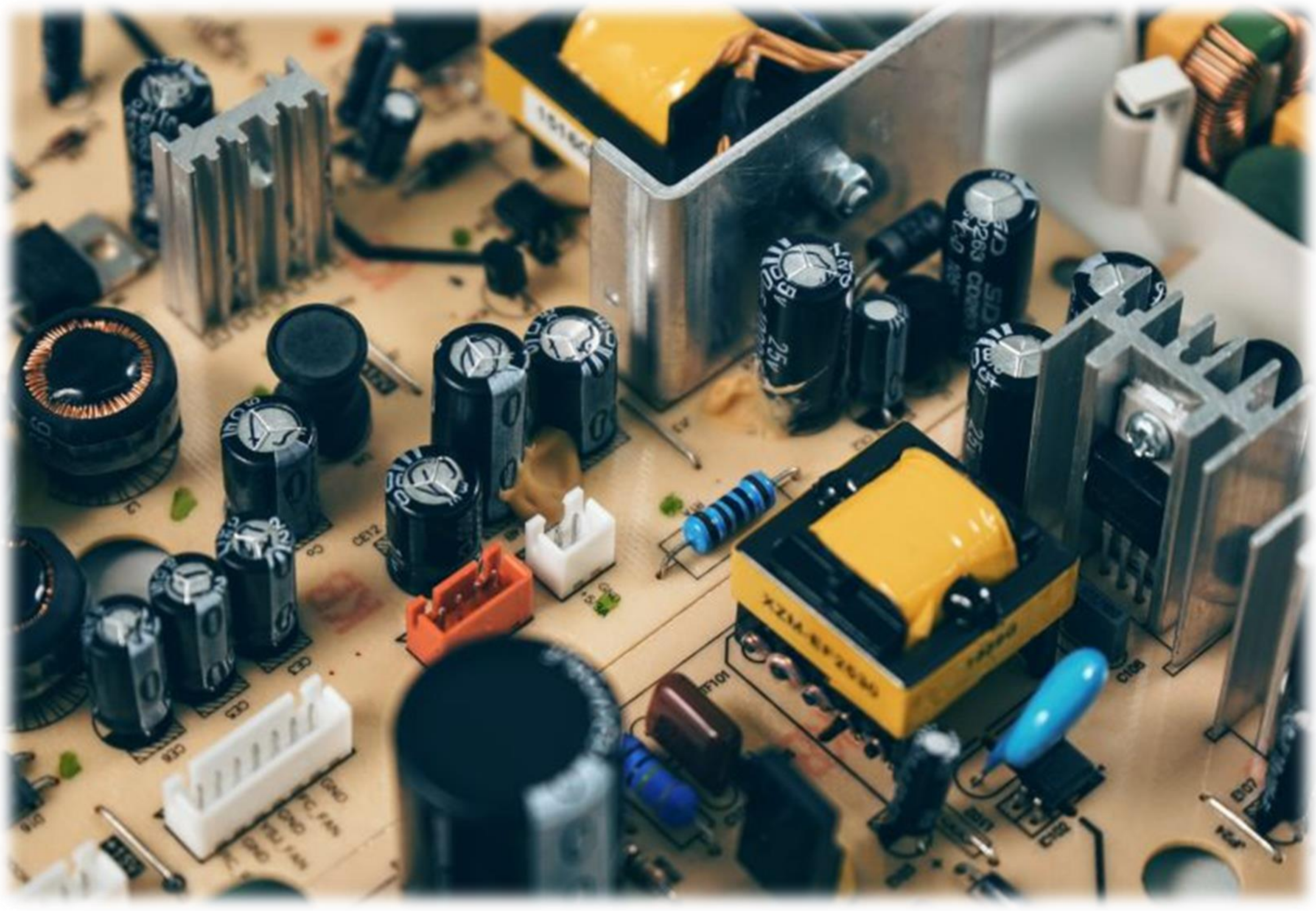
11. Electrical & Electronic Overhaul



This section covers the key areas to consider regarding electrical & electronic overhaul: Planning, Sharing information and Technical investigation.

11 Electrical & Electronic Overhaul

11.1 Summary

This section was developed jointly by ReFocus members and SET Ltd. It covers the following key areas to consider regarding electrical & electronic overhaul:

- **Contracts:** Consider and establish a with well-defined interfaces and expertise requirements. Set a performance benchmark to monitor electrical component reliability for a better improvement plan against cost. Ensure rigorous testing to replicate real operating conditions for new, modified or repaired electrical components.
- **Supply Chains:** Share emerging obsolescence and reliability issues promptly through User groups (and ReFocus) to streamline and share solutions development and prevent float crises and minimise reliability hits. Consider embedding personnel/ swapping roles to enhance understanding of different priorities. Capture evidence through component logs, in-service videos to share insights with the supplier.
- **Frontline Maintenance:** Level Checks can be an effective way to maintain process control and gather data to enable fault resolution when root cause isn’t immediately obvious.
- **Technical Investigations:** Using Investigative Remote Condition Monitoring (IRCM) where faults are intermittent so as to link symptoms to root cause(s). Use Predictive Maintenance tools (RCM) to identify future emerging issues earlier & consider requirements for fleet mods.

