Railway Accident Investigation Unit Ireland

INVESTIGATION REPORT

Luas pantograph collision with railway bridge, Beresford Place,

11th June 2021

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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 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 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 01:16 hrs on the 11th June 2021 the *Parafil termination* failed on the *cross-span* between a pole and the *Strong Registration Arm* attached to the Luas network *Overhead Contact System* (OCS) on the Outbound line, *cess* side, close to Beresford Place Iarnród Éireann (IÉ) railway bridge; causing the Strong Registration Arm to hang down over the tram line. This results in the *contact wire* losing *stagger* and striking the negative copper strip on the *insulated plates* located under the railway bridge resulting in a *dead-short* and *tripping* (stopping the electrical flow) the electrical power in the O'Connell to Spencer Dock section. There were no trams in the section, the last outbound tram to pass the section was Tram 3026 at approximately 01:00 hrs.

Luas Network Management Centre (LNMC) were alerted to the Electrical Sub-Station (ESS) *trip-out* and contacted Infrastructure Maintenance who arrived at O'Connell ESS at 01:25 hrs and reset both *Traction* and *High Speed Circuit Breakers* with no issues; the Infrastructure Maintenance staff did not inspect the OCS as it was not required under any Transdev internal documents.

At 04:35 hrs, *Sweep Tram* 3016 (a tram used to check the line is free from obstacles / obstructions prior to passenger service) departed the Red Cow travelling inbound to the Point Depot, travelling at a maximum speed of 25 km/h.

At 05:12 hrs, on Sweep Tram 3016's approach to Beresford Place railway bridge, and the location of the partially detached Strong Registration Arm, the pantograph of Tram 3016 loses contact with the contact wire and strikes with the cross-span assembly. The force of impact on the cross-span assembly causes the Strong Registration Arm to become detached from the contact wire and becomes entangled on the pantograph, contacting both the foot of the pantograph and roof of the tram; causing a dead-short and trips the power in the O'Connell to Spencer Dock electrical section. Sweep Tram 3016 continues forward, pulling down the *feeder cable*; with the pantograph colliding with and damaging the insulated plates under the railway bridge.

Sweep Tram 3016 comes to a stop approximately 30 m from the first impact with the cross-span assembly (approximately seven seconds). Driver 3016 contacts LNMC and reports hearing a loud bang and loss of power.

In this accident, there are two distinct events, namely the failure of the Kevlar parafil and the Infrastructure Maintenance response to the trip-out at 01:16 hrs, and as such the causal, contributing and systemic factors (where identified) are separated.

In terms of the failure of the Kevlar Parafil terminations, the mechanism of failure is likely the result of the failure of the core fibres (which cannot be visually inspected) deteriorating over period of time as a result of in-service stresses (paragraph 119). At the time of the accident, there was a programme in place for the replacement of the Kevlar parafil for 6 mm diameter stainless steel wire rope with inline discreet insulators (paragraph 126), however, the replacement had not yet been undertaken at the location of the accident. Causal factors are:

- CaF-01 – The planned inspections of the OCS cannot identify the deterioration of the Kevlar parafil fibres at the terminations.
- CaF-02 – The Kevlar parafil rope had not been replaced with 6 mm diameter stainless steel wire rope with inline discreet insulators, an ongoing Luas network maintenance project, at the time of the accident.
- CaF-03 – No ground level survey of the electrical section was carried out after the notification of the first trip-out; this inspection would have identified the partially detached Strong Registration Arm.

No contributing or systemic factors were identified in terms of the failure of the Parafil rope.

In terms of the response to the initial trip-out, Infrastructure Maintenance did attend the relevant ESS and reset the circuit breakers, however, they did not conduct a ground level inspection prior to handing back the track. No causal or contributing factors were identified, however the systemic factor is as follows:

- SF-01 – Transdev/ S2M did not have any documentation in relation to the requirement to carry out a ground level visual inspection of a section after an electric trip-out, at the time of the accident.

Due to a number of actions already taken by Transdev no safety recommendations are warranted as a result of the accident. The actions taken include the Parafil replacement project, which is ongoing, whereby the existing Kevlar Parafils are being replaced with 6 mm diameter stainless steel wire rope with inline discreet insulators. In addition, Transdev now require a full ground level survey of the electrical section to be taken in the event of a trip-out.

Contents

RAIU Investigation

RAIU decision to investigate

1 In accordance with the Railway Safety Act 2005 and Railway Safety (Reporting and Investigation of Serious Accidents, Accidents and Incidents Involving Certain Railways) Act 2020 (No. 18 2020) with reference to S.I. 430 2020 Regulation 5 (5), 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 On 15th June 2021 an RAIU investigator received information from a member of the public in relation to an OCS failure at Beresford Place that occurred on 11th June 2021. RAIU guidance document "Guidance: Notification of occurrences to the RAIU for RUs, IMs and other ROs[1]", RAIU-GU001, first issued in 2012 with Version 2, effective since the 1st January 2020, would have required the immediate notification as there was a collision which caused damage, which under slightly different conditions may have led to a fatality or serious injury (ID 1.03, 1.13)[2].

3 The RAIU investigator contacted Transdev's Safety Department and requested further information on the accident; after reviewing this information, the RAIU conducted a preliminary examination and the RAIU's Chief Investigator (CI) made the decision to conduct a full investigation into the failure, given its impact on railway safety (S.I. 430 2020 Regulation 6(2)(b)) as under slightly different circumstances the failure may have led to serious accident or serious injuries due heavy objects from the OCS falling onto a public location.

4 If classified under the EU Agency for Railways categorisation, this occurrence would be considered: Accident – Collision (due to the pantograph colliding with the railway).

5 The RAIU's CI allocated RAIU Senior Investigators, trained in accident investigation, to conduct this investigation, as appropriate.

[1] RU – Railway Undertaking; IM – Infrastructure Manager; RO – Railway Organisation.

[2] On the 25/02/2022, the Head of Safety in Transdev, sent a reminder email to all the Duty Manager, Team Leaders, Safety Teams, Executive Team and other relevant staff members of their statutory requirement to notify the RAIU of incidents and accidents in line with the RAIU's Guidance: Notification of occurrences to the RAIU for RUs, IMs and other ROs.

Scope & limits of investigation

6 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 the OCS;
- Review previous Parafil termination failure reports;
- Examine the relevant operation standards/ procedures relating to failures of the OCS.

Communications & evidence collection

7 During the investigation, the RAIU collate evidence through the submission of Requests For Information and interviewing. Related to this investigation, the RAIU collated and logged the following evidence:

- Forward Facing CCTV (FFCCTV) of the accident from Sweep Tram 3016;
- CCTV from Abbey Street Stop;
- Witness statements from parties involved in the failure;
- Maintenance specifications for the OCS;
- Maintenance records for the inspection and repair of the OCS on the Red Line;
- Event log from the Traction Power Supply, Supervisory Control And Data Acquisition (SCADA) system;
- Investigation reports into previous incidents;
- Consultants reports into the use of Parafil ropes.

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

Other stakeholder inputs

9 No judicial authorities or emergency service were involved in this accident.

Other information relevant to the investigation process

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

Summary of the failure & background information

Synopsis of the accident

11 At approximately 01:16 hrs on the 11th June 2021 the Parafil termination failed on the cross-span between a pole and the Strong Registration Arm attached to the Luas network OCS on the Outbound line, cess side, close to Beresford Place IÉ railway bridge; causing the Strong Registration Arm to hang down over the tram line. This results in the contact wire losing stagger and striking the negative copper strip on the insulated plates located under the railway bridge resulting in a dead-short and tripping (stopping the electrical flow) the electrical power in the O'Connell to Spencer Dock section. There were no trams in the section, the last outbound tram to pass the section was Tram 3026 at approximately 01:00 hrs.

12 LNMC were alerted to the ESS trip-out and contacted Infrastructure Maintenance who arrived on at O'Connell ESS at 01:25 hrs and reset both *Traction* and *High Speed Circuit Breakers* with no issues; they did not inspect the OCS.

