Railway Accident Investigation Unit Ireland

INVESTIGATION REPORT

Failure of a Current Return Cable on a Luas Tram, Connolly Stop, 25th October 2022

RAIU Investigation Report No: 2023-R004

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Report Description

Report publication

Where the report has been altered following its original publication, details on the changes will be given.

Report structure

The report structure is written as close as possible to the structure set out in the "Commission Implementation Regulation (EU) 2020/572 of 24 April 2020 on the reporting structure to be followed for railway accident and incident investigation reports" having regard to "Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety".

Reader guide

All dimensions and speeds in this report are given using the International System of Units (SI Units). Where the normal railway practice, in some railway organisations, is to use imperial dimensions; imperial dimensions are used, and the SI Unit is also given.

All abbreviations and technical terms (which appear in italics the first time they appear in the report) are explained in the glossary.

Descriptions and figures may be simplified in order to illustrate concepts to non-technical readers.

Further information

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Preface

The RAIU is an independent investigation unit within the Department of Transport which conducts investigations into accidents and incidents on the national railway network including the Dublin Area Rapid Transit (DART) network, the LUAS light rail system, heritage and industrial railways in Ireland. Investigations are carried out in accordance with the Railway Safety Directive (EU) 2016/798 enshrined in the European Union (Railway Safety) (Reporting and Investigation of Serious Accidents, Accidents and Incidents) Regulations 2020; and, where relevant, by the application of the Railway Safety (Reporting and Investigation of Serious Accidents, Accidents and Incidents Involving Certain Railways) Act 2020.

The RAIU investigate all serious accidents. A serious accident means any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other similar accident with an obvious impact on railway or tramline safety regulation or the management of safety. During an investigation, if the RAIU make some early findings on safety issues that require immediate action, the RAIU will issue an Urgent Safety Advice Notice outlining the associated safety recommendation(s); other issues may require a Safety Advice Notice.

The RAIU may investigate and report on accidents and incidents which under slightly different conditions may have led to a serious accident.

The RAIU may also carry out trend investigations where the occurrence is part of a group of related occurrences that may or may not have warranted an investigation as individual occurrences, but the apparent trend warrants investigation.

The RAIU investigation shall analyse the established facts and findings (i.e. performance of operators, rolling stock and/or technical installations) which caused the occurrence. The analyses shall then lead to the identification of the safety critical factors that caused or otherwise contributed to the occurrence, including facts identified as precursors. An accident or incident may be caused by *causal, contributing* and *systemic factors* which are equally important and should be consider during the RAIU investigation. From this, the RAIU may make safety recommendations in order to prevent accidents and incidents in the future and improve railway safety.

It is not the purpose of an RAIU investigation to attribute blame or liability.

Contents

Summary

1 At approximately 08:08 hours (hrs) on 25th October 2022 Tram 3012 was departing Connolly Stop, when the driver of Tram 4012 (Driver 4012), approaching Connolly Stop in the opposite direction, saw what they thought was a hose protruding from the underframe of Tram 3012.

2 Driver Tram 4012 contacted the Traffic Supervisor responsible for the Red Line in the Luas Network Management Centre (LNMC) who in turn contacted the driver of Tram 3012. The Traffic Supervisor advised the driver of Tram 3012 (Driver 3012) to continue in passenger service to the Red Cow where the service would terminate and transfer into the Red Cow Maintenance Depot.

3 Tram 3012 served all stops as required to the Red Cow without incident where it was taken from service and transferred to the Red Cow depot for investigation.

4 On investigation it was found that what was initially reported as a hose was in fact Side 1 (S1) *Current Return Cable* of Motor (M)1 *Bogie* 176DU, which had severed. In addition Side 3 (S3) *Earth Shunt Cable* also on M1 Bogie 176DU had also severed and the S3 Axle End Assembly was showing signs of extreme overheating. Side 1 and Side 3 are on adjacent wheelsets diagonally opposite on Motor Bogie 176DU of Tram 3012.

5 The last maintenance intervention which involved contact with S1 Current Return and S3 Earth Shunt Cables took place twenty days before the incident, as part of the *wheel turning* preparation; where both cables were detached to facilitate the wheel turning. The work must be carried out in accordance to Work Instruction, TDLR-LUAS-WI-00814 (WI-00814), Preparation before and after wheel turning (2019), the ends of the Current Return and Earth Shunt Cables need to be checked for corrosion; and if corrosion is present, this must be reported to the team leader. Also, as part of WI-00814, the contact surfaces of the Current Return and Earth Shunt Cables must be coated with a small amount of *contactal paste* before being re-attached.

6 The post-incident inspection identified soiling and *oxidation* on the *Lugs* of S1 Current Return and S3 Earth Shunt Cables; and the absence of contactal paste. It is probable that that some corrosion on surface of the Lugs was present during the wheel turning process twenty days previous as it is unlikely that the extent of corrosion on the Lugs post-incident had accumulated in that time period (in addition, the absence of contactal paste made the Lugs more susceptible to soiling and oxidation).

7 Analysis of the failed components found that soiling and oxidation on the Lugs resulted in the overheating of the Lugs which, in turn, conducted into S1 Current Return and S3 Earth Shunt Cables.

8 This returned in elevated temperature creep strain accumulating in both the S1 Current Return and S3 End Shunt Cables, over a significant period of service (again indicating that it was probable there was oxidation and corrosion of the Lugs twenty days previous). In both cables, successive failures of individual strands caused the electrical and mechanical loading on the remaining strands to be increased. Eventually, a point was reached when the cumulative failures of individual strands caused the S1 Current Return Cable to separate completely.

9 Separation of the S1 Current Return Cable caused the electrical load on the S3 Earth Shunt Cable to instantaneously increase significantly as the return circuit found the only alternative path through S3 Earth Shunt Cable causing it to fail immediately.

10 Outlined above is the failure mechanism, the RAIU have identified the following causal factors to this failure mechanism:

- CaF-01 – Soiling and oxidation on S1 Current Return and S3 Earth Shunt Cables ends, which was likely to have been present during the wheel turning process twenty days before the incident, was not reported to the team leader, as set out in WI-00814;
- CaF-02 – Contactal paste (used to protect against soiling and oxidation) was not coated on the contact surfaces of S1 Current Return and S3 Earth Shunt Cables at the time of re-attachment as part of the wheel turning process twenty days before the incident, as required by WI-00814.

11 The following may have been a contributory factor:

- CoF-01 – WI-00814 does not have any supporting guidance documents in relation to identifying defects, to assist maintenance technicians in their requirements to report defects to the team leaders.

12 Although not causal, contributing, or systemic to the incident, the RAIU make the following additional observations:

- AO-01 – TDLR did not immediately notify the RAIU of the incident and partially disassembled evidential components from Tram 3012 prior to notification;
- AO-02 – Tram 3012 remained in passenger service with a live high voltage cable protruding from the underframe; as the TDLR suite of documents for Traffic Supervisors in the safe management of trams does not contain any reference on how to respond to equipment protrusions from a tram.
- AO-03 – There is no location on the Wheel Turning Certificate to record the torque wrench asset number or torque testing, as set out in WI-00814.
- AO-04 – Fleet audits carried out by the Maintenance Team Manager (MTM) did not identify that the tasks outlined in Paragraph 14 of WI-00814 were not carried out as prescribed and a torque wrench was not signed out for the completion of the task.

13 As a result of the RAIU investigation, the RAIU make the following safety recommendations:

- Safety Recommendation 2023004-01 – TDLR should develop supporting guidance documentation to WI-00814, Preparation before and after wheel turning, to include information on possible defects e.g. photographs of unacceptable levels of corrosion on the Current Return and Earth Shunt cable Lugs;
- Safety Recommendation 2023004-02 – TDLR should consider updating LNMC Manual Document (TDLR-OP-M-0001) to include guidance for Traffic Supervisors in relation to actions to be taken in the case of failed cables and hoses;
- Safety Recommendation 2023004-03 – TDLR should consider updating WI-00814, Preparation before and after wheel turning to include the recording of the testing and serial number of the torque wrench into TDLR-FRM-ENG-023 Citadis 401 Wheel Turning Certificate Issue A November 2020;
- Safety Recommendation 2023004-04 – TDLR should consider updating the Wheel Turning Certificate to provide a space for the torque wrench registration number conformation of test and torque value achieved when reattaching the Current return and Earth Shunt cables with a space for sign off;
- Safety Recommendation 2023004-05 – For instances where rolling stock is withdrawal from service as a result of damage; TDLR should develop notification procedures to identify where immediate notification to the RAIU is required.

RAIU Investigation and its context

Decision & motivation to investigate this occurrence

14 On 25th October 2022, the RAIU on call investigator received a notification from TDLR in relation to a failure of a tram Current Return Cable with the exposure of a live cable protruding from the underframe of an in-service Luas tram on the Red Line (see paragraph 22).

15 The RAIU conducted a preliminary examination and the RAIU's Chief Investigator made the decision to conduct a full investigation into the incident given the seriousness of the incident. As under slightly different circumstances the incident may have led to a serious accident with the potential for a fatality or serious injuries, due to the exposure of a live high voltage cable protruding from the underframe of a tram in-service. The investigation is carried out under Railway Safety (Reporting and Investigation of Serious Accidents, Accidents and Incidents Involving Certain Railways) Act 2020.

Scope & limits of investigation

16 The RAIU established the scope and limits of the investigation as follows:

- Establish the sequence of events leading up to, during and after the incident;
- Identify any other precursors which led to the incident;
- Identify the previous maintenance interventions for all the Current Return and Earth Shunt Cable components;
- Conduct a metallurgical examination of all the failed components;
- Establish, where applicable, causal, contributing and systemic factors.

