Railway Accident Investigation Unit

Ireland

INVESTIGATION REPORT

Tram fire on approach to Busáras Luas Stop

7th November 2013

RAIU Report No: R2014 – 004
Published: 28th August 2014

Report publication

RAIU
2nd Floor, 2 Leeson Lane
Dublin 2
Ireland

email: info@raiu.ie
website: www.raiu.ie
telephone: + 353 1 604 1241
fax: + 353 1 604 1351

The original publication details are given below:

Title	Tram fire on approach to Busáras Luas Stop on the 7th November 2013
Document type	Investigation Report
Document number	2014-R004
Document issue date	28th August 2014

Where the report has been altered following its original publication, details on the changes are given below:

Revision number	Revision date	Summary of changes

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.

Report preface

The RAIU is an independent investigation unit within the Department of Transport, Tourism and Sport (DTTAS) which conducts investigations into accidents and incidents on the national railway network, the DART network, the Luas, heritage and industrial railways in Ireland. Investigations are carried out in accordance with the Railway Safety Directive 2004/49/EC and the Railway Safety Act 2005.

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 safety regulation or the management of safety.

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

RAIU investigations are 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 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.

Report summary

On Thursday 7th November 2013 at approximately 16:30 hours (hrs) a flash fire occurred on Luas Tram 3002 as it approached Busáras Stop in Dublin City. The tram was operating a Red Line Service, travelling from The Point to Tallaght. There were no injuries as result of the fire and the damage to the Tram was minor.

The *immediate cause* of the fire on Tram 3002 was the combination of an arc in traction Cable 1 and a rupture in hydraulic Hose 1 atomising and igniting the fluid producing a flash fire. This was as a result of the following *causal* factor:

Contributory Factors (CFs) associated with the accident are as follows:

- The interaction between Hose 1 and Cable 1 led to both components sustaining damage that ultimately initiated the fire;
- The cable involved in the accident did not contain the protective braid which was present in the original 401 fleet which may have provided additional protection to the conductor;
- A number of the free lengths on the traction cables were measured to be longer than the length detailed in the original design which may have allowed a greater degree of movement in the cables during operation;
- The electrical protection built into the traction system did not isolate the arcing fault, which may have led to the arc being sustained for a longer period of time.

Underlying causes (UCs) associated with the accident are as follows:

- The requirement to maintain Hose 1 at a 15° offset from the vertical was not prescribed in relevant maintenance instructions;
- The 401 fleet *hazard log* did not identify the undesirable event of the interaction between the braking hoses and traction cables and the resultant potential events, for example a flash fire;
- Maintenance defect management processes in Alstom had not identified the potential consequences of fretting between the braking hoses and traction cables and there were also no procedures directly related to the repair of traction cables;
- The investigation undertaken in 2008, into the failure of the hydraulic brake circuit, and resulting actions was insufficient to avoid reoccurrence

The following Additional Observation (AO), not relating to the cause of the accident, were made during the investigation:

- An independent fire report into the accident identified that the flash point of the hydraulic fluid used was relatively low compared to other hydraulic fluids referenced in an ignition handbook.

The RAIU has made six new safety recommendations related to the occurrence, these are:

- Transdev should ensure that Alstom, as the contracted VMC, review maintenance instructions to ensure separation is maintained between hydraulic circuit and the traction cables at installation and during operation;
- Transdev should ensure that Alstom, as the contracted VMC, add the interaction between the braking hoses and traction cables and the potential event of a flash fire to the hazard log of the 401 Type Tram and implement all identified mitigation actions;
- Transdev should ensure that Alstom, as the contracted VMC, review the requirements for traction cables in the MIC bogie and produce and implement a suitable specification for this component. Installation procedures should also be reviewed to ensure that the free length requirements of these components are fulfilled;
- Transdev should ensure that Alstom, as the contracted VMC, review the performance requirements for the isolation protection system in the MIC bogie to ensure that it meets the requirements of the 401 hazard log or revise the 401 hazard log accordingly;
- Transdev should ensure that Alstom, as the contracted VMC, review the defect priority matrix with regards to damage to traction cable insulation and fretting between these components and hydraulic hoses. In addition to this, maintenance procedures should be introduced to specify actions for the repair of traction cables.
- Transdev should ensure that Alstom, as the contracted VMC, review their incident / accident investigation process to ensure that investigations are of sufficient depth and produce clear recommendations.

One other recommendation was made due to an AO, this is.

- Transdev should undertake a review of higher ignition temperature hydraulic oils to identify if they would be feasible in the braking circuit and add a safety benefit.

Contents

The Accident

Summary of the accident

1 On Thursday 7th November 2013 at approximately 16:30 hrs a flash fire occurred on Luas Tram 3002 as it approached Busáras Stop in Dublin City (Figure 1). The tram was operating a Red Line Service, travelling from The Point to Tallaght.

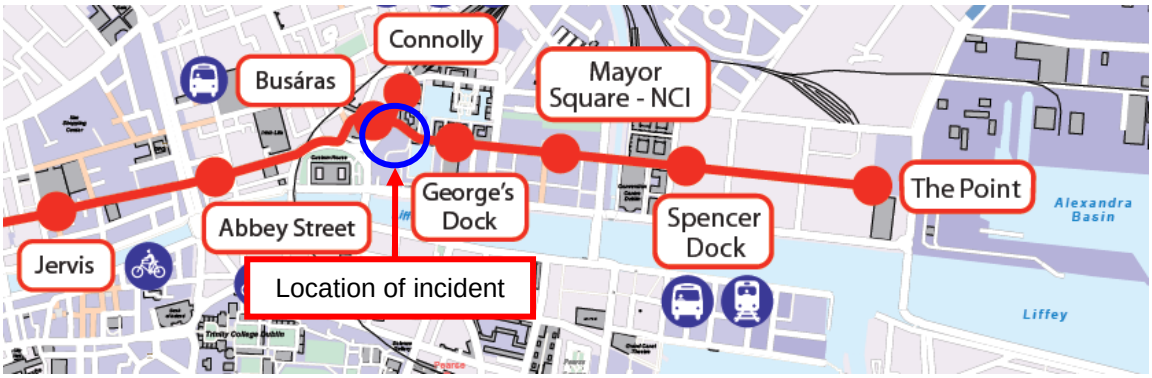

Figure 1 – Location Map

2 Previous to this at 16:28 hrs Tram 3002 had departed George's Dock on the outbound track, stopping at the signal on the junction with Amiens St. At this time a second tram, Tram 4011, was stopped on route to The Point at Busáras Stop on the opposite side of the junction.

3 At 16:29 hrs both trams received a proceed signal to pass through the junction and as they approached each other the driver of the Tram 4011, heading to The Point, saw a fire on Tram 3002.

4 The driver of Tram 3002 had heard an initial 'pop' and then a commotion on his tram. He then heard the driver of Tram 4011 using the open Luas communication system to notify him that his tram was on fire.

5 The driver of Tram 3002 checked his cameras and could not see a fire therefore he took the decision to proceed slowly to Busáras Stop which was within 40 metres (m) and then stop the tram.

6 Tram 3002 stopped at Busáras at 16:30 hrs and after ensuring that the passengers were not in danger from any fire the driver opened the doors and allowed them to evacuate.

7 Closed Circuit Television (CCTV) footage shows that as Tram 3002 passes through the junction, flames can be seen escaping from underneath the second *bogie*. The volume of flames varies as the Tram travels through the junction and into the stop as shown in Figure 2.

Figure 2 – CCTV showing Trams 3002 and 4011 passing through the junction

8 During the first two seconds after ignition the initial burst of flames grows and reaches its peak volume which is sustained for under a second (Figure 2B). The flame then begins to recede in size (Figure 2C and 2D) until the Tram is stationary in the Stop and the flames are contained to within the side skirts of the Tram.

9 Dublin Fire Brigade were on site from 16:35 hrs and took control of the site to manage the fire.

10 Full service was restored to the Luas Red Line at 17:49 hrs.

11 There were no reported injuries as a result of this accident.

Description of the railway

Infrastructure

12 At the time of the accident the Luas Red Line was 20.7 kilometres (km) in length. The line was originally constructed from Tallaght to Connolly Station with additional extensions being added to the Point and Saggart. The trams operate on a combination of separated track, segregated track and shared running (where the trams share the road with other road users).

Figure 3 – Junction of Amiens and Store Street

13 At the junction of Amiens Street and Store Street, the trams operate in-joint running (Figure 3).

14 Trams are powered by an *Overhead Conductor System* (OCS) providing a 750 volt (V) DC supply.

15 No defects were identified with the track infrastructure which could have contributed to this accident.

Rolling Stock

16 The tram involved was a Citadis 401 Type Tram manufactured by Alstom Transport. It has a mass of 49,616 kilograms (kg) and is 40.813 m long. The tram is a bi-directional vehicle with driving cabs at both ends.

Signalling and communications

17 Tram movements are controlled by line side signals normally positioned to the left of the leading driving cab on the kerb. The signals are provided by an array of light emitting diodes (LEDs) which are lit according to the type of signal to be displayed, this is either horizontal, vertical or diagonal lines or a central cluster.