13 At 04:35 hrs, Sweep Tram 3016 departed the Red Cow, inbound to the Point Depot, travelling at a maximum speed of 25 km/h.

14 At 05:11:50 hrs, Sweep Tram 3016 stopped at Tram Signal C39, on the approach to Beresford Place railway bridge and the location of the partially detached Strong Registration Arm.

15 At approximately 05:12 hrs, Sweep Tram 3016 receives a proceed aspect at Tram Signal C39 and begins to travel towards Beresford Place railway bridge.

16 Due to the loss of stagger, the pantograph of Tram 3016 rises above the displaced contact wire and strikes the cross-span assembly. The force of impact on the cross-span assembly causes the Strong Registration Arm to detach from the contact wire and becomes entangled on the pantograph, contacting both the foot of the pantograph and roof of the tram; causing a dead-short and trips the power in the O'Connell to Spencer Dock electrical section. Sweep Tram 3016 continues forward, pulling down the feeder cable; with the pantograph colliding with and dislodging a number of insulated plates under the railway bridge. Sweep Tram 3016 comes to a stop approximately 30 m from the first impact with the cross-span assembly (approximately seven seconds).

17 Driver 3016 contacts LNMC and reports hearing a loud bang and loss of power.

External circumstances at the accident location

Weather

18 The weather was dry and fine; weather data was taken from the nearest Met Éireann Weather Station at Phoenix Park, four kilometres west of the Beresford Place, recorded that there was no rainfall at the time of the accident. The minimum and maximum temperatures for the day were recorded at 11ºC 18.9ºC, respectively. The weather conditions were not contributory to the accident.

19 Sunrise was at 04:57 hrs on the day of the incident; meaning that the detachment of the Strong Registration Arm occurred during darkness; however, as the infrastructure staff did not travel to the location, this was not contributory to the incident. Tram 3016 proceeded to the location of the Strong Registration Arm at 05:12 hrs, daylight hours, see Figure 1, however, he did not see the fault; as a result, this was also not contributory to the incident.

Figure 1 – Daylight on approach to the detached Strong Registration Arm

Fatalities, injuries & material damage

Fatalities & injuries

20 There were no fatalities or injuries to staff or passengers as a result of the accident.

Material damage

Tram 3016

21 The pantograph, pantograph base, wiring and other pantograph components were replaced along with the right side roof panelling.

Overhead Contact System

22 All OCS supports over the 100 meters (m) linear length of the contact wire were replaced as a result of the accident.

Iarnród Éireann Beresford Place Railway Bridge

23 Replacement of three insulated plates to IÉ Beresford Place railway bridge.

Other consequences as a result of the accident

24 As a result of the accident inbound Red Line trams operated as far as Smithfield where they turned for an outbound journey until 18:48 hrs when the first tram crossed the section after the OCS had been repaired and power reinstated.

25 Train E200, the IÉ 06:06 hrs passenger service from Dublin Connolly to Bray was delayed for thirteen and a half minutes while IÉ inspected Beresford Place railway bridge to assess the damage caused by the pantograph striking the underside of the IÉ railway bridge.

Parties & roles associated with the accident

Parties involved in the accident

26 Transdev 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.

27 S2M carry out infrastructure maintenance for Transdev. S2M is a joint venture between Transdev and Efacec formed to deliver power and systems maintenance for the Luas infrastructure. There are four disciplines: Track; Overhead Line (OHL); Traction Power; and, Communications. The Infrastructure Technicians report to a Discipline Supervisor who reports to a Discipline Manager. The four Discipline Managers report to the Joint Venture Manager who in turn reports to the Head of Infrastructure. Transdev provides shared services to S2M including human resources, planning, procurement, and safety.

Roles involved in the accident

28 Driver 3026 operated Tram 3026, the last tram to pass Beresford Place prior to the first trip-out. Driver 3026 is employed by Transdev and had trained and was deemed competent to drive Luas trams since October 2019. Driver 3026 was due a competency assessment on the 29/12/2019; however, it was cancelled due to Covid-19 restrictions[3].

29 Driver 3016 operated Sweep Tram 3016. Driver 3016 is employed by Transdev and had been trained and was deemed competent to drive Luas trams at the time of the accident and has approximately 3½ years' experience in the driving grade. Driver 3016 passed his last assessment on the 24/02/2020 (with no restrictions).

30 The Traffic Supervisor, based in the Red Cow LNMC, is employed by Transdev. At the time of the accident the Traffic Supervisor had been trained and deemed competent to carry out Traffic Supervisor duties. The Traffic Supervisor had over 15 years' experience in the Traffic Supervisor's role and passed his last assessment on 21/07/2019 (with no restrictions).

31 Infrastructure staff who attended the trip-out at O'Connell ESS consisted of a Lead Technician and two supporting technicians; all qualified with required electrical engineering competences and Luas specific safety training; with the Lead Technician having over ten years of electrical engineering experience.

[3] Driver competency was risk assessed by Transdev during the Covid-19 pandemic. At the time of publication of this report, driver competency has returned scheduled frequency.

Parties not directly involved in the accident

Transport Infrastructure Ireland

32 Transport Infrastructure Ireland's (TII) primary function is to provide an integrated approach to the future development and operation of the national roads network and light rail infrastructure throughout Ireland. TII is the Irish State body that provides the rolling stock and infrastructure required for the Luas light rail network.

Linear Composites Limited

33 Linear Composites Limited (LCL) based in Keighley, West Yorkshire, England are one of the leading manufacturers of synthetic ropes. LC produce high-specification technical fibre products that are used in civil engineering, marine, transport, mining and military sectors and are used in over fifty countries across every continent; their portfolio includes Parafil rope used extensively for supporting light rail OCS.

Brecknell Willis

34 Brecknell Willis designed and constructed the Luas OCS and also procured and machined the Parafil terminations.

Pod-Track

35 Pod-Track design, develop, build and maintain projects across all transport infrastructures and were contracted by TII to consider the Luas OCS assets and determine appropriate interventions given the age and condition addressing issues relating to wear and tear and weather conditions. One of the main known failure modes that required addressing was the Parafil rope failures at the terminations, this was achieved by replacing the parafil rope with a steel rope and inline discreet *insulators* the work commenced in October 2020 by Pod-Trak under contract to TII.

General description of the tramway

36 Dublin's Luas network is made up of the Red and Green Lines; the network has sixty-seven stop and 44.5 kilometres (km) of track, see Figure 2.