Technical capabilities & investigation methods

17 The RAIU's Chief Investigator allocated RAIU Senior Investigators, trained in accident investigation, to conduct this investigation, as appropriate.

18 For this investigation, a metallurgical specialist consultant (ms4i) was contracted to assist the RAIU in evaluation of the failed Current Return and Earth Shunt cables.

19 During the investigation, the RAIU visited the Luas Red Cow Depot and later collated evidence through the submission of Requests for Information (RFIs) to the TDLR Safety Department. Related to this investigation, the RAIU collated and logged the following evidence:

- Photographs taken on the day from the Connolly Stop and the Red Cow Depot;
- Training and competence records for those directly involved;
- Maintenance interventions for Tram 3012 associated with the Current Return and Earth Shunt Cables (and interventions that required the detaching of the Current Return and Earth Shunt Cables);
- A metallurgical analysis into the failure, the ms4i Luas Tram Electrical Cables, Failure Analysis Report, TR/23/691, issued on the 26th April 2023 (to be referred to as the ms4i Report);
- Reporting and response to the incident;
- LNMC Manual Document ID Code TDLR-OP-M-0001 Issue 2 06/07/2021 (LNMC Manual);
- TDLR-LUAS-WI-00814 (WI-00814), Preparation before and after wheel turning, Rev A, September 2019;
- TDLR Citadis 401 Wheel Turning Certificate, TDLR-FRM-ENG-023, Issue A, November 2020, completed 28/09/2022 to 05/10/2022.

Communications & evidence collection

20 Communications were conducted through established processes (such as RFIs).

21 All relevant parties co-operated with the RAIU investigation.

22 However, under the RAIU's guidance document "Guidance: Notification of occurrences to the RAIU for RUs, IMs & other ROs", Version 3, effective since the 1st January 2020, the RAIU require immediate notification for "Wrong side failures of safety critical equipment that led to an unsafe condition requiring withdrawal from service" and/or "Occurrences that under slightly different conditions may have led to a fatality, serious injury or extensive damage." Given that the maintenance team would have determined that the component was an electrical cable rather than a hose, upon visual inspection, this should have been immediately reported. Instead, TDLR carried out a partial disassembly of the failed components (TDLR advised that the disassembly had taken place to mitigate against a possible fleet wide risk). Had the incident been reported immediately, the RAIU, under Statutory Instruments No. 430 of 2020, European Union (Railway Safety) (Reporting and investigation of serious accident, accident and incident) Regulations 2020, direct that the railway property be left undisturbed until such time that the RAIU would have arrange examination of the property[1].

23 Relevant stakeholders were issued the draft investigation report for comment, stakeholders' responses were considered, and the stakeholders were advised of the conclusion. In this instance the stakeholders were: TDLR Safety (parties and roles) and the Commission for Railway Regulation (CRR)[2].

Other stakeholder inputs

24 No other stakeholder inputs (such as emergency services) were required in this incident.

[1] The RAIU consider this to be an additional observation AO-01 (paragraph 106), which warrants a safety recommendation, Safety Recommendation 2023004-04 (paragraph 125).

[2] The CRR is the National Safety Authority (NSA) for the Republic of Ireland and is responsible for the regulatory oversight of the application and effectiveness of railway organisations Safety Management System (SMS) and enforcement of railway safety in the Republic of Ireland in accordance with the Railway Safety Act 2005 and the European Railway Safety Directive.

Description of the occurrence & background information

Description of the occurrence type

25 At approximately 08:08 hrs on 25th October 2022, at Connolly Stop, Driver 4012 saw a protrusion from the underframe of another tram, Tram 3012. It was later identified as live high-voltage S1 Earth Return Cable, and it was also later identified that there was S3 Earth Shunt Cable had also severed and extreme overheating of S3 Axle End Assembly.

26 The EU Agency for Railways categorisation for this occurrence is an: Incident – Rolling Stock.

Background to the occurrence

27 The protrusion was first seen at Connolly Stop (see Figure 1) while Tram 3012 was operating in passenger service; however, it cannot be determined when it first severed.

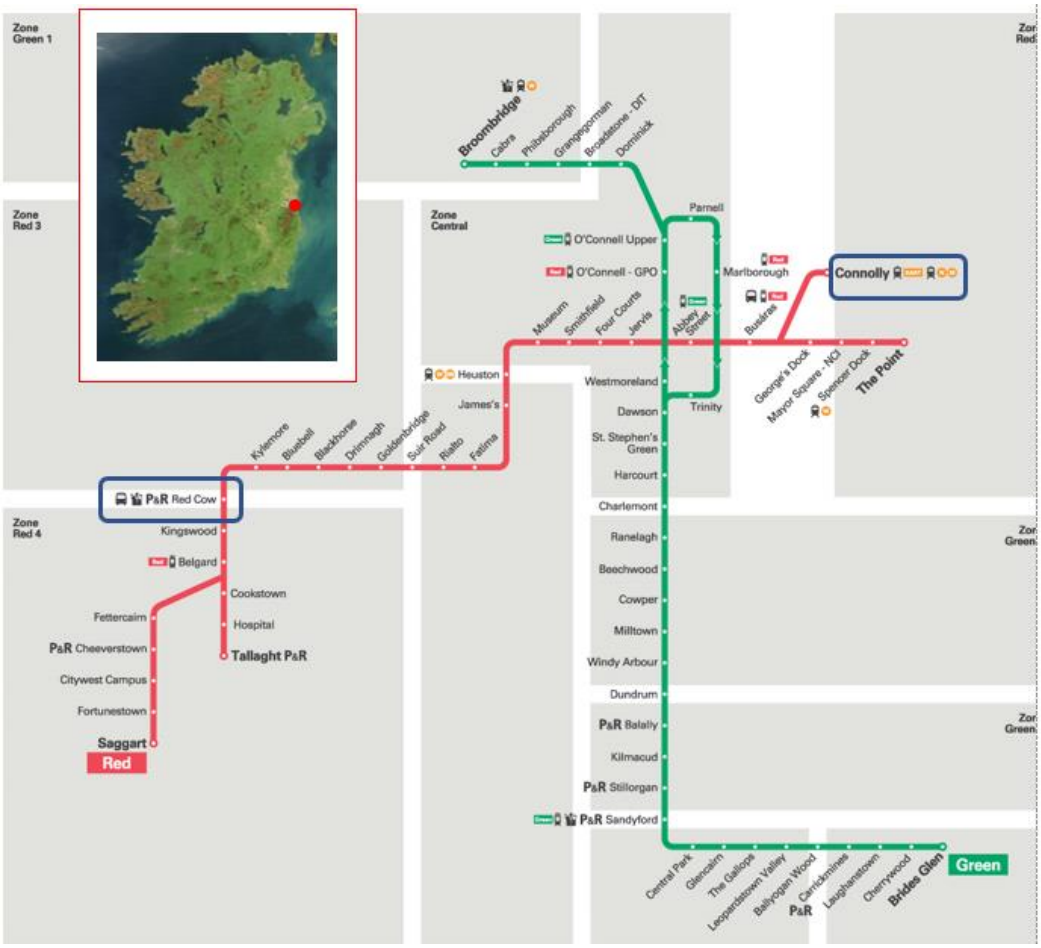

Figure 1 – Location Connolly Stop and Red Cow Depot

28 The incident occurred during daylight and the weather was fine with no rain.

Deaths, injuries & material damage

29 No members of the public or staff received injuries.

30 There was material damage to the S1 Current Return Cable, S3 Earth Shunt Cable and S3 Axle End Assembly.

Other consequences as a result of the incident

31 There was a nine minute delay to tram services as a result of the incident.

Parties & roles associated with the incident

Transdev Dublin Light Rail (TDLR)

32 TDLR operates the Luas light rail tram system in Dublin. As of the 1st December 2019, Transdev are the Vehicle Maintenance Contractor (VMC) and Infrastructure Maintenance Contractor (IMC); and also provide security staff.

33 The TDLR roles involved, directly and indirectly, in the incident, are as follows:

- Driver 3012 – who was in his second week post training in the tram driving grade at the time of the incident and was certified and passed competent to carry out all driving tasks required;
- Driver 4012 – who was twelve years in the tram driving grade at the time of the incident and was certified and passed competent to carry out all driving tasks. Driver 4012 was last competency assessed on 17th October 2022 and passed competent to carry out all driving tasks required;
- Traffic Supervisor – who commenced working on the Luas in January 2011 and as a Traffic Supervisor since May 2017. The Traffic Supervisor was last competency assessed in September 2021 and deemed competent without endorsement;
- Maintenance Technician – who commenced working on the Luas as a technician in February 2014 and a review of his training records showed that he was in date for all tram maintenance activities.

Infrastructure

Track

34 The Red Line (where the incident took place) is 20.5 kilometres (km) in length and has thirty-two stops and runs from Tallaght to The Point and from Saggart to Connolly.

35 Trams operate on a combination of separated track, segregated track, and shared running (where the trams share the road with other road users).

36 The tram lines are generally double track, with the exception of certain areas e.g. O'Connell Street and Dawson Street.

Signalling & communications

37 Tram movements are regulated through the use of line side signals which must be obeyed by tram drivers and other road users. The signals, normally positioned to the left of the leading driving cab on the kerb, are provided by an array of light emitting diodes (LED) which are illuminated according to the type of signal to be displayed e.g. horizontal (stop), vertical (proceed). Tram signals and regulatory stationary signs are set out in the Department of Transport's Traffic Signs Manual, last updated in August 2019.

