Railway Accident Investigation Unit

Ireland

INVESTIGATION REPORT

Operational incidents at Ardrahan on the 23rd October 2015 & Spa on the 28th November 2015

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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 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 Dublin Area Rapid Transit (DART) network, the LUAS, heritage and industrial railways in Ireland. Investigations are carried out in accordance with the Railway Safety Directive 2004/49/EC, the Railway Safety Act 2005 and Statutory Instrument No. 258 of 2014 European Union (Railway Safety) (Reporting and investigation of serious accidents, accidents and incidents) Regulations 2014.

The RAIU investigate 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.

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.

Report summary

This publication investigates two incidents involving the same Class 2600 rolling stock that occurred within five weeks of each other:

- On Friday 23rd of October 2015 at 19:50 hrs, the 18:00 hrs passenger service, from Limerick to Galway, was involved in a platform overrun and Signal Passed at Danger (SPAD) without authority at Ardrahan Station (Galway) and travelled through Level Crossing XE156 Ardrahan, with barriers raised and open to road traffic. There was no material damage to infrastructure as a result of the incident at Ardrahan. The units involved showed *wheel flats* on all wheels that required *wheel turning*.
- On Saturday 28th November at 21:16 hrs, the 19:00 hrs passenger service from Ballybrophy to Limerick, passed signal XN159DS at danger without authority and collided with the level crossing gates at Level Crossing XN159 Spa (Castleconnell, Limerick) as they were being opened. The gates at XN159 were beyond repair and required replacement as a result of the collision.

The RAIU investigation found that the immediate cause of both overruns was an insufficient rate of adhesion to bring the vehicle to a stop before the relevant signals.

As a result of the RAIU investigation one new safety recommendation was made:

IÉ-RU should review all traction fleets that do not have sanding capabilities, and fit suitable systems to minimise the risk of low adhesion incidents.

Contents

Part 1 - RAIU Investigation

RAIU decision to investigate

1 In accordance with the Railway Safety Act 2005 and Statutory Instrument No. 258 of 2014 European Union (Railway Safety) (Reporting and investigation of Serious Accidents, Accidents and Incidents) Regulations 2014, the RAIU investigate all 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.

Introduction to RAIU investigation

2 On Friday 23rd October 2015 at 19:50 hrs, the 18:00 hrs passenger service (which will be referred to as Train A788 for the remainder of the report), from Limerick to Galway, was involved in an operational *incident* at Ardrahan (Galway). The incident involved Train A788:

- Overrunning the platform at Ardrahan Station;
- Passing Signal XE156DS at danger without authority;
- Crossing Level Crossing XE156 Ardrahan with barriers raised and open to road traffic.

3 On Saturday the 28th November at 21:16 hrs, the 19:00 hrs passenger service from Ballybrophy to Limerick (which will be referred to as Train A464 for the remainder of the report), was involved in an operational incident at Castleconnell (Limerick). The incident involved Train A464:

- Passing Signal XN159DS at danger without authority;
- Colliding with the level crossing gates at Level Crossing XN159 Spa as they were being opened by a gatekeeper.

4 As the operational incidents were similar the RAIU made the decision to investigate the operational incidents together.

5 To present the findings of the RAIU investigation, the RAIU have divided this report into six sections.

- Part 1 - Contains an introduction to the RAIU investigation and general information on the parties and roles involved in both incidents;
- Part 2 – Presents the factual information related to the incident at Level Crossing XE156 Ardrahan on Friday 23rd October 2015;
- Part 3 – Presents the factual information related to the incident at Level Crossing XN159 Spa on Saturday 28th November;
- Part 4 – Presents the evidence for both incidents;
- Part 5 – Presents the analysis of evidence for both incidents;
- Part 6 – Presents the conclusions drawn from the analysis and makes safety recommendations to be implemented to help prevent similar incidents occurring in the future.

Scope of investigation

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

- Establish the sequence of events;
- Establish, where applicable, the *immediate cause*, *contributory factors* (CF) and *underlying causes* (UC) and *root causes*;
- Examine the operation and braking performance of train;
- Examine the relevant elements of the safety management system;
- Examine any other significant safety deficiencies identified as a result of this investigation.

Investigation and evidence

7 During the on-site and off-site investigation the RAIU collated the following evidence:

- Photographic record of damage;
- Witness evidence from parties involved in the incident;
- Other evidence from members of Iarnród Éireann (IÉ) Railway Undertaking (RU) with information pertaining to the incident;
- Infrastructure Manager (IM) and RU standards, procedures and other documentation;
- Standards, procedures and documentation from other relevant bodies;
- Safety Management System (SMS) documentation from the RU;
- Maintenance regime of the unit involved;
- CCTV recordings available;
- Design specifications for the braking system.

Parties and roles involved in the incident

Parties involved in the incident

8 IÉ-RU owns and operates mainline and suburban railway services in Ireland and operates under a safety certificate issued by the Commission for Railway Regulation (CRR). The Railway Undertaking Licence is issued in conformity with Directive 2012/34/EU and S.I. 249 of 2015. The Certification was renewed on 24/09/2015 for a period of five years.

9 IÉ-IM owns and operates the railway infrastructure in Ireland and operates under a safety authorisation issued by the CRR. The Infrastructure Manager Safety Authorisation is issued in conformity with Directive 2004/49/EC. The authorisation was renewed on 25/03/2013 for a period of five years.

10 The purpose of the safety certificate and the safety authorisation is to provide evidence that the RU and IM:

- Has established its Safety Management System (SMS) in accordance with Article nine and Annex III of the Railway Safety Directive (RSD), and;
- Can meet the requirements laid down in the Technical Specifications for Interoperability (TSI) and other relevant European Community legislation, and in National Safety Rules, in order to control risks and provide rail transport services safely on the network.

11 The departments associated with this incident are:

- RU Operations – responsible for the supervision and operation of trains on the network. This includes the supervision of train drivers;
- RU Chief Mechanical Engineer (CME) – The department responsible for the specification, purchasing, commissioning and maintenance of rolling stock, including management of the maintenance depots, associated personnel and procedures. Support on technical matters is provided through CME's Fleet Technical Support (FTS) staff.
- IÉ Infrastructure Manager (IM) – Responsible and accountable for all aspects of the management of the production activities within a Division including: track, structures, plant and machinery safety, occupational safety operations and supplier operations. As well as the train control function through CTC, Level Crossing Control Centres (LCCO) at Athlone and Mallow and signal cabins at locations throughout the network;
- The Signal, Electrical & Telecoms Department (SE&T) of the IM provides the signalling assets, their maintenance and provision of the level crossing equipment and its maintenance;
- Chief Civil Engineers (CCE) Department – Responsible for the design, inspection, maintenance and renewal of the railway's structural infrastructure, including rail head condition, and the management of risks associated with these assets, the CCE Department also collate *Low Rail Adhesion* (LRA) information.