18 A handheld portable radio is used by drivers and the Central Control Room (CCR) to communicate. This radio operates on an open call system, meaning that all radios tuned to the same channel will hear all communication initiated on the channel. Radio communication protocols are defined in the Tramway Safety Instruction manual (TSI), with communications in the main needing to go through the CCR.

Operations

19 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 or any vehicles or pedestrians on the track so he can stop the Tram without colliding', as stated in the TSI.

20 Tram operations are managed by the CCR, which is based at the Red Cow Depot. It has CCTV screens to allow monitoring of the Luas system and consoles to allow monitoring and control of the AVLS and the power supply for Luas.

21 The maximum permitted speed for tram movements across this junction was 15 km/h at the time of the accident.

Fatalities, injuries and material damage

Fatalities and injuries

22 There were no fatalities or injures as a result of this accident.

Material damage

23 There was minor fire damage to Tram 3002 including localised heat damage to areas of the hydraulic braking system and melting of air hoses of sanding units.

24 There was no damage caused to the infrastructure.

Parties and roles involved in the accident

Parties involved in the accident

25 Transdev Ireland operates the Luas light rail tram system in Dublin, they are the Duty Holder as defined in the Railway Safety Act 2005.

26 Alstom Ireland Limited are both the Vehicle Maintenance Contractor (VMC) and the Infrastructure Maintenance Contractor (IMC). This means the means they are contracted to maintain the Luas vehicles and infrastructure. Alstom are also the original manufacturers and suppliers of the tram.

Roles involved in the accident

27 Roles involved in the accident are as follows:

- Tram Driver A – The driver of Tram 4011, who made the initial emergency call, had been fully qualified since 16th November 2007 and last certified on 1st October 2013;
- Tram Driver B – The driver of Tram 3002, on which the fire occurred, had been fully qualified since 23rd January 2004 and last certified on 24th August 2012.

28 There was no evidence to indicate that actions of the drivers contributed to this accident.

Parties not directly involved in the accident

29 The RSC is the national safety authority, which is responsible for the regulatory oversight and enforcement of railway safety in the Republic of Ireland in accordance with the Railway Safety Act 2005. The RSC is required to ensure that each railway organisation operating in the State understands and effectively manages the risk to safety associated with its activities. In the case of the Luas the RSC issues the *Safety Certificate* to Transdev as the Duty Holder. The RSC's responsibilities include supervision and enforcement of railway safety standards and the authorisation to place in service of new rolling stock and infrastructure. The approval of the 401 Type Tram predated the Railway Safety Act 2005. However, the New Rolling Stock Assessment (NRSA) supplied by the RPA for this rolling stock was approved by the Interim Railway Safety Commission and this was undertaken in accordance with the principles of the Guidelines For The Design Of Railway Infrastructure And Rolling Stock (GDRIRS) Section 7.7, "Trams" and, where applicable, Section 6, "Trains". These were the applicable documents at the time of the approval.

30 The Railway Procurement Agency (RPA) is an independent commercial statutory body mandated to deliver new light railway and metro railway infrastructure in the state as provided for in the Transport (Railway Infrastructure) Act, 2001. The Agency was established by Ministerial Order on

28th December 2001 to take over the functions of the CIÉ Light Rail Project Office which had been responsible for implementing the light rail strategy for Dublin as outlined in the Dublin Transportation Initiative (DTI) report of April 1994. This included compiling NRSA for the 401 Type Tram. While the operation and maintenance of Luas is carried out under contract by Transdev Ireland and other contractors, RPA retains functions as the infrastructure and rolling stock owner.

External Circumstances

31 The weather at the time at the location of the accident was dry and bright. Met Éireann recorded a dry day with maximum temperature of 10.8 degrees Celsius (°C).

RAIU Investigation

RAIU decision to investigate

32 In accordance with the Railway Safety Act 2005 the RAIU investigate all serious accidents. The RAIU made the decision to investigate this accident; as, under slightly different conditions this accident may have led to serious injuries to persons in the vicinity of the fire.

Scope of investigation

33 The RAIU must establish the scope of the investigation to ensure that only pertinent information is recovered and reviewed. Therefore, for this accident, the RAIU have defined the following scope:

- Establish the sequence of events;
- Establish the immediate cause, contributory factors and underlying causes;
- Examination of the relevant elements of the safety case;
- Examination of the pertinent information available from the relevant parties and third parties;
- Examination of any other significant safety deficiencies identified as a result of this investigation.

Investigation and evidence

34 The RAIU was notified of the accident at on the 16:35 hrs on 7th November 2013 and immediately mobilised to the site of the accident to conduct an on-site investigation. During the on-site and off-site investigation the RAIU collated and logged the following evidence:

- Photographic record of accident site;
- In-situ surveys for positioning of infrastructure and rolling stock;
- Witness testimonies from parties involved in the accident;
- Other testimonies from members of staff from the relevant stakeholders with information pertaining to the accident;
- Inspection and maintenance records for inspections carried out on the rolling stock;
- Standards, procedures and other documentation;
- Data from the on-board tram fault recording systems;
- Footage from various sources of CCTV.

Evidence

Motorised Intermediate Car (MIC) bogie in 401 Type Tram

General description

35 The 401 Type Tram consists of four bogies. This includes two high floor bogies situated at either end of the tram and two low floor bogies in the centre. Both of the high floor bogies are powered and contain traction motors. One of the low floor bogies is powered and one is not (Figure 4).

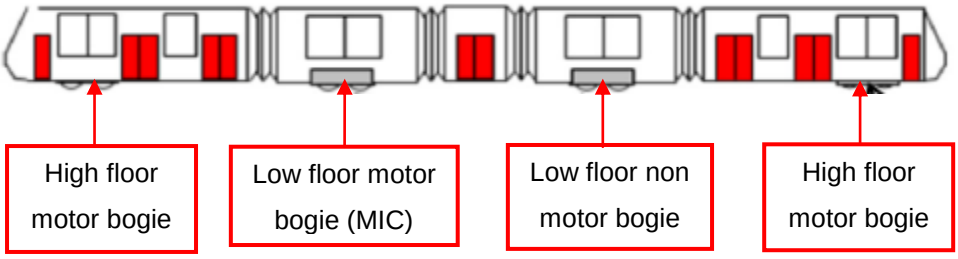

Figure 4 – 401 Type Tram layout

36 The fire in the accident originated from the low floor powered bogie in the centre of the Tram. This type of bogie is known as the MIC as shown in Figure 4.

37 Components of the MIC bogie, relevant to this accident are as follows:

- MIC Hydraulic braking circuit – Hydraulic fluid is used to transfer forces through high pressure hoses in the braking circuit. The friction brakes on the MIC bogie are automatically applied by default and hydraulic pressure is required in order to release them. The pressure in this circuit is regulated by the Hydraulic Braking Unit (HBU) and an accumulator is also installed to enable the system to cope with peak demand and smooth pulsations;
- MIC Traction cable network – The 750 V Direct Current (DC) supply from the OCS is converted to a three phase Variable Voltage Variable Frequency (VVVF) supply by an inverter in the Traction Braking Control Unit (TBCU) on the MIC bogie. The MIC traction cable network is used to transfer this supply from the inverter to the two traction motors.

Hydraulic braking circuit

General description

38 Hydraulic fluid is used to transfer forces through high pressure hoses in the hydraulic braking circuit. The component arrangement in the area the fire originated is shown in Figure 5 and the following two components are of particular interest in this investigation:

- Hose 1 which is a vertical connection between the accumulator and the HBU;
- Hose 2 which runs horizontally between a central manifold in the tram and the HBU.

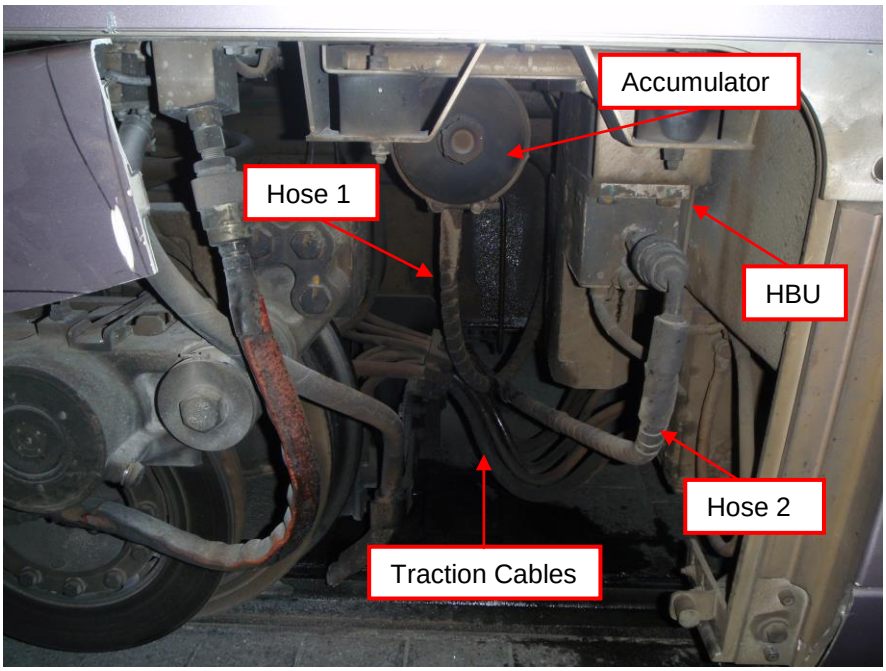

Figure 5 – MIC bogie post accident

39 The hydraulic fluid used in the hydraulic braking circuit is a high viscosity fluid suitable for hydraulic systems that experience wide temperature ranges. The *flash point* of the fluid is 103°C. The Lower Explosive Limit (LEL) is 0.9% whilst the Upper Explosive Limit (UEL) is 7% volume in air.