38 The means of communication between tram drivers and the LNMC is by Tetra radio and lineside help points.

Operations

39 Traffic Supervisors have a suite of documents related to the safe management of tram services including documents on faults and minimum operating requirements[3], however, on review, none of the documents contain any guidelines relating to protrusions from underframe of a tram or other related external faults; as such the Traffic Supervisor, on the day of the incident, had no document to reference when the fault was reported by Driver 4012[4] and should have referred the incident to the Depot Manager.

[3] LNMC Manual (2021); Tram Fault Management Manual (401 & 402) for Traffic Supervisors (2010); MOR 401/402/502 (2020); Defect Priority Matrix (2020).

[4] The RAIU consider this to be an additional observation, AO-02 (paragraph 106), which warrants a safety recommendation, Safety Recommendation 2023004-02 (paragraph 123).

Rolling Stock

General description of 401 series trams

40 Trams 3012 and Tram 4012 are part of the forty 401 tram fleet operating on the Dublin Luas Red Line.

41 The 401 trams are 40 metres (m) long, 2.4 m wide, 3.45 m high (with the pantograph lowered).

42 The 401 trams were manufactured by Alstom Transport in La-Rochelle, France and consist of five articulated modules, three motorised, one trailer and one suspended unit, see Figure 2 .

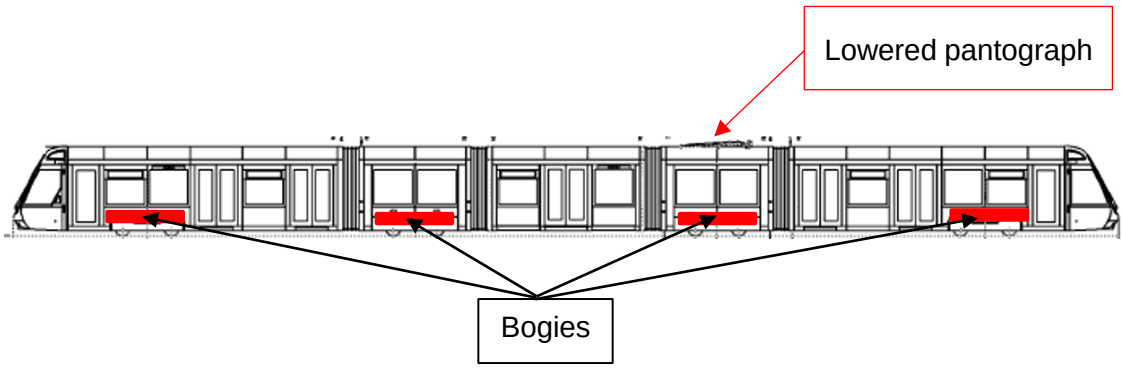

Figure 2 – 401 Tram configuration

43 Trams are powered by an Overhead Contact System (OCS) providing 750V Direct Current (DC) delivered from twenty Electrical Sub-Stations (ESS). Power is supplied to the ESSs from the national grid at 10 kilovolts (kV) *alternating current* (AC).

44 The 750 V DC supplied to the trams via a roof mounted pantograph is converted to AC by an *inverter*, to power the motorised bogies on the tram set. The return circuit is via the Current Return Cable, through the Axle End Assembly and wheel rail interface back to the ESS i.e. the pantograph is the current collector with the *return current* running through the rails, back to the source of power (the ESS). There is a carriage to carriage earthing link but in this case the redundancy was ineffective.

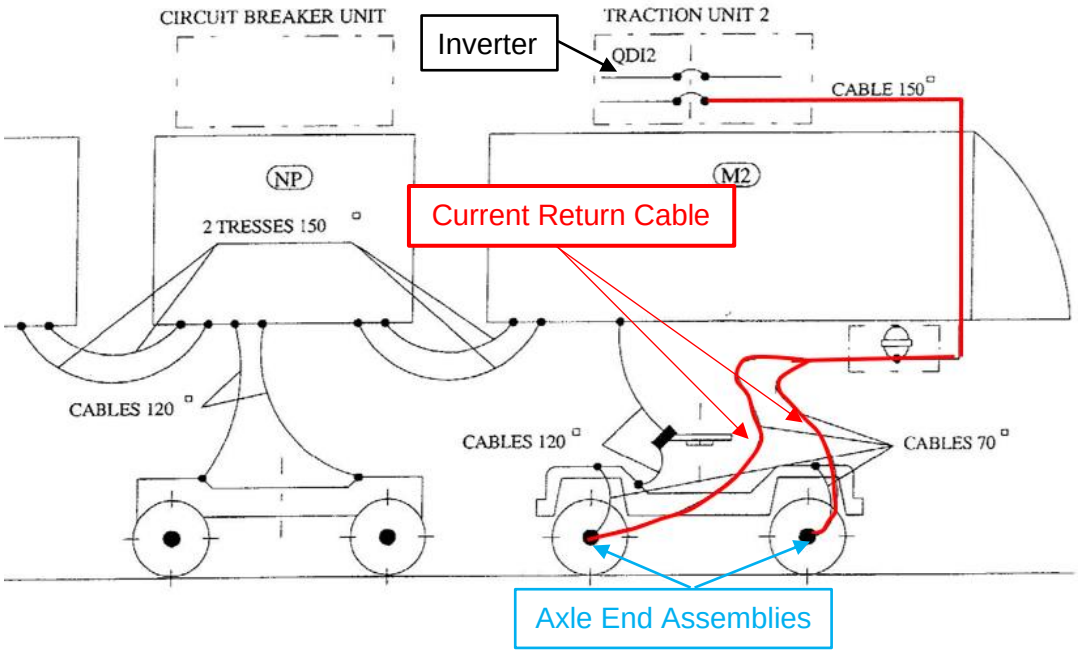

Figure 3 – Electrical path from the inverter through to the Axle End Assemblies

45 The Current Return Cable is sized at 150 millimetres^2 (mm), before it divides in two (these will be referred to, in this report, as S1 Current Return Cable and S3 Current Return Cable), reducing in size to 70 mm^2 to feed both traction motors (red cables in Figure 4) through S1 Axle End Assembly and S3 Axle End Assembly.

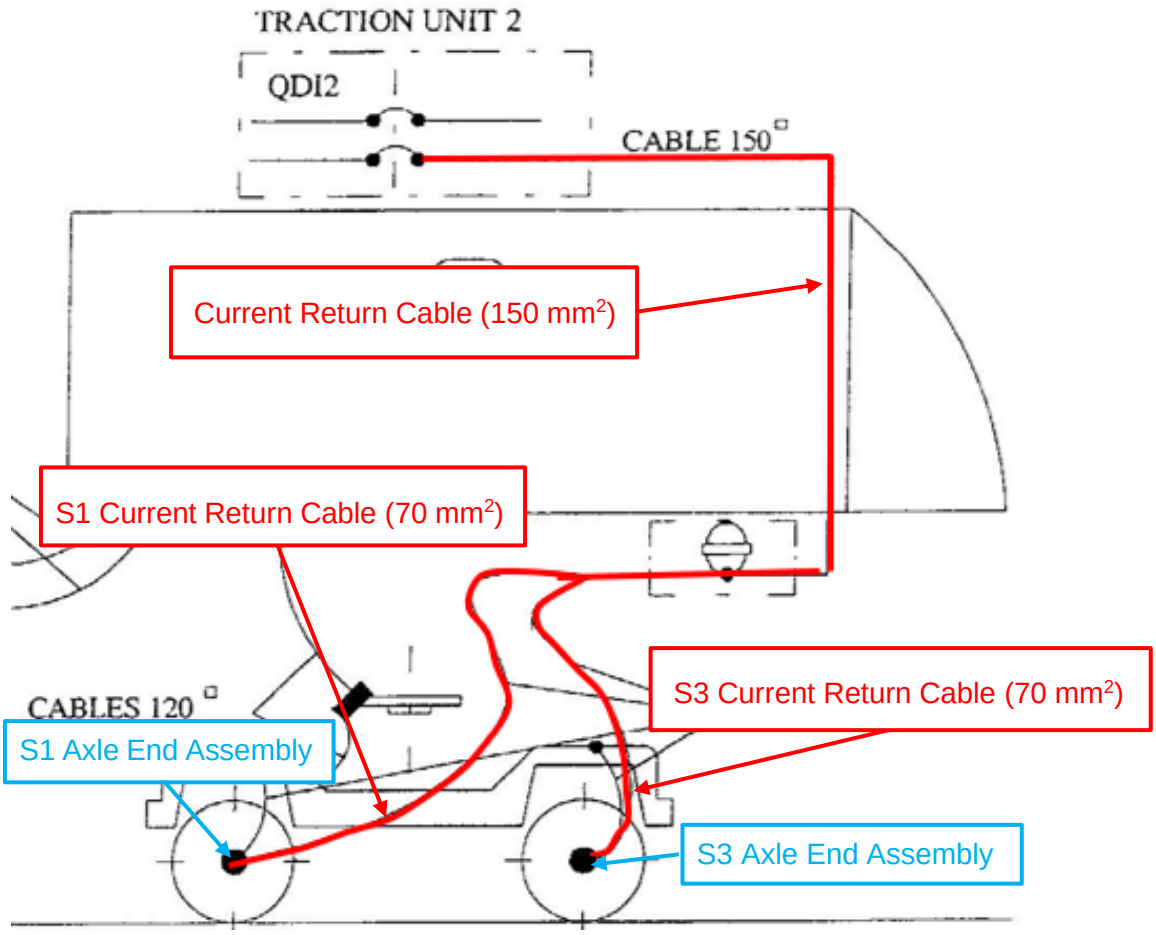

Figure 4 – Current Return Cable arrangement

Note: S1 and S3 are on opposite sides of the tram, however, they have been presented in this report to be on the same side for ease of understanding as to the mechanism of failure.