Roles involved in the incident

12 The IÉ employees involved in each incident were trained and competent to carry out their roles. The roles associated with the incident in Ardrahan are as follows:

- Driver A788 – Driver of the 18:00 hrs passenger service from Limerick to Galway (Train A788). Driver A788 was qualified, competent and trained in this class of train;
- Athlone Signalman – The Signalman was based at Athlone Control Centre and was qualified, competent and trained;
- LCCO – The crossing is controlled by the Level Crossing Control Operator (LCCO) located in Mallow Level Crossing Control Centre (MLCCC) and was qualified, competent and trained;
- Relief Driver A – A qualified driver engaged to operate the train after the operational incident.

13 The roles associated with the incident in Spa are as follows:

- Driver A464 - Qualified, competent and trained in this class of train;
- Birdhill Signalman – Based at Birdhill cabin and was qualified, competent and trained;
- Gatekeeper XN159 – This crossing is controlled by an onsite gatekeeper who opens the gates, normally closed against road traffic, once they receive a call from the signalman. Gatekeeper XN159 was qualified, competent and trained;
- Relief Driver B – A qualified driver, engaged to operate the train after the operational incident.

Other parties not directly involved in the occurrences

14 The CRR is the national safety authority, which is responsible for the regulatory oversight of the SMS and enforcement of railway safety in the Republic of Ireland in accordance with the Railway Safety Act 2005 and the European Railway Safety Directive. The CRR is required to ensure that each railway organisation operating in Ireland understands and effectively manages the risk to safety associated with its activities.

Part 2 – Incident at Ardrahan on the 23rd October 2015

Summary of the incident

15 On Friday 23rd of October 2015 at 19:50 hrs, Train A788 approached Ardrahan Station, see Figure 1 for location of the incident, it approaches the down *distant signal*, XE156DD (which indicated that the next signal (Signal XE156DS) was displaying a red aspect).

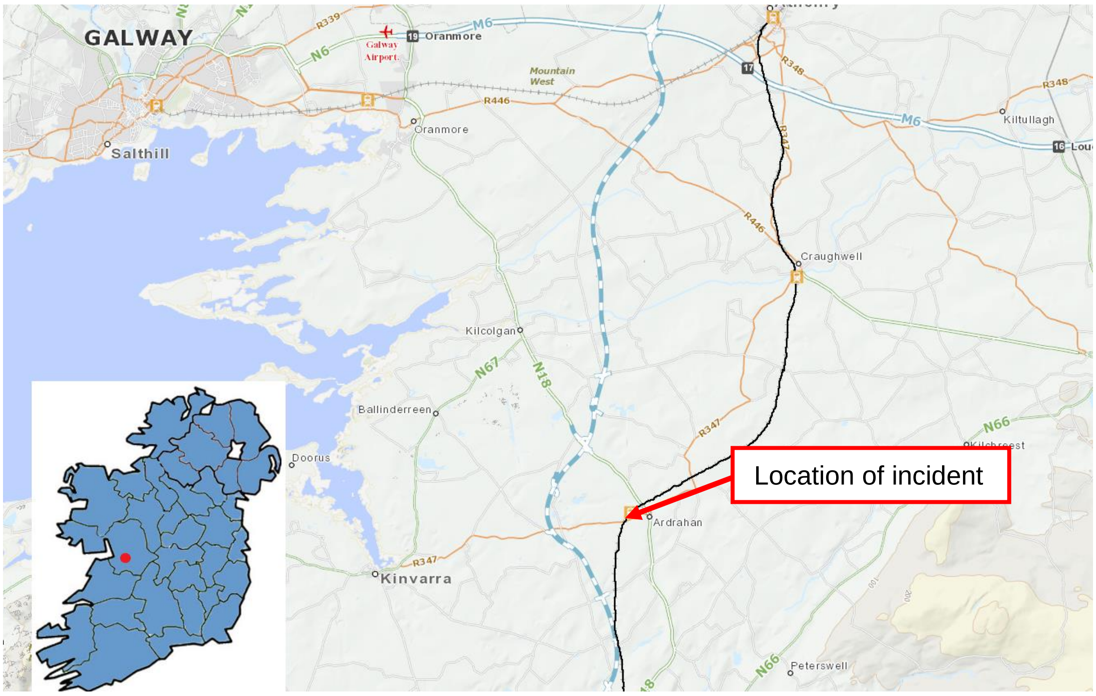

Figure 1 – Location of the incident

16 Driver A788 applied brake and felt that the train was not slowing as normally expected, and four seconds after the initial brake application, Driver A788 made a full brake application. At this stage the train was approximately 1158m from Ardrahan Station platform (and approximately 753m from XE156DD) travelling at a speed of 63mph (101 km/h).

17 On passing Signal XE156DD, Driver A788 became more concerned that the train was not going to stop at Ardrahan Station and in rear of Signal XE156DS at danger, and at 19:51:31 Driver A788 placed the brake into the emergency position.

18 Seventeen seconds later, Driver A788 realised that the train was not slowing sufficiently to stop at Ardrahan Station platform, and at 19:51:48 Driver A788 begins to sound horn in repeated blasts.

19 At 19:52:00 the train passed through Ardrahan Station, where it was due to stop at and serve.

20 At 19:52:15 the train passed Signal XE156DS at danger. This started the red lights flashing on Level Crossing XE156 Ardrahan to warn road traffic to stop immediately.

21 At 19:52:29 the train passes over Level Crossing XE156 Ardrahan with barriers raised for road traffic. In the 138 seconds before the train crossed, thirty-one cars used Level Crossing XE156 Ardrahan.

22 The red lights for the road traffic cease flashing and CCTV footage shows twenty-seven cars pass over Level Crossing XE156 Ardrahan in the 157 seconds after the train had crossed.

23 At 19:53:14 the train comes to a stop approximately 894m beyond where it was intended to stop having crossing Level Crossing Ardrahan XE156 with barriers raised.

General description of the railway

Infrastructure

24 The line from Ennis to Athenry is *bidirectional* and was re-laid in 2010 as part of the western rail corridor re-opening. The track is flat bottom continuously welded rail (CWR) mounted on concrete sleepers set in ballast.

25 Mile Posts (MP) are measured from Limerick Station (0 MP) to Athenry (60½ MP). Ardrahan Station, see Figure 2, is located at 48 miles 1290 yards from Limerick Station.

Figure 2 – Ardrahan Station (viewing in the direction from which the train was travelling)

26 Trains travelling on the line from Limerick towards Athenry are heading in the Down direction and trains travelling towards Limerick are heading in the Up direction. The maximum permitted line speed along the route is 80km/h (50mph) between Limerick and Ennis and 130km/h (80mph) between Ennis and Athenry subject to any permanent, emergency or temporary speed restrictions. On the approach to Ardrahan there is a permanent speed restriction of 95km/h (60mph) recorded in working timetable.

27 Level Crossing XE156 Ardrahan is a CCTV type crossing on the Limerick to Athenry line located in the Gort to Athenry section at 49 miles and 313 yards, see Figure 3. The crossing is controlled by the LCCO located in MLCCC.

