Railway Accident Investigation Unit Ireland

INVESTIGATION REPORT

Overhead Line detachment, Pearse Station,

1st October 2020

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Report Description

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

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Report structure

The report structure is taken from guidelines set out in “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.

Preface

The RAIU is an independent investigation unit within the Department of Transport (DOT) which conducts investigations into accidents and incidents on the national railway network, 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 might 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 purpose of RAIU investigations is to make safety recommendations, based on the findings of investigations, 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.

Summary

At approximately 12:55 hours (hrs) on Thursday 1st October 2020, the 12:04 hrs Iarnród Éireann (IÉ) DART service from Greystones to Howth (Train E920) was coming to a stop in Pearse Station when the second *pantograph* (Pantograph 396) of the train set (Unit 8128) lost contact with the *Contact Wire* of the *Overhead Line Equipment* (OHLE). The Pantograph Head and Upper Arm lowered rapidly resulting in the Pantograph Lower Arm extending to its maximum reach and contacting the OHLE. This action caused the Pantograph Lower Arm to flip, driving the Upper Arm and Pantograph Head on to the roof of the train resulting a short circuit and a large *flashover*. The short circuit caused a loss of power to the OHLE in the section. Train E920 coasted before been brought to a stop, on Platform 1, by the driver (Driver E920).

Driver E920, having heard the noise from the flashover, stepped onto Platform 1 to check the train and after observing the OHLE vibrating, returned to the cab and pressed the "*Pan Down*" button. This resulted in the lead and rear pantographs lowering but the Lower Arm of the Pantograph 396 did not lower (which was later determined to be as a result of the failure of the pantograph chains).

The DART electrification system is fitted with an *Auto* Reclose function which allows a high speed circuit breaker to automatically reclose after a tripping event provided a successful Line Test has been passed. After the pantograph failure, and following a successful Line Test, the Auto Reclose restored power to the OHLE causing a second short circuit. This resulted in the *Catenary Wire* from the OHLE breaking and falling onto Platform 1. While the Catenary Wire was on Platform 1 a second Auto Reclose resulted in power been restored to the fallen Catenary Wire. The Catenary Wire remained live on Platform 1 for approximately forty-six seconds before the Electrical Control Operator (ECO) isolated the section. There were two passengers on Platform 1 at the time but not in the vicinity of the fallen Catenary Wire.

Passengers were detained on the train until confirmation of an isolation had taken place. There were no reports of injuries.

The Catenary Wire of the OHLE detached, and was live on Platform 1, as a result of the following *causal factors* (CaF):

- CaF-01 – The short circuit between the Pantograph Head and the roof of the train caused the Catenary Wire to overheat, reducing its strength, detaching and falling onto Platform 1;
- CaF-02 – The OHLE in Pearse Station is positioned at 4.46 m above the rail allowing the Pantograph Lower Arm to strike the OHLE in the event of a Pantograph elbow chain failure;
- CaF-03 - The elbow chains on Pantograph 396, on EMU 8128, failed due to excessive wear of the chain pins and chain link holes over a period of time due to the lack of lubrication;
- CaF-04 - The failure of Pantograph 396's elbow chains resulted in the Pantograph Lower Arm rising and the Upper Arm and Pantograph Head lowering; provided an electrical path for a direct connection between the OHLE and the train body;
- CaF-05 - The High Speed Circuit Breaker Auto-Reclose restored power to the failed section.

Contributory factors (CoF) include:

- CoF-01 – The Pantograph on EMU 8128 had not been overhauled for over eight years.

Systemic factors (SF) include:

- SF-01 – The pantograph planned preventative maintenance regime did not identify the deterioration in the chains of Pantograph 396 or the poor condition of the grease that had previously been applied;
- SF-02 – The information contained in the IÉ CME-TMS-316 Department Engineering Change files for the extension of the pantograph overhaul from three to five years does not substantiate the conclusion reached, highlighting a lack of governance in the outsourcing of the overhaul of EMU pantographs;
- SF-03 – The compliance checks on the EMU fleet did not include the checking of pantographs.

The RAIU made the following safety recommendations:

- Safety Recommendation 202105-01 – IÉ Railway Undertaking (RU) Chief Mechanical Engineer's (CME) Department should in conjunction with the Original Equipment Manufacturer (OEM) develop a maintenance regime for the pantographs, taking into consideration the operational conditions and traceability of safety critical components;
- Safety Recommendation 202105-02 – IÉ-RU CME Department should carry out, in conjunction with the OEM, a condition assessment to determine the correct period for the overhaul of the IÉ-RU pantographs;
- Safety Recommendation 202105-03 – IÉ-RU and IÉ Infrastructure Manager (IM) should review the current Engineering Change Request and Safety Approval of Changes documents, to ensure that the appropriate stakeholders are consulted, and the correct processes followed;
- Safety Recommendation 202105-04 – IÉ-RU CME to include requirements to check pantograph maintenance activities in the Compliance Coordinators documentation records / check sheets.
- Safety Recommendation 202105-05 – IÉ-IM Signalling, Electrical and Telecommunications (SET) Department should evaluate the auto-reclose function of the OHLE control system on the DART network to ensure the safe operation in the event of failures which could expose staff and passengers to live OHLE.

In addition, the RAIU made two safety recommendations as a result of additional observations:

- Safety Recommendation 202105-06 – IÉ-RU CME to include requirements to check Class 8100 EMU Forward Facing Closed Circuit Television (FFCCTV) maintenance activities in the Compliance Coordinators documentation records / check sheets;
- Safety Recommendation 202105-07 – IÉ-RU CME to review and develop a maintenance strategy for the 8100 EMU On Train Data Recorders (OTDRs) to ensure that the correct information is recorded.

Contents

RAIU Investigation

RAIU decision to investigate

1 In accordance with the Railway Safety Act 2005 and Statutory Instrument No. 258 of 2014 European Union (Railway Safety) (Reporting and investigation of Serious Accidents, Accidents and Incidents) Regulations 2014, the RAIU investigate *serious accidents*, the RAIU may also investigate and report on *accidents* and *incidents* which under slightly different conditions might have led to a serious accident.

2 The RAIU on call investigator received a notification of the OHLE failure at Pearse Station on 1st October 2020. After the RAIU conducted a Preliminary Examination, the RAIU's Chief Investigator (CI) made the decision to conduct a full investigation into the failure, given its impact on railway safety (*Article 20* (2) (c)), as under slightly different circumstances the failure may have led to serious accident with the potential for fatality or serious injuries due to the live Catenary Wire falling onto Platform 1.

3 In terms of categorisation, the EU Agency for Railways categorisation for this occurrence is an: Incident – Energy.

4 The RAIU's CI allocated RAIU Senior Investigators, trained in accident investigation, to conduct this investigation, as appropriate. In this instance, no external parties were required to assist with the investigation.

Scope & limits of investigation

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

- Establish the sequence of events leading up to the failure;
- Identify any other precursors which led to the failure;
- Establish, where applicable, causal, contributing and systemic factors;
- Examine the failure mode of Pantograph 396;
- Examine the relevant operation, standards and manuals in relation to the monitoring and reinstatement of OHLE power in the event of a failure.

Communications & evidence collection

6 During the investigation, the RAIU collate evidence through the submission of Requests for Information (RFIs) and interviewing. Related to this investigation, the RAIU collated and logged the following evidence:

- Closed Circuit Television (CCTV) of the incident from Pearse Station CCTV;
- Witness statements from parties involved in the investigation into the failure;
- Maintenance specifications for the pantograph from IÉ-RU and the OEM;
- Maintenance interventions to Pantograph 396 since its last overhaul;
- A copy of the IÉ Chief Chemist and Metallurgist report into Pantograph 396 failure;
- Maintenance records for the inspection and repair of the OHLE at Pearse Station;
- Event log from the Traction Power Supply, Supervisory Control And Data Acquisition (SCADA) system;
- Analysis of the OTDR;
- OHLE digital control and protection unit for line feeder cubicles in Direct Current (DC) traction networks manual.

7 All relevant parties co-operated fully with the RAIU investigation; with no difficulties arising.

Other stakeholder inputs

8 No judicial authorities or emergency service were involved in this incident.

Other information relevant to the investigation process

9 In this investigation, there is no other information relevant to the investigation process.

RAIU report format

10 The RAIU report is divided into a number of key sections, namely:

- Summary of the failure & background information – which provides factual information surrounding the incident, including:
  - Synopsis of the incident, which provides an abridged version of failure events;
  - External circumstances surrounding the failure or accident location (such as weather conditions or location geography);
  - Consequences of the failure, including fatalities, injuries or material damage;
  - Parties and roles associated with the incident;
  - Description of the relevant parts of infrastructure, rolling stock, signalling and communications, operations or other equipment associated with the incident.
- Evidence – which provides further factual details on supporting information for the background information, for example, this section may include details on: Safety Management Systems, standards and procedures; risk assessments, etc;
- Events before, during and after the accident – which gives a proximate chain of events:
  - Leading up to the occurrence including actions taken by persons involved; the functioning of rolling stock and technical installation and the operating system;
  - During the occurrence, by describing the occurrence;
  - After the occurrence including: occurrence consequences; measures taken to protect the occurrence site; and, the efforts of the rescue and emergency services.
- Similar occurrences – which outlines occurrences similar in nature to the occurrence subject to this report.
- Analysis – which analyses the combined findings from the above established facts, such as: roles and duties; rolling stock and technical installations; human factors; feedback and control mechanisms; and, trends related to similar occurrences.
- Conclusion – which includes: concluding information from the analysis of the factual findings; measures taken since the occurrence; additional observations.
- Safety Recommendations – where appropriate, safety recommendations will be made with the sole aim of preventing a similar occurrence in the future; safety recommendations may also be made as a result of additional observation with the aim of prevent another type of occurrence. The absence of safety recommendation shall be explained.

Summary of the failure & background information

Synopsis of the incident

11 At approximately 12:55 hrs on Thursday 1st October 2020, the 12:04 hrs DART service from Greystones to Howth (Train E920) was coming to a stop in Pearse Station when the second pantograph (Pantograph 396) of the train set (Unit 8128) lost contact with the Contact Wire of the OHLE. The Pantograph Head and Upper Arm lowered rapidly resulting in the Pantograph Lower Arm extending to its maximum reach and contacting the OHLE. The action caused the Pantograph Lower Arm to flip, driving the Upper Arm and Pantograph Head on to the roof of the train causing a short circuit and a large flashover. The short circuit resulted in a loss of power to the OHLE in the section. Train E920 coasted along Platform 1 before been brought to a stop by Driver E920.

12 Driver E920, having heard the noise from the short circuit, stepped onto Platform 1 to assess the train. Driver E920 saw the OHLE vibrating, returned to the cab and pressed the “Pan Down” button. This resulted in the lead and rear pantographs lowering but the Lower Arm of the Pantograph 396 did not lower (which was later determined to be as a result of the failure of the pantograph chains).

13 The DART electrification system is fitted with an Auto Reclose function which allows a high speed circuit breaker to automatically reclose after a tripping event, provided a successful Line Test has been passed. After the pantograph failure, and following a successful Line Test, the Auto Reclose restored power to the OHLE causing a second short circuit. This resulted in the Catenary Wire from the OHLE breaking and falling onto Platform 1. While the Catenary Wire was on Platform 1 a second Auto Reclose resulted in power been restored to the fallen Catenary Wire. The Catenary Wire remained live on Platform 1 for approximately forty-six seconds before the ECO isolated the section. There were two passengers on Platform 1 at the time but not in the vicinity of the fallen Catenary Wire.

14 Passengers were detained on Train E920 until confirmation of an electrical isolation had taken place. There were no reports of injuries at the time of the incident.

External circumstances at the incident location

Weather

15 The weather was mainly dry and fine; weather data was taken from the nearest Met Éireann Weather Station at Phoenix Park, 5 kilometres (km) North-West of Pearse Station, recorded that there was no rainfall at the time of the incident. The maximum temperature was recorded at 9 ºC, and mean wind speed was recorded at 7 knots.