Design

40 Each hydraulic hose is designed to comply with the European Standard EN 857 – Rubber hoses and hose assemblies - Wire braid reinforced compact type for hydraulic applications – and to have a working range up to 16 megapascal (MPa). Both hoses have an inner bore of approximately 12 millimetres (mm) diameter with an outer bore of 20.3 mm. The hoses are constructed of an inner and outer layer of rubber about 1.4 mm thick with a layer of steel braid

approximately 1.8 mm thick enclosed between them. Each hose is then surrounded in a protective spiral wrap around 2 mm thick (Figure 6).

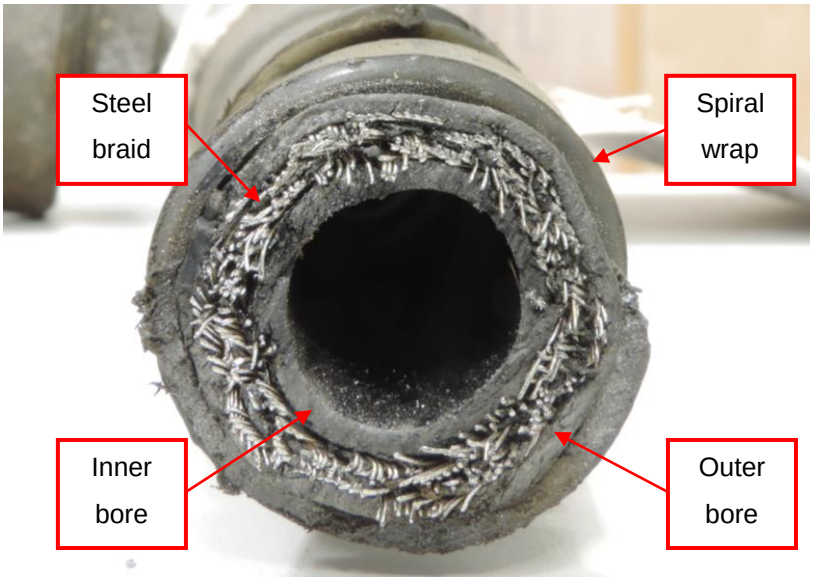

Figure 6 – Cross section of hydraulic hose

41 Hose 1 and 2 are designed to be approximately 0.785 m and 1.275 m in length respectively. Both Hose 1 and Hose 2 were within the required specification with regards to length.

42 Figure 7 is taken from the original design drawings for the area where the fire was observed to have occurred. It can be seen that Hose 1 is installed at a 15° offset to the vertical. This orientates the hydraulic hose away from the traction cables.

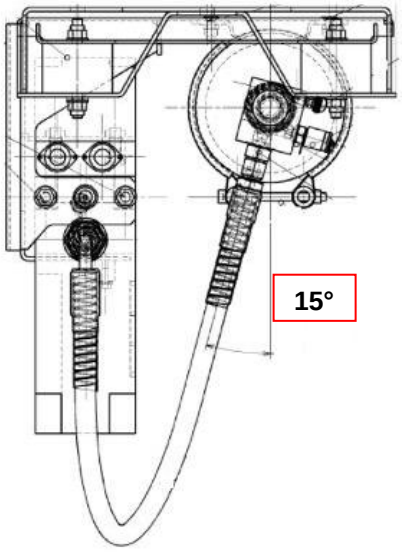

Figure 7 – Design for arrangement for Hose 1 in MIC (view from centreline of bogie).

43 Separation of powered systems is a requirements of GDRIRS section 6.4.1.4 which states: "Flexible connections, air lines, control cables etc. should be positioned to avoid mechanical damage during normal and adverse train movements, the action of brake block sparks and other accidental damage during train running".

44 In the NRSA submission by the RPA this item was addressed by the statement that "flexible connections are positioned to avoid mechanical damage".

45 At the time of the accident the hazard log for the 401 fleet identified the following undesirable events:

- Abnormal heating of oil;
- Discharge of oil on rails.

These events were mitigated by separation from the brake discs and the maintenance and inspection of proven fittings, respectively. The 401 fleet hazard log did not identify the risk associated with the interaction between the braking hoses and traction cables and the resultant hazards, for example a flash fire.

Maintenance

46 At the time of the accident the trams were examined under a balanced exam regime. This means that exams on the various systems are pre-planned and balanced so that each exam is a similar duration of time to complete while ensuring that over the whole cycle (of 120,000 km) all aspects of the maintenance regime are covered.

47 Balanced exams were undertaken every 10,000 km (with an allowable tolerance of 5% for scheduling) and would include re-occurring features that would be required to be undertaken at this frequency, in addition to changing items that are prescribed to be undertaken less frequently. The dates of the last three examinations are shown in Figure 8.

Exam	Date	Distance travelled
Balanced exam 9	16/09/2013	449,448 km
Balanced exam 8	26/07/2013	439,660 km
Balanced exam 7	30/05/2013	429,400 km

Figure 8 – Examinations for Tram 3002

48 The elements of an examination are prescribed in templated exam certificates. These documents refer to work instructions which give details on how different tasks should be performed. The work instructions relevant to the hydraulic brake circuit are:

- ATS-LUAS-WI-00756 – General inspection of a low floor motor bogie;
- ATS-LUAS-WI-00580 – Hydraulic brakes: Check brake pads and tightness of hydraulic circuit.

49 ATS-LUAS-WI-00756 is a general inspection of all low floor motor bogie equipment and fixings. This is a visual inspection and would include looking for wear or damage to the hydraulic hoses.

50 ATS-LUAS-WI-00580 is a detailed examination of the hydraulic brake circuit and includes the following requirement: “Visually inspect the hydraulic circuits of each bogie in turn. Report any oil leaks, damaged hoses or damaged equipment. In particular check:

- The hydraulic unit;
- The accumulator;
- The hose connection on the accumulator;
- The brake callipers;
- The connections to the brake callipers;
- The auxiliary unit;
- The connections to the auxiliary brake release unit”.

51 None of these examinations identified wear on Hose 1. There was also no other recorded defects identified or maintenance undertaken on Hose 1 in these examinations.

52 Neither of these instructions, at the time of the accident, included a requirement to check that the hydraulic hose from the accumulator was installed at an angle of 15° from the vertical axis, as designed, and staff undertaking this task were unaware of this requirement.

53 Alstom’s defect priority matrix categorises defects and prescribes actions to be taken. This database states that minor wear of the outer sleeve is a minor point and should be “Repaired or reviewed no later than the next planned maintenance activity, however trams may enter service pending repair. Fleet planning will review the outstanding defects to ensure they are closed in a timely manner”. Wear that exposes the inner sleeve (with metal visible) is a serious defect that should be actioned as follows “repair or review of these defects shall be planned before the tram re-enters service” the repair of these defects should take place no later than seven days after the defect was identified.

Post accident inspection

54 Initial inspection of the MIC bogie on Tram 3002 showed that Hose 1 from the accumulator was being held just past the vertical and orientated slightly towards the centre of the bogie (Figure 9). It was also noted the lower end of this hose was in very close proximity to the traction cables below creating an area of potential interaction (Figure 10).