Figure 3 – Level Crossing XE156 Ardrahan

28 Level Crossing XE156 Ardrahan is equipped with warning bells and four flashing road traffic lights to warn road users to the presence of an approaching train. It is also equipped with four skirted barriers that lower to close off the roadway. Lighting is provided at the level crossing and there are telephones at the level crossing that provide communication with the LCCO based at MLCCC.

29 The N18 national road (Limerick/Galway) passes through crossing XE156 in an approximate North/South direction.

Signalling and communications

30 The line from Ennis to Athenry is operated under the Rules and Regulation for trains signalled by track circuit block with colour light signals. It is controlled by the Galway Line Signalman located in the Athlone Control Centre.

31 The LCCO is normally alerted to the approach of a train towards the CCTV level crossing by auto-initiation where the passage of a train at a certain point activates an audible alarm on the panel at the MLCCC. The barriers are then lowered automatically after a time interval, the LCCO checks that the level crossing is clear, i.e. there are no objects or persons within the lowered barriers, and presses the crossing clear button. The signals associated with the level crossing subsequently clear to green and the display to the LCCO is then extinguished.

32 Level Crossing XE136 Kiltartan is a CCTV Level Crossing in the Gort to Athenry section. It is located at 44 miles 1270 yards. Immediately after a passenger train passes through Level Crossing XE136 Kiltartan a four minute initiation sequence is triggered for Level Crossing XE156 Ardrahan. This allows time for the train to arrive at and serve Ardrahan Station before the initiation sequence is complete for Level Crossing XE156 Ardrahan after which the LCCO checks the crossing and clears the signal.

33 Signal XE156DD, see Figure 4, is a two aspect LED colour light signal mounted on a standard height pole and positioned on the left hand side of the line 805m in rear of signal XE156DS. It is capable of displaying a Yellow or Green aspect. The signal is 505m before the platform (Down direction) at Level Crossing XE156 Ardrahan.

34 Signal XE156DS, see Figure 5, is a two aspect LED colour light signal. It is mounted on a standard height pole and positioned on the left hand side of the line at the 49MP. The signal is capable of displaying a Green or Red aspect and is situated 210m beyond the end of Ardrahan platform and 210m in rear of Level Crossing XE156 Ardrahan.

35 Signal XE156DS will clear to a green aspect following the actions of the LCCO. The barriers at Level Crossing XE156 Ardrahan are lowered when the crossing is observed to be clear and acknowledged safe for the passage of trains by the LCCO.

Figure 4 – Distant Signal XE156DD

Figure 5 – Down Stop Signal XE156DS

36 Figure 6 shows general layout and distances of signalling for Level Crossing XE156 Ardrahan.

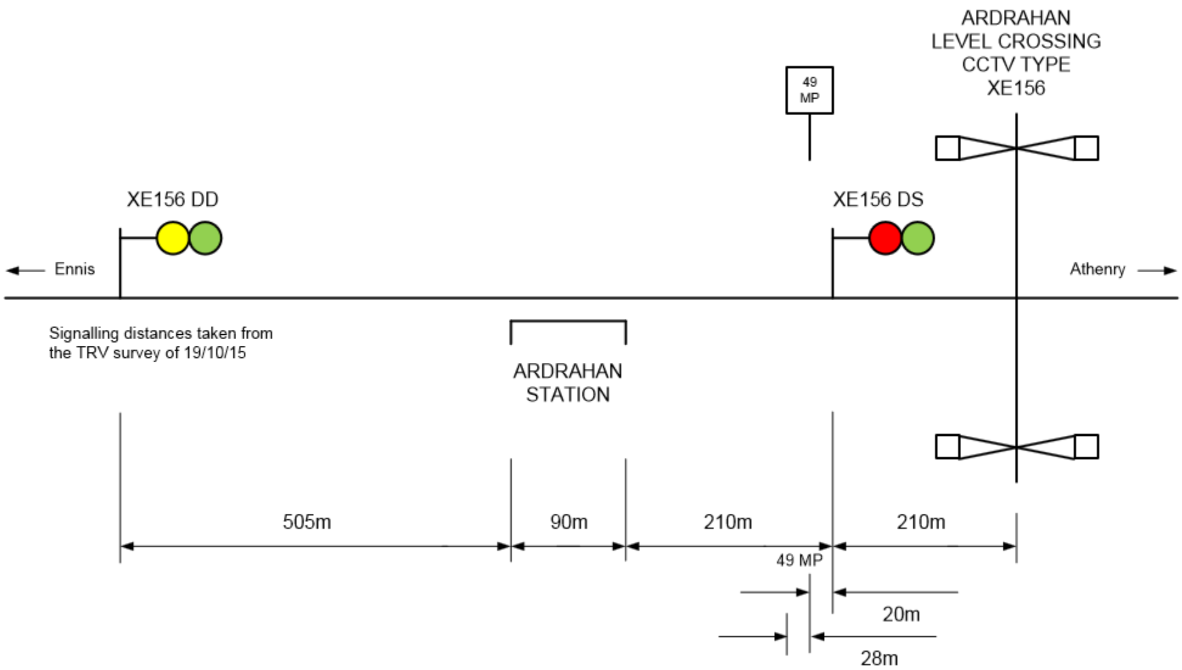

Figure 6 – Signal layout at Ardrahan

Rolling stock

37 Train A788 was a Class 2600 Diesel Multiple Unit (DMU), see Figure 7. A total of seventeen individual railcars were constructed by Tokyo Car Corporation in Japan and delivered between 1993 and 1994. The Class 2600 DMUs entered service in 1994.

Figure 7 – 2600 Class DMU

38 The unit configuration of the Class 2600 rolling stock operates in two car sets compromising of a Drive Car one(DC1 (toilet)) and Drive Car two (DC2) car which are illustrated in Figure 8.

Figure 8 – Unit configuration of Class 2600

39 The power of each vehicle is 261 kW (350 hp). The train is driver only operated. The Class 2600 DMUs have a tare weight of 81,400 kilograms (kg). The maximum service speed is 110km/h (70 mph). Figure 9 provides statistics on the Class 2600 fleet governing size, weight, passenger capacity and train performance.

	DC1	***DC2***	***Unit (coupled)***
Length (m)	20.265 (body)	20.265 (body)	40.830 (approx.)
Height (m)	3.985	3.985	3.985
Width (m)	2.900	2.900	2.900
Mass (Tare) (kg)	41,200	40,200	81,400
Mass (Crush) (kg)	57,216	57,390	114,606
Passengers			
(Avg. mass * kg)			
- Seated	58	71	129
-Standing (at */m^2)	108	98	206
- Total	166	169	335

Figure 9 – Statistics on Class 2600 DMU

40 The maximum service braking rate is 0.88 metres per second (m/s^2). The emergency braking rate is 0.96m/s^2. The braking system is a two pipe air pressure brake system with wheel mounted disc brakes.

41 Further descriptions of the braking system are discussed in Part 4 – Evidence.

Fatalities, injuries and material damage

Fatalities and injuries

42 There were no fatalities or injuries as a result of the incident.

Material damage

43 There was no material damage to infrastructure as a result of the incident at Ardrahan. The units involved, units 2601 and 2602 showed *wheel flats* on all wheels. This unit required *wheel turning*.