16 As the incident took place under the canopy of the station; the weather conditions were not contributory to the incident.

Fatalities, injuries & material damage

Fatalities & injuries

17 There were no fatalities or injuries to staff or members of the public as a result of the incident.

Material damage

Pantograph

18 The chains at the Elbow of Pantograph 396 were broken and the 4th Bar was bent (see Figure 10 for locations of damage), the damage was estimated at €6,576.

OHLE

19 The Catenary Wire from the OHLE separated and a section of the wire had to be replaced. The bridle wire supporting the Catenary Wire had frayed under tension during the incident and also had to be replaced. The damage to the OHLE was estimated at €18,500.

Other consequences as a result of the incident

20 There was a total of 1,091 delayed primary minutes to Train E920 and thirty-eight other trains and 1,530 delayed secondary minutes to another seventy-eight other train services. Eleven passenger services were cancelled.

Parties & roles associated with the incident

Parties involved in the incident

21 IÉ-RU is the railway undertaking (RU) who owns and operates mainline and suburban railway services in Ireland and operates under a safety certificate issued by the Commission for Railway Regulation (CRR). The RU Safety Certificate is issued in conformity with European Directive 2004/49/EC and S.I. 249 of 2015; the Safety Certificate was renewed on 23rd March 2018 for a period of five years. The IÉ-RU department involved in this incident and relevant to this investigation is:

- IÉ-RU Chief Mechanical Engineer's (CME) Department – The European Union (EU) Entity in Charge of Maintenance (ECM), responsible for the specification, purchasing, commissioning and maintenance of rolling stock, including management of the maintenance depots, associated personnel, and procedures. Support on technical matters is provided through the CME's Fleet Technical Support (FTS) staff.

22 IÉ–IM is the infrastructure manager (IM) who owns and operates the railway infrastructure in Ireland and operates under a Safety Authorisation certificate issued by the CRR. The IM Safety Authorisation is issued in conformity with Commission Regulation (EU) 1169/2010; the authorisation was renewed on the 24th March 2018 for a period of four years. The IÉ-IM department involved in the incident and relevant to this investigation is:

- IÉ-IM SET Department – Responsible for the design, inspection, maintenance, and renewal of the railway's SET system, including the OHLE, and the management of risks associated with these assets.

Parties not directly involved in the incident

23 Brecknell Willis the OEM of the pantographs. Brecknell Willis are now part of the Fandstan Group which is owned by the Wabtec Corporation. Wabtec have been contracted to overhaul IÉ-RU pantographs since May 2016.

24 Neopul Ireland a subsidiary of Sacyr specialising in the electrification and maintenance of railway infrastructure and who carry out OHLE inspections on behalf of IÉ-IM.

Roles involved in the incident

25 The roles involved in the incident, from IÉ-RU, are as follows:

- Driver E920 – Driver of Train E920. Driver E920 holds a current train driver's licence and has been in the driving grade nine years.

26 The roles involved in the incident, from É-IM, are as follows:

- ECO – Responsible for both the electrical control and monitoring of the traction power condition for each substation and switch house and is located at the ECO Desk at Centralised Traffic Control (CTC), in Connolly. The ECO had been in the role for thirteen years.

Infrastructure

27 Pearse Station is situated at the 0 Mile Post (MP) on the Dublin South Eastern Line, Figure 1, and comprises of a double line with two platforms, Platform 1 (northbound) and Platform 2 (southbound), which are 190 metres (m) and 192 m in length, respectively.

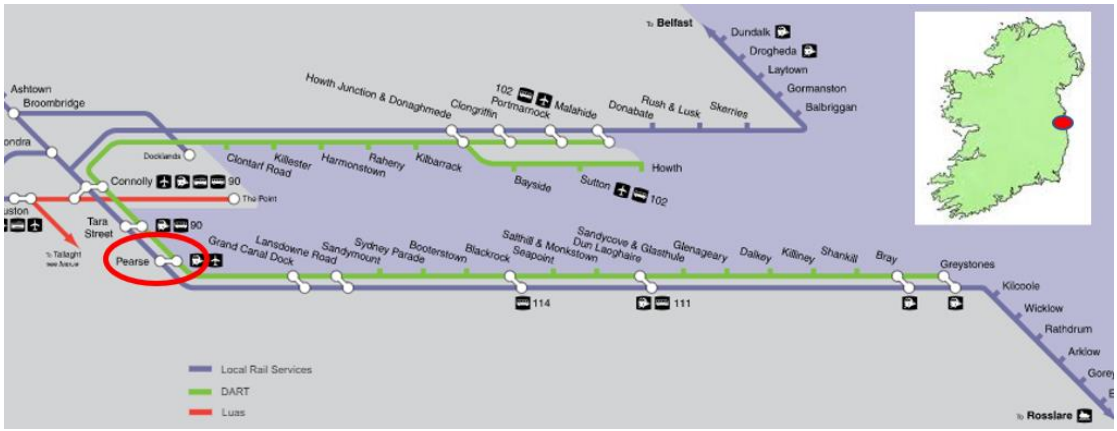

Figure 1 – Location of Pearse Station

28 The IÉ electrified rail system was originally installed in 1983 between Howth and Bray Stations and extended in 1999 from Howth Junction to Malahide and from Bray to Greystones for the DART system. The route compromises of 54 km of double track and 8 km of single line (Bray to Greystones). The OHLE supplies traction current of 1,500 volts DC to electric trains and is controlled by the ECO located at the ECO Desk in CTC.

29 There is OHLE installed through Pearse Station which forms part of the electrification for the DART system, see Figure 2. The IÉ-IM electrification system is further discussed in the Evidence section of this report, see paragraphs 43 to 53.

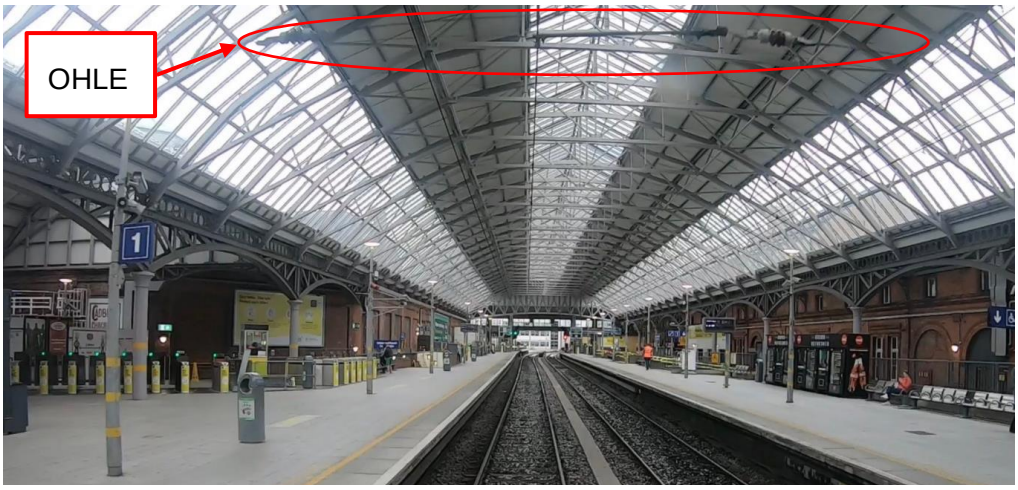

Figure 2 – The OHLE at Pearse Station

Rolling Stock

General description

30 Train E920, the train involved in the incident, was an 8100 EMU. 8100 EMUs were manufactured by Linke-Hofmann-Bush in Germany and entered service in Ireland in 1984.

31 The 8100 EMU fleet are two car sets with both bogies of the motor car providing traction and the second car in the set comprising of two non-powered bogies. The motor cars have a pantograph for collection of the 1,500V DC from the OHLE, pantographs are discussed in paragraphs 58 to 74. The two cars set can be coupled to additional units to give a maximum eight carriages in service.

32 Train E920 was made up of three, two-carriage 8100 EMU sets, coupled together, comprising of 8131-8331, 8128-8328, and 8118-8318 with 8131 leading, see Figure 3.

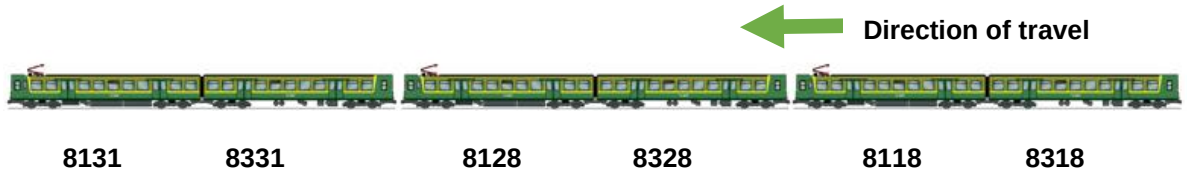

Figure 3 – EMU involved in the incident

33 The above configuration is approximately 126 m long with a combined weight of 213.78 tonnes.

34 The maximum permitted speed for an 8100 EMU is 100 km/h subject to permanent or temporary speed restriction on the route.

Forward-facing CCTV

35 FFCCTV cameras are fitted to the 8100 EMU fleet. At the time of the incident the FFCCTV was not operational on the lead unit 8131 of Train E920. The CCTV has a system check every 20,000 km and also a system performance check once a year. The last CCTV check of EMU 8131 was on 23rd June 2020, 100 days before the incident. There are no compliance checks, during maintenance, of the FFCCTV tasks[1].

[1] Issues surrounding the FFCCTV have been identified as an additional observation, AO-01 (paragraph 131), and warrant a safety recommendation, 202105-06, paragraph 145.

On Train Data Recorder

36 The OTDR clock for EMU 8128 showed a time of 09:30 hrs for the incident whereas the correct time for the incident was 12:55 hrs as shown by the CCTV at Pearse Station and the SCADA system. At the time of the incident, it was noted that the 8100 EMU maintenance schedule does not prescribe an examination of the OTDR.

37 The RAIU have previously identified discrepancies in the OTDR inspection and maintenance and made a safety recommendation related to the OTDR maintenance in 2008[2]; which was closed by the CRR in 2010[3][4].

Signalling and communications

38 The route through Pearse Station is comprised of a double line with three aspect colour light signalling in place. The signalling system is designed to enable trains to be signalled bi-directionally when necessary. It is operated under track circuit block regulations, with train detection achieved by track circuits.

39 The route is also fitted with the Continuous Automatic Warning System (CAWS) and the Automatic Train Protection System (ATP). Train radio communication is provided throughout between drivers and the Central Signalmen, based at Centralised Traffic Control (CTC) in Connolly Station, Dublin.

40 No factors in relation to the condition of the signalling and communications systems were found to have contributed to the incident.

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[2] "Report into the Collision at Level Crossing XN 104 between Ballybrophy and Killonan on the 28th of June 2007" (published 2008) made a safety recommendation related to OTDRs, namely "IÉ to review the standards relating to on-board data recorders, ensuring that correct operation, accuracy and post incident downloads are effectively addressed".

[3] The CRR noted: "Demonstration was given of IÉ's Event Recorder Website which contains all manner of information and tutorial / instruction videos as to how to do certain activities, e.g., check dates, times, wheel diameter etc. The following fleets are covered: 071, 201 Class Locomotives, 22000, 29000 Class DMUs, 8100, 8500, 8510 & 8520 Class EMUs and the Mk4 Intercity".

[4] Issues surrounding the OTDR have been identified as an additional observation, AO-02 (paragraph 131), and warrant a safety recommendation, 202105-07, paragraph 146.

Operations

41 Trains travelling to Dublin Connolly are travelling in the Up direction, and trains travelling from Dublin Connolly are travelling in the Down direction.