The guidelines in this section are intended to promote a structured approach to electrical and electronic systems overhaul. The document is categories into four subsections to make good practice easy to adopt according to individual business needs:

1. *Planning and specifying contracts and scope of overhauls*
2. *Sharing information along repair/ overhaul/ mod supply chains*
3. *Systematic identification of root cause – frontline maintenance*
4. *Systematic identification of root cause – technical investigation*

11.2 Planning and Specifying Contracts and Scope of Overhauls

Overhauls for electrical and electronic equipment are notoriously difficult to specify at the new train build stage and may not be structured to incorporate learning from experience in service. Generic overhauls may be embedded within Train Services & Spares Supply Agreements (TSSSA), or a blanket “fit and forget” approach may have been applied. Fit and forget may become “change on failure” and could suit relatively cheap and easy-to-change equipment which has relatively low safety and reliability impact.

However, it is worth investing the effort in planning and specifying overhauls for mission-critical systems, especially when there is a significant increase in No Fault Found (NFF) defects, changes in related systems performance due to train utilisation (mileage run, stopping frequency).

Best Practice Principles for Contracts

When and where possible during overhaul contract select an overhauler with sufficient real expertise and interest in the particular equipment and/ or underlying technology. Be aware that some OEMs are focused on new build, not overhaul: whatever Key Performance Indicators are contractualised, sometimes overhaulers choose to take the financial penalty, rather than create the performance improvement.

Alternatively, many electronics repair companies in the UK are not necessarily focused on railways, but have been found to provide real, relevant expertise and deliver solutions to previously “insoluble” rail vehicle component problems.

Checklist for specifying electrical/ electronic overhauls/ repairs/ modifications

Most of the issues to consider are relevant to all component overhaul contracts, but electrical/ electronic ones should particularly emphasise:

Get an accurate enough picture to optimise the overhaul scope:

- Understand the in-service duty cycle: what is actually experienced by the component (which may differ from the original specification it was designed to meet)
- Examine the rate of components failure: collect all available data
- Understand any previous repairs done: it can be difficult to capture information on what repairers do (the repair/ overhaul)
- Understand failures: systematically capture relevant data and home in on actual defects
- Really understand failures: particularly interactions e.g. software change consequences, transients impacting different components and

Make a good enough plan to efficiently deliver an overhaul that lasts:

- Consider the spares float e.g. sufficient to support overhaul/ future needs or requires injection/ reverse engineering?
- Assess obsolescence threats e.g. critical sub-component risk review
- Future-proofing e.g. opportunities to increase redundancy, improve fault handling analytics?

11.2.1 **Case Studies**

As ever in the 20PP, there is no magic bullet, but different solutions can be made to work in different circumstances, by contracting with experts either OEMs/ large corporations who design and build rolling stock fleets or small companies which have railway-compliant workshops.

11.2.2 **Eversholt and Southeastern Class 465 Traction Equipment Replacement Project**

To improve overall reliability of the fleet Hitachi was contracted to develop the new traction equipment as well as complete the running maintenance and heavy overhaul of the equipment. To encourage collaborative work across all parties Hitachi staff were allowed on Southeastern Slade Green depot and had access to SE technical staff if required.

The Outcome:

“The Class 465 Traction project was very successful given that only two equipment failures had been reported since its fitment almost 10 years ago.

<u>Good Practice:</u>

- Clear contractual process for tracking failures and allocating root cause
- Clear understanding of interaction with other systems – what actually happens on the train (beware unintended software consequences, being the root cause of failures elsewhere)
- Achievable performance criteria (mindful of the risk of mis-specifying interfaces and interactions, knowing that the TOC inevitably bears a higher risk of non-performance overall)
- Collaboration

<u>Recommendation</u>:

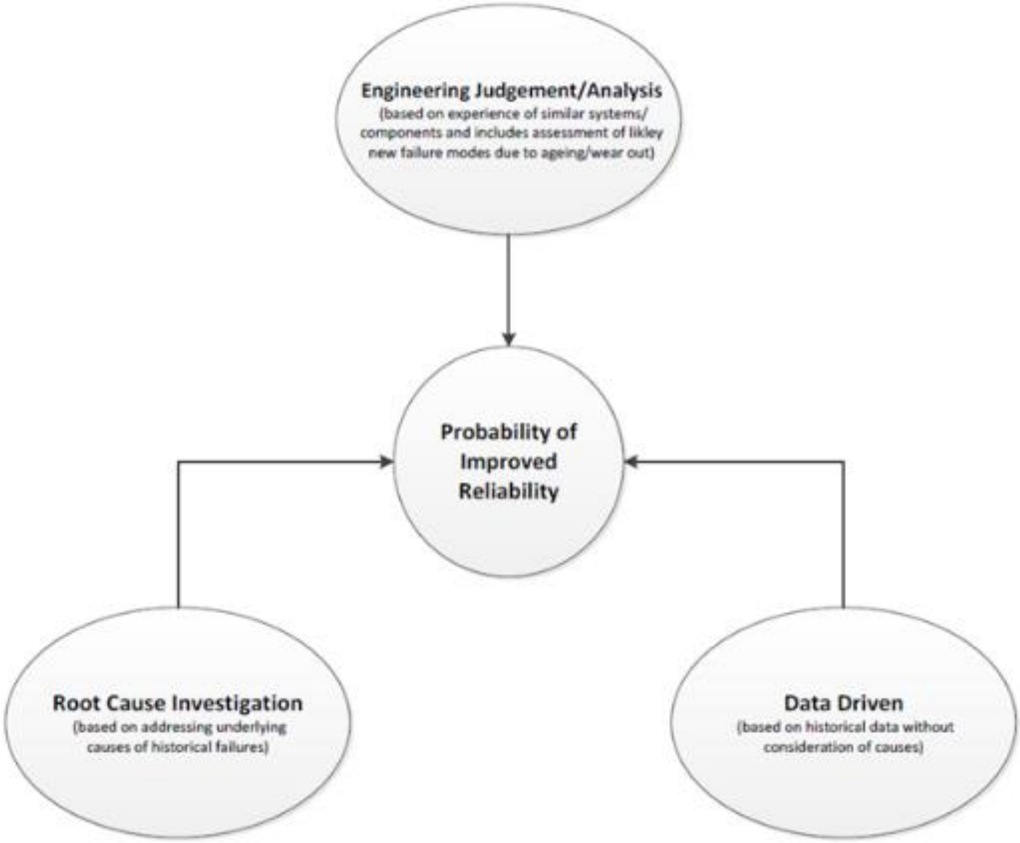
Where there is enough physical space in the relevant maintenance depot to accommodate OEM staff, and where the TOC (or whoever is maintaining the train) is able to provide technical support staff should be encouraged.