46 The Earth Shunt Cables (used to discharge any static charge and to carry return current in case of any disconnection in return current circuit) are sized at 70 mm^2 (Figure 5) and are referred to as S1 Earth Shunt Cable and S3 Earth Shunt Cable.

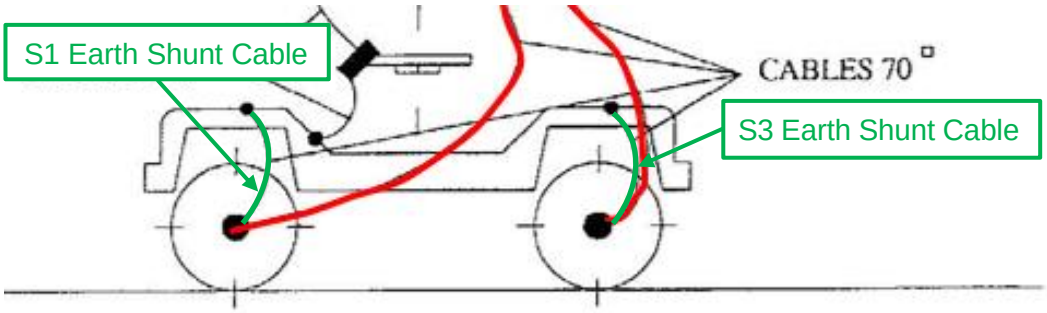

Figure 5 – Earth Shunt Cables

47 The Current Return and Earth Shunt Cables (apart from the length and size) are similar in appearance and are made up with the following components: Cable, Insulation, Heat Shrink and Lug (see Figure 6).

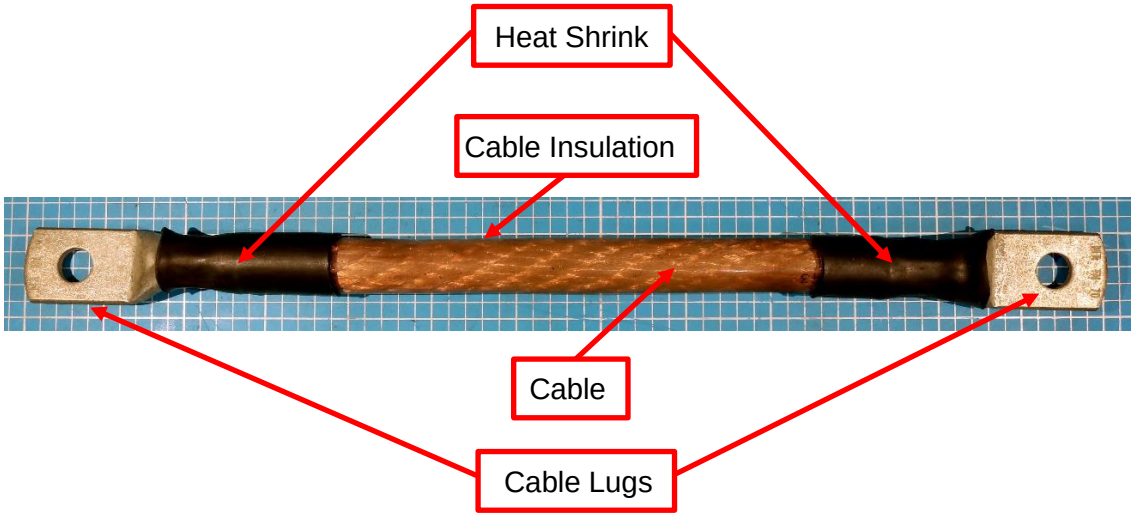

Figure 6 – Components making up Current Return and Earth Shunt Cables

TDLR rolling stock maintenance

Training, competency management and compliance

48 Maintenance Technicians receive initial training and competency assessment on the maintenance tasks before been allowed to carry out maintenance exams using Work Instructions.

General description of maintenance documentation

49 TDLR have a comprehensive suite of maintenance documents to ensure the tram fleet operate safely and reliably in service. Each exam task is backed up with a more descriptive Work Instruction. The front page of each exam document contains clear instructions for the Maintenance Technicians on how to complete the exam sheet, with the sign-off of tasks to be completed, listing of any failed tests and recording of defects on the Record Defect Sheet.

Work Instructions – Inspections

50 The Work Instructions are used when carrying out the A, C and D Exams every 15,000 km, 60,000 km and 120,000 km, respectively. Of relevance to this incident are the following Work Instructions:

- TDLR-LUAS-WI-00767 High Floor Motor Bogie Earthing Cables Visual Inspection for M1 and M2 (carried out in the A, C & D Exams);
- TDLR-LUAS-WI-00760 Low Floor Motor Bogie Earthing MIC Bogie Visual Inspection (carried out in the A, C & D Exams);
- TDLR-LUAS-WI-00693 Trailer bogie earthing and low voltage wiring visual inspection (carried out in the C & D Exams);
- TDLR-LUAS-WI-00784 Low floor motor bogie visual inspection of return current device (carried out in the C Exam);
- TDLR-LUAS-WI-00675 Grounding box inspection of carbon brush and collector shoe 120k Task. M1 and M2 (carried out in the D Exam);
- TDLR-LUAS-WI-00784 Low floor motor bogie visual inspection of return current device 60k task MIC Bogie (carried out in the D Exam).

Work Instruction – Preparation before and after wheel turning

51 Also relevant to the incident is TDLR-LUAS-WI-00814 Preparation before and after wheel turning (2019).

52 Section 9 of WI-00814 outlines the procedures before and after wheel turning. Step 7 (before wheel turning) requires the disconnection of the earth return and shunt cables by unscrewing and removing the fixing screws and placing the cables away from the clamping holes; which is illustrated Figure 7 (the RAIU have added the orange text for ease of understanding).

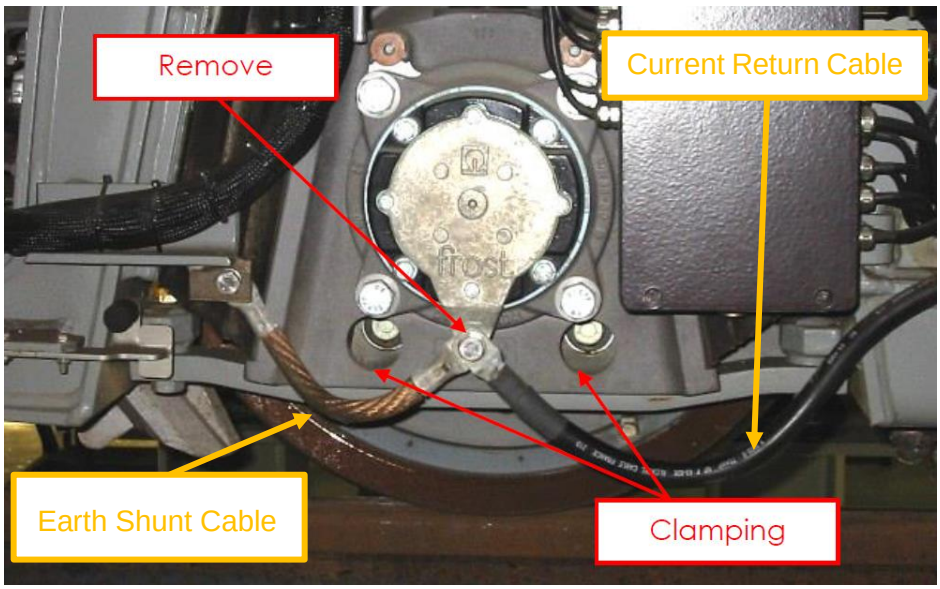

Figure 7 – Figure taken from WI-00814

53 Step 14 (after wheel turning) of WI-00814 states, “Check the ends of the earth cables and report any corrosion to your team leader.

54 Coat the contact surfaces of the earthing cables with a small amount of contactal paste (which provides protection against corrosion, external pollutants; and resistance to oxidation).

55 Attach the earthing cables on each high floor bogie and tighten to a torque of 45 Nm. In terms of the torque wrench, Section 7, Materials and Specials Tools, requires the 45 Nm torque wrench, to have the asset number recorded and be “tested” before use. The importance of fitting the earth cables correctly is highlighted in Section 4 of WI-00814, Safety Critical Working, which states: “If the side skirts, or earth cables are not fitted correctly they could become detached.” The text is coloured red on the document to further emphasise the importance of the task.

56 At the end of the steps section of WI-00814, the document states “Report any defects to your team leader or manager”.

57 The tasks are to be recorded in the Wheel Turning Certificate (2020).

Tram involved in the incident (Tram 3012)

A Exam, C Exam, D Exam

58 In terms of compliance to exams Tram 3012 received its scheduled maintenance as planned. Most recent to the time of the incident was an "A Exam" (carried out every 15,000 km) which was carried out on the 28th August 2022 (distance travelled 1,157,105 km). The relevant WIs were carried out (as set out in paragraph 50). The Defect Record Sheet identified four Wheel Shunt Cables were broken with closed work order showing task completed.