42 The maximum permitted line speed within Pearse Station is 50 km/h.

Evidence

General Description of the IÉ Electrification System

43 The OHLE forms part of the overall DART electrification system, which is designed to distribute the 1,500V DC electric traction power to DART trains during the nominated traffic hours. The system is made up of four subsystems:

- Traction power supply – The traction power supply includes the substation which takes in power at 38 Kilovolts (kV) from the Electric Supply Board (ESB) Network, converts this power to 1,500 V DC supply and connects it to the OHLE system;
- OHLE – Distributes the 1,500 V DC to the electric trains via an overhead contact system which comprises of a Contact Wire, supported by a Catenary Wire, which is in turn supported by cantilever arms, head-spans, and *portal frames*;
- Traction return path – To complete the electric circuit the traction returns to the substation via the rails, traction bonding, impedance bonds, traction cabling and cross bonding;
- ECO Desk – Situated in the CTC, Connolly, the ECO is responsible for both the electrical control and monitoring of the traction power condition for each substation and switch-house. The control and monitoring are carried out via the SCADA (Supervisory Control and Data Acquisition) system.

Overhead Line Equipment

Physical Infrastructure

44 The OHLE distributes the 1,500 V DC to the electric trains via an overhead contact system which comprises of a Contact Wire, supported by a Catenary Wire, which is in turn supported by cantilever arms, head-span, and portal frames, see Figure 4.

45 The nominal height of the Contact Wire is 4.7 m above high rail level[5] but is decreased to a minimum of 4.2 m at overbridges and other low structures, increasing to 5.6 m at public road level crossings and to 5.1 metres in certain sidings.

46 The Contact Wire height at Pearse Station is 4.46 m above the rail. Due to the infrastructure in place at Pearse Station and to limit the visual impact of the railway electrification, the OHLE within the station structure is of a 'Head Span' arrangement (i.e. the OHLE is supported by a system of wires, as opposed to cantilever arms or portal frames). This arrangement has been in situ since 1983 without any major issues.

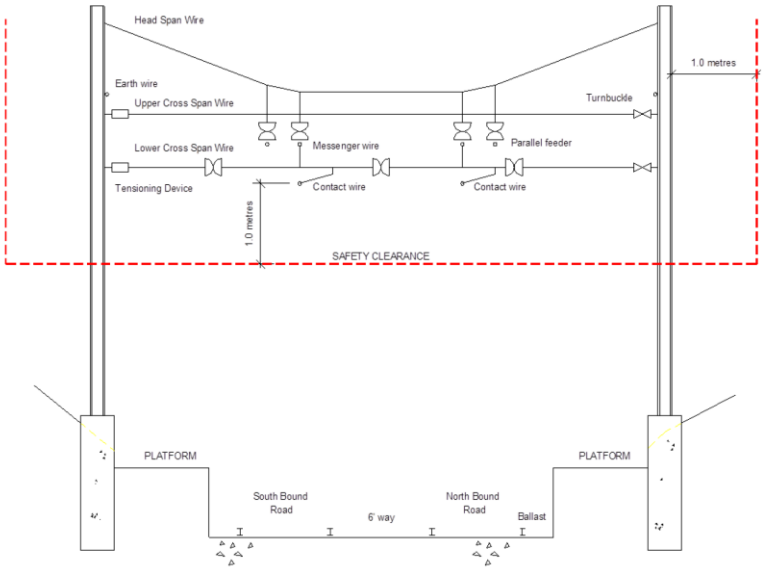

Figure 4 – Illustration of Overhead Line Equipment Head-Span arrangement

The Catenary Wire is labelled as the Messenger Wire in this illustration

47 The roof of Pearse Station was replaced in recent years, with the work being completed in July 2020, Figure 5 shows a cross section of the new roof design, with the Head Span design arrangement remaining.

[5] The Technical Specification for Interoperability (TSI) specify a 5 m height, but IÉ-IM have a derogation for the current DART system.

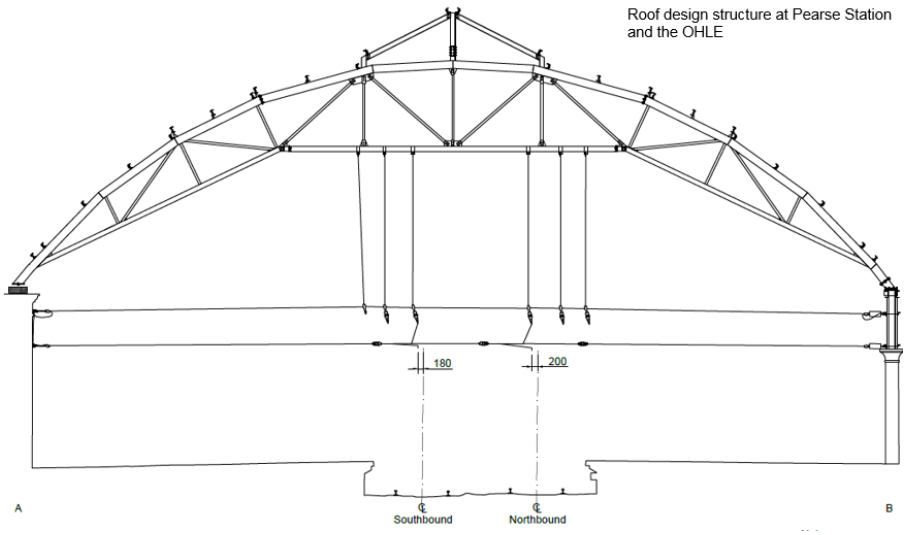

Figure 5 – Roof design structure and OHLE at Pearse Station

48 The OHLE is comprised of a series of discrete electrical sections (e.g. OHLE on any particular track between individual sub-stations and/or switch-houses is designated as a specific electrical section) and are given unique identification numbers. The OHLE in the Pearse area is within the electrical section known as PE109, which is divided into three subsections PE109 A, B and C. The section is approximately 1.5 km long and is made up of three tension lengths; Pearse is within "Tension Length" 202 i.e. Tension Length 202, is within subsection PE109, which in turn is within an electrical section.

OHLE Inspections and Maintenance

49 OHLE maintenance is carried out by Neopul Ireland on behalf of IÉ at three month intervals on tension lengths and specific assets within these lengths. In addition, there are a number of ground level inspections that are carried out.

50 The records indicated that the previous maintenance carried out on the Pearse OHLE section (Tension Length 202) was on 25th and 26th July 2020 as per the planned schedule. The records also indicated the following, relevant to the SET assets associated with Pearse:

- The annual traction substation maintenance was carried in July 2020;
- The high speed circuit breaker for the Pearse area was overhauled on the 21st March 2019;
- The annual Voltage Limiting Device maintenance was carried out on 10th August 2020;
- The SCADA system was maintained by the OEM engineers on 8th October 2019.

OHLE Digital Control and Protection System

51 The DART electrification system is fitted with a Digital Control and Protection (DCP) system (with integrated “Line Testing” and Auto-Reclose” functions. The system allows for a high speed circuit breaker to automatically reclose (Auto Reclose) after a tripping event, provided an automatic Line Test has been successfully passed. Three Auto-Reclose attempts are allowed in a one minute period before a lock out occurs and a period of fifteen seconds (for PE109 (Pearse)) must elapse before another Auto-Reclose attempt takes place.

Traction return path

52 The earthing of vehicle is achieved through earth connections and inter-vehicle earth bond cables ensuring a good electrical connection between the body of the train and wheelsets. Earth connections and inter-vehicle earth bond cables are checked every 10,000 km with a visual examination every 20,000 km (“A” Exam) and a more thorough examination every 20,000 km (“C” Exam); these examinations are alternated, so a visual examination or examination is carried out every 10,000 km.

53 It is noted that there is no requirement to measure the resistance of the earth bonding with the use of a digital Milliohm Meter Continuity Tester. Whereas, the resistance testing of the earth bonding is required on all other IÉ passenger vehicles[6].

[6] This has been identified as an Additional Observation, AO-03, paragraph 131. IÉ-RU have taken actions in relation to this additional observation (paragraph 137).

ECO's Desk

Supervisory Control and Data Acquisition (SCADA)

54 SCADA is a system of software and hardware elements that allows the ECO to monitor, gather and process real time data in relation to the OHLE and record the events into a log file. As well as monitoring the status of the OHLE the SCADA system can also carry out test functions, generate alarms and reinstate current after a fault. The SCADA log file for the time period (Figure 6), these are discussed further in this report.

01-10-2020 12:55:44.621	SS PE	109 DC	AL OT	CB static overcurrent trip	ON	First trip seen on system
01-10-2020 12:55:44.661	SS PE	856 DC	CB	DC rectifier circuit breaker	Open	Trip out
01-10-2020 12:55:44.698	TPH CY_	109 DC	CB	1.5 kV circuit breaker position indication	Open	Trip out
01-10-2020 12:55:44.729	TPH CY_	109 DC	AL1	Feeder lack of voltage	Alarm	Trip out
01-10-2020 12:55:44.843	SS PE	109 DC	CB	1.5 kV circuit breaker	Open	Trip out
01-10-2020 12:55:44.843	SS PE	109 DC	AL UV	1500 V DC undervoltage	ON	Trip out
01-10-2020 12:55:44.843	SS PE	109 DC	AL LO	LTD in operation	ON	Line Test
01-10-2020 12:55:44.843	SS PE	109 DC	AL PT	DCP protection tripping	ON	
01-10-2020 12:55:44.843	SS PE	109 DC	AL OC	Overcurrent time protection	ON	
01-10-2020 12:55:44.857	TPH CY_	109 DC	CB	Unexpected switch change	On	Alarm for ECO
01-10-2020 12:55:44.863	TPH CY_	109 DC	CB	Unexpected switch change	Off	Alarm for ECO
01-10-2020 12:55:45.279	SS PE	109 DC	AL LO	LTD in operation	OFF	Line Test complete and OK
01-10-2020 12:55:45.548	SS PE	856 DC	AL PT	DCP protection tripping	ON	
01-10-2020 12:55:45.934	SS PE	856 DC	CB	Unexpected switch change	Registered	Alarm for ECO
01-10-2020 12:55:45.935	SS PE	856 DC	CB	Unexpected switch change	Alarmed	Alarm for ECO
01-10-2020 12:55:47.011	SS PE	109 DC	CB	Unexpected switch change	Alarmed	Alarm for ECO
01-10-2020 12:55:47.011	SS PE	109 DC	CB	Unexpected switch change	Registered	Alarm for ECO
01-10-2020 12:55:47.155	SS PE	109 DC	AL LO	LTD in operation	ON	Line Test
01-10-2020 12:55:49.538	SS PE	109 DC	AL OT	CB static overcurrent trip	OFF	Resets
01-10-2020 12:55:49.766	SS PE	109 DC	AL OC	Overcurrent time protection	OFF	Resets
01-10-2020 12:55:49.766	SS PE	109 DC	AL PT	DCP protection tripping	OFF	Resets
01-10-2020 12:55:50.597	SS PE	856 DC	AL PT	DCP protection tripping	OFF	Resets
01-10-2020 12:56:03.103	SS PE	109 DC	AL UV	1500 V DC undervoltage	OFF	Power back on second big flash
01-10-2020 12:56:03.907	SS PE	109 DC	AL OT	CB static overcurrent trip	ON	Fault identified again
01-10-2020 12:56:03.907	SS PE	109 DC	AL UV	1500 V DC undervoltage	ON	
01-10-2020 12:56:04.666	SS PE	109 DC	AL OC	Overcurrent time protection	ON	
01-10-2020 12:56:08.933	SS PE	109 DC	AL OT	CB static overcurrent trip	OFF	
01-10-2020 12:56:09.770	SS PE	109 DC	AL OC	Overcurrent time protection	OFF	
01-10-2020 12:56:21.002	SS PE	109 DC	AL UV	1500 V DC undervoltage	OFF	Power back on
01-10-2020 12:56:21.110	TPH CY_	109 DC	AL1	Feeder lack of voltage	Normal	
01-10-2020 12:56:22.508	SS PE	109 DC	AL UV	1500 V DC undervoltage	ON	
01-10-2020 12:56:22.597	TPH CY_	109 DC	AL1	Feeder lack of voltage	Alarm	
01-10-2020 12:56:22.736	SS PE	109 DC	CB	1.5 kV circuit breaker	Closed	
01-10-2020 12:56:22.736	SS PE	109 DC	AL UV	1500 V DC undervoltage	OFF	Breaker closed voltage on the lin
01-10-2020 12:56:22.736	TPH CY_	109 DC	AL1	Feeder lack of voltage	Normal	
01-10-2020 12:56:29.408	SS PE	109 DC	AL LO	LTD in operation	OFF	
01-10-2020 12:57:08.216	SS PE	109 DC	CB	1.5 kV circuit breaker	Open executed	
01-10-2020 12:57:08.217	System	WS3			Operation perfo	ECO on duty opened breaker

Figure 6 – SCADA Log for the time of the incident

Post-incident examination of the OHLE

55 After the second flashover, the OHLE wire separated and fell onto Platform 1, Figure 7.

Figure 7 – OHLE wire on Platform 1, Pearse Station

56 The wire that separated was identified as a Catenary Wire. Post-incident, the damaged OHLE was removed and subsequently misplaced and was therefore not available for examination to determine the failure mode. However, a photograph was taken of the Catenary Wire shortly after the incident, Figure 8, which shows evidence of heat damage.