11.2.3 **VTEC Frequency Division Multiplexer Reliability Improvement**

VTEC contracted SET Ltd to address increasingly poor reliability (estimated 70 failures per annum from 300 units) of ageing Frequency Division Multiplexer (FDM) Racks across the Class 91 and Mk4 fleet, resulting in service delays. No overhaul had been scheduled from new, so an investigation was required to scope the overhaul needed to improve reliability (and to create from scratch a float stock of 20 reverse-engineered units to support the overhaul programme).

The Process:

Overhaul Scope definition: This required an initial investigation to identify actions with the highest probability of improving reliability, by combining 3 information sources:



Engineering Judgement Findings:

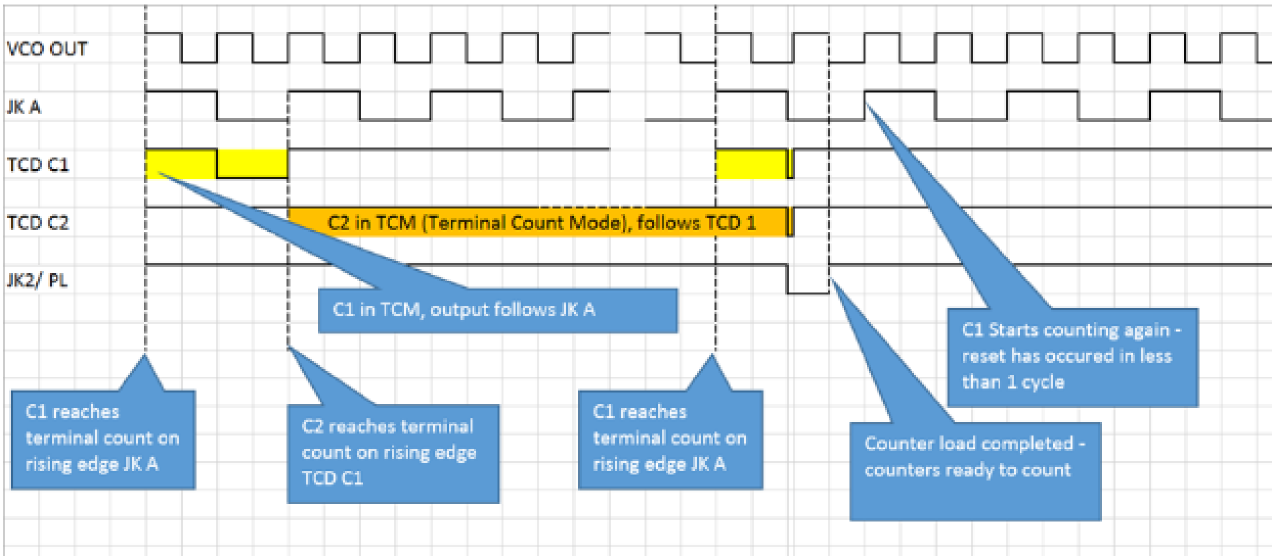
- Many ICs (should last 40 years, if operated within specified conditions)
- Electrolytic capacitors (that usually degrade within 10-20 years)
- Many electro-mechanical relays (wear with switching operations)
- Several heavily reworked PCBs (increased risk of failure from soldering)

Data Analysis Findings:

- relatively high number of failures on a few units, implying that root cause is not understood and therefore not addressed in the repair;
- more IC failures than expected, otherwise relay failures consistent with engineering judgement

Root Cause Investigation Findings:

- contrary to expectations, high IC failure rates were *not* found to be caused by transient overvoltage on the equipment supply. However, thermal trials led to the discovery of timing issues consistent with some of the symptoms reported when ICs were being replaced, see timing diagram for FDM PLL transmitter section:



A set of costed options and the likely impact of each was produced. The selected 'gold' option included:

- Replacing all transmitter cards (to address the timing issue impacting the ICs and heavy PCB rework issues found in the investigation)
- Replacing all receiver cards (to address the drift issues found)
- Replacing all electromechanical relays (based on wear-out predictions and historical failures)
- Replacing all aluminium electrolytic capacitors (based on evolving ageing issues)
- Replacing rear covers (to improve robustness and address reported damage)
- Replacing weak plastic front plates with metal ones (to address a common issue of plates and connector mountings breaking)
- Adding an earth stud (to address the issue of damaged handles)
- Cleaning all parts and recalibrating all filters
- Where possible, replacing through-hole components with surface-mounts, since they are generally cheaper, quicker to assemble, enable full automation of PCB assembly (hence more accurate PCBs), perform better under tough vibration, thermal and EMC environments

Overhaul Process: included significant enabling work to reverse-engineer, design and manufacture a complete spares float of 20 units - and to create automatic test equipment. These were in addition to undertaking the overhaul itself, which included:

- Inbound inspection, to ensure that there were no functional faults prior to overhaul
- Purchasing enough parts to cover items not routinely included in the overhaul – including full sets of electronic cards (using the float stock injection design), cases, handles etc

<u>The Outcome:</u>
Overhauled units have now been in service since the beginning of 2017, with the last units installed November 2017.

- Analysis of the few units returned shows drift to be negligible so the modification appears to be effective.
- No problems with spurious transmissions caused by PLL instability. This was previously a problem that could result in multiple IC replacement (12% of repairs).
- Returns data following the full installation showed an 85% reduction in failure rate.

Recommendation:

When a key electronic/ electrical component is hitting your reliability bottom line, it is worth:

- Thoroughly investigating (with expert engineering judgement, data analysis and root cause hypothesis-testing) to scope any overhaul, trading likely reliability improvement against cost
- Consciously choosing between new design and overhaul (different risks)
- Replicating the original function and redundancy/ supervisory protection in any new design, to retain the main elements of the original safety case as a Direct Replacement Component (hence minimising project complexity, cost and timescale)
- Capturing the EMC performance of the original unit (where relevant), before starting any design work – and agreeing all standards, approvals, certification up front, so they're built-in to the process

11.2.4 **Southern Mk1 WSP Racks Reliability Improvement**

The reliability their WSP Racks post Overhaul was poor due to poor quality and service from the repairer.

The Process:
Southern engaged with a new repairer (Servotech) who specialised in electronic obsolescence. They now overhaul all Southern's Mark 1 and Mark 2-1 converted WSP racks. Every repair includes a complete overhaul, irrespective of why the rack was returned.

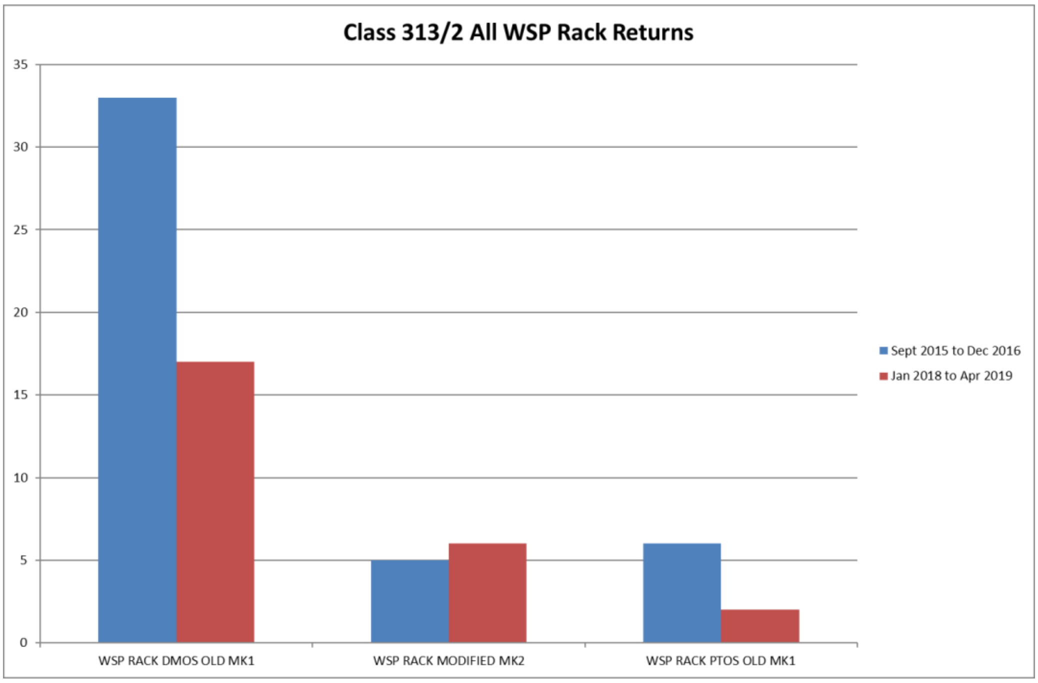
The Outcome:

The cost of each overhauled rack has increased, but the reliability has more than doubled (and availability is improving too), so Southern considers the extra cost is worth paying. This graph compares 2016 returns from OEM repairer, with 2018-9 from the new repairer:

Recommendation A3:

In order to deliver the reliability needed from key systems, it can be worth:

- investing the effort to bring a new repairer into the market; and
- increasing the scope of repair to include a more comprehensive overhaul



11.3 **Sharing information along repair/ overhaul/ mod supply chains**

<u>Sharing Information Through User Groups</u>
Cost-effective approaches to share data, investigative effort and results are worthwhile at many levels, engaging relevant people effectively. Firstly, agglomerating from individual experience of separate sub-fleets, User Groups focus on particular fleets/ vehicle types and share common reliability challenges and solutions. They typically involve train maintainers, owners, overhaulers, but rarely component repairers/ overhaulers.