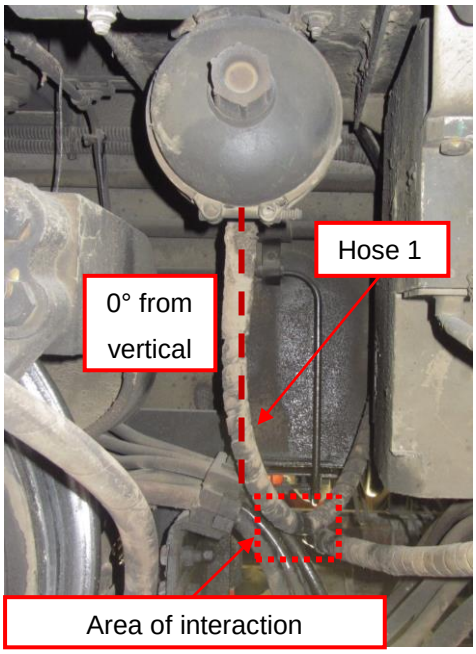

Figure 9 – Post accident position of Hose 1

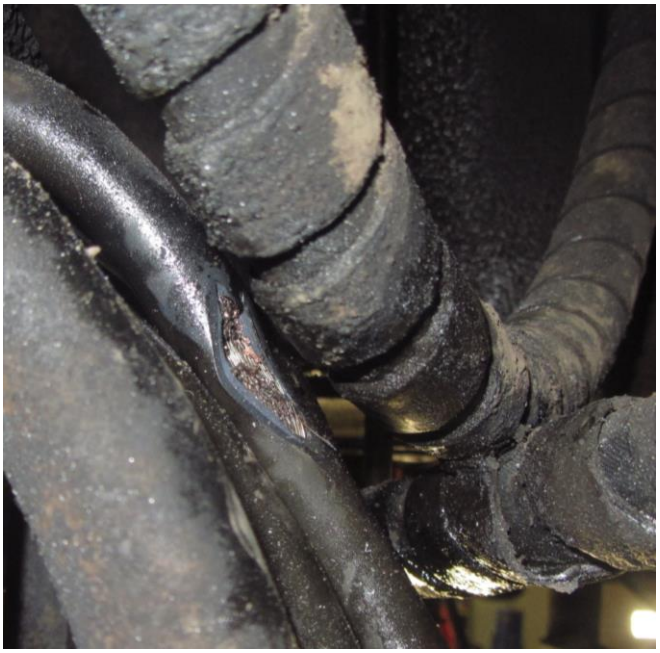

Figure 10 – Area of interaction

55 Damage to Hose 1 was noted where it was in close proximately to the traction cables. There was a small hole 5mm in diameter surrounded by an area of smoothness on the outer anti-abrasion spiral wrap as shown in Figure 11. The smoothness is consistent with damage caused by *fretting* with a second surface.

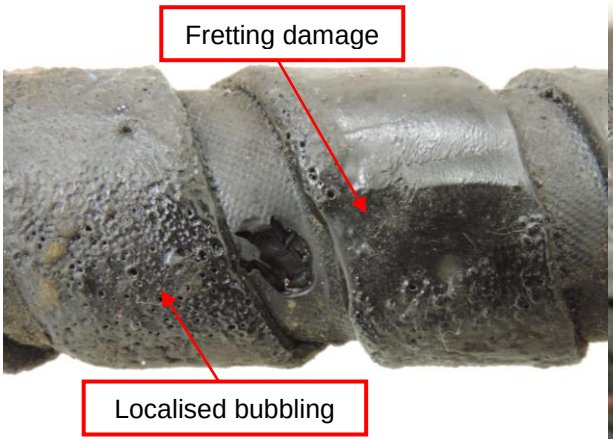

Figure 11 – Damage to Hose 1

Figure 12 – Point of rupture in Hose 1

56 An enlarged view of this hole (Figure 12) shows damage to the inner bore of the hose indicating that this is the point of the rupture in Hose 1. The physical size of this rupture and high pressure operating conditions of this hose would mean the escaping fluid would be released in an atomised spray.

57 A trail of dark fluid was observed to be present in the vicinity of the track that Tram 3002 was travelling on. The same fluid was also observed in the MIC bogie and was later identified as hydraulic oil from the braking circuit.

58 The hydraulic fluid observed on site would indicate that the rupture in the braking circuit occurred in the vicinity of the junction of Amiens Street and Store Street.

59 Both hoses also had localised areas of a “bubbling” appearance in their outer surfaces which is consistent with their exposure to flames from the ensuing fire as the melting temperature of the material was exceeded causing partial melting and bubbles to be formed. It was also observed that at one point the two hoses had been fused together by the heat of the fire where localised melting and re-solidification had allowed a bond to form.

60 When the outer surfaces were removed, it was clearer to see the damage to the braid. There were no signs that there had been a mechanical penetration or impact of the braid in the area of the hole. However, globules of metal were observed in the remaining braid around the hole which are potentially indicative of an electrical arc (Figure 13).

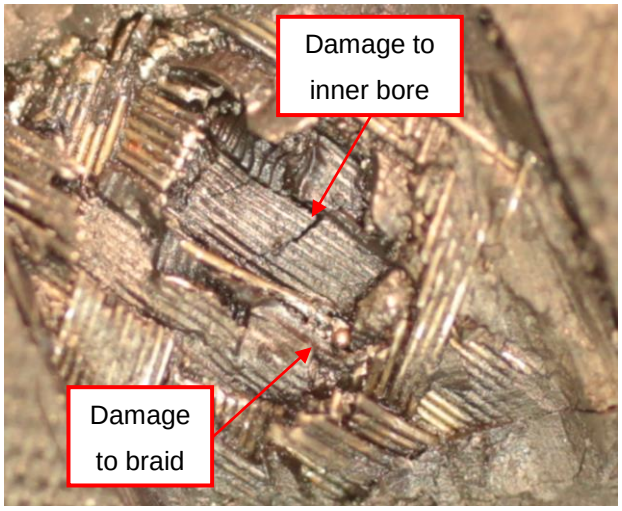

Figure 13 – Damage to braid in Hose 1

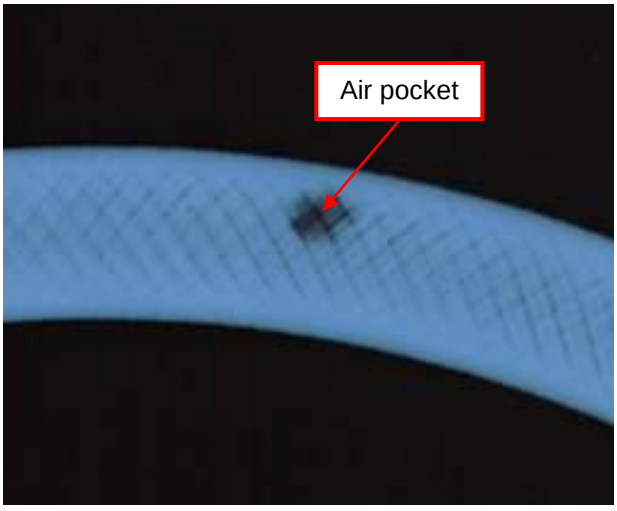

Figure 14 – Radiograph of Hose 1

61 A radiograph of Hose 1 confirmed that as designed a steel braid was present throughout the hose. An electrical continuity test verified that the steel braid ran and imparted electrical continuity to the full length of the hose and therefore any bare conductor that comes into contact with the

braid would arc to ground due to the voltage difference. The hole in the braid at the point of failure can be identified by the black air pocket shown in Figure 14.

Fault download

62 Defects recorded by the on-board condition monitoring system with regards to the hydraulic system included inconsistency in the brake application/release on the MIC unit at 16:30:00 hrs and a failure of the braking system on the MIC meaning that the brakes were no longer able to release at 16:31:11 hrs.

MIC traction cable network

General description

63 The traction cable network consists of seven cables. One of these cables is a larger diameter earth cable (E). The others are separated into two groups and are used to power the two traction motors positioned on the MIC bogie. Three of the cables (Cables 2,4 and 6) are approximately 2.25m in length and connected to the traction motor on the opposite side of the tram and the other three (Cables 1,3 and 5) are longer (approximately 4.62m in length) and are used to power the traction motor on the same side of the tram (Figure 15).

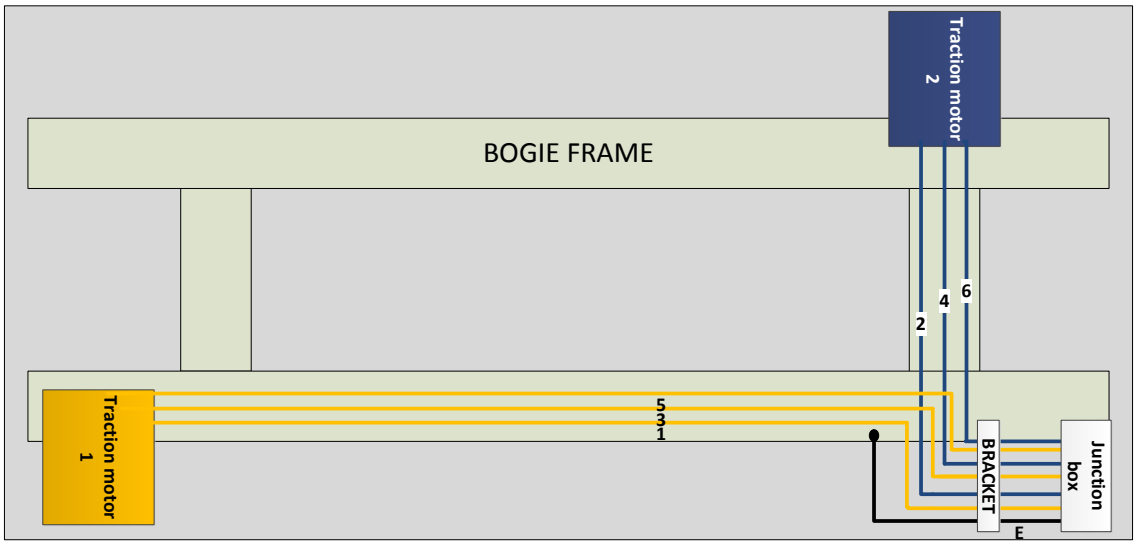

Figure 15 – Illustration of the traction cable network

Design

64 The design of the routing of the traction cables in the MIC bogie is specific to the 401 Type Tram and is different in the later model 402 Type Tram that is also used on the Dublin Luas network.