Figure 8 – Broken Catenary Wire

57 Detailed inspections carried out following the occurrence indicated that a cross span wire had been struck and the bridle wire supporting the catenary wire at the upper cross span (see Figure 9) frayed under tension due to the stress the system was placed under during the events.

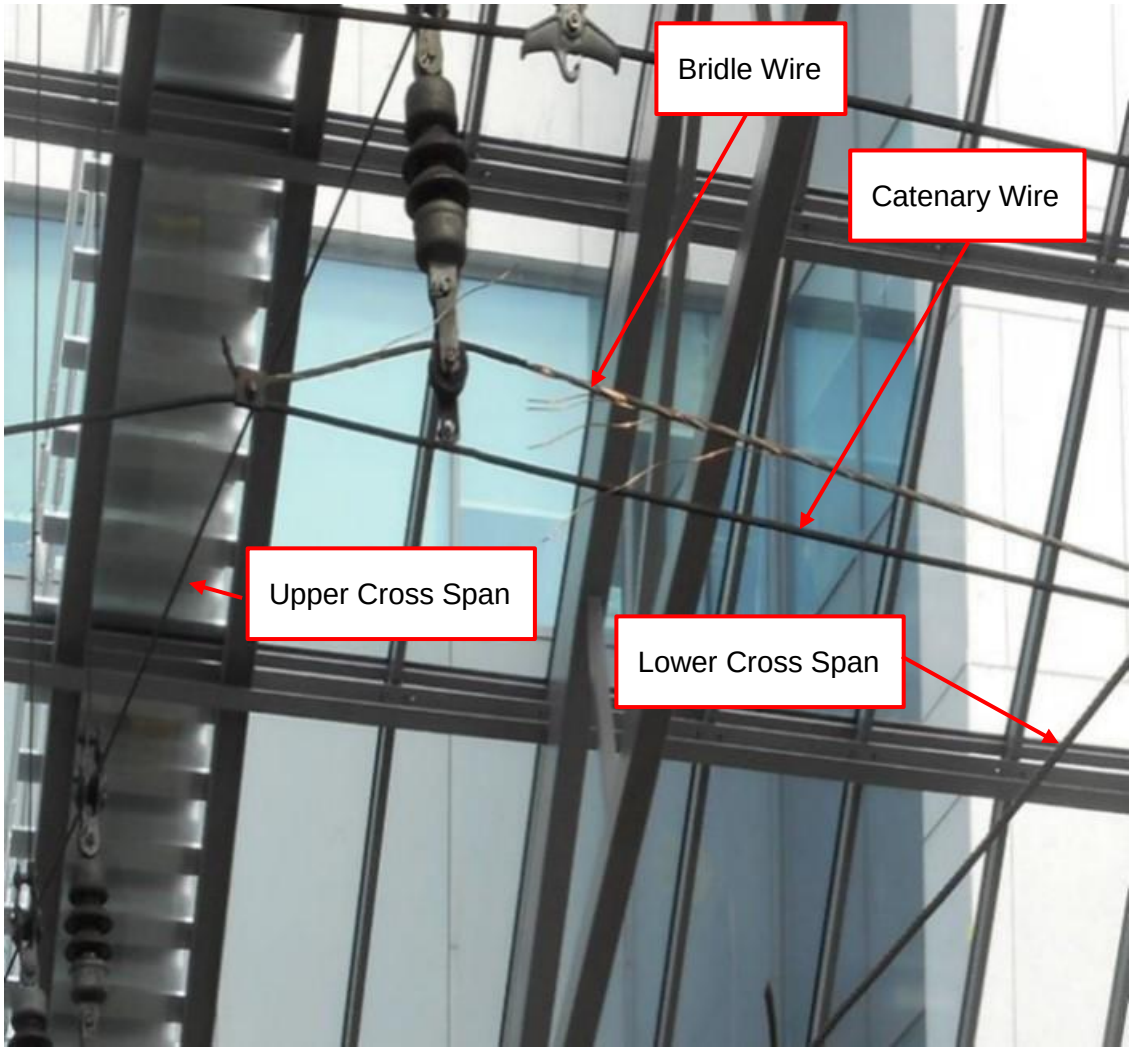

Figure 9 – Frayed Bridle Wire of Cross Span

Pantograph

Physical description of pantographs

58 A pantograph is a mechanical system mounted on the roof of the Class 8100 EMU trains to convey the 1,500V DC from the OHLE line to the train. The pantograph consists of a base frame, Lower Arm and Upper Arm (hinged at the joining of the two arms is the Elbow Joint), and the Pan Head, see Figure 10. The Pantograph Head houses contact carbon strips that slide along the overhead line as the train moves.

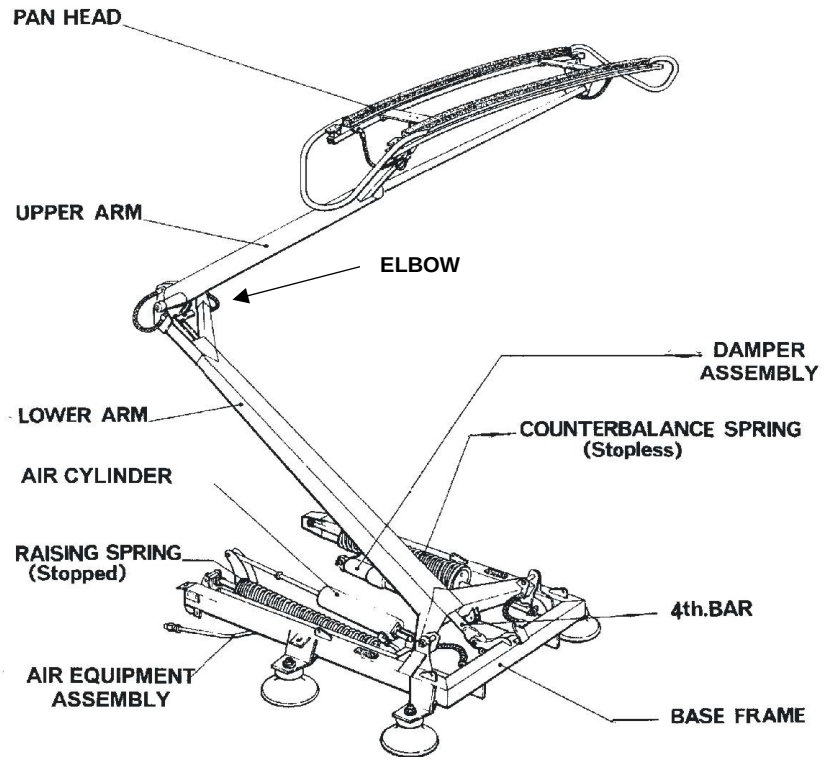

Figure 10 – Pantograph assembly on 1800 EMUs

59 When raised the spring assembly pushes the head upwards against the contact wire, and the entire pantograph assembly is live at the supply voltage of 1,500V DC. The assembly is insulated from the train by four securing insulator assemblies.

60 The angle of the Pantograph Upper Arm and Lower Arm is set by three adjustable chains in the Elbow Joint (see Figure 11), which ensures the angle between the Upper Arm and the Lower Arm is twice that between the Lower Arm and the base unit.

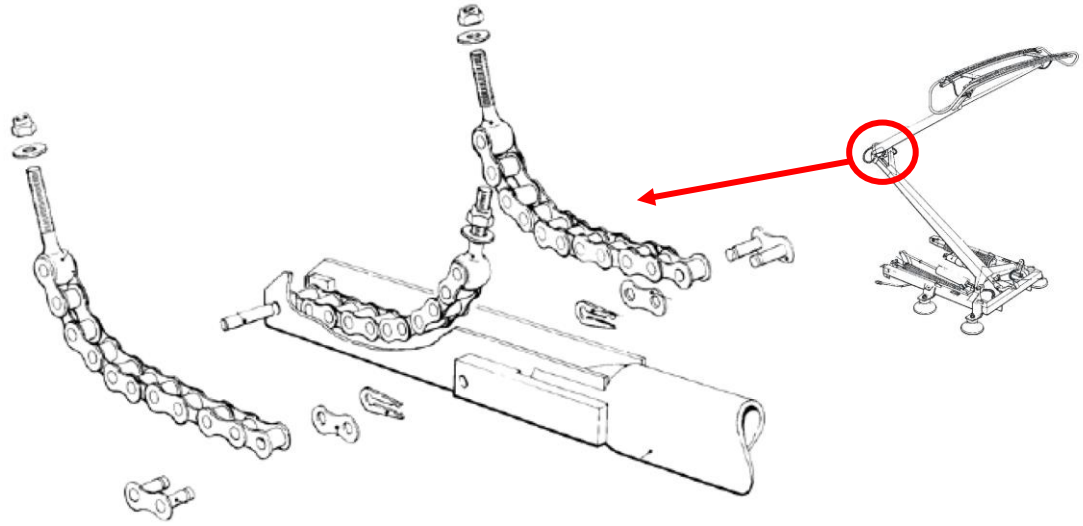

Figure 11 – Pantograph elbow chain arrangement

61 The pantograph elbow chains are a roller type and made up of four components, namely: outer plate, inner plate, pin and roller, see Figure 12.