For example, despite the huge delay minutes caused by the magamps an obsolete magnetic amplifier component on the Alternator Voltage Regulator (AVR). Magamps cause unreliable start-up of the Class 15x charging system, which leads to a wide variety of symptoms in service. Through information sharing at the Class 15x User group meeting, the TOCs/ Roscos were able to understand the root cause and the alternative technical solutions; SET was able to understand their commercial constraints (e.g. longevity of the fleets, current maintenance budgets); and so, the preferred technical solution was identified, along with next steps to implementation.

<u>Recommendation:</u>

Each User group should actively seek early dialogue directly between TOCs, Roscos and repairers around reliability and obsolescence issues, so that problems can be resolved significantly more quickly, improving fleet reliability and assuring the availability of parts.

Bombardier provides an example of open collaboration in the Aventra operated by MTR Crossrail, addressing problems with passenger door and battery performance. They changed the perception from "airing your dirty washing in public", to encourage all parties to own the problem and seek a solution, acknowledging that the commercial challenges that arise would probably have emerged eventually anyway. This spirit of awareness and tolerance "seeing from the eyes of the operator" (and passengers!) helps to foster long-term relationships for more reliable performance.

Checklist for Transparent Supply Chain Mechanisms

Long term, collaborative relationships are key to transparency, with achievable contracts that incentivise all parties to deliver a common performance improvement goal. Benefit-sharing contract mechanisms that can help create a "one team" approach along the supply chain include:

- Profit securement schemes e.g. "cost plus" – if the customer respects the supplier's need for margin, they can work together to improve the product (which improves the customer's bottom line);
- Targeted pricing e.g. "baseline and vary" – derive an average price from best historical knowledge to set the "baseline", then include a risk/ benefits sharing scheme, to incentivise reliability improvement work by paying the supplier for the contribution they make to the customer's better performance
- Incentivising Key Performance Indicators e.g. MTIN – pay a bonus for KPIs delivered, relying on aligned business models.

Historically, success has been limited by KPIs that are disconnected from suppliers' actions (or that cap out at a pre-determined level), discouraging suppliers from investing effort (or more effort). Worse still, mis-specified KPIs may encourage suppliers to simply price-in the financial penalty without improving what they share – or what they deliver.

11.3.1 **Case Studies**

11.3.2 **Unipart and Porterbrook Collaborative Support**

Relationships between Unipart and its customers and suppliers are strained and adversarial at times.

To improve the relationship with their customers and gain better understanding of impact of their activities on the customer.

Good Practice:

A dedicated Customer Liaison Manager is allocated to Porterbrook: she spends approximately 3 days a week at Porterbrook London and Derby offices and the remainder of her time at Unipart's T&RS Head Office in Doncaster. The dimensions of the job include:

- Optimise performance, supporting the customer with the resolution of issues / concerns and reporting of risks and opportunities with the objectives of delivering high levels of customer satisfaction.
- Support the development of new and existing product and service offerings though value-add initiatives with the customer. Working with all relevant areas of Unipart Rail's business to support the customer, resolve issues and convert opportunities.
- No staff responsibility – management by influence.

Porterbrook has found their embedded Unipart rep useful to resolve general issues affecting material supply. Noteworthy progress made in producing an Engineering Change process to support Unipart's Contract Variation requests.

Recommendation:

It can be worth dedicated human effort to aid information flows and understanding of different priorities, although this resource will only be justified where the volume of business is high enough. Short term strategic/ trainee placements/ job swaps may improve understanding and interworking more cost-effectively along supply chains.

11.3.3 **West Midland Train Class 170s Door Control Units Failure**

After door system components were overhauled at C6 in 2015, WMT door failure rates rose. A common symptom was external passenger doors not responding to local pushbuttons, despite controls being energised to permit door opening. Several DCUs were replaced and sent to the OEM for investigation, but most were returned with No Fault Found.

The Process:

Most failures were allocated fault codes by the self-diagnostic function on the DCUs. To supplement this information, the TOC made several videos capturing as many fault details as possible and sharing them with the OEM.

Joint investigations into root cause were made at the OEM's facilities in the UK and Austria. Relevant findings included:

- In 2015, Improved understanding of the process of testing - and why faults were not found on DCUs tested (because the OEM routinely wiped the DCU fault code data, prior to loading test software to allow all inputs and outputs to be tested – thereby destroying potentially useful information);
- However, the video evidence clarified that when the Open button was pressed, the DCU would not operate – the Door Open command was not generated.
- In 2016, a non-standard testing approach was adopted to simulate the situation on the videos, and the fault captured on video was successfully replicated, identifying a programming anomaly within the software.
- During 2017, improved software was developed by the component OEM, validated by the train builder and functionally tested.