External circumstances

44 The weather on the 23rd around the time (20:00 hrs) of the incident was recorded by Met Éireann (Athenry) as 12.5 degrees Celsius; the mean wind speed was 8.2 knots and there was very light rain fall of 0.35 mm recorded, see Figure 10.

REPORTS FROM ATHENRY (A)

Date	Rainfall (mm)	Max Temp (°C)	Min Temp (°C)	Grass Min Temp (°C)	Mean Wind Speed (knots)	Maximum Gust (if >= 34 knots)	Sunshine (hours)
23/10/2015	9.3	14.2	9.1	6.8	8.2		

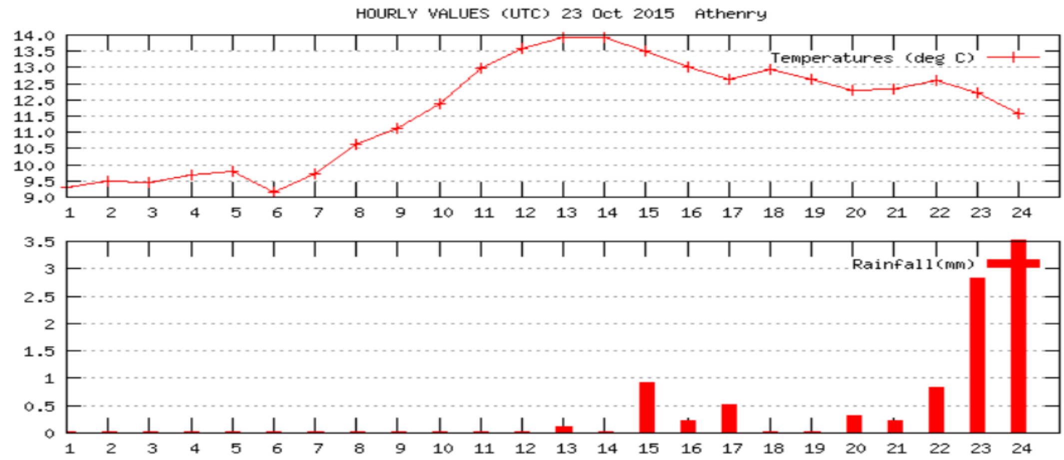

Figure 10 – Data from Met Éireann Weather Station, Athenry

Events before, during and after the incident

Events before the incident

45 Driver A788 had worked the same roster the previous two days and signed off duty the previous day (Thursday) at 22:00 hrs which provided for a rest period of fifteen hours between shifts.

46 At 18:00 hrs on Friday 23rd October 2015, Train A788 departed Limerick, for Galway, on time. Train A788 served Sixmilebridge Station, Ennis Station and Gort Station without incident. Between Limerick Station and Gort Station, Driver A788 operated the train brakes on a number of occasions (to slow for speed restrictions and stop at the stations); the train brakes performed as expected. The weather was dry for this part of the journey.

47 Train A788 was held at Gort Station due to a delayed service that it was due to cross at Gort Station, this delayed Train A788 for thirteen minutes. Train A788 departed Gort Station at 19:45 hrs, the next Station was Ardrahan Station.

48 At approximately 19:48 hrs Train A788, on route to Ardrahan Station, passed over Level Crossing XE136 Kiltartan, it was at this point the signalling system sent the *auto-initiation* request with a four minute time delay for Ardrahan Level Crossing activation, see Figure 11 below for illustrated layout:

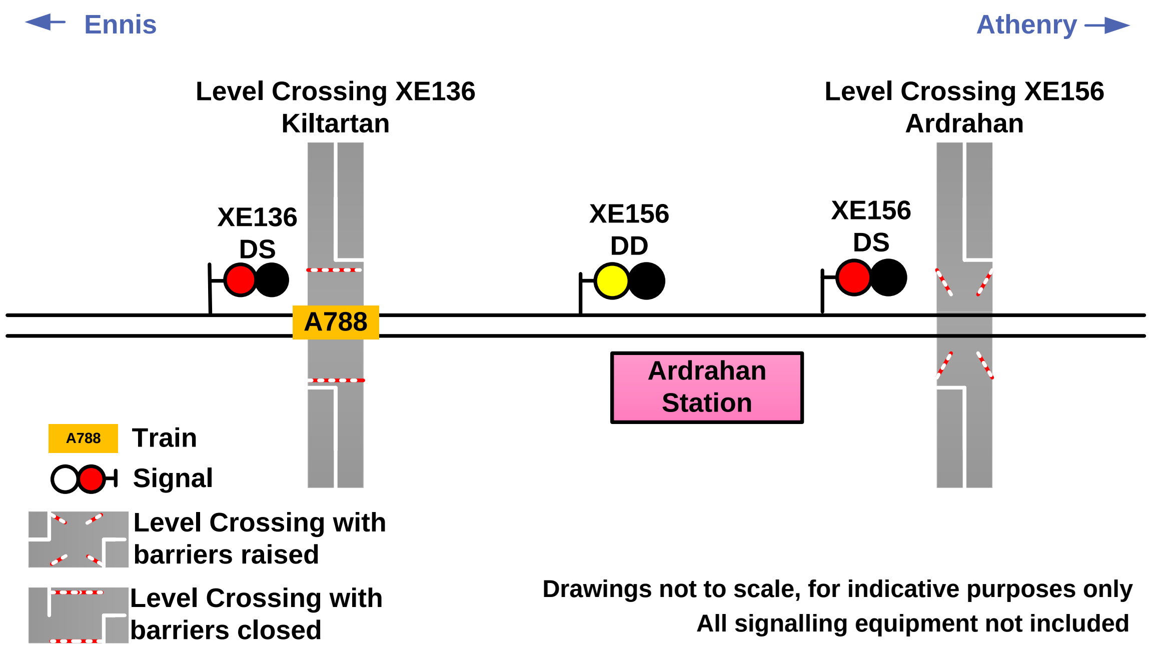

Figure 11 – At 19:48 hrs Train A788 triggers the auto-initiation for the lowering of barriers of Level Crossing XE156

49 On passing through the level crossing, Driver A788 stated that there was some light drizzle and at this stage the train experienced some *wheel slip* in traction. As the train continued under power the *Slip/Slide light* illuminated and the speedometer began giving some erratic readings.

50 Driver A788 applied some brake to reduce the speed for a PSR of 96 km/h (60 mph) and the erratic speedometer readings persisted; power was applied after the PSR to increase train speed and the wheel slip continued.

51 Due to the light drizzle and the wheel slip, Driver A788 applies brake in advance of normal braking zone, at 19:50:56 see Figure 12, in order to stop the train at Ardrahan Station. On applying the brakes, the Slip/Slide light illuminated again. Train A788 was estimated to be approximately 1310m from the normal stopping point on the platform and travelling at a speed of 101 km/h (63 mph).