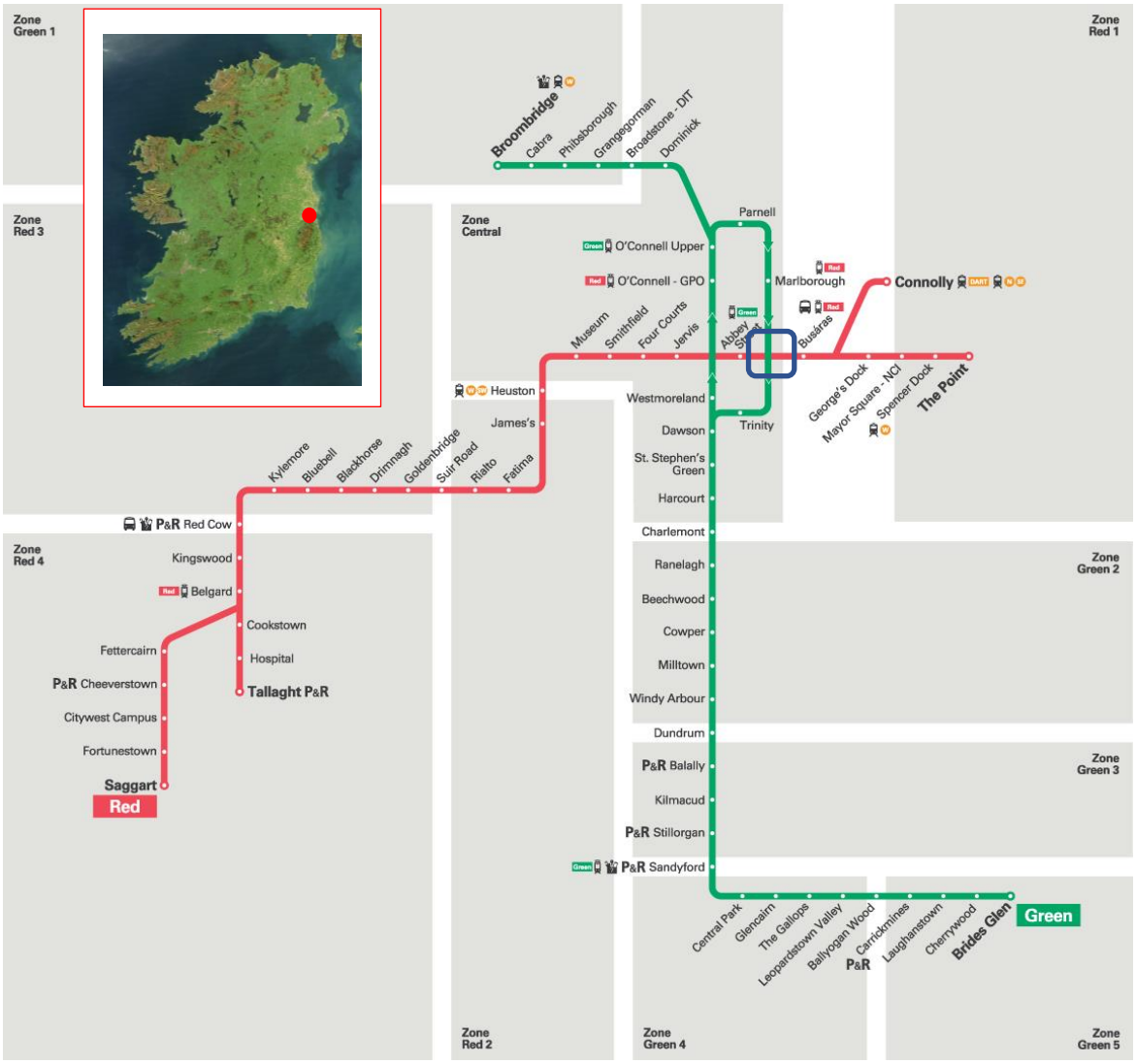

Figure 2 – Luas's network map (Beresford Place is identified in blue)

37 The Red Line (where the accident took place) is 20 km in length and has thirty-two stops running from Tallaght to The Point and from Saggart to Connolly. The Green Line is 24.5 km in length and has thirty-five stops running from Brides Glen to Broombridge via the City Centre. Tram stops are fitted with a CCTV system that allows for live viewing by the Traffic Supervisor as well as recording and play back facility.

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

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

40 Trams are powered by an OCS providing 750 Voltage (V) *Direct Current* (DC) delivered from twenty electrical sub-stations, the OCS is discussed further in paragraphs 57 to 80.

41 Beresford Place railway bridge is an IÉ owned railway bridge that passes over the Red Line between Abbey Street and Busáras tram stops, see Figure 3.

Figure 3 – Beresford Place railway bridge

Rolling Stock

42 Trams 3026 and Tram 3016 are part of the forty 401 tram fleet operating on the Dublin Luas Red Line. The 401 trams are 40 m long, 2.4 m wide, 3.45 m high (with the pantograph lowered).

43 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 4.

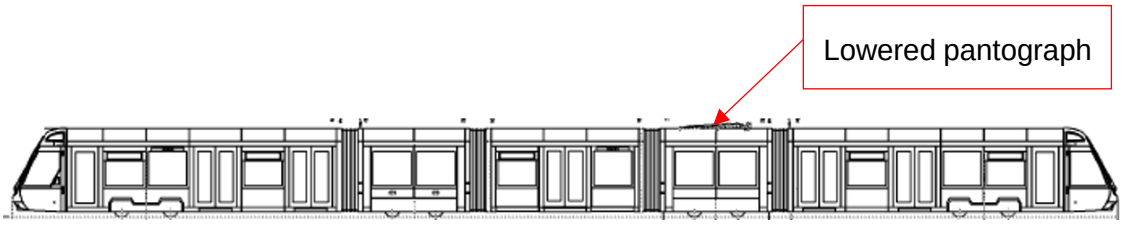

Figure 4 – 401 Tram configuration

Signalling & Communications

44 Trams 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 lit 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.

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

Operations

46 Trams are regulated on track by "line-of-sight driving" where the driver is responsible for observing and maintaining a sufficient distance from trams ahead, motor vehicles, pedestrians, hazards or obstacles that are present or can be expected to be present on the track so the driver can stop the tram without causing a collision.

Evidence

Luas Pantograph

General description

47 The pantograph (see Figure 5) is an articulated, mechanical assembly that facilitates the pickup of current in the OCS wire and transfers it to the high tension supply cabinet, called the Collector Circuit Breaker cabinet. They are manufactured by Schunk Transit Systems.

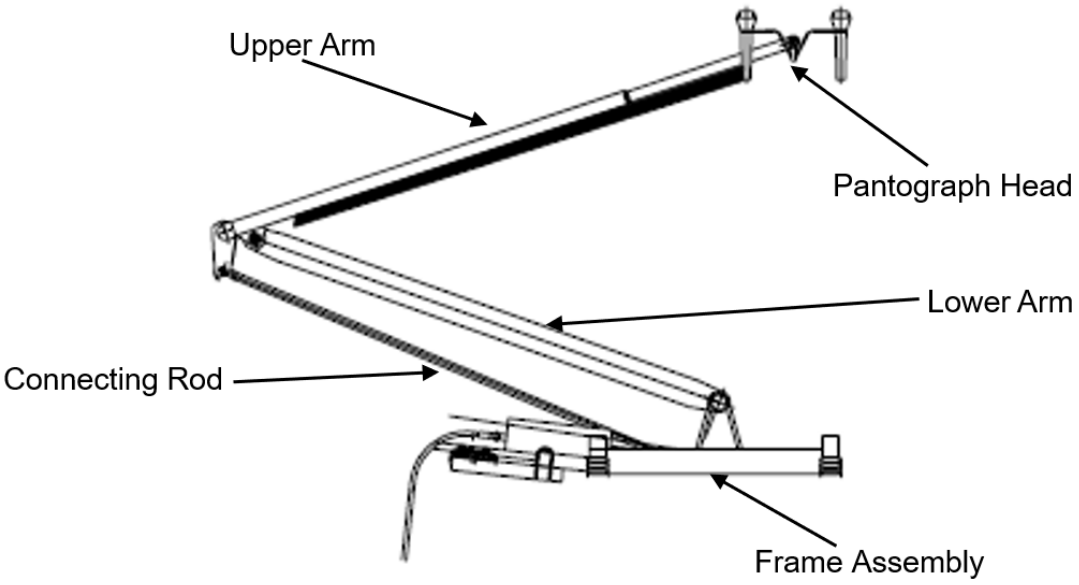

Figure 5 – Illustration of the pantograph assembly fitted to 401 trams

48 When raised the spring assembly pushes the pantograph head upwards against the contact wire, the entire pantograph assembly is live at the supply voltage of 750V DC[4]. The assembly is insulated from the tram by four securing insulator assemblies.

49 Carbon bands are a long-extruded carbon fitted into an aluminium carrier that is provided on top of the pantograph and collects current from an overhead wire. This is the point of interface between the tram and the OCS.

[4] Luas trams are not fitted with an automatic dropping device (ADD), a protection device fitted to a pantograph which lowers in case of an unwanted railway incident at the level of the catenary. ADDs are generally not fitted to light rail vehicles due to the tram's ability to stop quickly in the event of an incident.

Pantograph inspection and maintenance

50 Pantographs are maintained by Transdev at intervals of 15,000 km, 60,000 km and 600,000 km.

51 Tram 3026 received its last maintenance intervention (15,000 km) prior to the accident on the 29th March 2021 with no faults found.

52 Sweep Tram 3016 received its last maintenance intervention (15,000 km) prior to the accident on the 28th April 2021 with not faults recorded.