65 In the area where the fire originated the traction cables leave a junction box and pass through a bracket where they are held as shown in Figure 16 and 17.

Figure 16 – Cable holding bracket

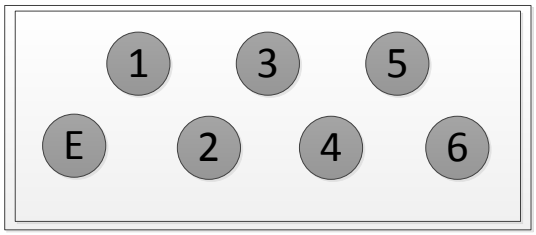

Figure 17 – Cable arrangement in holding bracket

66 The design of the MIC bogie prescribes the free lengths of the traction cables between the junction box and the bracket. A comparison of the designed lengths and measured lengths post accident identified that six out of the seven cables were installed with a free length in excess of the design. This included Cable 1 which had a free length of 475mm instead of the designed 400mm. There were no installation tolerances for the free length measurements stated on the design drawings.

67 The original design for the tram requires each cable to be in compliance with French standard NF-F 63-826 - Halogen free electrical conductors and cables; which is used by Alstom's manufacturing plant based in France. This standard prescribes the parameters for three series of cable. These are the:

- Y series which is a single core cable with a single layer of insulation;
- Z series which is also a single core cable but this has additional protection layers in the insulation;
- NY series cable which is a multicore cable.

68 The cables originally installed on the 401 Type Tram were Z series and are shown in Figure 18. This shows that the insulation surrounding the cable core contained a braid in the insulation rubber. NF-F 63-826 does not state that the installation of a braid is required.

69 Two types of cable were installed on Tram 3002 both of which had insulation that differed from that shown in Figure 18. Cables 2,4,5 and 6 were manufactured in either 2006 or 2007 by a different manufacturer and contained a protective sheath and silicone rubber insulation as shown in Figure 19. Cables 1 and 3 were manufactured in 2010 by the same company as the original cables but were a Y series cable. The copper core of this cable which is surrounded by a polyester tape and insulated by approximately 3.2 mm of silicone rubber shown in Figure 20.

Figure 18 – Z series cable from original build

Figure 19 – Z series cable from Tram 3002 (cables 2,4,5 and 6)

Figure 20 – Y series cable from Tram 3002 (cables 1 and 3)

70 At the time of the accident the hazard log for the 401 fleet identified the undesirable event of earthing by arcing/flashing of HV circuits resulting in hot spots and potentially fire. The hazard log states that these items are mitigated by "Installation of current balancing relay and short-circuiting device per Traction Brake Control Unit (TBCU) / carbody-bogie-rail equipotentiality / dielectric characteristics / Inspection during maintenance".

71 This extract from the 401 fleet hazard log shows that electrical protection in the MIC bogie includes:

- Current balancing relay – Which checks the balance between the outgoing current and the return current to within 100A. A circuit breaker opens if there is a difference and a fault is indicated;
- Short circuiting device – This protects the power components against voltages that are too high from the overhead supply.

72 Each bogie also contains an isolating switch to protect the motor in case of a TBCU short circuit. The isolating switch installed has an initiation time short enough to prevent the short circuit from reaching its otherwise attainable peak value. This occurs in the event of a short circuit or overcurrent that is deemed too excessive for the traction motor and the inverter components, the isolation switch will isolate the power to these components.

73 Voltage and current monitoring devices are integrated in the control electronics and initiate the isolating switch, in order to protect the power equipment, if certain faults are detected. Overcurrent is one of the variables monitored and has the following fault parameters:

- Overcurrent fault greater than 1400 A;
- Three overcurrent faults within five minutes.

74 The 401 fleet hazard log did not identify the risk interaction between the braking hoses and traction cables and the resultant hazards, for example a flash fire.

Maintenance

75 The traction cabling in the MIC bogie are examined as part of the same balanced regime as discussed in paragraph 46 and the last three exams are as stated in paragraph 47.

76 The work instructions relevant to the high voltage traction cables are:

- ATS-LUAS-WI-00756 – General inspection of a low floor motor bogie;
- ATS-LUAS-WI-00785 – Low floor bogie high and low voltage wiring: visual inspection.

77 ATS-LUAS-WI-00756 is a general inspection of all low floor motor bogie equipment and fixings. This is a visual inspection and would include looking for wear or damage to the cables.

78 ATS-LUAS-WI-00785 is a visual examination of the high voltage cables and states the following requirement:

- Inspect the high voltage connections to the traction motor. Ensure that they are in good condition. Check for overheating and cracks;
- Visually inspect the remainder of the trunking of the low floor motor bogie. Ensure that the trunking is not hanging loose and that it is undamaged. Ensure that no copper or wires are exposed.

79 None of these examinations identified wear on the traction cables in the location of the fire. There was also no other recorded defects identified or maintenance undertaken on the traction cables in these examinations.

80 Altsom's defect priority matrix, identified damage to the insulation that did not expose the conductor as a "minor defect" that should be: "Repaired no later than the next planned maintenance activity, however trams may enter service pending repair. Fleet planning will review the outstanding defects to ensure they are closed in a timely manner".

81 Damage to the insulation which had resulted in the conductor being exposed identified as a "major defect" which required the tram to be removed from service, the defect priority matrix states "The tram shall not leave the depot to enter passenger service until the defect has been investigated and repaired or closed out satisfactorily".

82 Examining maintenance data from 2012 to 2014 identified that fretting defects on traction cables due to interaction with the hydraulic hoses were being found at a rate in excess of 10 per year.

83 The data shows that these types of fretting defects were being rectified as they were found. At the time of the accident there were no prescribed procedures for cable rectification and defects were assessed individually by maintenance personnel. Repairs included tying the hoses away from the cables and applying insulation tape to areas damaged by fretting. Post accident the action of applying insulation tape has been stopped by Alstom.

84 Post accident checks of the tram fleet identified a further eleven trams which exhibited fretting damage in the same location. One of the trams was inspected on the 15th November 2013 and was identified to have insulation tape applied to three of the traction cables and signs of slight wear, a follow up inspection on this tram was undertaken on the 23rd November 2013 during which the tape was removed and it was identified that the conductor was exposed. This tram was taken out of service and all of the damaged cables were replaced. No other trams exhibited fretting damage that exposed the conductor and all of the fretted cables identified during the post accident checks were replaced to avoid repeat occurrence.

Post accident inspection

85 Examination of the MIC bogie showed significant wear on Cable 1 had occurred in a location where it was in close proximity to Hose 1 (which runs between the accumulator an the HBU) as shown in Figure 21. The inner core of Cable 1 was exposed and early signs of wear on the Earth Cable, Cable 2 and Cable 3.

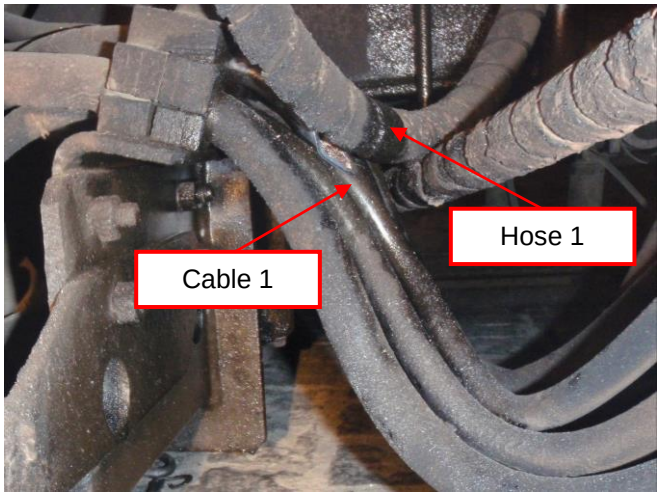

Figure 21 – Position of traction cables and hydraulic hoses

86 Closer inspection of Cable 1 in Figure 22 shows a polished surface on the insulation and outer sheath in the area of the damaged core indicating that fretting has taken place. In addition to this

localised melting in the core itself and the "bite mark" shape of this damage would indicate that arcing has taken place.

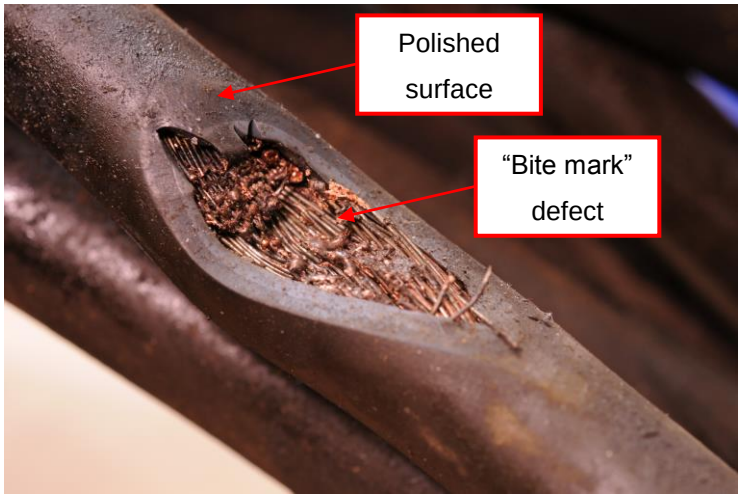

Figure 22 – Damage to Cable 1

87 The damage to the insulation of Cable 1 indicates that fretting has occurred with a second surface over a period of time prior to the cable becoming exposed. The concave nature of this defect is consistent with damage caused by a cylindrical surface which would indicate that the damage was caused by Hose 1.