59 A "C Exam" (carried out every 60,000 km) was carried out on the 28th June 2022 (distance travelled 1,141,407 km). The relevant Work Instructions were carried out (as set out in paragraph 50). The Defect Record Sheet identified all Wheel Shunt Cables needed to be replaced with closed work order showing the task completed.

60 A "D Exam" (carried out every 120,000 km) was carried out on the 21st March 2022 (distance travelled 1,130,431 km[5]). No additional items were recorded in the Defect Record Sheet against the tasks but work order 104761 for Earth Cable damaged is marked as closed but there is no explanation as to the location of the Earth Cable. On the IC Bogie Work Order 104764 was created for "No heat shrink on the bogie frame to body earth". The Defect Record Sheet recorded Earth Cable damaged side roof with Work Order 105557.

[5] The distance Tram 3012 travelled between the D exam on 21st March 2022 and the C exam on 28th June 2022 was 10,976 km despite an allowance of 60,000 km on the schedule. This was explained by a balancing out of the exams schedule due to depot congestion caused by trams utilising the full tolerance of 1,500 km during the Covid-19 pandemic. The balancing out of the schedule resulted in many trams receiving planned scheduled maintenance ahead of time.

Wheel Turning

61 In addition to the planned scheduled maintenance (paragraphs 58 to 60), Tram 3012 received wheel turning between the 28th September and the 5th October 2022.

62 As part of the wheel turning preparation the Current Return and Earth Shunts at the axle end were removed to facilitate the wheel turning and reattached post wheel turning in accordance with WI-00814 (paragraphs 51 to 55).

63 The Wheel Turning Certificate, completed for Tram 3012, indicates that the earth cables were connected (highlighted in yellow in Figure 8).

transdev the mobility company Transdev Dublin Light Rail — Citadis 401 Wheel Turning Certificate

3. 401 POST WHEEL TURNING TASKS

TDLR-LUAS-WI-00816: Wheel lathe post-use	Initial
Cleaning, housekeeping	
Visual inspection	
Powered down	

UNCOUPLE UNILOC	Initial each applicable section															
TDLR-LUAS-WI-00759: Re-profiling Wheel Tread	M1				MIC				IC				M2			
	1A	1B	2A	2B	1A	1B	2A	2B	1A	1B	2A	2B	1A	1B	2A	2B
TDLR-LUAS-WI-00814: Tram preparation post wheel turning	M1				MIC				IC				M2			
Reset Brakes																
Mechanically uncouple UNILOC																
Inspect axle boxes and remove any swarf																
Earth cables connected (M1, M2)																
Side skirts replaced as required																

Figure 8 – Wheel Turning Certificate for Tram 3012

64 It is noted that the torque wrench asset number was not recorded as there is no location on the Wheel Turning Certificate to record the asset number of the torque wrench[6].

[6] The RAIU consider the absence of recording the torque wrench asset number to be an additional observation, AO-03 (paragraph 106), which warrants a safety recommendation, Safety Recommendations 2023004-03 (paragraph 124). Additionally it is noted that the fact that this was not highlighted during routine audits is also an additional observation AO-04; however, measures taken by TDLR (paragraph 120) means that this does not warrant a safety recommendation.

65 The Wheel Turning Certificate states that “defects identified during this maintenance activity, including both tram and wheel lathe defects are to be recorded” with a specific table provided in the certificate. Under WI-00814, the defect “IC Flange lube tank leaking oil”. No other defects are recorded under the WI-00814 i.e. corrosion of the Lugs.

Post-incident inspection of Tram 3012

66 On inspection of Tram 3012 on return to the Red Cow Maintenance Depot, the S1 Current Return Cable was found to be severed and was protruding from the underframe of Tram 3012 (on Bogie 176DU), see Figure 9.

Figure 9 – S1 Current Return Cable

67 Further inspection on Bogie 176DU identified the failure of S3 Earth Shunt Cable (circled, Figure 10) and heat damage to the S3 Axle End Assembly (inset red, Figure 10).

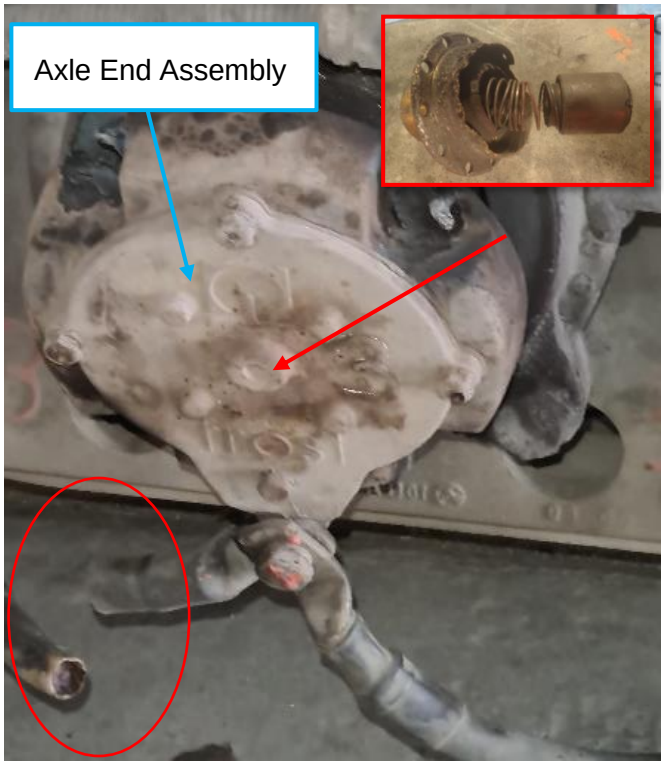

Figure 10 – S3 Earth Shunt Cable & S3 Axle End Assembly

68 A visual examination of the failed Current Return and End Shunt Cables identified soiling and oxidisation and the absence of contactal paste on the cable Lugs close to the failure points.

69 The fixings for the S1 Current Return and S3 Earth Shunt Cables were found to be “tight” during disassembly and “not considered to be a contributing factor in the failure”[7].

[7] Despite the fixings being “tight”, it was noted that the torque mark was broken (possibly occurring during previous wheel turning). Given the importance of the re-attachment of the cables to 45 Nm, due to this potential risk of derailment if not done correctly (paragraph 55), the RAIU consider that this should be linked to additional observation, AO-03 (paragraph 106) and Safety Recommendation 2023004-03 (paragraph 124).

Metallurgical Report

Evidence reviewed

70 The RAIU sent a metallurgical specialist (ms4i) the following items to analyse and report on the failed Current Return and Earth Shunt Cables:

- Item 1 – The failed S1 Current Return Cable;
- Item 2 – The failed S3 Earth Shunt Cable;
- Item 3 – An exemplar of a service run, but not failed, Earth Shunt Cable;
- Item 4 – An exemplar of an unused Earth Shunt Cable.

Figure 11 – Cables delivered to the RAIU metallurgical specialist

71 The cables were initially examined as received before magnification up to forty-five times using a hand magnifiers and *stereomicroscope*.

S1 Current Return Cable

72 The failure surface on S1 Current Return Cable occurred approximately 30 mm from the cable Lug (see Figure 6 for location of the Lug), but when the individual cable strands were straightened (for examination) it was apparent that the cable strands failed at lengths from a few mm up to 60 mm from the Lug. The cable strands were blackened by *thermal oxidation* in service but there was no significant evidence of *aqueous corrosion*.

73 Close to the failure, the cable strands were much thinner and more angular in cross-section indicating the cable strands had been mechanically stretched, thinned and deformed against adjacent cable strands, prior to the failure (see Figure 12). Many of the cable strands showed a “chisel edged” form at their points of fracture, consistent with tensile overloading. Many cable strands showed a globule (small round particle of substance) of previously molten and re-solidified material at the point of fracture (Figure 12).

Figure 12 – Failed Current Return cables strands

S3 Earth Shunt Cable

74 On the Lug side of the S3 Earth Shunt Cable, the cable strands had fused together across almost the entire cross-section of the cable (see Figure 13).

75 On the opposite side, fusing of the cable strands was evident in the central region but much less on the outer regions (see Figure 14), with the cable strands failing at different lengths with evidence of stretching and deformation before failure (similar to S1 Current Return Cable failure). The fusing indicated that *arcing* had taken place between the two sides.

Figure 13 – Lug side fused cable strands

Figure 14 – Central fused cable strands

76 The cable strands had been blackened by thermal oxidation in service. There was also some evidence of superficial aqueous corrosion of the cable strands; however, not significant enough to have contributed to the failure.

Cable Lugs

77 The Lugs associated with the S1 Current Return Cable (Figure 15) and S3 Earth Shunt Cable (Figure 16) closest to the failed ends were significantly more soiled and oxidised that those away from the failure (Figure 17); suggesting that there may have been higher than normal electrical resistance through the connections at the failed ends of the cables; which in return resulted in a degree of resistive heating.

Figure 15 – S1 Current Return Cable Lug closest to the failure

Figure 16 – S3 Earth Shunt Cable Lug closest to the failure

Figure 17 – S1 Earth Shunt Cable Lug furthest from the failure

Inspection of the Cables

78 The metallurgical report concluded that on both the S1 Current Return and S3 Earth Shunt Cables, there was evidence that the strands had been mechanically stretched prior to failure. It was considered possible that resistive heating may have caused the strands to stretch by a creep mechanism, over a long period of service. The surfaces of the strands on the failed cables were covered with black deposits, which were most likely cupric oxide. The presence of these thermally grown oxides may have been evidence that the cables had been running hot for a significant period of time.