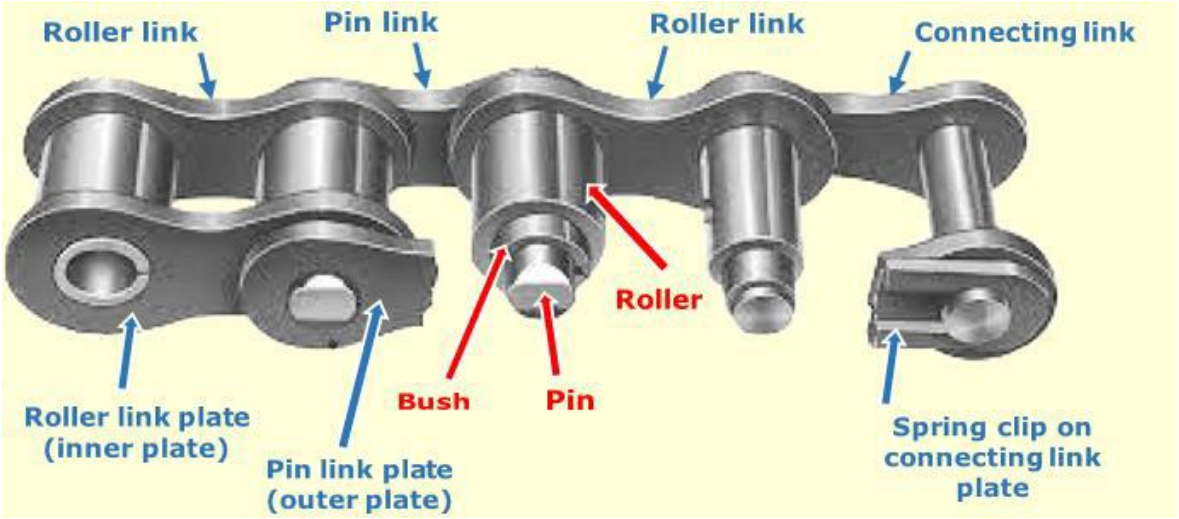

Figure 12 – Elbow chain components

Pantograph maintenance

Brecknell Willis Manual

62 On supplying the pantographs, Brecknell Willis issued IÉ with manuals to provide the necessary information on preventive maintenance routines to maintain the equipment in a serviceable condition. The manual in place, at the time of the incident was "Brecknell Willis, Pantograph MU20A (M02785-01-L) Installation, Maintenance and Spare Parts Manual TS 4517", Issue A, delivered in September 1999 (to be referred as the Brecknell Willis Manual for the remainder of this report).

63 Of relevance to this investigation, the Brecknell Willis Manual recommended the running maintenance of the pantographs to be scheduled:

- Weekly – Visual inspection of the pantograph for damage and an examination for evidence of the wear to the carbons;
- Three-monthly – Check the elbow chains are grease covered with Shell Malleus C[7] and to apply grease as necessary to give a generous covering to the chains;
- Twelve-monthly – Repeat the three monthly examination but wipe off old surplus grease from the elbow chains and re-apply grease;
- Three-yearly overhaul – This included:
    - Replacement of all elbow chain assemblies. Outer chains are fastened with joint links (which must be renewed if chain is renewed) and the centre "recoil" chain is retained by a 5mm spirol pin. Use only proprietary Brecknell Willis supplied chain assemblies;
    - If the fourth bar needs painting the three chains must be removed and the bearing and conical seal faces must be masked. Refit chains and thoroughly grease pack them. Unmask bearing end of bar and protect with grease. If storage is necessary, cover each end with polythene bag.

[7] Post-incident IÉ-RU contacted Brecknell Willis in relation to the pantograph chain grease and were informed that Shell Malleus C was discontinue by Shell and Brecknell Willis now recommended Ambersil FLT Chain Lube as an alternative. IÉ-RU were unaware that Shell had discontinued Malleus C grease as they still had grease in stock.

IÉ Pantograph Maintenance Specifications

64 The CME Department, on receipt of the Brecknell Willis Manual, drafted their own pantograph maintenance documents using the relevant information from the Brecknell Willis Manual, taking into consideration the operational conditions. For example, the 8100 EMU fleet accumulate approximately 120,000 km per year, therefore the maintenance cycle was divided into an "A" Exam every 20,000 km, six "C" Exam (C1 – C6) every 20,000 km (with each of the six "C" Exams varying in content). This means that an inspection of the pantograph is carried out, via either an "A" or "C", every 10,000 km, see Figure 13 for pictorial illustration of maintenance regime. An overhaul is carried out every five years.

Ref: CME-SC-081-4		Version No: 15								Status: LIVE				
Document Type	Maintenance Description	A	C1	C2	C3	C4	C5	C6	2	4	5	6	8	10
VMI	Pantograph Inspect		X	X	X	X	X	X						
VMI	Pantograph Examine		X		X		X							
VMI	Pantograph - Visual Inspection	X												
VOI	Pantograph - Change										X			X

Figure 13 – CME maintenance regime for 8100 Class EMU pantographs

65 The pertinent maintenance schedule is as follows:

- "A" Exam – 20,000 km – Pantograph Visual Inspection, as per Vehicle Maintenance Instruction (VMI) GP81J0004 (Issue No. 2 published in February 2012), which requires a visual examination of the pantograph for damage.
- "C" Exams (C1 – C6) – 20,000 km – Pantograph Inspect, as per VMI GP81J0001 (Issue No. 4 published in February 2011), which requires:
    - Checks to the elbow chains for wear;
    - Checks to ensure that elbow chains are not loose when the pantograph is in the lowered position; if loose, they should be tightened (Safety Critical Task);
    - Report any defects to the Supervisor;
    - All components repaired, renewed, or deferred to be recorded on the examination sheet.

- 40,000 km Pantograph Examine (every second “C” Exam), as per VMI GP81J0002 (Issue No. 1 published in June 2010), which requires:
    - Checks that the elbow chains have a liberal covering of Shell Malleus C. If they do not, apply new grease;
    - Report any defects to the Supervisor;
    - All components repaired, renewed or deferred to be recorded on the examination sheet.
- 600,000 km Pantograph Change (heavy maintenance) – Overhaul, as per VMI GP81J1001, this is further discussed below.

66 Pantograph maintenance was carried out by maintenance staff that were certified competent to carry out the tasks.

67 The CME department employ a Compliance Coordinator to sample vehicle maintenance activities at Fairview DART maintenance depot to verify the maintenance tasks are carried out correctly. No compliance checks were carried out on EMU pantographs maintenance.

Pantograph Overhauls

68 In August 2015 IÉ conducted an exercise to extend the period of overhaul of the pantographs from three to five years (equivalent to 600,000 km outlined in paragraph 65) utilising CME Technical Standard for Engineering Change CME-TMS-316, Version 8, published in December 2014 (to be referred to as CME-TMS-316 for the remainder of this report). CME-TMS-316 is a CME engineering change document applicable for changes that affect the CME department only. RU-SMS-014, Safety Validation of Changes in Plant Equipment, Infrastructure and Operations (PEIO), Issue 3, published on the 25th March 2013 (to be referred to as RU-SMS-014 for the remainder of this report) is an IÉ standard that caters for changes that affect more than one department e.g. pantographs interface between CME and SET assets.

69 The exercise included a condition assessment, carried out by Brecknell Willis, on two pantographs. The condition assessment did not entail a full strip of the pantograph. The pantographs sent for assessment were last overhauled in 2008 and 2009 (six and seven years previous i.e. these were not overhauled at the three-year required frequency); however, this was not identified in the CME-TMS-316 condition assessment documentation.

70 The Brecknell Willis report identified that: “There was no cushioning present when the pantograph lowered however cushioning is normally cylinder based and this could also be due to significant wear in the chains and the operating system in general”.

71 The Brecknell Willis report concluded that: “Both pantographs evaluated have been performing, prior to assessment, under par in service and this is due to significant stretching of elbow chains affecting elbow height and low contact forces well below the 85N required” and also stated that “some adjustment of dampers on reassembly may be required. It is therefore evident that overhaul of these pantographs is overdue, and Brecknell Willis recommend this to enable continued efficient running of these units”.

72 In the background section of the documentation for CME-TMS-316 states: “A condition assessment was carried out by Brecknell Willis on two pantographs randomly selected from the fleet. From this condition assessment Brecknell Willis proposed a heavy maintenance schedule optimised to a five year interval as is their custom and practice from similar pantographs on other fleets. This change does not alter the technical specification of the overhaul of each pantograph. However, the RAIU could not find evidence that Brecknell Willis proposed that the overhaul period should be changed from three to five years in the CME-TMS-316 documentation.

73 Within the year of this exercise, in May 2016, IÉ-RU outsourced the overhaul of the pantographs to Wabtec[8] at a five year interval.

74 Eighteen pantographs were overhauled in 2016; twenty-five in 2017; twenty-two in 2018; and fourteen in 2019; totalling seventy-nine. However, IÉ-RU issued eighty-two invoices for the time period. Of the eighty-two purchase orders issued by IÉ-RU, only thirty-four purchase orders contained the pantograph serial number making it impossible to explain the discrepancy in the number of pantographs overhauled.

75 Wabtec recorded the pantograph numbers (attached to the frame of the pantograph) of all pantographs overhauled, and Pantograph 396 was not one of the seventy-nine overhauled by Wabtec in the IÉ-RU contract.

[8] The overhauls were carried out by LH Group and Brecknell Willis both part of the Fandstan Group which is owned by the Wabtec Corporation.

Pantograph Maintenance of Pantograph 396

76 Prior to May 2016 IÉ-RU carried out all maintenance (running maintenance and overhauls).

77 Brecknell Willis overhauled Pantograph 396 on the 4th May 2006 as part mid-life refurbishment (under a Siemens contract) of the Class 8100 EMU fleet.

78 IÉ replaced Pantograph 396, on EMU 8128, on the 16th August 2012 as part of a four year heavy maintenance exam (this is separate from the running maintenance outlined above). The IÉ *SAP computer system* verifies that Pantograph 396 was replaced, overhauled at the bench and a function test carried out.

79 From 2016, Wabtec carried out the pantograph overhauls at five year intervals (paragraph 73). There is no evidence that Pantograph 396 was one of the seventy-nine pantographs overhauled (paragraph 75).

80 IÉ's SAP computer system shows a pantograph replacement for EMU 8128 on 14th June 2017. There are no materials booked against the work order or evidence that Pantograph 396 was overhauled at the bench and function tested.

81 In the six months prior to the failure of Pantograph 396 on 1st October 2020 IÉ records show Pantograph 396 was up to date for running maintenance: "C1" Exam on the 26/06/2020; "A" Exam on the 07/08/2020; "C2" Exam on the 23/08/2020; "A" Exam on the 20/09/2020 (see paragraph 64 for detail on visuals, inspection and examinations).

82 Pantograph 396 was not scheduled to be removed for overhaul until June 2022.

Post-incident examination of Pantograph 396

83 A post-incident examination of the Pantograph 396, while still mounted on the roof of EMU 8128, identified that the Pantograph Head and Upper Arm had lowered and the Lower Arm had raised (Pan Flip), see Figure 14.

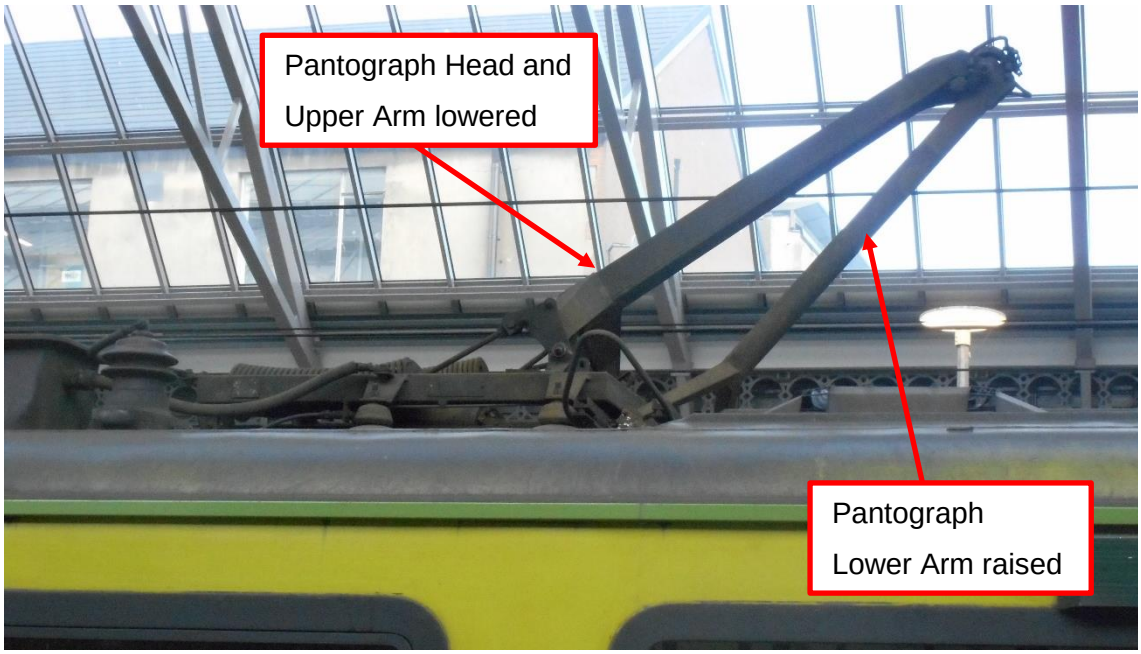

Figure 14 – Pantograph 396 post-incident

84 All three elbow chains had broken. The grease on the pantograph elbow chains from Pantograph 396 had broken down and formed a dark thick paste impregnated with grit and had lost its lubricating and rust preventative properties.