Fault download

88 The traction package fault recording software identified an inverter overcurrent at 16:29:51 hrs which signifies the current requested is above what is expected. The defect recorded is noted to be particularly significant due to the very high current demand of 1008 Amperes (A). The type and characteristics of this defect is indicative of a potential arcing fault.

89 The overcurrent fault did not reach the parameter of 1400 A or three incidents in five minutes to activate the isolation protection system. The current balancing relay was also tested post accident and was found to be operating as expected.

Events preceding the accident

90 Trams undergo a pre-service check on a daily basis between 00:00 hrs and 04:00 hrs The check involves functional tests performed from the cab, and a walk around and through the tram to inspect various items which include general functionality of the safety systems, traction system, driver aids and passenger comfort items. Tram 3002 was subject to a pre-service maintenance inspection before entering service on the morning of the 7th November 2013. No issues were found on the MIC bogie during this inspection.

Events during the accident

91 On the 7th November 2013 at approximately 16:28 hrs Tram 3002 departed George's Dock Stop on the outbound track, stopping at the signal on the junction with Amiens Street. At this time a second Tram, Tram 4011, was stopped on route to The Point at Busáras Stop on the opposite side of the junction.

92 At 16:29 hrs both trams received a proceed signal to pass through the junction and as they approached each other Driver A (of the Tram 4011), heading to The Point, saw a fire on Tram 3002.

93 Driver B had heard an initial 'pop' and then a commotion on his tram. He then heard Driver A using the open Luas communication system to notify him that his tram was on fire.

94 Driver B checked his cameras and could not see a fire therefore he took the decision to proceed slowly to Busáras Stop which was approximately 40 m away and then stop the tram.

95 CCTV footage shows that as Tram 3002 passes through the junction flames can be seen escaping from underneath the second bogie. The volume of flames varies as the tram travels through the junction and into the stop.

96 Initially a flash can be observed and combustion occurring as shown in Figure 23A and 23B, respectively.

Figure 23 – CCTV images of initial flash and fire initiation

97 During the first 2 seconds after ignition the initial burst of flames grows and reaches its peak volume which is sustained for under a second (Figure 24C). The flame then begins to recede in size (Figure 24D and 24E) until the Tram is stationary in the stop and the flames are contained to within the side skirts of the Tram. At no point did the fire penetrate into the passenger area of the tram.

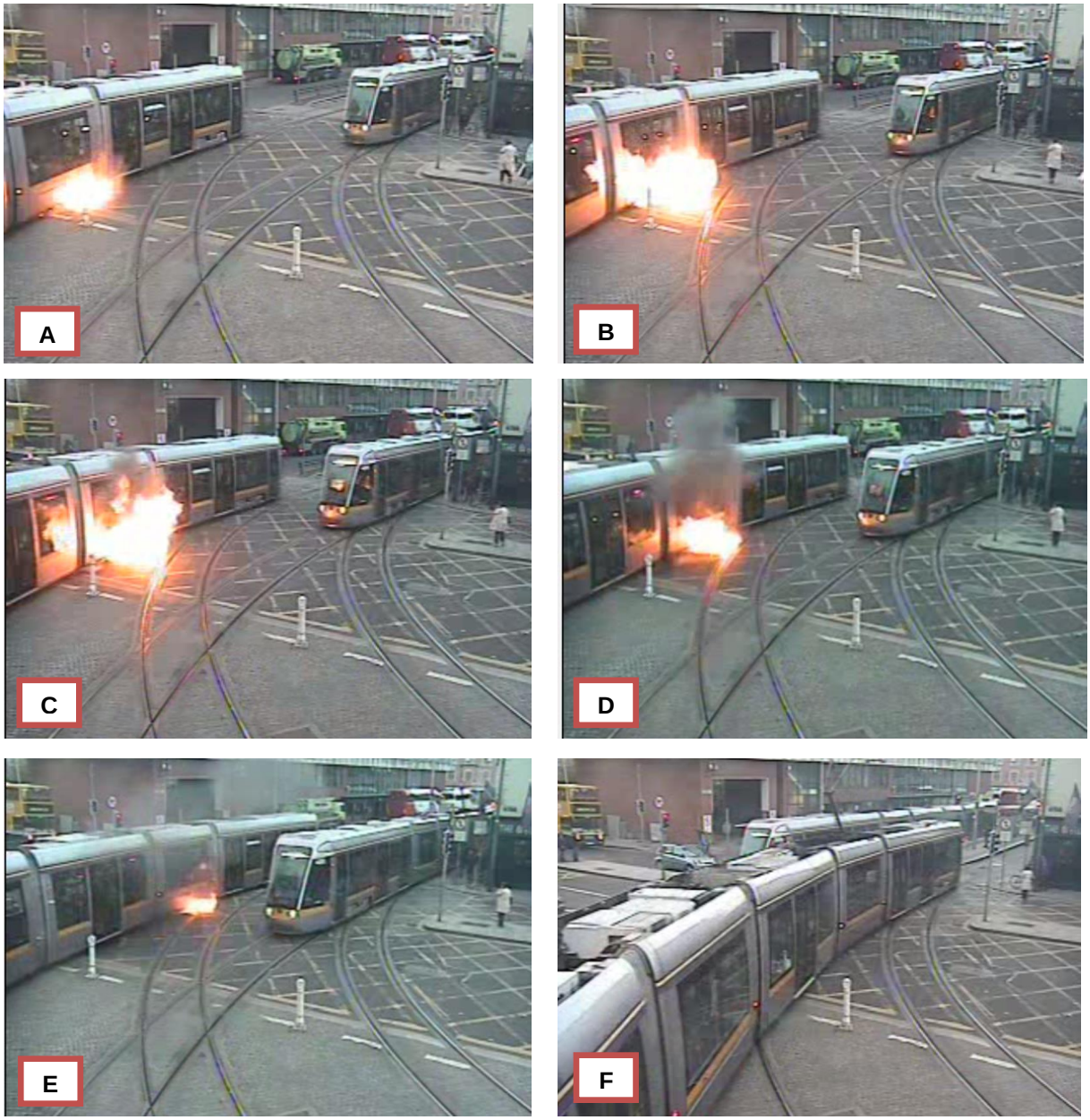

Figure 24 – CCTV images of events during the accident

Events after the accident

98 Tram 3002 stopped at Busáras at 16:30 hrs and after ensuring that the passengers were not in danger from the fire Driver B opened the doors and allowed them to evacuate.

99 Emergency services were contacted at approximately 16:31 hrs.

100 Dublin fire brigade were on site from 16:35 hrs and took control of the site to manage the fire. To assist them CCR arranged for the pantograph on Tram 3002 to be lowered and the overhead line in the vicinity of the accident to be isolated.

101 At 17:27 hrs Dublin fire brigade informed Luas on site staff that they were finished on site. Shortly after this point power was restored to the area and the Tram was moved to Connolly Stop.

102 Full service was restored to the Luas Red Line at 17:49 hrs.

Similar occurrences

103 On the 8th December 2008 a brake release failure occurred on a 401 Type Tram. The post incident inspection identified that the hydraulic hose was worn through and that caused the leak, however the core of the power cable (400 V) was also found to be exposed as shown in Figure 25.

Figure 25 – Damage on AC cable in 2008 incident

104 When identified by Alstom maintenance staff a safety concern was raised which instigated a standardised process of investigation, reporting and remedial action prior to closure. This process involved personnel from both the vehicle maintenance team for the Luas and other areas of Alstom.

105 Alstom undertook a fleet check and investigation which were completed on the 11th January 2009 and 27th April 2009, respectively.

106 These works identified that the routing of the Cable 1 and Hose 1, from the accumulator, on this unit were different to all the other units in the fleet and concluded that presumably this was due to an inconsistency in the initial assembly process.

107 The safety concern was closed on 13th May 2009 with the comment that the report submitted would be dealt with through the appropriate channels. However, the RAIU were not provided with information on any further actions taken as a result of this investigation.

Analysis

Design

108 The length and construction of the hydraulic hoses were within specified design limits (Paragraphs 40 and 41).

109 The design drawing for hydraulic Hose 1 shows the requirement for it to be maintained at a 15° offset from the vertical (paragraph 42). However, this requirement was not sustained on Tram 3002 (paragraph 54).

110 The design of the routing of the traction cables in the MIC bogie is specific to the 401 Type Tram and is different in the later model 402 Type Tram that is also used on the Dublin Luas network (paragraph 64).

111 A number of the free lengths on the traction cables were measured to be longer than the lengths stated in the original design (paragraph 66) which may have allowed a greater degree of movement during operation and additional contact between components.