79 The soiling and oxidation on the Lugs of S1 Current Return and S3 Earth Shunt Cables (paragraph 67), may have resulted in higher than normal resistance and consequent heating of the Lugs; which may have been conducted into the cables.

Mechanism of failure sequence of events

S1 Current Return Cable Failure

80 Elevated temperature creep strain accumulated on both the S1 Current Return and S3 End Shunt Cables, over a significant period of service. In both cables, successive failures of individual strands caused the electrical and mechanical loading on the remaining strands to increase. Eventually, a point was reached, when the cumulative failures of individual strands caused the S1 Current Return Cable to separate completely.

S3 Earth Shunt Cable

81 Separation of the S1 Current Return Cable (red X in Figure 18) caused the electrical load on the S3 Earth Shunt Cable to instantaneously increase significantly as there was no path for the current to flow through and the current found an alternative path (from that set out in paragraph 44 and Figure 3) through the S3 Earth Shunt, through Bogie 176DU and into the S1 Axle End Assembly via the S1 Earth Shunt Cable (see new path coloured yellow in Figure 18).

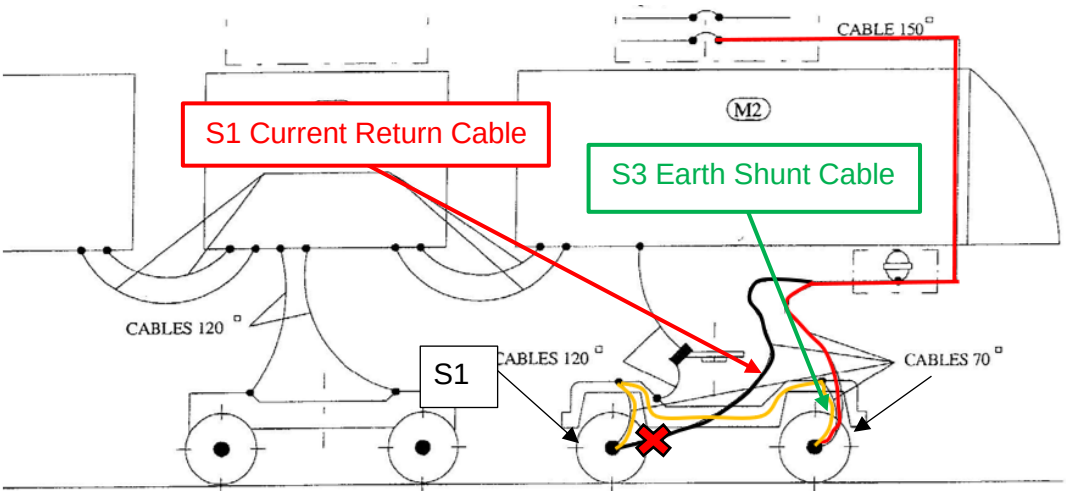

Figure 18 – Electrical path after the S1 Current Return Cable failed (yellow)

82 The overloading of S3 Earth Shunt Cable may have caused the strands in the centre of the cross-section to melt and the strands around the outer regions (which had already been weakened by the creep mechanism described in paragraph 78) to fail immediately afterwards (paragraph 74). Due to the short length (and resultant stiffness) of the S3 Earth Shunt Cable, the two sides of it were most likely held in close proximity, momentarily after the failure, by the heat shrink fitted to the Lug. During this short period, arcing occurred between the two sides (paragraph 75), causing melting on the Lug side of the cable.

83 When the S3 Earth Shunt Cable failed (green X in Figure 19), the only alternative was for all the current to return through the S3 Axle End Assembly which resulted in an overload of S3 Axle End Assembly and extensive heat damage to the assembly.

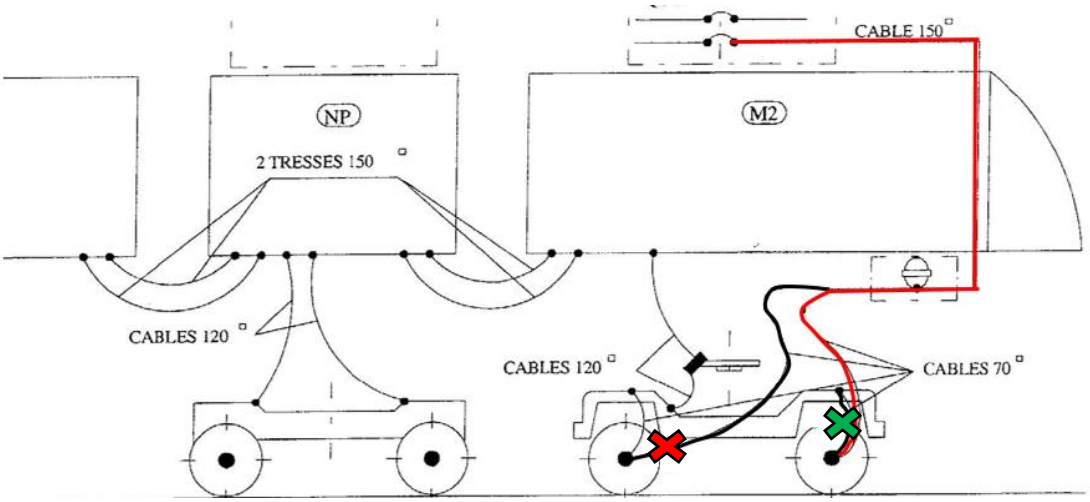

Figure 19 – Electrical path after the S3 Earth Shunt Cable failed

Events before, during and after the incident

Events before the incident

84 Tram 3012 was last subjected to planned maintenance on the 28th August 2022 (paragraph 58).

85 Between the 28th September and the 5th October 2022, as part of the wheel turning works, the Current Return and Earth Shunt Cables were removed to facilitate the work. The work was completed by a trained and competent Maintenance Technician.

86 Post wheel turning, there was also no evidence the contactal paste was applied, as required by WI-00814 (paragraph 53), which provides protection and resistance to oxidation (paragraph 67).

87 During this period, no defects were reported to the team leader or manager e.g. soiling and oxidisation of the Current Return and Earth Shunts (paragraph 64).

88 It is likely that sometime after this maintenance activity, the failure mechanism began where elevated temperature creep strain accumulated on both the S1 Current Return and S3 End Shunt Cables, over a significant period of service, with successive failures of individual strands eventually resulting in S1 Current Return Cable severing and S3 Earth Shunt Cable failing immediately afterwards, also leading to the overheating of S3 Axle End Assembly (paragraphs 80 to 83).

89 At 07:01 hrs on the 25th October 2022, Tram 3012 departed the Red Cow Depot to operate the S29 service, as set out in the timetable.

Events during the incident

90 The successive failures of individual cable strands continued, when eventually, a point was reached when cumulative failures of individual cable strands caused the S1 Current Return Cable to separate completely (paragraph 80).

91 The failure of S1 Current Return Cable resulted in the current finding an alternative path to S1 through S3 Earth Shunt Cable instantaneously and significantly increasing the electrical load on S3 Earth Shunt Cable resulting in its immediate failure (paragraph 82) and the subsequent overload of the S3 Axle End Assembly resulted in extreme overheating (paragraph 83).

Events after the incident

92 At approximately 08:08 hrs Tram 3012 was departing Connolly Stop, when Driver 4012, approaching Connolly Stop in the opposite direction, saw what they thought was a hose protruding from the underframe of Tram 3012. Driver 4012 reported the occurrence to the Traffic Supervisor at the LNMC.

93 The Traffic Supervisor contacted Driver 3012 who was unaware of the fault and had no warning notifications in the driving cab. The Traffic Supervisor advised Driver 3012 to continue in passenger service as far as the Red Cow before terminating and to proceed into the Red Cow Depot as there was no documentation to provide guidance on the failure mode (paragraphs 39).

94 Tram 3012 continued to the Red Cow, without further issue, where the severity of the incident was discovered, and the appropriate actions taken.

Previous occurrences

95 The tram operator had reported that previous cases of cable failure had been attributed to aqueous corrosion, due to entry of water into the cable, through the lugs. However, on the cables which are the subject of this report, only superficial aqueous corrosion was evident, which was not considered to have contributed to the failure.

96 TDLR advised that there have been no previous occurrences of cables failing in this manner.

Analysis

Tram 3012 Maintenance

97 Tram 3012 received its scheduled maintenance, as required (paragraphs 58 to 60). The last scheduled maintenance for Tram 3012 was on the 28th August 2022 (paragraph 58).

98 Between the 28th September and the 5th October 2022, Tram 3012 was subject to wheel turning, with WI-00814 providing comprehensive stepped guidelines on the tasks to be undertaken (paragraphs 52 to 56).

99 WI-00814 requires disconnection of the Current Return and Earth Shunt Cables (paragraph 52). Before the re-attachment of the Earth Return and Earth Shunt Cables, the cable ends should be checked for corrosion and contactal paste coated onto the contact surfaces of the Earth Return and Earth Shunts Cables (paragraph 53).

100 Given that the wheel turning work was concluded twenty days before the failure, there is likely to have been some corrosion, given the amounts of soiling and oxidation present on S1 Current Return and S3 Earth Shunt Cables (paragraph 68) post failure examination, however, this was not reported to the team leader (paragraph 87).

101 In addition, there was no evidence of contactal paste (which protects against corrosion and resists oxidation) on the cable Lugs close to the point of failure (paragraph 68).