The Outcome:

During 2018, component usage halved, indicating improved DCU reliability:

170 Door Control Units				
Year	2015	2016	2017	2018
Components used*	49	48	47	22

Recommendations:

Overhaulers should routinely review component fault logs, and the apparently widespread practice of wiping them should be ruled out contractually, especially for safety critical components and systems. Videos can be a great way of capturing additional evidence to enable resolution of “insoluble” problems, although in this case it took years.

11.4 Systematic Identification of Root Cause – Frontline Maintenance

The classic maintainer’s challenge of not being able to find fault with equipment that has apparently caused a failure in service becomes more difficult to address as the complexity of electronic systems increases.

The success probability of frontline maintainers promptly and cost-effectively diagnosing root causes is increased by identifying and capturing relevant information from operational circumstances and using it systematically.

Best Practice Principles

Many modern components and Train Management Systems log vast quantities of data which is worth extracting/ downloading at the time of any alleged incident or intermittent fault. Real time remote downloading is obviously ideal, but frontline maintainers with older and less sophisticated systems should have simple step-by-step guides to extract relevant data from units. Given a transparent and responsive supply chain, maintainers can then promptly exchange information with OEMs/ overhaulers and hopefully work together to determine and fix root cause.

Reactive maintenance approaches (to identify and correct faults) are most efficiently applied in a systematic way, with checks and downloading requirements and methods set out in Minimum Maintenance Instructions tailored to generic failures e.g. charging fault. Key to good practice is to have closed loop systems, so the instruction is promptly updated to incorporate learning from newly emerging fault scenarios and solutions.

Checklist

Reliability ‘Level Checks’ are a systematic process for addressing fault finding. They can ensure that repairs are dealt with in a controlled manner, by highlighting that repeat failures/ defects are occurring and working to minimise the likelihood of further repeats methodically. Level Checks aid fault-finding particularly after NFF. They engage subject matter expertise and use experience of common faults thoroughly; and escalate intervention on repeat defects by successively increasing the work done.

For example:

- Level 1 might involve downloading fault logs, reviewing data and testing key outputs in situ

- Level 2 might involve changing (or traceably swapping) a component that is known to be problematic (logically choosing first the component that is most likely, least expensive and easiest to change) and bench-testing (where facilities exist) or sending away for repair

- Level 3 might involve checking for findings on the component(s) changed/ swapped at Level 2; and then, if still NFF with the Level 2s, being sure to do something else, not more of the same e.g. changing other components – in other words, escalating the fault resolution effort applied. (technical investigation.)

11.4.1 **Case Studies: West Midland Train Systematic Approach to Fault Investigation:** Intermittent faults/ faults that cannot be replicated on depot. For example, a train fails with loss of interior lights and heating. It returns to depot for investigation, but on arrival the fault is no longer present, all systems are operating correctly.

The Process:
Level 1: Check is applied, and the train returned to service.
Level 2: If the same fault occurs, the unit returns to depot. If the fault still cannot be found or replicated, the history is checked to make sure that the Level 1 check was completed. Components are then likely to be changed or swapped at this stage, based on the experience/ expectation of different component failures.
Level 3: If the same fault occurs again, another lap round the procedure is likely to escalate the problem to joint investigation (see Case study 2.2).

	Operation	Comments	
	IF ANY FAULTS ARE FOUND, RECORD AND REPAIR BEFORE PROCEEDING TO THE NEXT STAGE.		
1	Read drivers books, record any relevant info in comments box.		
2	Start the engine and check back cupboard, look for any Generator Supply Faults or Hydro System Faults. Record any fault lights in comments box. Investigate and repair.		
3	Check all breakers, cab and cupboard, are in. Check CB-CV in underframe Auxiliary cupboard. Record whether this has tripped or not.		
4	With engine running, check the 3 LED's on the AVR. There should be a green LED. If any other colour is present, investigate and repair.		
5	If all of the above are correct, open the charger unit door (taking care of exposed capacitors) and check LED's inside. With the engine running, generally, all LED's should be green. Compare with other car if necessary.		
6	Change the AVR card and record serial numbers of the card removed and card fitted. (Usually a yellow barcode type label fitted to one of the heatsinks.)	Removed old serial number	Fitted new serial number
7	Record the date stamp on the meccalte chip. This consists of a week number and year, 46-11 for example	Removed old date stamp	Fitted new date stamp
8	Plug a laptop into the hydro box. Record any logged or current faults. Investigate and repair as necessary.		
9	Record the alternator frequency. Record the engine speed. Investigate and repair as necessary.	________Hz ________RPM	
9	Complete the following VMI job No's and record output voltage • 5.3.002 Battery electrolyte level check • 5.3.025 Battery Inspection and cell voltage check • 5.3.026 Battery charger output check	________V	
10	**Job complete. Ensure a copy of this check goes into the Fleet File for future reference.**		

The Outcome:

Although Level Checks impose a systematic discipline, they are a reactive measure and not an exact science, relying on continuous review and change as understanding of root cause(s) develops and ultimately to reflect component modifications and solutions. A key part of the approach is to require that the entire Level check is completed, even if a fault is identified at an early stage in the process – in order to gather the relevant information, ensuring that multiple faults are pinpointed, and every attempt is made not simply to manage symptoms which mask root cause.