Post-accident inspection of the pantographs

Tram 3026

53 The pantograph of Tram 3026 was inspected post-accident and found to be working correctly with the pantograph lowering and raising smoothly. The carbon bands had no signs of damage or arcing having been recently changed. The coupling rod was straight, the pantograph heads were able to swivel, and the pantograph locked down fully.

54 The average pantograph's uplift pressure was recorded as 8.68 kg which is within the specified parameters of between 7.65 kg to 9.7 kg, as set out in Transdev document TDLR-LUAS-WI-00652, "Check of upward contact force of the bow on the of the catenary", Issue E, published in October 2015.

Sweep Tram 3016

55 The pantograph of Tram 3016 was severely damaged in the collision with the Railway Bridge at Beresford Place. Transdev concluded that the pantograph was beyond economic repair at post-accident inspection and a new pantograph was fitted.

56 The damage to the pantograph of Tram 3016 prevented the checking of the pantograph uplift pressure.

Luas Overhead Contact System

General description

57 Trams are powered by an OCS providing 750V DC delivered from twenty ESSs. Power is supplied to the ESSs from the national grid at 10 kilovolts (kV) *alternating current* (AC). The 750 V DC supplied to the trams via a roof mounted pantograph is converted to AC to power the motorised bogies on the tram set. The return circuit is through the wheel rail interface and back to the sub-station.

58 The maximum height of the contact wire is 6.59 m above rail level (at St. Stephen's Green) and decreases to a minimum of 3.97 m above rail level (at Dundrum to Balally) at tram *overbridges* and other low structures. The contact wire height at Beresford Place was between 5.975 m and 6.236 m above rail level and not considered as contributory to the accident.

59 The OCS is sectioned electrically to allow maintenance intervention including planned and emergency repair of the OCS without the need to de-energise the complete line.

60 The assembly involved in the incident is a cross-span assembly.

Parafil rope

61 The OCS is supported by an arrangement of cables/ropes that ensure the contact cable is at the correct height and *stagger* and also provide electrical insulating between the contact cable and the supporting poles or structures.

62 The Parafil rope on the Luas OCS network was supplied by LCL to Brecknell Willis and is classified as 8.5 mm Kevlar rope and functions as both a support and electrical insulator. Kevlar is an organic fibre in the aromatic polyamide family and provides a combination of high strength, toughness, and thermal stability.

63 At the location and time of the accident, the Parafil rope had not been replaced (this is discussed in paragraphs 107 - 111) and the arrangement was similar to Figure 6.

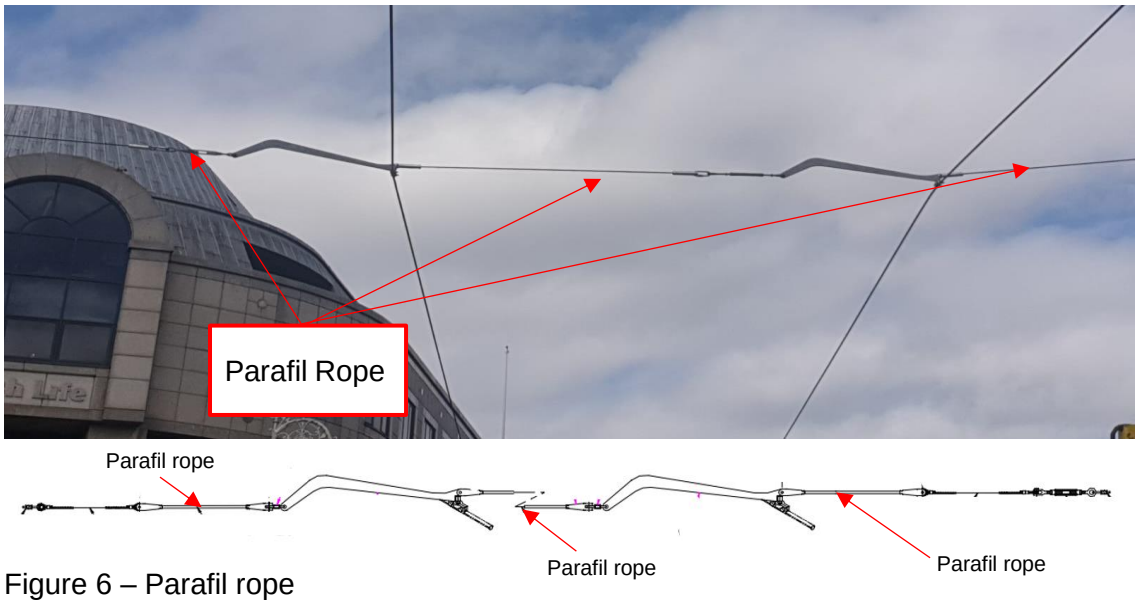

Figure 6 – Parafil rope

Strong Registration Arm

64 The Strong Registration Arm is an OCS component which attaches at one end to the bracket arm and to the contact wire at the other (see Figure 7 (A)); which allows the wire to lift under the force of a pantograph whilst maintaining it in the correct register. It is similar to the cross-span arrangement illustrated in Figure 7 (B).

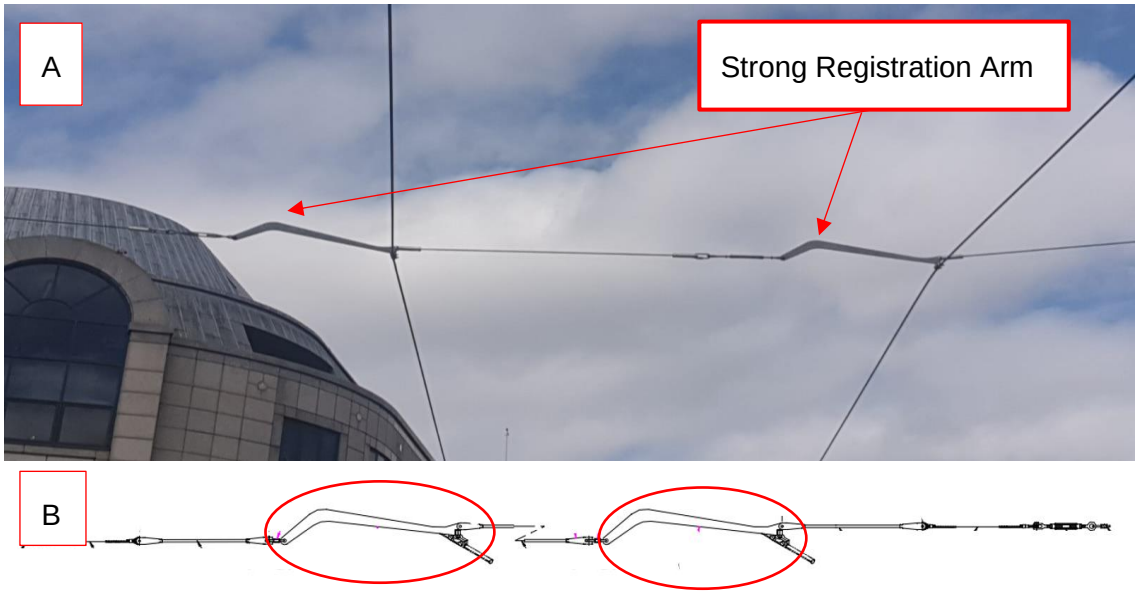

Figure 7 – Strong Registration Arm (encircled)

Parafil terminations

65 Parafil terminations (sometimes referred to as terminals) are located where the Strong Registration Arm and end of the Parafil rope join, see Figure 8.

Figure 8 – Parafil terminations

66 Parafil termination end fittings consist of a barrel and a spike (see Figure 9). The rope core fibres are placed through the barrel before the spike is inserted compressing the fibres securely against the barrel wall.