Figure 15 – Post-incident photograph of outer chains joined to the 4th Bar

85 After cleaning the elbow chains of Pantograph 396, the two outer chains were found to be broken at the chain links and the centre or recoil chain was broken at the anchoring screw, see Figure 16.

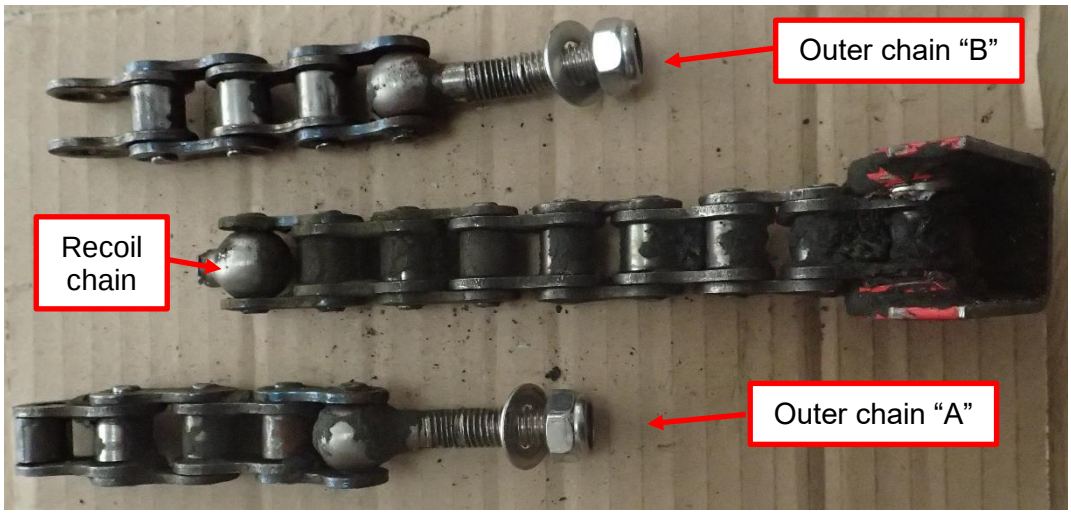

Figure 16 – Broken elbow chains

86 Further examination of the outer elbow chains found considerable wear and corrosion had taken place over a period of time. On outer chain “A” approximately half of the roller bush and pin was worn away with evidence of corrosion pitting at the failed link, see Figure 17. On outer chain “B” the pin and roller were missing, and the pin had worn away the link hole, there was clear evidence of corrosion pitting on the failed link, see Figure 18.

Figure 17 – Chain link “A” roller bush and pin worn

Figure 18 – Chain link “B” pin and bush missing. Pin wear mark on the link hole.

87 The centre or recoil chain had failed at the root of the third thread from the ball head of the anchoring screw. There were four distinct phases to the anchoring screw failure: initial slow development; followed by faster growth; fast fracture; and, finally tear out as a result of overload from the two outer chains failing, see Figure 19.

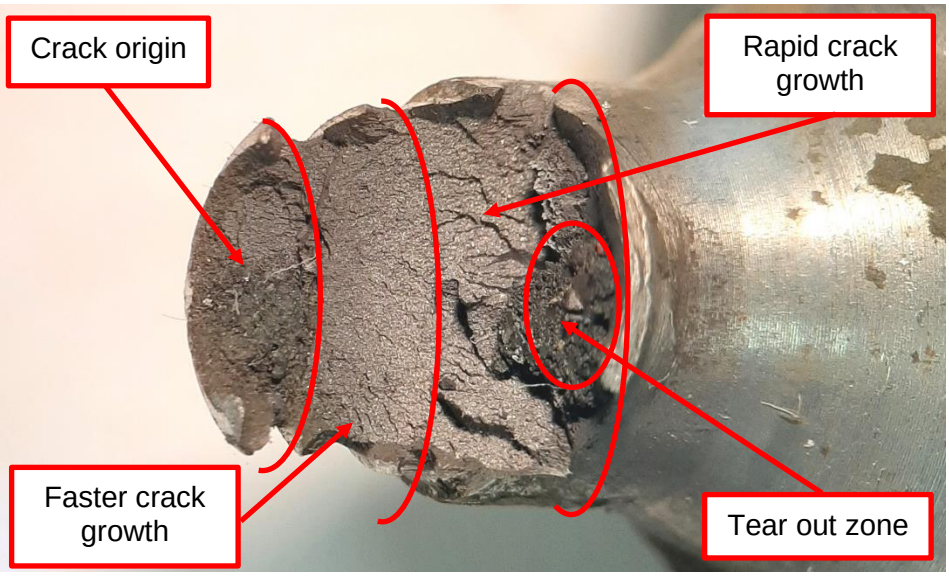

Figure 19 – Anchoring screw failure

Events before, during & after the incident

Events before the incident

88 In the six months prior to the incident, Pantograph 396 received maintenance intervention, as scheduled, with no issues identified (paragraph 81).

89 On Thursday 1st October 2020, Train E920, the 12:04 hrs DART service from Greystones to Howth, departed Greystones on time.

90 Train E920 served all scheduled stops as far as Grand Canal Dock Station on time, departing Grand Canal Dock at approximately 12:55 hrs heading for its next scheduled stop, Pearse Station.

91 At 12:55:30 hrs, Train E920, entered the canopied area of Pearse Station, and slowed on its approach to the stopping point of Platform 1.

92 At 12:55:43.625 hrs (times are taken from the CCTV clock), the head of Pantograph 396 (housed on EMU 8128) loses contact with the OHLE, resulting in an *arc flash*, circled red in Figure 20[9].

Figure 20 – Head of Pantograph 396 loses contact with OHLE resulting in arc flash

[9] Note: The following figures (Figure 20 to Figure 24) are screen shots taken from the CCTV camera situated at the North End of Platform 1 of Pearse Station; the clarity of some of the images are blurred due to enlarging the image that was recorded from a distance.

Events during the incident

93 At 12:55:44.625 hrs, the failure of the elbow chains on Pantograph 396 caused the Lower Arm of Pantograph 396 to rises to its maximum reach causing the Upper Arm and Pantograph Head to lower, see Figure 21; the insert in Figure 21 shows the position of Pantograph 396 arms after Train E920 came to a stop.

Figure 21 – Lower Arm of Pantograph 396 rises, causing the Upper Arm & Head to lower

94 The SCADA log notes “CB (Circuit Breaker) static overcurrent trip” at 12:55:44.621 hrs and “LTD (Line Test Detection) in operation”, “ON”, the system performs a Line Test at 12:55:44.843 hrs.

95 At 12:55:44.865 hrs, the raised Lower Arm of Pantograph 396 makes contact with the Lower Cross-Span Wire of the OHLE causing it to flip, forcing the Upper Arm and Pantograph Head onto the roof of the train, resulting in a short circuit and a large flash over, circled red in Figure 22.

Figure 22 - Pantograph Head short circuits against the train roof causing a large flash over

96 At 12:55:47.155 hrs, SCADA records that another line test is performed “LTD in operation” “ON”.

97 Driver E920 heard a loud bang and saw the OHLE wires shaking as he brought Train E920 to a stop at 12:55.51 hrs. Driver E920 exited the driving cab to check the OHLE and saw the OHLE vibrating and returned to the cab and pressed the “Pan Down” button to lower the pantographs from the OHLE. It should be noted that due to the failure of the chains on Pantograph 396, the Lower Arm of Pantograph 396 remained raised above the OHLE. The pantographs on the leading unit (EMU 8131) and trailing unit (EMU 8138) lowered and were undamaged.

98 At 12:56:03.907 hrs SCADA records “CB static overcurrent trip”. At 12:56:03.103 hrs "1500 V DC undervoltage" is recorded by SCADA. At 12:56:04.105 hrs, the Auto Reclose function activates (paragraph 51), restoring the power to the section, resulting in a second short circuit and large flash over (circled in red in Figure 22), just before the pantographs lowered.

Figure 23 – Second short circuit and second flash over

99 The Catenary Wire of the OHLE, then detached and fell onto Platform 1, see Figure 24.

100 At 12:56:22.736 hrs, SCADA records that the “1500V DC undervoltage” is “OFF”; clearing the “fault” and restoring the power. While the Catenary Wire was on Platform 1 the Auto Reclose initiated a second closure resulting in current been present on the Catenary Wire on Platform 1 for approximately forty-six seconds.

101 At 12:57:08.216 hrs, SCADA records “1.5 kV circuit breaker”, “Open Executed”; the ECO (paragraph 54) isolates the OHLE in the section.

Figure 24 – Catenary Wire on Platform 1

Events after the incident

102 Staff members from Pearse Station placed safety barriers around the Catenary Wire on Platform 1 (Figure 25).

Figure 25 – Catenary Wire with safety barriers

103 Driver E920 contacted the controlling signalman using a lineside phone as the train radio had lost power after pressing the “Pan Down” button. The controlling signalman then contacted the ECO; a member of station staff and the District Traffic Executive also contacted the ECO.

104 Passengers were detained on Train E920 until it was confirmed that the OHLE was isolated.

105 Members of staff from the SET, CME, and the CCE departments arrived on-site to assist and arrange for repairs to be carried out in order to return to normal service operation.

106 The damaged length of Catenary Wire went missing after the incident, as a result neither IÉ-RU or the RAIU accident investigators could analyse the Catenary Wire.

107 Pantograph 396, from EMU 8128, was removed from Train E920 prior to the train set being transferred to Fairview DART maintenance depot.

Similar Occurrences

108 The RAIU have not been notified of any previous failures on the IÉ network of pantographs that resulted in the OHLE detaching and falling onto a platform.

Analysis

Pantograph

EMU Pantograph maintenance & overhaul

109 The Brecknell Willis Manual recommended the running maintenance of the pantographs as a weekly visual inspection; a three-monthly inspection; and, a twelve-monthly examination; with a pantograph overhaul every three years (paragraphs 62 and 63).

110 In terms of the Elbow chains, it was recommended that, every three months, the chains should be checked to ensure they are covered in grease; and grease generously applied, as necessary. Every twelve months, the grease should be wiped off and new grease applied. Every three years the elbow chain assemblies should be replaced (paragraph 63); the IÉ-RU specification does not require that the grease should be wiped off and re-applied. The Brecknell Willis Manual does not refer to wear of the chains or checking for wear during maintenance.

111 IÉ-RU incorporated the Brecknell Willis instruction and produced their own maintenance tasks at specified kilometres, rather than time (paragraph 64). The pantographs are inspected every 10,000 km during an “A” or “C” Exam. Every 20,000 km requires the elbow chains to be checked for wear and to ensure that they are not loose when the pantograph is in the lowered position, tightening if required. Every 40,000 km, the elbow chains are to be checked for a liberal covering grease and to apply new grease if required. The IÉ pantograph maintenance does not state that the old grease should be removed, as in the Brecknell Willis Manual (paragraph 63 and 110). There are also no details on how to check for wear or what the allowable wear limits are permitted for chains in service. No compliance checks were carried out on EMU pantographs to verify the work had been carried out to the specification (paragraph 67).