Cable Failures

102 It is likely that creep failure mechanism was taking place over a number of years but the rate of failure increased significantly after the wheel turning activity, where elevated temperature creep accumulated (as a result of soiling and oxidation on the Lugs), on both the S1 Current Return and S3 End Shunt Cables, with successive failures of individual strands eventually resulting in S1 Current Return Cable severing and S3 Earth Shunt Cable failing immediately afterwards, also leading to the overheating of S3 Axle End Assembly (the full failure mechanism is outlined in paragraphs 70 to 83).

Conclusions

Causal, contributing, and systemic factors

103 The mechanism of failure of S1 Current Return Cable was as a result of elevated temperature creep initiating from soiling and oxidation of the cable Lugs, when severed, resulted in overloading on S3 Earth Shunt Cable, which failed immediately afterwards, and finally resulting in the overloading and overheating of S3 Axle End Assembly.

104 The RAIU have identified the following likely causal factors to the failure mechanism:

- CaF-01 – Soiling and oxidation on S1 Current Return and S3 Earth Shunt Cable ends, which was likely to have been present during the wheel turning process twenty days before the incident, was not reported to the team leader, as set out in WI-00814;
- CaF-02 – Contactal paste (used to protect against soiling and oxidation) was not coated on the contact surfaces of S1 Current Return and S3 Earth Shunt Cables at the time of re-attachment as part of the wheel turning process twenty days before the incident, as required by WI-00814.

105 The following may have been a contributory factor:

- CoF-01 – WI-00814 does not have any supporting guidance documents in relation to identifying defects, to assist maintenance technicians in their requirements to report defects to the team leaders.

Additional observations

106 Although not causal, contributing, or systemic to the incident on the 25th October 2022, the RAIU make the following additional observations:

- AO-01 – TDLR did not immediately notify the RAIU of the incident and partially disassembled evidential components from Tram 3012 prior to notification;
- AO-02 – Tram 3012 remained in passenger service with a live high voltage cable protruding from the underframe; as the TDLR suite of documents for Traffic Supervisors in the safe management of trams does not contain any reference on how to respond to equipment protrusions from a tram;
- AO-03 – There is no location on the Wheel Turning Certificate to record the torque wrench asset number or torque testing, as set out in WI-00814;
- AO-04 – Fleet audits carried out by the MTM did not identify that the tasks outlined in Paragraph 14 of WI-00814 were not carried out as prescribed and a torque wrench was not signed out for the completion of the task.

Measures taken since the incident

Measures taken by TDLR since the incident

107 TDLR carried out their own review and also held technical meetings with both the RAIU and the CRR, and as a result carried out the following measures in terms of safety of the fleet:

- Removed Tram 3012 from service and removed the bogie from the tram for full inspection;
- Carried out a fleet check of the condition of the Current Return Cables in the immediate aftermath post failure, which was completed by the end of October 2022;
- Carried out an in-depth check the security of the Current Return Cables (pull check), condition of the wiring and signs of overheating of the cables or connections; which was completed in early December 2022;
- Carried out an inspection of Current Return Cables on the fleet to ensure they were not loose; which was completed in early December 2022.

108 As part of the fleet check of the condition of the Current Return Cables in the immediate aftermath post failure, Tool Box Talks were given to all the maintenance technicians to highlight the requirements of Step 14 of WI-00814 in terms of reporting corrosion and coating cables with a small amount of contactal paste (paragraph 53).

109 TDLR issued two Safety Notices in relation to the incident. The first safety notice, SN 021/2022, issued on the 8th November 2022 and displayed for two months, was addressed to drivers, reminding them of the normal reporting procedures, stating:

- For your safety do not touch the component;
- If not already at a platform stop your tram at the next platform;
- Contact the LNMC immediately and give a full description;
- Wait for instructions from the LNMC.

110 On the 31st August 2023, Safety Notice SN 07/2023 was issued for display for two months, which included the information for drivers, similar to the above. In addition, this safety notice included instructions to Traffic Supervisors who have been notified of a defect by a driver, the actions are to contact the MTM for the relevant line, explain the situation and request advice from the MTM as to the following:

- Tram to be removed from service and returned to depot;
- Tram to be removed from service, de-prepped and out stabled in shunt while it awaits a maintenance inspection;
- Tram to be de-prepped in situ and tow pushed back to the depot;
- Should there be any risk to passengers ensure they are de-trammed away from the exposed component.

111 In terms of documentation associated with the incident, TDLR have added TDLR-FRM-ENG-023 Citadis 401 Wheel Turning Certificate to a list of certificates to be updated.

112 TDLR have also updated their Fleet Audit Objectives document, added to the requirements are:

- All necessary signatures to be in place;
- Checklists to be filled in correctly;
- Document calibrated/torqued tools and values, where called for.

Measures taken by the CRR since the incident

113 The CRR published a Post-Occurrence Inspection report into the incident, entitled "Tram Electrical Cable Fault on 25th October 2022", in September 2023 (Supervision Activity No. 229/22-POA). The report made a number of findings, namely:

- Finding 1 – The components involved in the incident were partially disassembled by TDLR before notification was made to the CRR and RAIU;
- Finding 2 – Insufficient RFI responses were provided by TDLR to the CRR.
- Finding 3 – The Traffic Supervisor allowed the tram to continue to Red Cow Luas Depot with a live fault when (in accordance with TDLR-OP-M-0001 cl. 9.1) they should have consulted with the Depot Manager to confirm the best course of action.
- Finding 4 – The driver who reported the fault misidentified the cable to be a "hose". A failed hose of unknown origin had the potential to be a serious defect according to TDLR-OP-PR-0003 and ENG-IE-INX-001 and the tram should have been stopped for review;
- Finding 5 – The quality controls in place at Red Cow Luas Depot were found to be insufficient to control the risk of unsecured critical fasteners;
- Finding 6 – The Current Return Device was subject to maintenance on 28/09/2022 whereby its earth cables were detached and reattached. Torque markings appear to have been applied incorrectly and no records exist of the tool used to torque the earthing cable bolt;
- Finding 7 – Outside of a poster located in the depot, there are no formal instructions, training or assessments for technicians on the correct method to be applied when securing critical fasteners;
- Finding 8 – There is no formal process in place for TDLR to review when a part or component of potentially tram-borne origin is identified on track;
- Finding 9 – 229/22-POA Action Plan 1[8] remains in progress.

[8] Upon the CRR finding that the use of calibrated tools in the depot was uncontrolled, a meeting was held on 20/04/2023 with the TDLR Head of Fleet and Head of Engineering to address the issue in the short term. An Action Plan was provided by the Head of Engineering which outlined the controls to be introduced and how the implementation of the controls would be monitored. At the time of completing this Post Occurrence Activity, some actions remain partially completed.

114 Two *Minor Non-compliances* were identified:

- 229/22-A miNC-01 – TDLR are found non-compliant with SMS Element B.4 through the non-application of TDLR-OP-M-0001 cl.9.0 (associated with Finding 3 and 4) with the associated recommendation “TDLR to put systems in place which ensure implementation of procedures which collect information on malfunctions and defects arising from day-to-day operation and to report them to those responsible for maintenance”;
- 229/22-A miNC-02 – TDLR are found non-compliant with SMS Element B.4 (associated with Finding 8). The following recommendation was made “TDLR to put a system in place which ensures any potential tram defects or tram components discovered during track walks are formally reported to those responsible for tram maintenance”.

115 Findings 5, 6 and 7 are being addressed through 229-22-POA Action Plan 1. As Action Plan 1 was not addressed by the date requested, the 2nd May 2023, there is an *Action Required* assigned to Finding 9, namely:

- 229/22-POA AR 1 – Closeout of 229/29-POA Action Plan 1. The associated recommendation is “TDLR are to complete their Action Plan which is intended to address the issues identified with the quality control of critical fasteners”, this must be completed within one month.

116 The following *Scopes For Improvements* were made in relation to two of the findings:

- TDLR should review their process for formally inspecting failed trams. TDLR should review their process of engineering inspections with a view to ensuring that evidence is preserved should a failed tram have potential to be involved in a *Notifiable Occurrence* (Finding 1);
- TDLR should consider briefing the responsible heads of department on the Railway Safety Act 2005 (Finding 2).

117 All outcomes outlined in paragraphs 114 to 116 are at status “open”, as of the time of publication of this RAIU report, meaning that feedback/ evidence from TDLR being sent to the CRR is pending or actions have not yet been completed.

Safety Recommendations

Introduction to safety recommendations

118 In accordance with the European Union (Railway Safety) (Reporting and Investigation of Serious Accidents, Accidents and Incidents) Regulations 2020), RAIU safety recommendations are addressed to the NSA, the CRR, and directed to the party identified in each safety recommendation.

Absence of safety recommendations due to measures already taken

119 As a result of the measures already carried out by TDLR in relation to fleet checks of the cables (paragraph 107), a safety recommendation is not warranted in relation to the equipment i.e. no modifications are required as the incident was as a result of maintenance tasks not being carried out in full.

120 Tool Box Talks have been given to maintenance technicians in relation to Step 14 of WI-00814 in terms of reporting corrosion and coating cables with a small amount of contactal paste (paragraph 108); this has addressed CaF-01 and CaF-02 (paragraph 104)

121 TDLR have also updated their Fleet Audit Objectives document and have added checks for signatures to be in place, checklists to be filled in correctly and for calibrated/torqued tools and values to be documented, where required (paragraph 112); this has addressed AO-03 (paragraph 106).