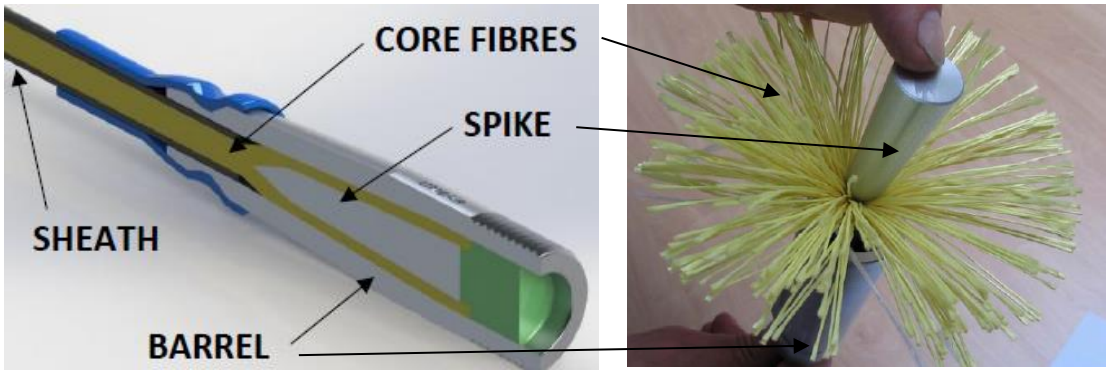

Figure 9 – Parafil termination (barrel and spike)

67 LCL state that "it is good practice to take steps to prevent ingress of water into terminations used on aramid[5] fibre Parafil ropes. The sealing is applied to two regions the junction between the 'nose' of the termination and the rope and into the 'tail' end of the barrel (left image of Figure 10). The nose seal is made of two components, a short length of silicone rubber which is over-wrapped by self-amalgamating tape while the tail seal is typically formed using a proprietary silicone mastic compound (see right image, Figure 10). The Luas terminations did not have silicone rubber sleeves fitted and relied on self-amalgamating tape to prevent water ingress at the nose end (see Figure 10).

Figure 10 – Sealing arrangement

68 LCL states in their Technical Notes (Issue A4, 2018) "to benefit from the extremely high levels of performance offered by Parafil rope, it must be used in combination with proprietary terminals from Linear Composites". LCL claim that Parafil ropes, combined with LCL terminations have a proven track record of achieving in excess of forty years in continuous-service working.

69 The termination castings for the Luas, were not LCL terminations, rather they were finished machined by Brecknell Willis.

[5] Kevlar

Insulated plates

70 Although not directly part of the OCS arrangement, insulated plates are part of the electrical protection measures, protecting other assets from conducting electricity, as was the arrangement under Beresford Place railway bridge.

71 Three insulated plates were damaged as a result of the accident (paragraph 23).

Figure 11 – Insulated plates under Beresford Place railway bridge

OCS Maintenance Inspections

72 OCS inspections are carried out every three months, six months, and two years. The Abbey to Connolly section received its last three monthly inspection on 15th April 2021 with no faults found and no requirement of a concession (i.e. an agreed deviation from design).

73 The Abbey to Connolly section received its last six monthly inspection on 11th February 2021 all measurement were within specification and no requirement of a concession.

74 It should be noted that it is not possible to evaluate the condition of the parafil core fibres (pictured in Figure 9) at the terminations during planned inspections, as the core fibres are covered by the sheath (pictured in Figure 9), termination casting and self-amalgamating tape (described in paragraph 67).

Post-accident inspection of the OCS at Beresford Place

75 Post-accident, a failure point was identified at the termination of the parafil rope and the Strong Registration Arm on the cess side of the Outbound line (see Figure 12).

Figure 12 – Parafil rope & Strong Registration Arm failure point

76 Examination of the failed termination revealed that the parafil core fibres had pulled out of the termination barrel (see Figure 13).

Figure 13 – Core fibres pulled from termination barrel

77 On closer examination approximately 15% of the core fibres were shorter when measured from the sheath. The shortened fibres were located evenly around the external diameter of the sheath. When the termination spike was removed the severed remains of the failed fibres were located (Figure 15).

Figure 14 – Close up of core fibres

Figure 15 – Severed core fibres removed from the termination

78 The failed ends of the parafil core fibres were not a clean cut, suggesting they failed as a result of being pulled apart over a period of time where subjected to in-service stresses.

79 There was no evidence of fibre discolouration as a result of water ingress.

80 To determine if poor workmanship resulted in the failure, the terminations were re-assembled, using new fibres, excessive force was used in inserting the spike at the centre position and over-centre position. No damage was identified to the core fibres for either assembly; coupled with the fact that there was no evidence of water ingress (paragraph 79) indicates that poor workmanship was not a cause of the failure.

Incident Management

81 The Transdev “Incident Management” document TDLR-S-PR-0013 (to be referred to as Incident Management Procedure for the remainder of this report), Rev 01.0, approved on the 25th October 2019, sets out Transdev’s response to accidents and incidents by defining roles and procedures to provide an effective and safe response to incidents, accidents and other emergencies which may occur on the Luas system.

82 The tripping-out of an ESS is not covered by the Incident Management Procedure or by any other Transdev standard or work instruction.

83 The drivers of sweep trams are not notified of previous incidents that have occurred over the section they are driving, as it could impede the intended function of the sweep tram, which is to check the line is free from obstacles / obstructions. Notification of occurrences, according to Transdev, could potentially “take away from line of sight driving where the driver could become particularly focussed on looking out for this prompt in a particular area, which may have features anyway such as bridges, signs, pedestrian and vehicular crossings. Following such a prompt could increase the risk of collision or SPADS or missing an object or obstruction on the ground”.

Events before, during & after the accident

Events before the accident

84 At approximately 01:00 hrs, Tram 3026, was the last tram to travel outbound through the road junction of Abbey Street and Gardiner Street.

85 At approximately 01:16 hrs the parafil termination failed on the cross-span between the pole and the Strong Registration Arm attached to the Outbound line, cess side, at Beresford Place. The Strong Registration Arm and hangs down (see Figure 16, note, this image is taken from later in the morning, it is for illustrative purposes only).

Figure 16 – Hanging Strong Registration Arm

86 Due to the sudden release of the tension on the cross-span the contact wire losses stagger and strikes the negative copper strip on the insulated plates located under the bridge resulting in a dead-short and tripping the electrical power in the O'Connell to Spencer Dock electrical section. There were no trams in the section at the time (Tram 3026 was 5.3 km away at Golden Bridge).

87 LNMC were alerted to the ESS trip-out on the console. The flash at O'Connell ESS from the trip-out was visible on the Abbey Street Platform CCTV, Figure 17.

88 Infrastructure Maintenance were advised of the fault and arrived at O'Connell ESS at 01:25 hrs and reset both Traction and High Speed Circuit Breakers with no issues. Infrastructure Maintenance staff did not inspect the electrical section as this was not a requirement (paragraph 82).

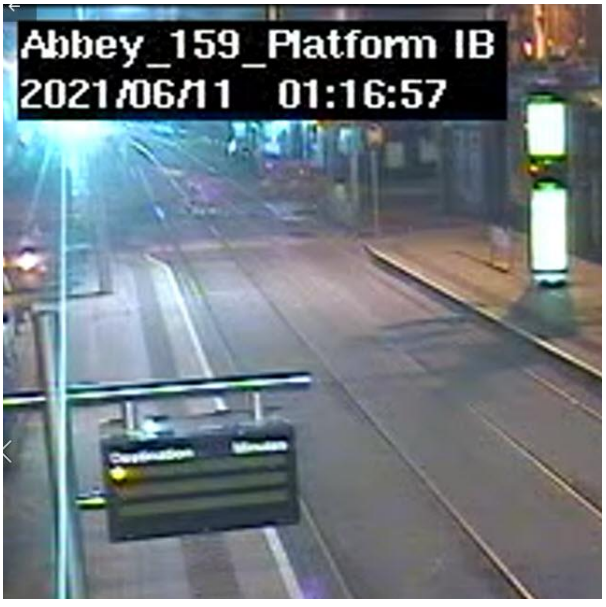

Figure 17 – Flash at O'Connell ESS

89 At 04:35 hrs, Sweep Tram 3016 departed the Red Cow travelling inbound to the Point Depot, travelling at a maximum speed of 25 km/h.