112 Two different types of cable were installed on Tram 3002 and insulation protection was different on each. Neither of these types of cable contained a braid which was present in the cables initially supplied with the 401 fleet (paragraphs 68 and 69). Examination of the cables would indicate that the braid present in the original 401 fleet may have provided additional protection to the cable core from fretting.

Maintenance

113 The last three 10,000 km exams undertaken on Tram 3002 did not identify any fretting damage to either the hydraulic hoses or the electrical cables on the MIC bogie (paragraphs 51 and 79).

114 The design drawing for hydraulic Hose 1 shows the requirement for it to be installed at a 15° offset from the vertical. However, this requirement was not identified in the relevant maintenance exams (paragraph 52).

115 Historical maintenance records show that fretting between the hydraulic hoses and cables in this area was being recorded at a rate of more than 10 per year (paragraph 82) and post accident checks of the tram fleet identified a further eleven trams which exhibited fretting damage in the same location.

116 Unless the conductor of the traction cable was exposed fretting defects between the traction cables and hydraulic hoses were identified as minor defects and being rectified in accordance with the timescales stated in the defect priority matrix. This included repairing the defect either within seven days or the next planned maintenance activity (paragraph 80). At the time of the accident there was no prescribed procedures for cable repairs and rectification would often involve tying the hoses away from the cables and applying insulation tape to the area damaged by fretting. Post accident the action of applying insulation tape has been stopped by Alstom (paragraph 83).

117 A similar incident had occurred in 2008 involving the interaction between the same components (paragraph 103). However, the investigation undertaken in 2008 and resulting actions was insufficient to avoid reoccurrence.

Risk assessment

118 The 401 fleet hazard log did not identify the undesirable event of the interaction between the braking hoses and traction cables and the resultant potential events, for example a flash fire (paragraphs 45 and 71).

Fire initiation

119 The damage observed on Cable 1 and Hose 1 indicates that fretting had occurred between the components where they were in close proximity to each other. This had led to the inner core of the cable and the protective braid of the hose becoming exposed (paragraphs 55 and 85).

120 Examination of the hydraulic hoses identified the source of the rupture to be a hole in Hose 1 located where the hose braid had been compromised. The size of this hole and pressurised nature of the hose meant that escaping fluid would have been atomised (Paragraph 56).

121 Hydraulic fluid observed over the junction (Paragraph 58) and the braking fault recorded by the on-board condition monitoring system at 16:30:00 hrs with the brakes not being able to release at 16:31:11 hrs (Paragraph 62) would indicate the rupture occurred as the tram passed over the junction.

122 The hydraulic fluid has a flash point of 103°C; it is considered unlikely that the hydraulic fluid was ignited by a hot surface, such as an overheating brake. This is due to the high autoignition temperature (AIT) (approximately 388°C). This figure is even greater with increasing air velocity i.e. if the vehicle is moving, which was the case in this instance. However, 103°C which would be within the temperature range of an electrical arc and low LEL of the hydraulic fluid also indicates that a relatively small volume of vapour is required to create an explosive reaction (paragraph 39).

123 An independent fire expert was commissioned by Transdev to analyse and report on the accident. The subsequent report identified that the flash point of the hydraulic fluid used in this accident was relatively low compared to other hydraulic fluids referenced in an ignition handbook[1]. However, it is not believed that this contributed to the accident due to the very high temperature of an electrical arc (excess 1000°C).

124 The exposed braid in Hose 1 was proven to have electrical continuity and therefore would be susceptible to an arcing from an electrical source in close proximity (paragraph 61).

125 There was physical evidence of an arc occurring on both the core of Cable 1 and the braid of Hose 1 (Paragraph 6059 and 86).

126 Further evidence from the fault recording software showed that a potential arcing fault occurred at 16:29:51 hrs as Tram 3002 was passing over the junction (paragraph 88).

127 The duration of this arc cannot be quantified. However, the available evidence would indicate that it was either sustained long enough to ignite the escaping hydraulic fluid directly or create sufficient hot debris to ignite the fluid.

128 At the time of the accident the hazard log for the 401 fleet identified the risk of earthing by arcing/flashing of HV circuits resulting in hot spots and potentially fire and is mitigated by a number of electrical protection systems (paragraph 70). However, the arc that occurred in this accident did not trigger the isolation protection system.

129 The overcurrent fault did not reach the parameter of 1400 A or three incidents in five minutes to activate the isolation protection system. The current balancing relay was tested and found to be operational. However, this also did not initiate isolation during the accident (paragraph 89).

[1] Babrauskas, V. (2003). Ignition Handbook. Fire Science Publishers: Issaquah. p862 Table 152.

Conclusions

Design and Maintenance

130 The design of the MIC unit in the location of the fire prescribes that Hose 1 be held at a 15° offset from the vertical away from the traction cables. This angle was not sustained on the MIC unit involved in the accident and there was no requirement to check for this in the maintenance instructions (Paragraphs 109 and 114).

131 A number of the free lengths on the traction cables were measured to be larger than the lengths stated in the original design (Paragraph 111). This may have created a greater degree of movement during operation and additional contact between components.

132 Two different types of cable were installed on Tram 3002 and insulation protection was different on each. Neither of these types of cable contained a braid which was present in the cables initially supplied with the 401 fleet (paragraphs 112). Examination of the cables would indicate that the braid present in the original 401 fleet may have provided additional protection to the conductor from fretting.

133 Fretting defects between the traction cables and hydraulic hoses did not require cable replacement unless the conductor was exposed. Fretting defects in this area were identified as minor defects and being rectified accordingly (paragraph 116). At the time of the accident there was also no prescribed procedures for repair of traction cables.

134 A similar incident had occurred in 2008 and there was evidence showing fretting between these components had been identified in maintenance exams during 2012 and 2013. However, maintenance concentrated on reactive measures and the investigation undertaken in 2008, and resulting actions, was insufficient to avoid reoccurrence (Paragraphs 115, 116 and 117).

Risk assessment

135 The 401 fleet hazard log did not identify the undesirable event of the interaction between the braking hoses and traction cables and the resultant potential accidents, for example a flash fire similar to that which occurred in this accident (paragraph 118).

136 At the time of the accident the hazard log for the 401 fleet identified the risk of earthing by arcing/flashing of HV circuits resulting in hot spots and potentially fire and is mitigated by a number of electrical protection systems. However, the arc that occurred in this accident did not trigger the isolation protection system (paragraph 128 and 129).

Fire initiation

137 The fretting damage on Cable 1 and Hose 1 was observed at a location where the two items were in close proximately to each other. This in addition to the nature of the damage observed on Cable 1 and Hose 1 indicates that an interaction between these items was the cause of the damage (Paragraph 119).

138 This damage resulted in an arcing fault between the core of the Cable 1 and the braid of the Hose 1 (paragraphs 123 and 125) which affected the integrity of the hose and ultimately led to it rupturing (paragraph 120).

139 The duration of this arc cannot be quantified. However, the available evidence would indicate that it was either sustained long enough to ignite the escaping hydraulic fluid directly or create sufficient hot debris to ignite the fluid (paragraph 127).

Immediate cause, causal factors, contributory factors and underlying factors

140 The immediate cause of the fire on Tram 3002 was the combination of arc in traction Cable 1 and a rupture in hydraulic Hose 1 atomising and igniting the fluid producing a high pressure fire.

141 The CFs associated with the accident are:

- CF-01 – The interaction between Hose 1 and Cable 1 led to both components sustaining damage that ultimately initiated the fire;
- CF-02 – The cable involved in the accident did not contain the protective braid which was present in the original 401 fleet which may have provided additional protection to the conductor;
- CF-03 – A number of the free lengths on the traction cables were measured to be longer than the length detailed in the original design which may have allowed a greater degree of movement in the cables during operation;
- CF-04 – The electrical protection built into the traction system did not isolate the arcing fault, which may have led to the arc being sustained for a longer period of time.

142 The UCs associated with the accident were:

- UC-01 – The requirement to maintain Hose 1 at a 15° offset from the vertical was not prescribed in relevant maintenance instructions;

- UC-02 – The 401 fleet hazard log did not identify the undesirable event of the interaction between the braking hoses and traction cables and the resultant potential events, for example a flash fire;
- UC-03 – Maintenance defect management processes in Alstom had not identified the potential consequences of fretting between the braking hoses and traction cables and there were also no procedures directly related to the repair of traction cables;
- UC-04 - The investigation undertaken in 2008, into the failure of the hydraulic brake circuit, and resulting actions was insufficient to avoid reoccurrence

143 The following AO, not relating to the cause of the accident, was made during the investigation:

- AO-01 – An independent fire report into the accident identified that the flash point of the hydraulic fluid used was relatively low compared to other hydraulic fluids referenced in an ignition handbook.

Relevant actions taken or in progress

Transdev

144 As of the 25th May 2014, Transdev had advised that a number of actions have been taken since the accident. These are detailed in the following paragraphs and include actions taken by Alstom.