Events during the incident

52 Driver A788 felt that the train was not slowing as normally expected, and four seconds after the initial brake application, Driver A788 made a full brake application, at 19:51:00. At this stage the train was approximately 1158m from Ardrahan Station platform (and approximately 753m from XE156DD) travelling at a speed of 101 km/h, see Figure 12.

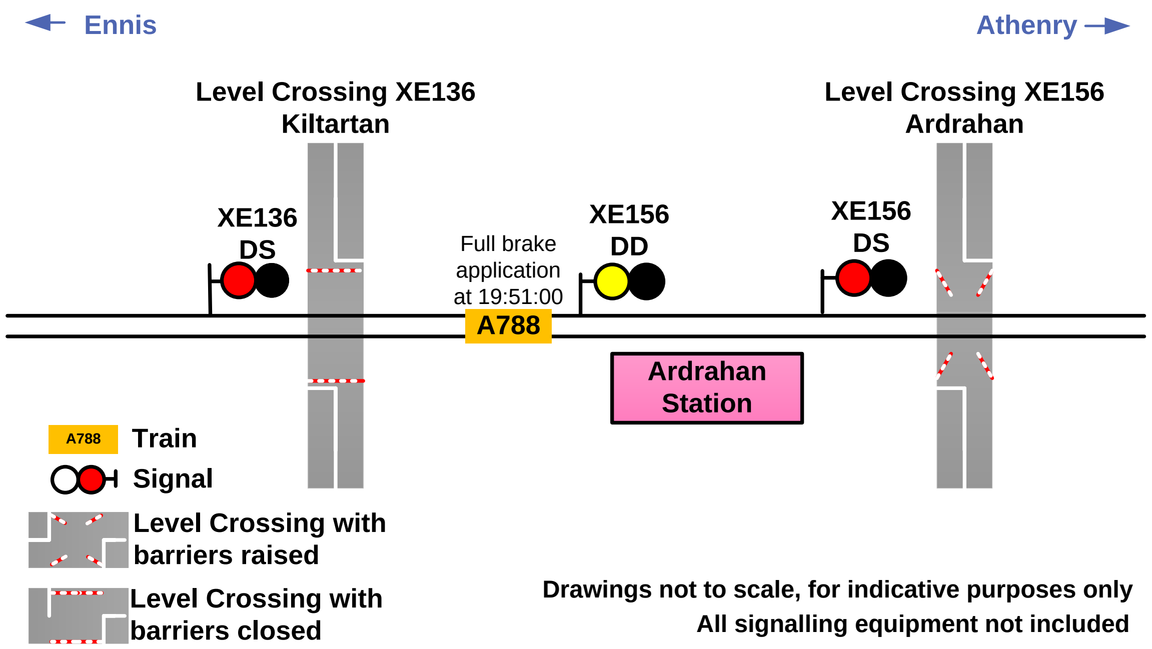

Figure 12 – Initial brake application at 19:50:56 & full brake application at 19:51:00

53 Train A788 continued its approach to Ardrahan Station, and approached the down distant signal, XE156DD for Level Crossing XE156 Ardrahan indicating next signal (Signal XE156DS) was at danger. However, the train was not slowing and passed Signal XE156DD at yellow at 19:51:27, see Figure 13. At this time, the On Train Data Recorder (OTDR) download showing brakes applying and releasing due to operation of WSP system trying to prevent the train sliding.

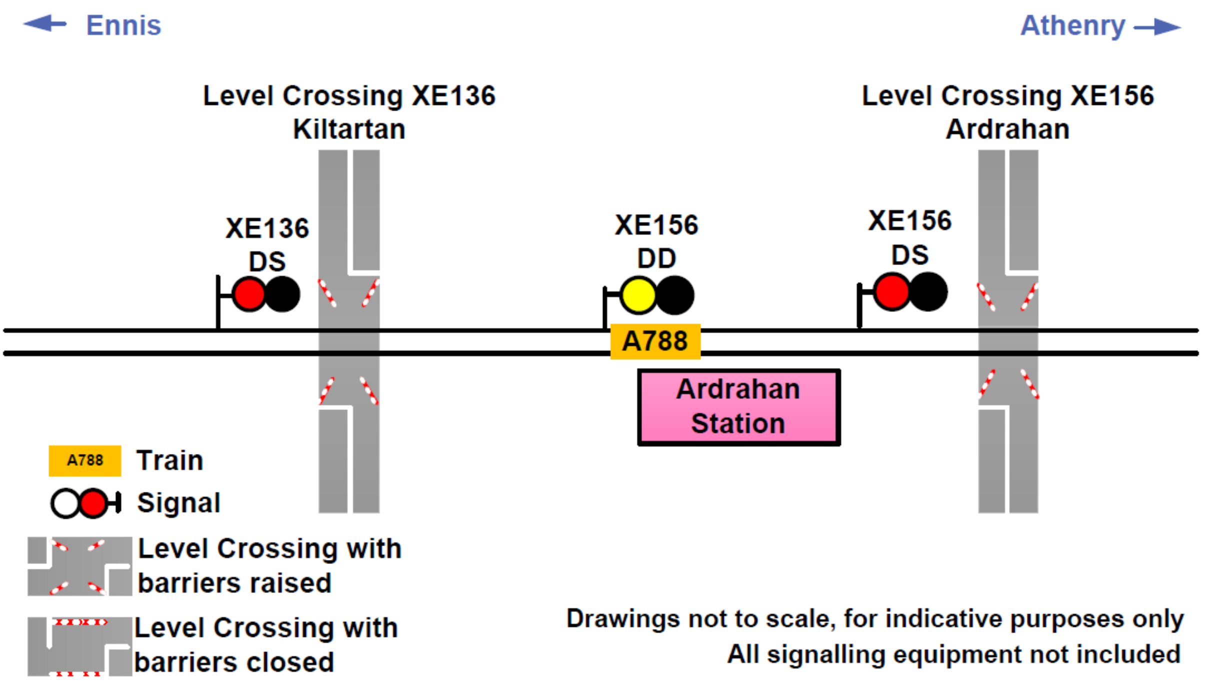

Figure 13 – Train A788 passed Signal XE156DD indicating that the next signal, Signal XE156DS is at danger

54 On passing Signal XE156DD, Driver A788 became more concerned that the train was not going to stop at Ardrahan Station and in advance of Signal XE156DS at danger; and at 19:51:31 Driver A788 placed the brake into the emergency position.

55 Seventeen seconds later, Driver A788 realised that the train was not slowing sufficiently to stop at Ardrahan Station Platform, and at 19:51:48 Driver A788 begins to sound horn in repeated blasts.