Safety recommendations as a result of this incident

122 WI-00814, Preparation before and after wheel turning is an eighteen page document detailing actions that are required to prepare the tram for wheel turning and the reinstatement of components post turning. WI-00814 is enhanced with thirteen photographs to assist the Maintenance Technician completing the tasks but there is no photograph showing the different levels of corrosion on the Current Return and Earth Shunt cables Lugs and the required actions. As a result, the RAIU make the following safety recommendation to address CoF-01 (paragraph 106):

Safety Recommendation 2023004-01

TDLR should develop supporting guidance documentation to WI-00814, Preparation before and after wheel turning, to include information on possible defects e.g. photographs of unacceptable levels of corrosion on the Current Return and Earth Shunt cable Lugs.

Safety recommendations as a result of additional observations

123 The failure of a Current Return Cable or Hose is not covered in any of the TDLR documents available to the Traffic Supervisor in deciding a course of action to be taken in the event of a failure. Although noted that Safety Notice SN 07/2023 provided instructions to Traffic Supervisors in relation to actions to be taken when a defect is reported by a drivers (paragraph 110), this now needs to be incorporated into relevant documentation, as a result the RAIU make the following safety recommendation to address AO-02 (paragraph 106):

Safety Recommendation 2023004-02

TDLR should consider updating LNMC Manual Document (TDLR-OP-M-0001) to include guidance for Traffic Supervisors in relation to actions to be taken in the case of failed cables and hoses.

124 WI-00814, Preparation before and after wheel turning requires the asset number and a test of the torque wrench to be carried out but does not state where the asset number should be recorded. TDLR-FRM-ENG-023 Citadis 401 Wheel Turning Certificate Issue A November 2020 contains space for the Maintenance Technician to record many critical dimensions and conformation of completing tasks. The recording of the torque wrench test, serial number and torque achieved in the Certificate would provide an easy means of spot checking by the MTMs that all safety critical tasks were completed. Although, noted that TDLR-FRM-ENG-023 is scheduled to be updated (paragraph 111), the RAIU consider that the following safety recommendations are warranted to address AO-02 (paragraph 106):

Safety Recommendation 2023004-03

TDLR should consider updating WI-00814, Preparation before and after wheel turning to include the recording of the testing and serial number of the torque wrench into TDLR-FRM-ENG-023 Citadis 401 Wheel Turning Certificate Issue A November 2020.

Safety Recommendation 2023004-04

TDLR should consider updating the Wheel Turning Certificate to provide a space for the torque wrench registration number conformation of test and torque value achieved when reattaching the Current return and Earth Shunt cables with a space for sign off.

125 TDLR maintenance partially dissembled evidential components from Tram 3012, prior to notifying the RAIU, despite being aware that an electrical cable, rather than a hose was severed (paragraph 22). To RAIU make the following safety recommendation to address AO-01 (paragraph 106):

Safety Recommendation 2023004-05

For instances where rolling stock is withdrawal from service as a result of damage; TDLR should develop notification procedures to identify where immediate notification to the RAIU is required[9].

[9] Excepting certain condition, such as damage as a result of road traffic collisions where a road vehicle has breached the traffic lights.

Additional Information

List of abbreviations

AC	Alternating Current
AO	Additional Observations
CaF	Causal Factors
CCE	Chief Civil Engineer
CME	Chief Mechanical Engineer
CoF	Contributory Factors
CRR	Commission for Railway Regulation
DART	Dublin Area Rapid Transport
DC	Direct Current
ESS	Electrical Sub-Station
EU	European Union
hr	hour
IMC	Infrastructure Maintenance Contractor
km	kilometre
km/h	kilometres per hour
LED	Light Emitting Diodes
LNMC	Luas Network Management Centare
m	metre
mph	miles per hour
MTM	Maintenance Team Manager
NSA	National Safety Authority
Nm	Newton Meters
OCS	Overhead Contact System
PIC-RRV	Person In Charge Road Rail Vehicle
PTS	Personal Track Safety
RAIU	Railway Accident Investigation Unit
RFI	Request for Information
SI	Statuary Instrument
SI	International System of Units
SMS	Safety Management System
TDLR	Transdev Dublin Light Rail

Glossary of terms

Accident	An unwanted or unintended sudden event or a specific chain of such events which have harmful consequences. For heavy rail, the EU Agency for Railways divides accidents into the following categories: collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others.
Accident to persons due rolling stock in motion	Accidents to one or more persons that are either hit by a railway vehicle or part of it or hit by an object attached to or that has become detached from the vehicle. Persons that fall from railway vehicles are included, as well as persons that fall or are hit by loose objects when travelling on-board vehicles.
Action Required	The CRR define an AR as an area where potential exists for a non-compliance to occur unless remedial action is taken or improvement is made, an isolated error that requires correction, or some other action arising from the audit.
Alternating Current	Alternating Current (AC) is a type of electrical current, in which the direction of the flow of electrons switches back and forth at regular intervals or cycles.
Arcing	Arcing, or electrical arcing, occurs when an electric current flows through the air from one conductive point to another.
Article 20 of Directive (EU) 2016/798, Obligation to investigation	Article 20 (1) Member States shall ensure that an investigation is carried out by the investigating body referred to in Article 22 after any serious accident on the Union rail system. The objective of the investigation shall be to improve, where possible, railway safety and the prevention of accidents. Article 20 (2) The investigating body referred to in Article 22 may also investigate those accidents and incidents which under slightly different conditions might have led to serious accidents, including technical failures of the structural subsystems or of interoperability constituents of the Union rail system. The investigating body may decide whether or not an investigation of such an accident or incident is to be undertaken. In making its decision it shall take into account: (a) the seriousness of the accident or incident;

	(b) whether it forms part of a series of accidents or incidents relevant to the system as a whole; (c) its impact on railway safety; and (d) requests from infrastructure managers, railway undertakings, the national safety authority or the Member States.
Aqueous corrosion	Is an electrochemical reaction of materials due to a wet environment, resulting in the deterioration of the material and its vital properties.
Bogie	A metal frame equipped with wheelsets and able to rotate freely in plan, used in pairs under rail vehicles to improve ride quality and better distribute forces to the track.
Causal Factor	Any action, omission, event or condition, or a combination thereof that if corrected, eliminated, or avoided would have prevented the occurrence, in all likelihood.
Contributing Factor	Any action, omission, event or condition that affects an occurrence by increasing its likelihood, accelerating the effect in time or increasing the severity of the consequences, but the elimination of which would not have prevented the occurrence.
Contactal paste	Contactal paste (contact paste) is a conductive mineral grease and applied for electrical contacts on rolling stock. Two of the main advantages for using the paste is the protection against corrosion against external pollutants (dust, vapours, electrolytes, etc) and resistance to oxidation.
Current Return Cable	The return circuit (from the pantograph) is via the Current Return Cable, through the Axle End Assembly and wheel rail interface back to the ESS.
Direct Current	Direct current (DC) is an electric current that is uni-directional, so the flow of charge is always in the same direction.
Earth Shunt Cable	The purpose of the Earth Shunt Cable is to discharge any static charge and to carry return current in case of any disconnection in return current circuit.
Incident	Any occurrence, other than an accident or serious accident, associated with the operation of trains and affecting the safety of operation. For heavy rail, the EU Agency for Railways divides incidents into the

	following categories: infrastructure; energy; control-command & signalling; rolling stock; traffic operations & management and others.
Inverter	Fundamentally, an inverter accomplishes the DC-to-AC conversion by switching the direction of a DC input back and forth very rapidly. As a result, a DC input becomes an AC output.
Investigation	A process conducted for the purpose of accident and incident prevention which includes the gathering and analysis of information, the drawing of conclusions, including the determination of causes and, when appropriate, the making of safety recommendations
Lugs	Are devices used for connecting cables to electrical appliances, other cables, surfaces, or mechanisms.
Minor Non-Compliance	The CRR define a minor non-compliance as an area of non-compliance with a railway organisation's internal, an applicable external standard, or legislation that is evidence of a sporadic lapse in implementation of a system or deviation from a system.
Notifiable Occurrence	The CRR and the RAIU have agreed occurrence types that have to be notified to the relevant bodies in set time constraints.
Oxidation	Iron metal is oxidised and forms an iron oxide which is known as rust.
Safety Critical	system is a system whose failure or malfunction may result in one (or more) of the following outcomes: death or serious injury to people. loss or severe damage to equipment/property/environmental harm.
Scope for improvement	The CRR define a scope for improvement as an area highlighted where, in the opinion of the Auditor, system or business improvement can be achieved by the company. Typically this is phrased as a recommendation, the merits and implementation of which should be decided by audited organisation.
Serious Accident	Any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other similar accident with an obvious impact on railway safety regulation or the management of safety. For heavy rail, the EU Agency for Railways divides serious accidents into the following categories:

	collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others.
Shunt	Shunt is a device that creates a low-resistance path for electric current, to allow it to pass around another point in the circuit.
Stereomicroscope	A stereomicroscope, sometimes called a dissecting microscope or a binocular inspection microscope, is a low-power compound instrument used for a closer examination of three-dimensional specimens than is possible with a hand lens.
Systemic factor	Any causal or contributing factor of an organisational, managerial, societal or regulatory nature that is likely to affect similar and related occurrences in the future, including, in particular the regulatory framework conditions, the design and application of the safety management system, skills of the staff, procedures and maintenance.
Thermal oxidation	Is the production of a thin layer of oxide on the surface of a material. The process forces an oxidizing agent to diffuse into the material at high temperature and react with it.
Torque Wrench	A tool used to tighten nuts and bolts to a predetermined torque value.
Wheel turning	Is the machining of worn material from a wheel to remove wheel defects and to reprofile the wheel.

References

CRR (2023), Tram Electrical Cable Fault on 25th October 2022, 229/22-POA.

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