90 At 05:11:50 hrs, Sweep Tram 3016 stopped at Tram Signal C39. The FFCCTV shows the Strong Registration Arm on the Outbound line is partially detached, see Figure 18 (image taken from FFCCTV of Sweep Tram 3016). Driver 3016 did not see the Strong Registration Arm hanging down.

Figure 18 – Strong Registration Arm (circled) hanging (image from FFCCTV)

91 At approximately 05:12 hrs, Sweep Tram 3016 receives a proceed aspect at Tram Signal C39 and begins to travel towards Beresford Place bridge.

Events during the accident

92 Due to the loss of stagger (paragraph 61), the pantograph of Tram 3016 lost contact with the contact wire and strikes the cross-span assembly. The force of impact on the cross-span assembly causes the Strong Registration Arm to become detached from the contact wire and becomes entangled on the pantograph, contacting both the foot of the pantograph and roof of the tram; resulting in a dead-short and the tripping of the power supply in O'Connell to Spencer Dock electrical section.

93 Sweep Tram 3016 continued forward, pulling down the feeder cable (Figure 19); with the pantograph colliding with the railway bridge, damaging the insulated plates (Figure 20).

Figure 19 – Feeder cable down

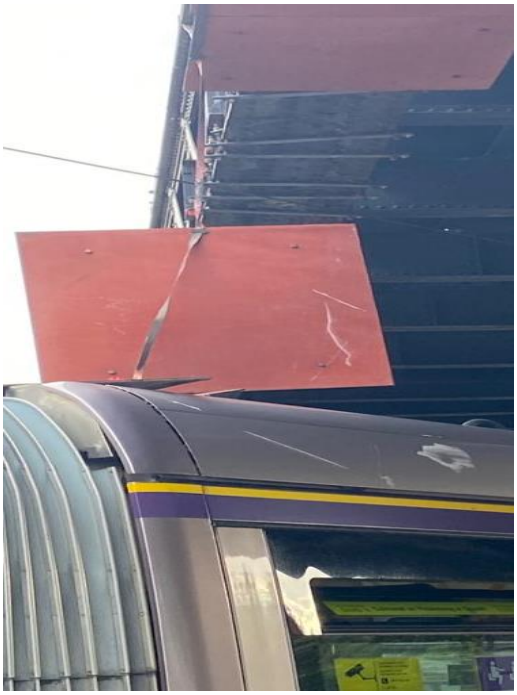

Figure 20 – Damage to insulated plates

94 The force of the impact causes the footings on the base of the pantograph to be torn back, see Figure 21.

Figure 21 – Pantograph of Sweep Tram 3016 in collision with bridge

95 Sweep Tram 3016 came to a stop approximately 30 m from the first impact with the cross-span assembly (approximately seven seconds). Driver 3016 contacts LNMC and reports hearing a loud bang and loss of power.

96 With the outbound Strong Registration Arm detached having fallen to the ground (see Figure 22) the Inbound Strong Registration Arm failed on one side and rotated freely from the contact wire (see Figure 23, image is taken from the RFCCTV of Sweep Tram 3016).

Figure 22 – Outbound Arm

Figure 23 – Inbound Arm

Events after the accident

97 At 05:12 hrs LNMC were alerted to the ESS trip-out in the O'Connell to Spencer Dock electrical section. LNMC, using nearby cameras on Abbey Street, see parafil damage and possible pantograph damage.

98 At 05: 12hrs LNMC de-energises the line between Heuston Stop and the Point Stop and prevents any trams entering the section.

99 At 05:13 hrs LNMC notify Infrastructure Maintenance of the fault.

100 At 05:17 hrs LNMC notify IÉ of the bridge strike at Beresford Place.

101 At 05:30 hrs Infrastructure Maintenance arrive on site and advised LNMC that the fault was local and LNMC reconfigured the isolation from Abbey Street to the Point Depot with trams turning at Smithfield from 06:00 hrs.

102 Infrastructure Maintenance staff completed repairs and the line was re-energised with the first tram crossing the section at 18:48 hrs.

Similar Occurrences

Previous Parafil failures

103 Although there have been parafil failures in the past, the RAIU are not aware of any parafil failure, where an initial OCS fault was not identified resulting in a more severe second occurrence.

104 In terms of previous Parafil failures, from October 2006 to June 2021 there have been thirty-five Parafil failures (at terminations) on the Luas system. All failures occurred close to the parafil termination. Parafil ropes as a component of the Luas OHLE system are subject to many stresses; primarily mechanical and electrical stresses during operation, but they are also subject to the effects of weather. TII has worked with the existing and previous maintainers to investigate failures as they have occurred. These investigations are ongoing and will continue until all parafil ropes are removed from the OHLE system. TII have developed a renewal strategy in consultation with OHLE industry experts which is described below (as outlined in paragraphs 76 - 80).

Luas OCS Parafil renewal Strategy and Approach

105 TII commissioned Pod-Trak to carry out a study of Parafil failures and to propose a solution to the problem on the Luas network resulting in the “Luas OCS Parafil renewal Strategy and Approach – A risk based approach to the selection and prioritisation of Parafil renewals on Luas OCS” reviewed Kevlar Parafil failures on the Luas Dublin Light Rail Network from 2010 to 2017 (to be referred to as Pod-Trak Report), the report was published on the 4th December 2018 (Document Number PTL-LUAS-RA-OLE). The document identified 26 separate incidents and analysed the failures in relation to:

- Length of time in service;
- Calendar month failure occurred;
- Location;
- Environment: Track, Road Running, Depot / Delta;
- Arrangement type e.g. cross-span.

106 The report concluded that: “Review of the historical data suggests that areas of high risk are predominantly and almost exclusively to road running sections of the system and complex junctions. It is expected that the steady rate of incidents that has been experienced will continue in the future. The road running sections and complex junction risk assessment demonstrate that risk created by failure in these environments is in many

cases more severe. Public safety, damage to assets, building, vehicles, and delay to service are all factors more vulnerable when compared with tracked sectioned area.

107 The Pod-Trak Report considered two types of replacement, a polyester parafil rope which would be a "direct replacement option for Kevlar parafil rope" as it has "very similar" material properties and profile and "offers the same insulation levels as Kevlar and is secured via the same method". However, it was found that polyester parafil is commonly used by Manchester Metrolink, Croydon tram and West Midland Metro to replace Kevlar Parafil rope and "is now experiencing failures of polyester parafil rope", suggesting that "Polyester parafil rope is not as reliable as originally believed by many within the industry".

108 The second option, outlined in the Pod-Trak Report was for stainless steel wire rope with discreet insulators, the report stated that "wire rope is commonly used within light rail OCS because of its versatility, strength, low cost and resistance to corrosion and fatigue. Unlike parafil rope this material does not offer any level of electrical protection and so it is necessary to install insulation, which is in-line and discreet in profile".

109 The Pod-Trak Report recommended that as a priority that: "Parafil rope utilised within all high radially loaded complex junctions throughout the system should be changed out for 6 mm diameter wire rope and discreet insulation following the completion of complex junction's alternation should continue onto road running sections of track, starting with Abbey Street". This stainless steel rope, which according to the Pod-Trak Report is the "preferred choice for all light rail new build projects and extensions in recent years, most notably the Phase 3A & 3B of the Manchester Metrolink. According to the maintainer, zero cases of stainless steel wire rope failure have occurred on the system since installation began in 2010".

Parafil replacement

110 Pod-Trak were awarded a single supplier framework contract by TII, in 2020, to complete the replacement from Kevlar Parafil rope to 6 mm diameter stainless steel wire rope and discreet insulators.

111 Work commenced in October 2020 but the planned rate of change out was not achieved due to Transdev's inability to resource isolation crews in the first six months of 2020. Progress was made in the second six months of 2020 with work scheduled for weekend shutdowns and on extended weekend isolations resulting is the majority of high risk areas been completed. Covid-19 slowed progress, but work is expected to be completed in 2022.

Analysis

Pantograph

112 The pantographs on Tram 3026 and Sweep Tram 3016 were in date for scheduled maintenance at the time of the accident and records show no faults were detected (paragraphs 51 and 52).