56 At 19:52:00 the train passes through Ardrahan Station, that it was due to stop at and serve, see Figure 14.

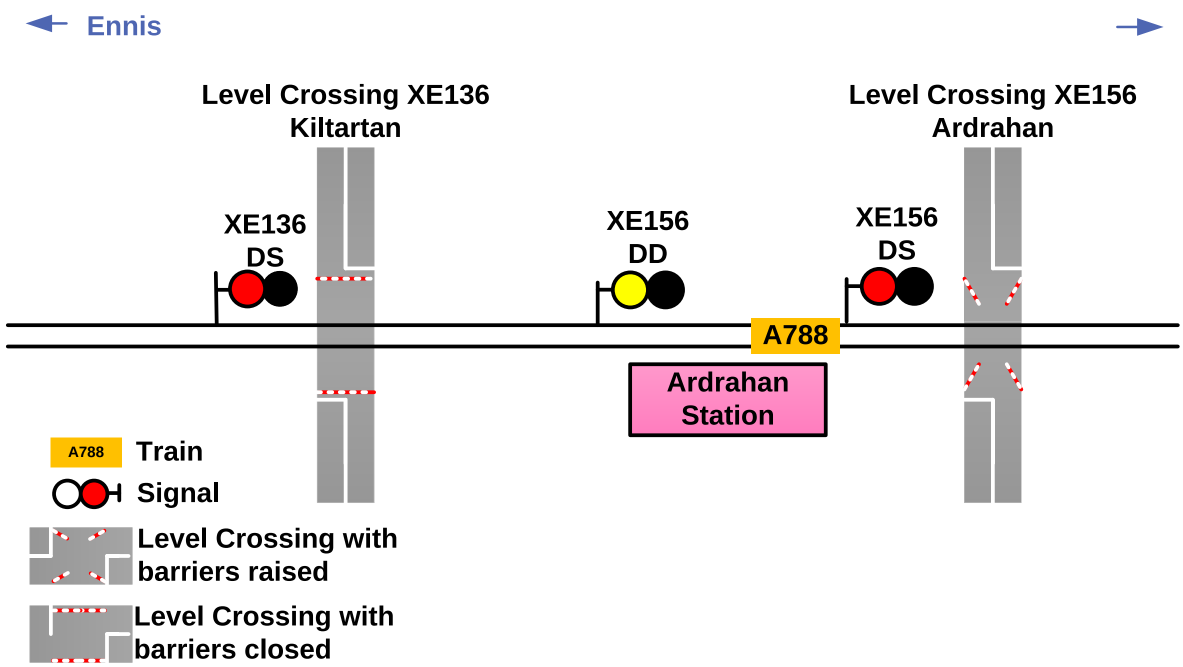

Figure 14 – Train A788 passing through Ardrahan Station

57 At 19:52:10 a road vehicle crosses Level Crossing XE156 Ardrahan, see Figure 15. The train was approximately 280m away.

Figure 15 – CCTV screenshot at 19:52:10 showing a road vehicle travelling over the level crossing, with Train A788 nineteen seconds from reaching the level crossing.

58 At 19:52:15 the train passes Signal XE156DS at danger, see Figure 16. This cancels the four minute auto-initiation sequence for barriers, which starts flashing red lights on Level Crossing XE156 Ardrahan to warn road traffic to stop immediately; the count had reached 3 minutes 52 seconds.

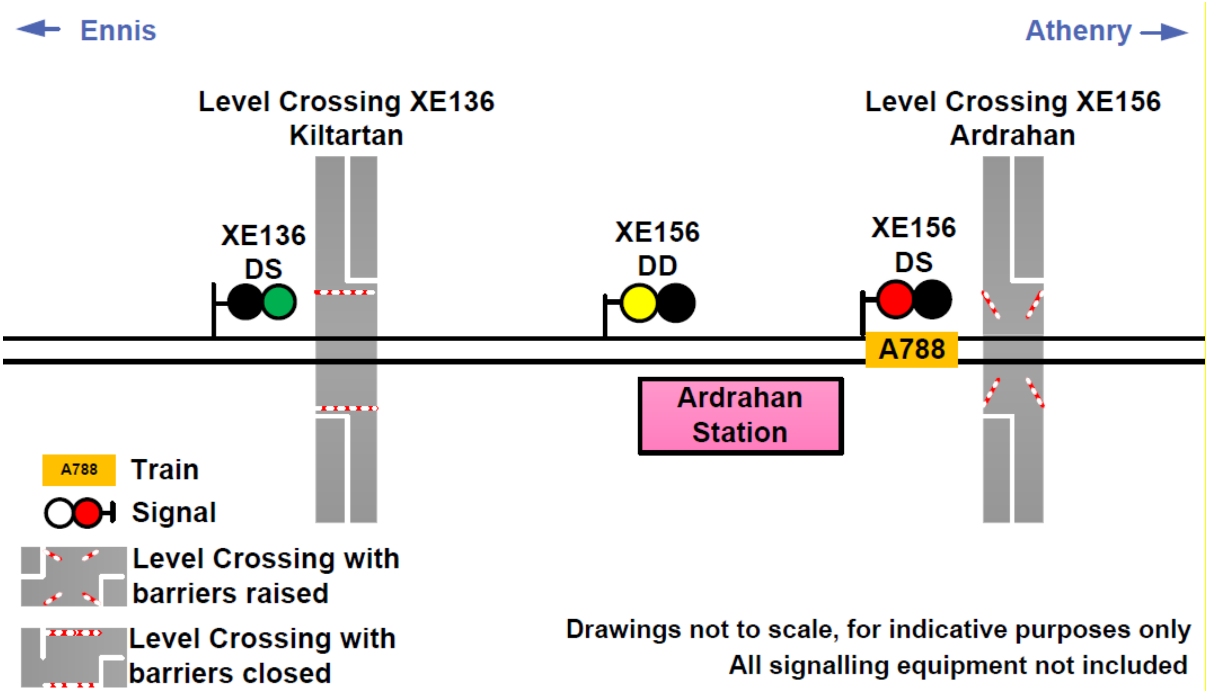

Figure 16 – Train A788 passing Signal XE156DS at danger

59 At 19:52:29 the train passes over Level Crossing XE156 Ardrahan with barriers raised for road traffic. In the 138 seconds before the train crossed, thirty-one cars used Level Crossing XE156 Ardrahan, see Figure 17.

Figure 17 – Train A788 passing through Level Crossing XE156 Ardrahan with the barriers raised to road traffic.

60 The red lights for the road traffic cease flashing and CCTV footage shows twenty-seven cars pass over Level Crossing XE156 Ardrahan in the 157 seconds after the train had crossed.

61 At 19:53:14 the train comes to a stop approximately 894m beyond where it was intended to stop.

Events after the incident

62 Driver A788 contacts Athlone Signalman and reports the events of the incident.

63 Athlone Signalman reports the occurrence to the Deputy District Manager Galway, who speaks with Driver A788 by phone, and organises Relief Driver A to be transported by taxi to the site. Driver A788 was then brought to his depot by taxi where he was met by his District Traction Executive and underwent screening for drugs and alcohol in accordance with the IÉ post-incident policy as per Railway Safety Act 2005.

64 A brake test and train preparation was carried out by Relief Driver A and the train continued on its journey to Galway arriving one hour, twenty-three minutes late. The train was then taken out of service and subsequently transferred to the CME Maintenance Depot at Limerick for post-incident technical examination.