Recommendation: Level Checks are worth considering as an effective mechanism to communicate emerging fault management information, and to maintain process control whilst at the same time gathering more data for eventual fault resolution

11.5 Systematic Identification of Root Cause – Technical Investigation

Industry-standard investigation techniques include the 8 disciplines of problem-solving which sets out a structured approach worth adopting:

1. Teamworking across all the companies involved, drawing in subject matter experts and reviewing all the data
2. Describing the problem (who, what, where, when, why, how, how many)
3. Decide a coping strategy (how to run a railway while we work out how to can fix it properly)
4. Really get to root causes
5. Develop and verify potential solutions
6. Decide which solution(s) to implement – corrective actions
7. Prevent future occurrences – modify maintenance checks, ops procedures, etc
8. Celebrate the team's success!

However, the Task & Finish Group drawing up this chapter struggled to find a succinct and complete 8D example to share, so we created an Ishikawa or fishbone diagram, which offers one of the best techniques to support teams exploring potential root causes (see p14 for Ishikawa example). Whatever technique is used, high-level engagement in a formal process can be key to ensure that the full implications (e.g. for similar equipment or processes) are understood across the business/ industry; that solutions are fully embedded; and that information is disseminated effectively.

Step 4 cannot always be rigorously applied, since 8D generally relies on the data we have already, including the teams' brains. But faults emerge that cannot be diagnosed (let alone fixed) by collecting and reviewing all known data within across-team expertise: more is needed. This increasingly applies to electronics and electrical systems interactions where intermittent and transient symptoms adversely affect performance in service but cannot be replicated in the maintenance environment.

Modern fleets often have comprehensive data logging equipment which collects the necessary data; but mid-life fleets generally do not and would benefit from selectively retrofitting Remote Condition Monitoring (RCM) to enable systematic identification (and resolution) of long-term root causes.

Best Practice Principles

Investigative RCM can be deployed when no clear picture has emerged from the structured frontline maintenance processes of Minimum Maintenance Instructions and Level Checks (testing in situ, reviewing logs, and systematically assessing the impact of swapping components). Essentially, RCM can be the Level 4 Check, as faults aren't found, and the symptoms continue to arise. Transient symptoms (e.g. intermittent driver's warning light) can often be traced to a root cause which turns out not to be the "suspect" component (e.g. the AVR), but another (e.g. in the engine control system).

RCM can be applied to continuously collect and record all relevant system states but may need a significant amount of work to identify the detail required. It is worth remembering that an RCM approach is likely to be taken for the most intractable problems, when all the obvious potential solutions have failed.

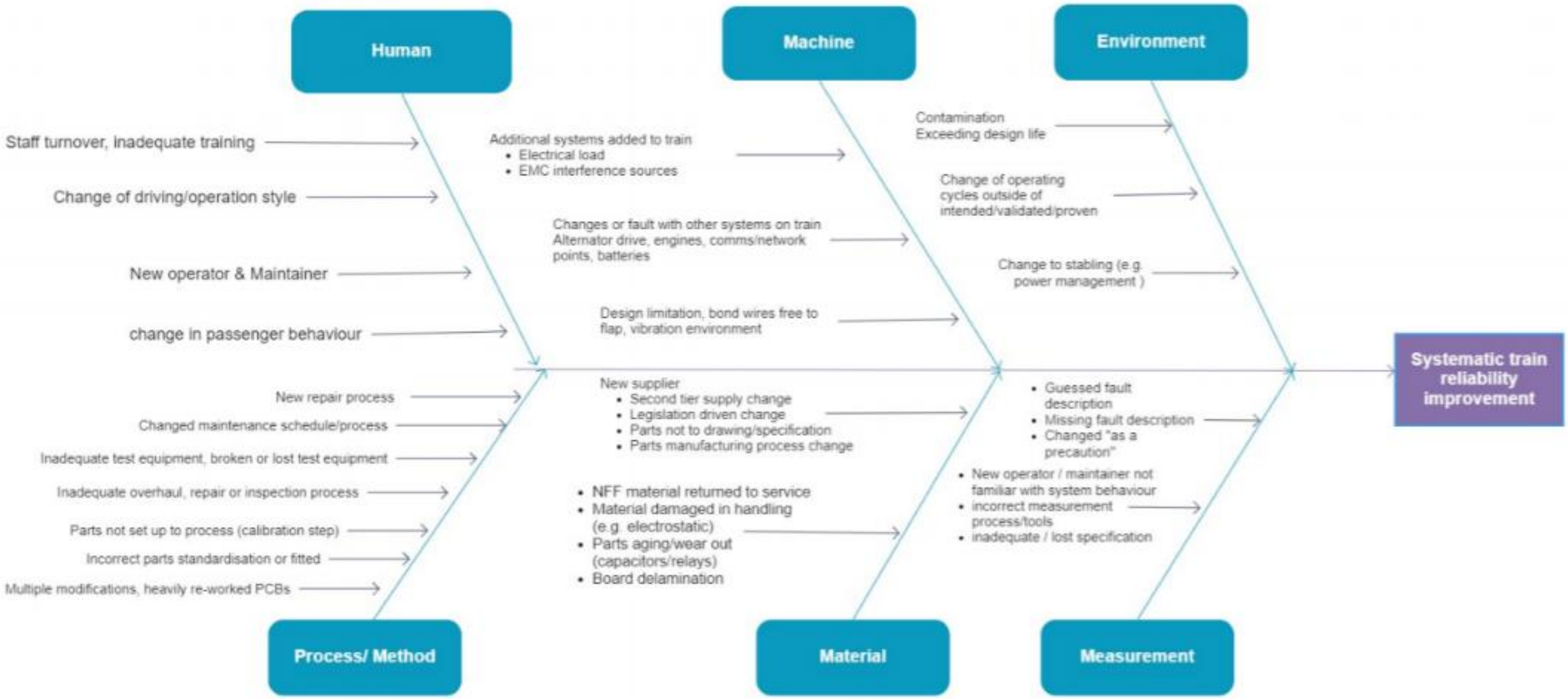
Once the fault(s) is found and resolved, RCM can continue to add value, potentially forming a basis for overhaul specification, or identifying cost-effective changes to procedures instead of an overhaul. RCM findings should inform future predictive maintenance. RCM investigations may even uncover fundamental design issues, requiring upgrade rather than overhaul, if equipment is not (or no longer) capable of delivering requirements.