113 Post-accident the pantograph on Tram 3026 was examined and found to be operating to specification (paragraph 54). The pantograph on Sweep Tram 3016 was too badly damaged as a result of striking Beresford Place Railway Bridge and could not be tested post-accident (paragraph 55).

OCS

Inspections

114 Inspections are carried out every three months, six months, and two years on the OCS (paragraph 72). The Abbey Street to Connolly OCS section was in date for both three and six monthly inspections at the time of the accident, with no concession requirements. It should be noted that the core fibres cannot be inspected at the terminations during inspections as the termination castings, self-amalgamating tape and parafil sheath cover the core fibres (as described in paragraph 67).

Parafil replacement

115 The Pod-Trak Report analysed Kevlar parafil failure modes in relation to age, month of failure, location, environment, and arrangement type; identifying high risk locations as road running sections, particularly those at complex junctions (paragraphs 105 - 106).

116 The Pod-Trak Report, after considering two replacement options (polyester and stainless steel) recommended that the Parafil rope should be replaced with stainless steel wire rope (6 mm diameter) stainless steel wire rope and discreet insulators, starting with complex junctions and running sections (paragraph 107 - 109).

117 At the time of the accident, Pod-Trak (who were awarded the contract for the work) had commenced the replacement programme (paragraphs 110 - 111).

Parafil mechanism of failure & consequences

118 The Parafil (Kevlar) ropes had not been replaced at the location of the accident (paragraph 63).

119 Post-accident examination of the failed Kevlar parafil termination revealed the core fibres were not discoloured due to water ingress and had pulled out of the termination, with approximately 15% of the fibres being severed 10 mm from the cable sheath with the remaining severed fibres inside the termination. The loss of approximately 15% of the core fibres would have resulted in the remaining fibres taking the full stresses exerted on the termination and eventually resulting in the remaining fibres sliding out of the termination (paragraphs 77 - 80), this is likely to have occurred over a period of time as a result of in-service stresses.

120 The failed Kevlar Parafil terminations resulted in the Strong Registration Arm on the Outbound line hanging down (as seen from the FFCCTV images from Sweep Tram 3016 as it approached Beresford Place (paragraph 90).

121 The consequences of failure are outlined previously in paragraphs 91 - 95.

Incident management

122 The initial ESS trip-out at 01:16 hrs on 11th June 2021 was attended to by Infrastructure Maintenance staff who reset both the Traction and High Speed Circuit Breakers without the fault reoccurring. As the Circuit Breakers reset without fault there was no requirement for the Infrastructure Maintenance staff to carry out a ground level inspection of the section despite being in the location (paragraphs 81 and 82).

123 The Luas Incident Management Procedure is a high level document, which primarily deals with major incidents and accidents i.e. fatalities or serious injuries as a result, there is no guidance in relation to incidents such as circuit breaker resetting (paragraph 80).

124 At the time of the accident, there were no Infrastructure Maintenance work instructions or standards in relation to resetting circuit breakers or the need to inspect the OCS for the reason for the trip-out (paragraph 81).

Conclusions

Pantograph

125 The pantographs on Tram 3026 and Sweep Tram 3016 were in date for scheduled maintenance at the time of the accident and records show no faults were detected (paragraph 112 and 113). Although, post-accident examination of the pantograph on Sweep Tram 3016 was not possible, due to damage (paragraph 113), it is unlikely the condition of the pantograph contributed to the accident

OCS

126 Inspections of the Abbey Street to Connolly OCS section were in date, with no concession requirements (paragraph 114); however, the core fibres (which failed on the day of the accident) cannot be inspected during inspections as the termination castings, self-amalgamating tape and parafil sheath cover the core fibres (paragraph 114).

127 The Pod-Trak Report (a report commissioned as a result of a number of Kevlar parafil failures) analysed the failure modes and identified high risk locations i.e. running sections and complex junctions (paragraph 115); ultimately recommending the replacement of the Kevlar Parafil rope for a 6 mm diameter stainless steel wire rope (with discreet insulation), with priority given to the high risk areas (paragraph 116).

128 The replacement programme had commenced but had not occurred at the location of the accident, with the post-accident inspection of the parafil termination identifying the failure of the core fibres; which ultimately resulted in the Strong Registration Arm detaching (paragraph 119).

Incident management

129 At the time of the accident, there was no documentation in relation to resetting circuit breakers and the requirement to carry out a ground survey after a trip-out (paragraph 121 - 123) which resulted in Infrastructure Maintenance not visually inspecting the section in the vicinity of the accident.

Causal, contributing and systemic factors

130 In this accident, there are two distinct events, namely the failure of the Kevlar parafil and the Infrastructure Maintenance response to the trip-out at 01:16 hrs, and as such the causal, contributing and systemic factors (where identified) are separated.

131 In terms of the failure of the Kevlar Parafil terminations, the mechanism of failure is likely as a result of the failure of the core fibres (which cannot be visually inspected) deteriorating over period of time as a result of in-service stresses (paragraph 119). At the time of the accident, there was a programme in place for the replacement of the Kevlar parafil for 6 mm diameter stainless steel wire rope with inline discreet insulators (paragraph 126), however, replacement had not yet been undertaken at the location of the accident. Causal factors are:

- CaF-01 – The planned inspections of the OCS cannot identify the deterioration of the Kevlar parafil fibres at the terminations.
- CaF-02 – The Kevlar parafil rope had not been replaced with 6 mm diameter stainless steel wire rope with inline discreet insulators, an ongoing Luas network maintenance project, at the time of the accident.
- CaF-03 – No ground level survey of the electrical section was carried out after the notification of the first trip-out; this inspection would have identified the partially detached Strong Registration Arm.

132 No contributing or systemic factors were identified in terms of the failure of the Parafil rope.

133 In terms of the response to the initial trip-out, Infrastructure Maintenance did attend the relevant ESS and reset the circuit breakers, however, they did not conduct a ground level inspection prior to handing back the track. No causal or contributing factors were identified, however the systemic factor is as follows:

- SF-01 – Transdev/ S2M did not have any documentation in relation to the requirement to carry out a ground level visual inspection of a section after an electric trip-out, at the time of the accident.

Measures taken by Transdev since the accident

OCS

134 In relation to the Kevlar parafil failures on the LUAS network, Pod-Trak have identified an alternative, namely the 6 mm diameter stainless steel wire rope and discreet insulators (see Figure 24), with works due to be completed by the end of 2022 (paragraph 126 - 128). Stainless steel wire rope is the preferred choice for all international light rail new build projects and extensions in recent years, with the maintainers of the Manchester Metrolink recording zero cases of stainless steel wire rope failure since installation began in 2010 (paragraph 109).

Figure 24 – Stainless Steel Wire Rope

OCS inspection

135 Transdev published “OCS Failure – Involving HSBC & Transformer”, document number TDLR-INFRA-PR-0002 on the 21st December 2021, with Revision 2.0 published on the 4th January 2022. The purpose of the document is “To ensure that all work is undertaken on, near or adjacent to Transdev Dublin Light Rail Ltd Infrastructure is properly implemented and controlled to safeguard: The safety of the Transdev Dublin Light Rail Ltd system, staff, passengers, contractor's staff, vehicles and members of the general public; and, the reliable operation of the Transdev Dublin Light Rail Ltd System” and is applicable to LUAS Infrastructure Maintenance project, specifically OCS failures involving High Speed Circuit Breakers (HSCB) and transformers.

136 In the case where LNMC notify Infrastructure Maintenance where a High Speed Circuit Breaker and transformer fail at the same time, Infrastructure Maintenance are required to attend the affected area (with one electrician and two technicians). The sequence of work now includes for the crew to complete a full ground level survey of the electrical section involved in the tripping-out and further outlines two scenarios in terms of actions, namely where no issues are detected and where issues are detected. Where additional issues are detected an additional ground level survey after remedial actions are taken. These actions have to be taken prior to the re-energisation of the section.