65 The railhead through Ardrahan was visually examined on the evening of the occurrence by a member of the CCE Department and there was no apparent evidence of contamination. No swabs were taken of the railhead or train wheels post incident, although it should be noted that this was not a requirement at the time of the incident.

Similar occurrences

66 There are no records of the Class 2600 fleet having experienced LRA at or in the vicinity of Ardrahan Station previously; however, LRA had been reported by other fleets in the general area. The approach to Ardrahan from Gort, in particular, was not known for LRA.

67 The Class 2800 fleet has recorded eight instances of LRA in the general area for the previous four years[1], see top row of Figure 18. The Class 2600 fleet has had a number of LRA instances, all focused on the Cork branch lines, as the majority of routes operated by 2600 fleet are Cork based, see bottom row of Figure 18.

Fleet Type	2012	2013	2014	2015	Location
2800	3	2	0	3	Ardrahan
2600	1	2	13	2	Cork/Cobh

Figure 18 – Reported incidents of LRA on Class 2600 & 2800

[1] There are no recorded instances of LRA previous to 2012 as these were not recorded.

Part 3 – Incident at Spa on the 28th November 2015

Summary of the incident

68 On the 28th November at 21:16 hrs, Train A464 was operating approximately fifty-five minutes late due to the late running of a connecting service, as it approached Level Crossing XN159 Spa; see Figure 19 for location of the incident.

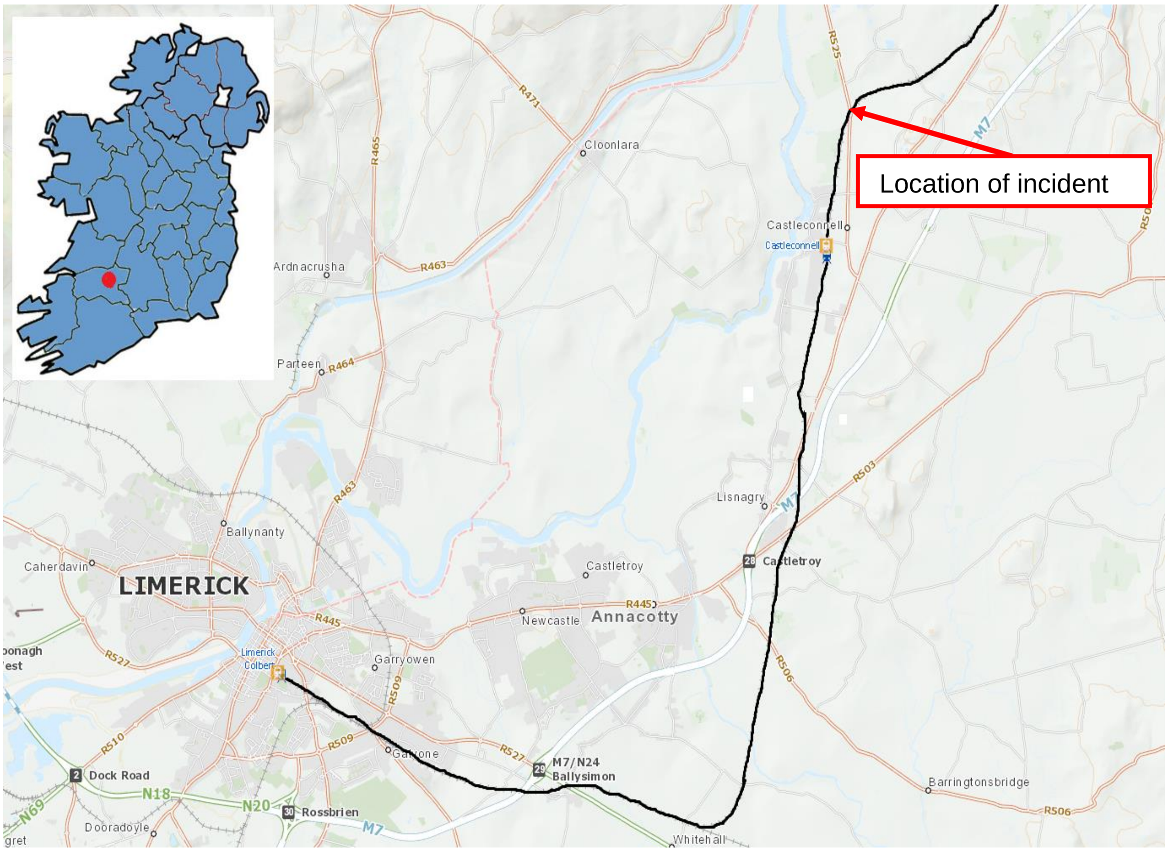

Figure 19 – Location of the incident

69 At 21:16:22 Train A464 was 961m (1222 yards) from Level Crossing XN159 Spa, travelling at 68 km/h (42 mph), approaching Signal XN159DD, which indicated that the next signal would be displaying a red aspect.

70 At 21:16:31 1021m (1117 yards) the brake handle is placed into a braking position. The train speed is 68 km/h (42 mph). This resulted in severe wheel slide and WSP activity which was recorded on OTDR.

71 At 21:16:35 Driver A464 applies a full service train brake, as the train is not slowing as expected. Five seconds later Driver A464 put the train in emergency braking as the train was still not slowing as expected.

72 Gatekeeper XN159 crossed the track to begin the gate opening process.

73 At 21:16:45 the horn begins to be sounded continuously by Driver A464.

74 Gatekeeper XN159 hears the train approaching and sees that it is almost upon Level Crossing XN159 Spa. Gatekeeper XN159 abandons opening the gates and steps out of the way.

75 At 21:17:43 the train passes through the Level Crossing XN159 Spa with gates closed against train. The approximate speed that the train is travelling at is 16 km/h (10 mph).

76 At 21:18:03 the train comes to a stop 60m beyond Level Crossing XN159 Spa having collided with the closed gates.

Infrastructure

77 The line from Ballybrophy to Killonan Junction is a single line, bidirectional route. It is divided into three sections, Ballybrophy/Roscrea, Roscrea/Birdhill and Birdhill/Killonan Junction. The signalling system is a manual token system between Ballybrophy/Roscrea and an *Electric Token System* (ETS) between Roscrea/Birdhill and Birdhill/Killonan Junction. The signals along the route are a combination of *semaphore* and colour light.

78 On this line MPs are measured from Ballybrophy, (0 Miles) to Killonan Junction (52 Miles 1000 yards).

79 The incident occurred in the Birdhill/Killonan section at Level Crossing XN159 Spa, which is located at MP46 and 1028 yards in County Limerick, see Figure 20.

Figure 20 – Level Crossing XN159 Spa

80 The level crossing is operated as a 'CX' type crossing, meaning that the gates are normally open to public road traffic (closed across the railway).

81 There are two seventeen foot timber gates which are manually operated by the gatekeeper on duty.

Signalling and communications

82 The associated signals attached to Level Crossing XN159 from Ballybrophy to Limerick are of semaphore type and comprises of a Distant (Caution) signal and a Stop signal. This crossing is one of nine on the Ballybrophy to Limerick line that are operated by an onsite gatekeeper.