112 According to the Brecknell Willis Manual, the three year overhaul requires the elbow chains to be replaced (paragraph 63). To extend the frequency of overhauls, IÉ-RU, utilising CME-TMS-316, conducted a condition assessment, carried out by Brecknell Willis, on two randomly selected pantographs (paragraph 67). Brecknell Willis identified “significant wear in the chains” and “significant stretching of elbow chains”; concluding that the overhaul of the two pantographs was overdue (paragraph 69 – 70). On reviewing the Brecknell Willis condition assessment report, IÉ-RU stated that “Brecknell Willis proposed a heavy maintenance schedule optimised to a five year interval”. As a result, IÉ-RU’s specification requires the overhaul every five years (paragraph 64). However, it is not clear how IÉ-RU came to this determination, given that Brecknell Willis do not state this

(paragraph 69). It is also noted that RU-SMS-014, Safety approval of Change in PEIO should have been the document used instead of CME-TMS-316 due to the interface with the SET Department who have previously requested consultation if any change to periodicity of pantograph maintenance was proposed (paragraph 68).

113 Wabtec have overhauled seventy-nine pantographs between 2016 and 2019. IÉ records show eighty-two purchase orders were issued for pantograph overhauls to Wabtec for the same period. Neither Wabtec or IÉ-RU could explain the discrepancy (paragraphs 74).

Maintenance & Overhaul of Pantograph 396

114 IÉ-RU records show that Pantograph 396 for EMU 8128 received its planned running maintenance in accordance with its scheduled dates and by competency certified staff (paragraph 81).

115 Brecknell Willis overhauled Pantograph 396 on the 4th May 2006 as part of a mid-life refurbishment (under a Siemens contract) of the Class 8100 EMU fleet (paragraph 77).

116 IÉ-RU SAP Software heavy maintenance records show that EMU 8128 received a pantograph overhaul on the 6th August 2012; the records are complete and detail the overhaul at a bench and function test (paragraph 78).

117 IÉ-RU SAP Software records also show that EMU 8128 was due a five year overhaul on the 14th June 2017; however, the records do not definitively show that the overhaul was carried out as the records are incomplete; this is supported by the fact that IÉ-RU had already awarded the contract to overhaul the EMU Pantographs to Wabtec in May of 2016 (paragraph 73).

118 Brecknell Willis have no records of receiving or overhauling Pantograph 396 since the IÉ-RU contract commenced in 2016 (paragraph 75) i.e. Pantograph 396 had not been overhauled since the 6th August 2012.

119 Pantograph 396 received its last maintenance intervention an “A” exam on 20th September 2020 (paragraph 81), eleven days before the incident, and no issues were raised in relation to the condition of Pantograph 396.

Mechanisms of failure for Pantograph 396 & the Catenary Wire

120 Based on the sequence of events taken for the CCTV, the post-incident inspection of Pantograph 396, and the photographic evidence of the OHLE and Catenary Wire, the likely mechanisms of failure for are as follows:

- The post-incident examination of the Elbow Chains of Pantograph 396 showed that all three chain assemblies failed. The two outer chains failed first, failure was at the chain links (Figure 26) which were found to have been subject to considerable wear and corrosion over time (paragraph 86). The excessive wear in the chains was likely as a result of a loss of lubricant and rust preventing properties of the grease. This is based on the fact that the grease on the chains at the time of failure was impregnated with grit and dirt (paragraph 84) despite undergoing maintenance intervention eleven days before the failure (paragraph 81).
- The centre Recoil chain failed at the anchor screw (Figure 26) as a result of an overload from the two outer chains failing (paragraph 0).

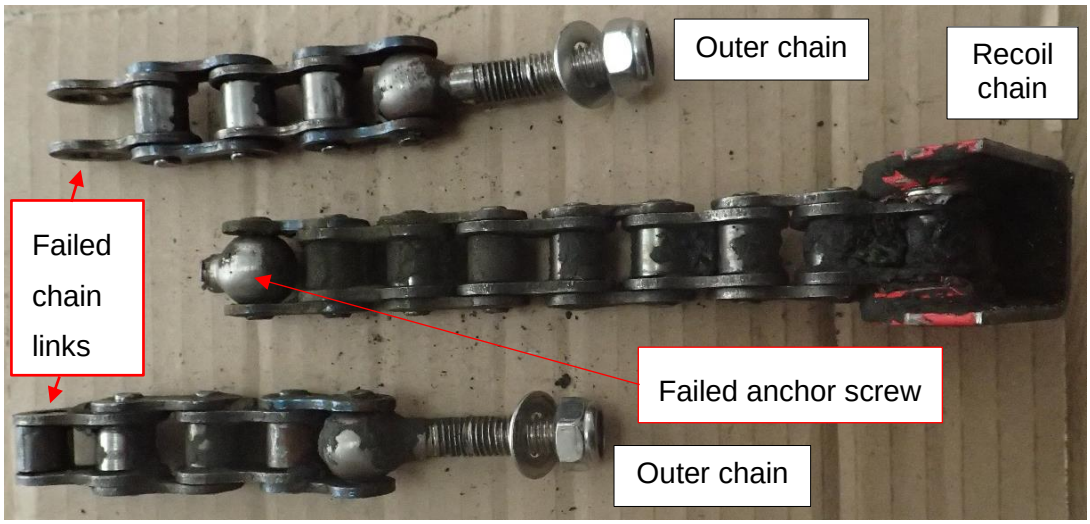

Figure 26 – Failed chain assemblies

- When the chains broke the Upper Arm of Pantograph 396 lowered; the initial gap between the Pantograph Head and the OHLE causing the current to arc;
- The spring loaded Lower Arm rose to its maximum reach striking the OHLE, the Upper Arm and Pantograph Head lowered (paragraph 93), with the Pantograph Head resting on the roof of the train, resulting in a short circuit and a large flash over (paragraph 95, Figure 22). This flashover caused the second short circuit and large flashover caused the Catenary Wire to overheat and separate from the OHLE and drop onto Platform 1.

OHLE Auto Reclose

121 While the Catenary Wire was on Platform 1 the Auto Reclose initiated a second closure resulting in current been present on the Catenary Wire on Platform 1 for approximately forty-six seconds.

Conclusions

122 The running maintenance for pantographs, IÉ-RU, in the most part, adhere to the recommendations set out by the OEM, Brecknell Willis (paragraph 109) and Pantograph 396 received its running maintenance at the required frequency (paragraphs 114 - 119).

123 Although it is noted that IÉ-RU extended the overhaul of pantographs from three years to five years using a tenuous process, whereby pantographs were condition assessed by Breckwell Wills, resulting in IÉ-RU interpreting the outcome as an affirmative to an extended five year overhaul (paragraph 112). It is also noted that RU-SMS-014, Safety approval of Change in PEIO should have been the document used instead of CME-TMS-316 due to the interface with the SET Department who have previously requested consultation if any change to periodicity of pantograph maintenance was proposed (paragraph 112).

124 The OEM running maintenance requirement for the elbow chains requires that every three months the grease should be checked and reapplied where necessary; and, every twelve months all grease should be wiped off and new grease applied (paragraph 110). The IÉ-RU specification does not require that the grease should be wiped off; and the grease was not wiped off as in the case of Pantograph 396, the grease on the chains at the time of failure was impregnated with grit and dirt despite undergoing maintenance eleven days before the failure (paragraph 120). Also, there was no requirement to carry out any compliance checks for maintenance activities of the pantograph (paragraph 111).

125 The lack of lubrication of the elbow chain, through insufficient greasing, not wiping off existing grease prior to the re-application of new grease and exceeding the recommended overhaul frequency (Pantograph 396 was last overhauled in 2012, paragraph 116) resulted in excessive wear of the chain pins and chain link holes over a period of time, eventually culminating in their failure (paragraph 120).

126 The failure of the chains on Pantograph 396, initially resulted in a small arc from the loss of contact between the Pantograph Head and the Contract Wire. The Pantograph Head then flipped, striking the roof of the train, while the Lower Arm extended upward touching the OHLE and causing a large flashover; coupled with a second flashover the live Catenary Wire separated from the OHLE and fell onto Platform 1 (paragraph 120).

127 The Catenary Wire was live on Platform 1, as the Auto-Reclose system did not detect a fault on its second closure resulting in current been present on the Catenary Wire on Platform 1 for approximately forty-six seconds, before the ECO isolated the power (paragraph 121).

Causal, contributing and systemic factors

128 The Catenary Wire of the OHLE detached, and was live on Platform 1, as a result of the following causal factors:

- CaF-01 – The short circuit between the Pantograph Head and the roof of the train caused the Catenary Wire to overheat, reducing its strength, detaching and falling onto Platform 1;
- CaF-02 – The OHLE in Pearse Station is positioned at 4.46 m above the rail allowing the Pantograph Lower Arm to strike the OHLE in the event of a Pantograph elbow chain failure;
- CaF-03 – The elbow chains on Pantograph 396, on EMU 8128, failed due to excessive wear of the chain pins and chain link holes over a period of time due to the lack of lubrication;
- CaF-04 – The failure of Pantograph 396's elbow chains resulted in the Pantograph Lower Arm rising and the Upper Arm and Pantograph Head lowering; provided an electrical path for a direct connection between the OHLE and the train body;
- CaF-05 - The High Speed Circuit Breaker Auto-Reclose restored power to the failed section.

129 Contributory factors include:

- CoF-01 – The Pantograph on EMU 8128 had not been overhauled for over eight years.

130 Systemic factors include:

- SF-01 – The pantograph planned preventative maintenance regime did not identify the deterioration in the chains of Pantograph 396 or the poor condition of the grease that had previously been applied;
- SF-02 – The information contained in the IÉ CME-TMS-316 Department Engineering Change files for the extension of the pantograph overhaul from three to five years does not substantiate the conclusion reached, highlighting a lack of governance in the outsourcing of the overhaul of EMU pantographs;
- SF-03 – The compliance checks on the EMU fleet did not include the checking of pantographs.

Additional observations

131 Although not identified as causal, contributing or systemic factors, the RAIU make the following additional observations:

- AO-01 – The FFCCTV on EMU 8131 was not operating despite receiving its scheduled maintenance on time (paragraph 35);
- AO-02 – The clock on the OTDR of EMU 8128 was reading the incorrect time (paragraph 36);
- AO-03 – The resistance testing of earth bonds is not included in the scheduled maintenance regime of the 8100 EMU fleet (paragraph 52);
- AO-04 – The damaged OHLE was not safeguarded as physical evidence for later inspection by the IÉ or RAIU accident investigators (paragraph 106).

Measures taken by IÉ-IM and IÉ-RU since the incident

132 The IÉ-IM Safety Department published a report of investigation into the incident on the 18th June 2021, entitled "Overhead line equipment damaged at Pearse Station October 2020". The report found that the immediate cause of the incident was: "The elbow joint between the upper and lower arms on the pantograph rose up and struck the OHLE wires causing damage". Causal factors were identified as: the elbow joint chains snapping; inadequate examination and lubrication on the chains resulting in abrasive wear to the chains; the pantograph not being overhauled at the required interval. Underlying factors were identified as: The Proactive Fleet Risk Register did not identify pantographs chain failure as a risk, resulting in no physical compliance checks being conducted on pantographs; and, the system for managing the maintenance of pantographs not identifying that the pantograph had not been overhauled. The root cause was identified as that the VMIs were not complied with on Unit 8128 as they related to the examination and lubrication of the pantograph chains.