Notification of incidents to the RAIU

137 The RAIU was not immediately notified of the accident (paragraph 2). On the 25/02/2022, the Head of Safety in Transdev, sent a reminder email to all the Duty Manager, Team Leaders, Safety Teams, Executive Team and other relevant staff members of their statutory requirement to notify the RAIU of incidents and accidents in line with the RAIU’s Guidance: Notification of occurrences to the RAIU for RUs, IMs and other ROs.

Safety Recommendations

Introduction to safety recommendation

138 In accordance with the European Union (Railway Safety) (Reporting and Investigation of Serious Accidents, Accidents and Incidents) Regulations 2020), recommendations are addressed to the national safety authority, the Commission for Railway Regulation (CRR). The recommendation is directed to the party identified in each recommendation.

Absence of safety recommendations due to measures already taken

OCS

139 The Parafil replacement project is ongoing with Pod-Trak replacing the existing Kevlar Parafils with 6 mm diameter stainless steel wire rope, discreet insulators, with works due to be completed by the end of 2022 (paragraph 134). As a result, the RAIU do not consider any further recommendations are warranted in relation to the OCS infrastructure; as had the stainless steel wire rope been in place at the time of the accident, the accident is unlikely to have occurred (CaF-01, CaF-02).

OCS Incident Management

140 Transdev published "OCS Failure – Involving HSBC & Transformer" on the 4th January 2022. Included in the document are actions to be taken by Infrastructure Maintenance where a HSCB and transformer fail at the same time. The sequence of works includes for the crew to complete a full ground level survey of the electrical section (two where remedial actions are taken) prior to the re-energisation of the section (paragraphs 135 - 136).

141 For this reason, the RAIU do not consider that a further safety recommendation is warranted in relation to the incident management of trip-outs, as had a ground level survey been conducted on the night of the accident, the partial detachment of Strong Regeneration Arm would have been detected (CaF-03, SF-01).

Notification of incidents to the RAIU

142 As Transdev have reminded staff of their statutory obligation to notify the RAIU of relevant accidents and incident, the RAIU do not consider any further safety recommendation is warranted (paragraph 137).

Safety recommendations as a result of this accident

143 There are no safety recommendations as a direct result of the accident.

Safety recommendations as a result of additional observations

144 As there are no additional observations, there are no safety recommendation as a result of this accident.

Additional Information

List of abbreviations

AC	Alternating Current
ADD	Automatic Dropping Device
AVLS	Automatic Vehicle Location System
CCTV	Close Circuit Television
CI	Chief Investigator
DC	Direct Current
DoT	Department Of Transport
ESS	Electrical Sub Station
FFCCTV	Forward Facing Closed Circuit Television
hr	hour
HSCB	High Speed Circuit Breaker
IMC	Infrastructure Maintenance Contractor
km	kilometre
LCL	Linear Composite Limited
LNMC	Luas Network Management Centre
m	metre
OCS	Overhead Contact System
OHL	Overhead Line
OTDR	On Tram Data Recorder
RAIU	Railway Accident Investigation Unit
S2M	Joint Venture Systems Maintenance Team
SCADA	Supervisory Control And Data Acquisition
TED	Traffic Event Database
TSI	Tramway Safety Instruction
VMC	Vehicle Maintenance Contractor

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.
Alternating current	Alternating current (AC) is an electric current which periodically reverses direction and changes its magnitude continuously with time in contrast to direct current (DC) which flows only in one direction.
Aramid fibre	A high strength synthetic fibre used to form the core of Parafil rope.
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.

Automatic dropping device	A protection device fitted to a pantograph which lowers it if it should be raised above a set maximum height limit. (i.e. if it is no longer touching the contact wire) or if the contact strip becomes damaged. The operation of the device may limit damage to the OCS.
Carbon band	This is a long-extruded carbon fitted into an aluminium carrier that is provided on top of the pantograph and collects current from an overhead wire. This is the point of interface between the tram and the OCS.
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.
Central Control Room	Location from which tram operations are managed and monitored now known as Luas Network Management Centre.
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 wire the pantograph makes contact with in order to collect electrical current.
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	In the non-segregated areas cross-span arrangements are used to support the overhead contact wire. The cross-span is made of an insulating rope and standard wire rope attached to poles or wall fixings positioned either side of the street. Each cross-span has a turnbuckle incorporated to allow tensioning and adjustment of the span length and position.

Dead-short	An electrical circuit that results in current flowing along an unintended path with no resistance or impedance. This results in an excessive current flowing through the circuit, which can damage equipment or cause electrical shocks to those nearby. With a dead-short, the measured between two points voltage is 0 V.
De-energised	The remote switching undertaken by the Traffic Supervisor through the SCADA system to remove the traction power supply feeding the OCS.
Direct Current	Direct current (DC) is one-directional flow of electric charge. Direct current may be converted into alternating current (AC) via an inverter.
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 overhead line equipment only, is the general mass of earth not directly connected to the traction return circuit.
Electrical Sub-Station	Supplying 750 V DC to the trams.
Feeder cable	Transmits the 750 V DC from the lineside boxes to the overhead line.
High Speed Circuit Breaker	A switch, in the tram, in an electric circuit which is usually remotely controlled and will open automatically should an excessive current pass through it.
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.
Insulated Plate	High resistance plate which offers protection to infrastructure against 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.
Kevlar	A heat-resistant synthetic fibre (para-aramid) of high tensile strength used especially as a reinforcing agent.
Luas Network Management Centre	Luas Network Management Centre Location from which tram operations are managed and monitored previously known as Central Control Room.
Overbridge	A bridge over a railway line.
Overhead Contact System	An assembly of metal conductor wires, insulating devices and support structures used to bring a taction supply current to the tram.
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.
Parafil®	Parafil ropes consist of a closely packed core of high strength synthetic fibres lying parallel to each other, and encased in a tough and durable polymeric sheath. The parallel fibre structure ensures that Parafil ropes have high strength and modulus characteristics coupled with excellent tension-tension fatigue performance and low creep values.
Register	The lateral position of the contact wire above the track.
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.
Stagger	Stagger of the contact wire is the horizontal distance of the contact wire from the vertical plane through the centre of pantograph pan at the contact surface. Ensures that the contact wire sweeps across the width of a pantograph head and wears it evenly.
Strong Registration Arm	An OCS component which attaches at one end to the bracket arm and to the contact wire at the other. Strong registration arms are used to register the position and create stagger +/- 250 cm of the contact wire; allowing the contact wire to lift under the force of a pantograph whilst maintaining it in the correct register.
Substation	A building that contains electrical equipment including transformers and high-speed circuit breakers and supplies electrical power to the OCS. There are 10 substations on the red line and 12 on the green line. The power to the substations is supplied from the national grid at 10.5Kv AC, this is converted to 750v DC, which is supplied to the trams via the OCS.
Supervisory Control And Data Acquisition	Used to remotely monitor and control all the power supply equipment of the Luas network. Information displayed on screen allows the operator to see which part of the Luas is energised or not, also equipment in failure mode. Commands can be sent to isolate one or more substations or a section of a line. All information relevant to the substations, i.e. fire alarm, intrusion is also reported on these screens. The status of the power is also represented by colour coding. Green: De-energised, Red: Energised, Yellow: Inconsistent status (unknown), Orange/Pink: Identifies a fault
Sweep Tram	A tram used to validate the line (i.e. which is to check the line is free from obstacles / obstructions) prior to passenger service, travelling at a maximum speed of 25 km/h.
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.
Traction Circuit Breaker	A current limiting device, located in the electrical sub-station, that switches off (“trips”), when an inconsistency is detected in the current. An inconsistency could be a short circuit causing a rapid rise in the current, or an overload situation in which demand is simply higher than supply. In both cases, the circuit-breaker must perform its job and disconnect the devices from the power system.
Traffic Event Database	A repository for everything that occurs on or near the network during an operational shift is recorded. All incident details must be recorded in Traffic Event Database with each incident detail recorded chronologically.
Trip-out / tripping-out / tripping	A circuit breaker “trips” (shuts off the electrical flow) when the current exceeds a specified value depending on the type of breaker and the value set for that breaker, in order to protect the circuit from overheating. It's a safeguard that helps prevent damage and electrical fires.

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