<u>Checklist</u>

A typical RCM investigation needs to be specified carefully to add value, based on:

- Establishing the fault symptoms to be investigated, based on historic failures and actions taken (noting that the component exhibiting the fault may not be the root cause e.g. IGBTs blowing up because of thermal fatigue cracking in a component on a distant control board);
- Understanding the system states (including characterising relevant systems where documentation is inadequate e.g. conditions that could lead to the symptom "battery charger lock out" weren't set out in OEM information, so responses under various input/ output conditions were modelled).

Once specified, the data analyser needs to be designed and configured to capture each system/ sub-system state in enough detail for states to be correlated with fault symptoms. Given the nature of the operation, sufficient robustness should be built-in e.g. remote re-set facilities, watchdogs etc.



Ishikawa Diagram

11.5.1 **Case Studies**

11.5.2 **SET Investigative Remote Condition Monitoring (iRCM) on Turbostars**

The Turbostar fleet had variable symptoms, including ‘battery charger lock-out” and “intermittent loss of vehicle lighting”. Various theories had evolved over 10 years, and replacement of the AVR has become the first line of response for vehicles with power generation symptoms, often followed by battery charger replacement/ recalibration and alternator replacement.

The Process: SET Ltd broke the deadlock of not being able to identify the root cause of the symptoms experienced by undertaking:

- Bench testing and detailed investigation of suspect AVRs that had been repeatedly replaced/ swapped in response to intermittent or transient fault conditions;
- Designing and installing a remotely accessible datalogger (iRCM) to monitor all relevant system states continuously (this required the characterisation relevant systems e.g. the conditions that led to ‘battery charger lock-out” were inadequately specified within the OEM battery charger documentation and it was therefore necessary for SET to characterise the response of this unit to various input and output conditions).

Custom RCM unit installed under a vehicle:

The Outcome:

Key Findings: No evidence was found for intermittent AVR failures being the root cause of the train faults. RCM data has shown that complex subsystem interactions explain the power generation symptoms seen. Correlating fault symptoms with system states has shown a sequence of events starting with driver actions and leading to temporary loss of lighting:

- Driver changes power request from engine
- Imperfections in the driver’s control unit mean that the request contains unwanted transient states
- The engine control system responds to the requested change, with momentary deviations from ideal behaviour – potentially exacerbated for the transient states from the driver’s control unit

- The hydrostatic coupling/drive (engine to alternator) responds to the engine speed fluctuations – attempting to maintain a constant alternator speed. Occasionally the hydrostatic drive output speed drops significantly as the engine speed dips, and takes a second or two to recover
- The AVR detects the low alternator speed and drops the alternator output voltage as a protective measure
- The battery charger detects the low input voltage and performs a power cycle reset.
- The load-shedder unit detects the loss of DC supply from the battery charger and switches to emergency lighting, until the battery charger has reset.
- The driver's warning light illuminates when the battery charger output is lost

In total, there are 5 cascaded control systems involved in generating the symptom of lost vehicle lighting – each with its own specifications, calibration and maintenance processes.

It is easy to see why the root cause can evade detection and the problems persist for many years, when each subsystem is often considered separately from the others, and where the troublesome interactions may be transient – meaning that they are often completely absent during depot investigations or are difficult to detect unless several system states are observed simultaneously.

So, what started as an investigation into an AVR and battery charger led to issues with the driver control unit, engine control and fuelling system, and the hydrostatic drive performance and control. Resolution is ongoing and likely to involve: overhaul or upgrade of one or more of these systems; changes to calibration procedures; other maintenance activities.

Recommendation:

Consider deploying investigative Remote Condition Monitoring (iRCM) where faults are intermittent/ transient and symptoms hard to link to root cause. Existing RCM systems (if any) are often not adequate (nor sufficiently extensive) for the problem under investigation.

Building on the characterisation of systems and the collection of data in the iRCM, consider developing Predictive Maintenance tools which could lead to:

- Catching issues early – leading to individual effective interventions, and avoiding the need for fleet-wide modification programmes, which tend to be specified in a reactive manner after experiencing increasing reliability issues over a long period
- Identifying requirements for any fleet-wide changes, overhaul or enhancements (and informing the specification of any interventions already planned).