133 Based on the IÉ-IM report findings the following actions were taken or are in progress, by IÉ-RU CME, since the incident:

- Conducted a CME technical investigation with an analysis of the failed components from the pantograph which was carried out by the IÉ Chief Chemist and Metallurgist;
- A fleet check document was composed and issued based on the results of the Chief Chemist & Metallurgist report. The fleet check of seventy-two pantographs identified twenty-five pantographs with chains showing signs of wear requiring the chains to be replaced and were removed from service until repaired;
- A Pantograph Working Group was established consisting of relevant stakeholders;
- The OEM of the pantograph were contacted for further advice on pantograph in-service checks; they provided two Technical Bulletins; BW14122 – Lubrication for Pantograph Elbows Chains; and, TB9035 – Summary of Lubricants, corrosion inhibitors, anti-ice cleaners used on OEM equipment;
- A Technical Bulletin was created highlighting the findings of the investigation to Fairview Depot staff;
- All pantographs are to be lubricated using Ambersil FLT chain lube and Shell Gadus S3 V100 S2 greases as per recommendations from the OEM;
- A new VMI (to be carried out every C exam at 20,000Km) was completed which includes the requirement to measure the elbow chains using a feeler gauge and

recording the condition of the elbow chains and the method of lubrication of the pantograph;

- Component traceability of the pantographs on SAP has been established, so that the serial numbers of all pantographs and the vehicle they are fitted to is known;
- The maintenance schedule of the pantograph elbow chains was altered to be a standalone heavy maintenance task every 2.5 or 3 years (i.e. over a six month period); the elbow chains also being replaced at the five-year overhaul;
- A system has been put in place to allow for the placing of DART units for physical verification checks to be completed post pantograph examination in the Fairview Depot;
- The CME fleet risk register for 8100 & 8500 DART units was updated to reflect the issues with the pantograph;
- The CME have updated a VMI with the addition of conducting an earth bonding test as part of the examination process;
- IÉ-RU CME have issued a VMI for the examination of the OTDR every 120,000 km ("C6" Exam), there is also a running maintenance check every "C" Exam i.e. every 20,000 km;
- The current design specification for the new EMU fleet includes auto-dropping function on the pantographs.

134 Based on the IÉ-IM report findings the following actions were taken or are in progress, by IÉ-IM SET, since the incident:

- Staff were briefed on chain of custody for management of evidence post occurrence; and, produced a standard on the handling of evidence following an occurrence: I-SET-5204, Preservation of evidence following an incident;
- SET risk register has been updated to include the scenarios where an element of the OHLE ends up on a platform;
- The auto-reclose function on the DART network was evaluated by the SET Department and no change to the current design was recommended at that stage. However, as part of the ongoing review of the DC electrified lines work instructions and the technical upskilling of the relevant staff, the requirement for the auto-reclose function for the OHLE will be further reviewed.

135 Based on the IÉ-IM report findings the following actions were taken or are in progress, by DART District Safety, since the incident:

- The Pearse Station Local Emergency Plan (LEP), and associated risk assessment, was updated to include hazards & risks for OHLE occurrences, such as the events on the day of the occurrence.

Safety Recommendations

Introduction to safety recommendation

136 In accordance with the Railway Safety Act 2005 (Government of Ireland, 2005a) and the European railway safety directive (European Union, 2004), recommendations are addressed to the national safety authority, the CRR. The recommendation is directed to the party identified in each recommendation.

Absence of safety recommendations due to measures already taken

137 The earthing of vehicle is achieved through earth connections and inter-vehicle earth bond cables ensuring a good electrical connection between the body of the train and wheelset. It is noted that, at the time of the incident, there was no requirement to measure the resistance of the earth bonding, despite being required on all other IÉ passenger vehicles (paragraphs 52 - 53). This was identified as an additional observation by the RAIU (AO-03, paragraph 131). It is noted that since the incident, the CME have updated a VMI with the addition of conducting an earth bonding test as part of the examination process; as a result, no further safety recommendation, from the RAIU, is warranted.

138 The damaged length of Catenary Wire went missing after the incident, as a result neither IÉ-RU or RAIU accident investigators could analyse the Catenary Wire. The RAIU identified this as an additional observation (AO-04, paragraph 131). However, it is noted that IÉ-IM SET staff were briefed on chain of custody for management of evidence post-incident and produced a standard on the handling of evidence following an occurrence (paragraph 134), as a result, no further safety recommendation, from the RAIU, is warranted.

139 It is noted that the Contact Wire height at Pearse Station is 4.46 m above the rail, due to the infrastructure in place at Pearse Station and to limit the visual impact of the railway electrification. The RAIU do not consider a recommendation is warranted in relation to the heights of the OHLE at Pearse Station (CaF-02, paragraph 128).

Safety recommendations as a result of this incident

140 In relation to the planned preventative maintenance for the Class 8100 EMU Pantographs the regime was not robust enough to ensure that Pantograph 396 could operate without failure between overhaul periods. As a result, the RAIU make the following safety recommendation (CaF-01, CaF-03, CaF-04, CoF-01, SF-01):

Safety Recommendation 202105-01

IÉ-RU CME should in conjunction with the OEM develop a maintenance regime for the pantographs, taking into consideration the operational conditions and traceability of safety critical components.

141 The CME-TMS-316 Engineering Change files for the extension of the overhaul period of the EMU Pantographs from three to five years do not contain information to substantiate the change (CaF-01, SF-02). As a result, the RAIU make the following safety recommendation:

Safety Recommendation 202105-02

IÉ-RU-CME should carry out, in conjunction with the OEM, a condition assessment to determine the correct period for the overhaul of the IÉ-RU pantographs.

142 In terms of the use of CME-TMS-316, the RAIU do not consider that this was the right document for the introduction of changes to the pantographs overhauls, given that there is no allowance for other stakeholder input, as a result, the RAIU make the following safety recommendation (SaF-02):

Safety Recommendation 202105-03

IÉ-RU and IÉ-IM should review the current Engineering Change Request and Safety Approval of Changes documents, to ensure that the appropriate stakeholders are consulted, and the correct processes followed.

143 The compliance checks on the EMU fleet did not include the checking of pantographs (SF-03), as a result, the RAIU make the following safety recommendation:

Safety Recommendation 202105-04

IÉ-RU CME to include requirements to check pantograph maintenance activities in the Compliance Coordinators documentation records / check sheets.

144 The High Speed Circuit Breaker Auto-Reclose restored power to the failed section (CaF-05); as a result, the RAIU make the following safety recommendation:

Safety Recommendation 202105-05

IÉ-IM SET should evaluate the auto-reclose function of the OHLE control system on the DART network to ensure the safe operation in the event of failures which could expose staff and passengers to live OHLE.

Safety recommendations as a result of additional observations

145 The FFCCTV on EMU 8131 was not operating despite receiving its scheduled maintenance on time (paragraph 35); it is noted that compliance checking of the quality of maintenance on FFCCTV is not performed. As a result the RAIU make the following safety recommendation (AO-01, paragraph 131):

Safety Recommendation 202105-06

IÉ-RU CME to include requirements to check Class 8100 EMU FFCCTV maintenance activities in the Compliance Coordinators documentation records / check sheets.

146 The OTDR clock for EMU 8128 was not set to the correct time and the 8100 EMU maintenance schedule does not prescribe an examination of the OTDR (paragraph 36). The RAIU have previously identified issues related to the OTDR (paragraph 37). Although, the RAIU note that a VMI has been issued in relation to the OTDR (paragraph 133), given that a previous safety recommendation on the OTDR, the RAIU consider that this should be verified by the CRR and as a result, the RAIU make the following safety recommendation (AO-02, paragraph 131):

Safety Recommendation 202105-07

IÉ-RU CME to review and develop a maintenance strategy for the 8100 EMU OTDRs to ensure that the correct information is recorded.

Additional Information

List of abbreviations

ATP	Automatic Train Protection
CAWS	Continuous Automatic Warning System
CCTV	Close Circuit Television
CI	Chief Investigator
CME	Chief Mechanical Engineers
CRR	Commission for Railway Regulation
CTC	Centralised Traffic Control
CWR	Continuous Welded Rail
DART	Dublin Area Rapid Transport
DC	Direct Current
DMU	Diesel Multiple Unit
DOT	Department Of Transport
DTE	District Traffic Executive
ECO	Electric Control Operator
ECM	Entity in Charge of Maintenance
EMU	Electrical Multiple Unit
EU	European Union
hr	hour
IÉ-IM	Iarnród Éireann Infrastructure Manager
IÉ-RU	Iarnród Éireann Railway Undertaking
km	kilometre
m	metre
MP	Milepost
mph	miles per hour
OEM	Original Equipment Manufacturer
OHLE	Overhead Line Equipment
OTDR	On Train Data Recorder
RAIU	Railway Accident Investigation Unit
RFI	Request For Information
SCADA	Supervisory Control And Data Acquisition
SET	Signalling, Electrical and Telecommunications
TCB	Track Circuit Block
TSI	Technical Specification for Interoperability

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.
Arc Flash	The light and heat produced as part of an arc fault, a type of electrical explosion or discharge that results from a connection through air to ground or another voltage phase in an electrical system.
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.
Cantilever arms	Lineside masts which support the OHLE, using cantilevers; normally used where there is only one or two tracks.
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.
Catenary Wire	A bare copper stranded conductor being the uppermost of the wires forming the overhead line equipment by which electricity is supplied to the electric train.

Circuit Breaker	A switch arranged to open automatically when a current above a predetermined value flows through it.
Conductor	A body or substance which permits the flow of electricity.
Contact Wire	The lowermost of the wires forming the overhead line equipment. The pantograph of electric trains presses against the underside of this wire and collects the electric current required by the train.
Continuous Welded Rail	Sections of rail that are welded together.
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.
Cross Span	A wire carried on insulator stretched across tracks holding the contact wires in a desired position.
Down Direction	In this accident, trains travelling to Rosslare are travelling in the Down direction.
Earth	The potential of the general mass of the earth and of any conductor in direct electrical connection with it. Note: “Earth” for the purpose of OHLE only, is the general mass of earth not directly connected to the traction return circuit.
Earth Wire	A bare overhead wire electrically connecting the steelwork of two or more structures together and to the track return.
Electrical Control Operator	The person for the time being in charge of the Electric Control Panel and having control of the power supply to the electric traction system and responsible for all switching operations and isolation of electrical equipment there on.
Flashover	A high voltage electrical short circuit made through the air between exposed conductors.
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.
Insulator	Material which offers extremely high resistance to the passage of electricity.

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
Isolated	Electrical equipment is said to be isolated when it is disconnected from any source of electricity supply
Milepost	Marks distances.
Overhead Line Equipment	An arrangement of wires suspended over each electrified track for the supply of electricity to electric trains together with the associated fittings, insulators, and other attachments by means of which the wires are suspended or registered in position. Comprising of a contact wire suspended by droppers from a catenary. In addition, a parallel feeder is included which is electrically bonded to the catenary and contact wire every 120m approximately and normally run along the tops of the masts on insulators. The catenary is supported by insulators attached to the steel structures which are spaced normally 50m apart. At curves and where special track conditions exist the structure spacing is reduced. An earth wire is also run along the back of the masts and is bonded to each mast.
"Pan Down" Button	"Pan Down" in the driver's cab of 8100 Class EMU, a button to be pressed by drivers, in the case of an emergency, to lower the pantographs.
Pan Flip	Where the pantograph head lowers, raising the pantograph's lower arm to the maximum reach.
Pantograph	A collapsible frame mounted on insulators on the roof of electric motor cars which bears against the contact wire and through which the electrical current is collected from the overhead line equipment.
Portal Frame	A steel frame, spanning the tracks, consisting of masts joined by a horizontal boom; cantilevers, supporting the wires, are attached to the boom by vertical members. Portal frames are generally used where there are more than two tracks.
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.
Substation	An installation of electrical equipment for converting alternating to direct current for the supply of power for electric traction.
Technical Specification for Interoperability	The Technical Specifications for Interoperability (TSIs) define the technical and operational standards which must be met by each subsystem or part of subsystem in order to meet the essential requirements and ensure the interoperability of the railway system of the European Union.
Up Direction	In this accident, trains travelling from Rosslare are travelling in the Up direction.

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