145 Immediate actions taken post accident included:

- Drivers involved in the tram were interviewed;
- All technical data (tram data, CCTV footage) were reviewed to ascertain the issue;
- A risk assessment was performed by Alstom regarding the design of the system and the historical data;
- Alstom has consulted their network to identify if the same issue was identified on other system;
- Transdev has informed and consulted with other networks using the 401 Type Tram;
- Independent fire experts were commissioned by Transdev to analyse the accident.

146 In relation to the interaction between the Hose 1 and the traction cables the, following actions have been taken by Alstom:

- A check of the tram fleet was undertaken to identify if other trams presented the same issue;
- Tool box talk for maintenance personnel was organised;
- All trams with potential issues were rectified;
- New maintenance bulletin and instruction were issued in particular to ensure cable angle is correct and no rubbing is present;
- The defect priority matrix has been updated to include an action when the inner sheath of a high voltage cable is exposed;
- The maintenance instruction for checking the cables has been updated to include specific detail regarding the offset of the hydraulic hoses relative to the cables. This instruction has also been updated into include detailed checks of the full length of the cables and ensures that no temporary repairs are present;
- Tool box talk for maintenance personnel was organised & completed;
- The exam certificate has been updated to capture whether fretting on the cables was identified, and whether any temporary repairs were found.

147 The following long term actions have been taken;

- In 2011 Alstom changed to their incident investigation process from two separate management processes for safety related incidents and adopted the single process. Since these changes all events whether safety concerns or hazardous incidents have been treated the same and require a formal investigation via the 8D problem solving methodology.
- Transdev have conducted a review and issued a report of the event using input from the independent fire experts.

148 Other long term actions are also currently in progress, these are:

- Assessment of a high ignition temperature oils to identify if they would be feasible in braking circuit;
- Assess if short circuit protection could be developed for the type of fault that occurred;
- Review the type of cable used in the traction system;
- Review the procedures for traction cable repair.

Safety recommendations

General description

149 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 RSC. The recommendation is directed to the party identified in each recommendation.

150 As a result of the RAIU investigation seven new safety recommendations are made.

New safety recommendations

151 The interaction between Hose 1 and Cable 1 led to both components sustaining damage that ultimately initiated the fire (CF-01). The requirement to maintain Hose 1 at a 15° offset from the vertical was not prescribed in relevant maintenance instructions (UC-01). Therefore the RAIU make the following recommendation:

Transdev should ensure that Alstom, as the contracted VMC, review maintenance instructions to ensure separation is maintained between hydraulic circuit and the traction cables at installation and during operation.

152 The interaction between the braking hoses and traction cables and the resultant flash fire that was produced was not captured in the 401 fleet hazard log (UC–02), as a result of this the RAIU make the following recommendation:

Transdev should ensure that Alstom, as the contracted VMC, add the interaction between the braking hoses and traction cables and the potential event of a flash fire to the hazard log of the 401 Type Tram and implement all identified mitigation actions.

153 The cable involved in the accident did not contain the protective braid which was present in these components on original construction (CF-02), and in addition to this a number of the free lengths on the traction cables were measured to be greater in length than the figure detailed in the design drawing (CF-03), as a result the RAIU make the following recommendation:

Transdev should ensure that Alstom, as the contracted VMC, review the requirements for traction cables in the MIC bogie and produce and implement a suitable specification for this component. Installation procedures should also be reviewed to ensure that the free length requirements of these components are fulfilled.

154 The electrical protection built into the traction system did not isolate after the accident of the arcing fault, which may have led to the arc being sustained for a longer period of time (CF-04), as a result of this the RAIU make the following recommendation:

Transdev should ensure that Alstom, as the contracted VMC, review the performance requirements for the isolation protection system in the MIC bogie to ensure that it meets the requirements of the 401 hazard log or revise the 401 hazard log accordingly.

155 Maintenance risk management processes in Alstom had not identified potential consequences of fretting between the braking hoses and traction cables and there were also no procedures directly related to the repair of traction cables (UC–03), therefore the RAIU make the following recommendation:

Transdev should ensure that Alstom, as the contracted VMC, review the defect priority matrix with regards to damage to traction cable insulation and fretting between these components and hydraulic hoses. In addition to this, maintenance procedures should be introduced to specify actions for the repair of traction cables.

156 The investigation undertaken in 2008, into the failure of the hydraulic brake circuit, and resulting actions was insufficient to avoid reoccurrence (UC–04), therefore the RAIU make the following recommendation:

Transdev should ensure that Alstom, as the contracted VMC, review their incident / accident investigation process to ensure that investigations are of sufficient depth and produce clear recommendations.

New safety recommendations related to the additional observations

157 The report from the independent fire expert indicated that the flash point of the hydraulic fluid used in this accident was relatively low compared to other hydraulic fluids stated in reference material (AO-01). It is not believed that this contributed to the accident due to the very high temperature of an electrical arc. However, to ensure the system is as resilient as practicable the RAIU make the following recommendation:

Transdev should undertake a review of higher ignition temperature hydraulic oils to identify if they would be feasible in the braking circuit and add a safety benefit

Additional information

List of abbreviations

°C	Degrees Celcius
A	Ampere
AVLS	Automatic vehicle location system
CCR	Central Control Room
CCTV	Closed Circuit Television
CoF	Contributory factor
DC	Direct current
DCC	Dublin City Council
DTI	Dublin transport initiative
DTTAS	Department of transport tourism and sport
GDRIRS	Guidelines for the design of railway infrastructure and rolling stock
HBU	Hydraulic braking unit
Hrs	Hours
IMC	Infrastructure maintenance contractor
Kg	Kilogram
Km	Kilometre
km/h	Kilometres per hour
LED	Light emitting diode
LEL	Lower explosive limit
M	Metre
mm	Millimetre
No.	Number
NRSA	New rolling stock assessment
MIC	Motorised intermediate car
MPa	Megapascal
OCS	Overhead conductor system
RAIU	Railway Accident Investigation Unit
RPA	Railway procurement agency
RSC	Railway Safety Commission
TBCU	Traction braking control unit
SI Units	International System of Units
St	Street
UEL	Upper explosive limit
UF	Underlying factor
V	Voltage

VMC	Vehicle maintenance contractor
VVVF	Variable voltage variable frequency

Glossary of terms

Accident	An unwanted or unintended sudden event or a specific chain of such events which have harmful consequences including collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others.
Automatic Vehicle Location System	Antennae positioned under the tram driving cabs transmit signals to AVLS loops embedded in the road. The AVLS loops allow: • The location of the tram to be detected; • Tram drivers to request a proceed aspect from line side signals (in certain locations); • Tram drivers to request the movement of points..
Bogie	A metal frame equipped with two or three wheelsets able to rotate freely in plan.
Causal factor	Any factor(s) necessary for an occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.
CCR	Control Room at Red Cow Depot from which tram operations are managed and monitored.
Contributory factor	Factors relating to actions taken by persons involved or the condition of rolling stock or technical installations.
Extensive damage	Damage that can be immediately assessed by the RAIU to cost at least €2,000,000 in total.
Fretting	A type of wear that occurs between two surfaces in contact and subject cyclic to relative motion of small amplitude.
Hazard log	Risk management document that contains the identified hazards, potential accidents and mitigating actions taken for a system (or piece of equipment)
Immediate cause	The situation, event or behaviour that directly results in the occurrence.
Inbound	Travel of trams towards the city.
Incident	Any occurrence, other than an accident or serious accident, associated with the operation of trains and affecting the safety of operation.
Line-of-sight	A method of working trams where the driver observes the tram in front and controls the speed of their tram appropriately to maintain a safe distance between them, this also allows for the control of speed for road vehicles.
On Train Data Recorder	A device fitted to trains to store key train parameters and train driver actions.
Overhead Conductor System	System of overhead wires used to supply electricity to a tram
Segregated	Tram has a segregated right of way.

Running	
Shared Running	Where trams share the road with other road users
CCR	Control Room at Red Cow Depot from which tram operations are managed and monitored.
Outbound	Travel of trams away from city.
Root Cause	Cause relating to framework conditions and application of the safety management system (European Railway Safety Directive 2004/49/EC).
Safety Certificate	A certificate to provide evidence that the railway has established its Safety Management System and can meet the requirements laid down in national safety laws and European Legislation.
Serious accident	Any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to 5 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, where extensive damage means damage that can be immediately assessed by the RAIU to cost at least €2,000,000 in total.
Serious injury	Any injury requiring hospitalisation for over 24 hours.
Underlying cause	Cause relating to skills, procedures and maintenance (European Railway Safety Directive 2004/49/EC).

References

Babrauskas, V. (2003). Ignition Handbook. Fire Science Publishers: Issaquah. p862 Table 152.

European Union (2004), Directive 2004/49/EC of the European Parliament and of the Council of 29 April 2004 on safety on the Community's railways and amending Council Directive 95/18/EC on the licensing of railway undertakings and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification (Railway Safety Directive), 2004/49/EC, 29th April 2004.

Veolia Transport Ireland (2012), Tramway Safety Instruction Manual, revision 3, 1st August 2012.

Manus Coffey Associates LTD (2014), Technical investigation of flames on Luas tram, Amiens Street, Dublin, 30th January 2014.