83 The gates are manually operated by Gatekeeper XN159. Birdhill Signalman contacts Gatekeeper XN159 by means of a Block Telephone to advise that a train is about to depart Birdhill Station after which the gates are then closed across the public roadway /opened to the railway for the safe passage of the train.

84 When Gatekeeper XN159 opens the gates for the passage of a train the associated signals attached to the crossing are operated (pulled) directly via a wire cable attached to the gate heel i.e. the signals will only clear to green for rail traffic, by Gatekeeper XN159 opening the crossing gates.

85 Figure 21 illustrates the general layout of the line, level crossing and the associated signalling including measurements related to the occurrence.

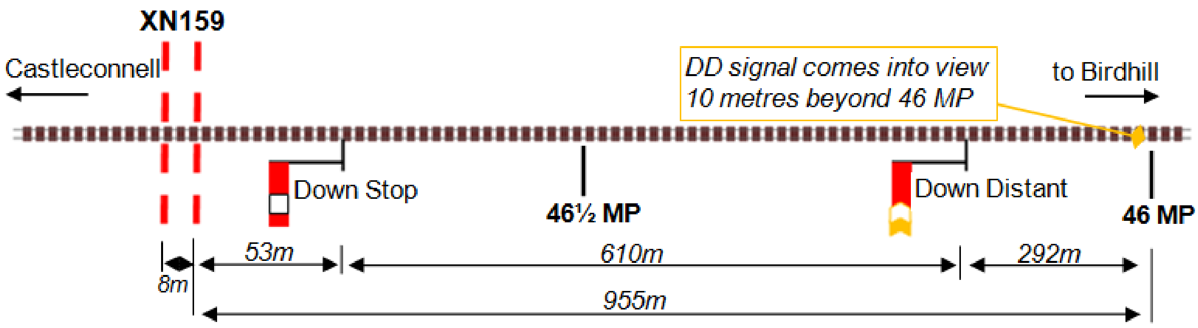

Figure 21 – Layout of signals at XN159

<u>Rolling stock</u>

86 Details of the rolling stock are set out in paragraphs 37 to 41.

Fatalities, injuries & material damage

<u>Fatalities and injuries</u>

87 There were no fatalities or injuries as a result of the incident.

<u>Material damage</u>

88 The gates at XN159 were beyond repair and required replacement as a result of the collision, see Figure 22. The units involved, units 2601 and 2602 showed wheel flats on all wheels. This unit required wheel turning.

Figure 22 – Damage to gates at Level Crossing XN159 Spa

External circumstances

89 The weather around the time (21:00 hrs) of the incident was recorded by Met Éireann (Shannon) as 9.5 degrees Celsius; the mean wind speed was 19.7 knots and there was a very light rainfall of 0.1mm recorded, see Figure 23.

REPORTS FROM SHANNON AIRPORT

Date	Rainfall (mm)	Max Temp (°C)	Min Temp (°C)	Grass Min Temp (°C)	Mean Wind Speed (knots)	Maximum Gust (if >= 34 knots)	Sunshine (hours)
28/11/2015	8.4	10.3	5.1	2.6	19.7	45	0

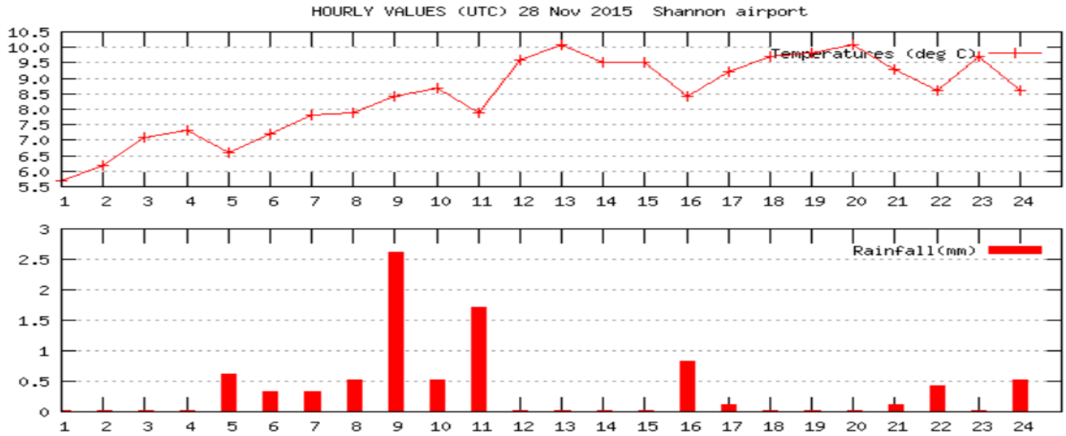

Figure 23 – Data from Met Éireann weather station, Shannon Airport

Events before, during and after the incident

Events before the incident

90 Driver A464 was on a rest day the previous day which provided for a sufficient rest period between duties. He had last worked the route three days previous on the earlier 06:30 hrs service to which a Class 2800 DMU was assigned on that day.

91 The 19:00 hrs passenger service from Ballybrophy to Limerick, Train A464, departed Ballybrophy 50 minutes late, due to the late running of a connecting service.

92 At 20:30 hrs the Birdhill Signalman contacted all nine gatekeepers within the Birdhill/ Killonan section and advised of the late running of the train. All nine gatekeepers answered the calls and acknowledged the late running of the train.

93 At 21:10 hrs the Birdhill Signalman attempted re-contact the gatekeepers to confirm that Train A464 was about to depart Birdhill Station. There was no answer, from the gatekeepers, in four of nine locations including Level Crossing XN159 Spa. Gatekeeper XN159 stated that they heard the phone ring but could not answer at the time. Gatekeeper XN159, through experience, was aware that they had approximately nine minutes to open the gate; and was aware that this time could vary and to have the gates open in good time..

94 At 21:11 hrs Train A464 arrived in Birdhill Station. The *section token* was exchanged between Birdhill Signalman and Driver A464 to allow train enter section. There was some discussion between the two parties, but there appears to be no effective discussion in relation cautioning for the four level crossings.

95 Train A464 departed Birdhill Station at 21:12 hrs. There were no passengers on-board at this time. The train accelerated up to the permitted speed of 40 mph (64 km/h), the train speed increases to 42 mph (68 km/h) when the permitted speed increased to 50 mph (80 km/h).

96 At 21:16:22 Train A464 was 961m (1222 yards) from Level Crossing XN159 Spa, travelling at 68 km/h (42 mph), approaching Signal XN159DD, which indicated that the next signal would be displaying a red aspect.

97 Gatekeeper XN159 stated that the weather at Level Crossing XN159 Spa was wet and windy.

Events during the incident

98 At 21:16:31, the brake handle is placed into a braking position. The train speed is 68 km/h (42 mph). This resulted in severe wheel slide and WSP activity which is recorded on OTDR, see Figure 24.

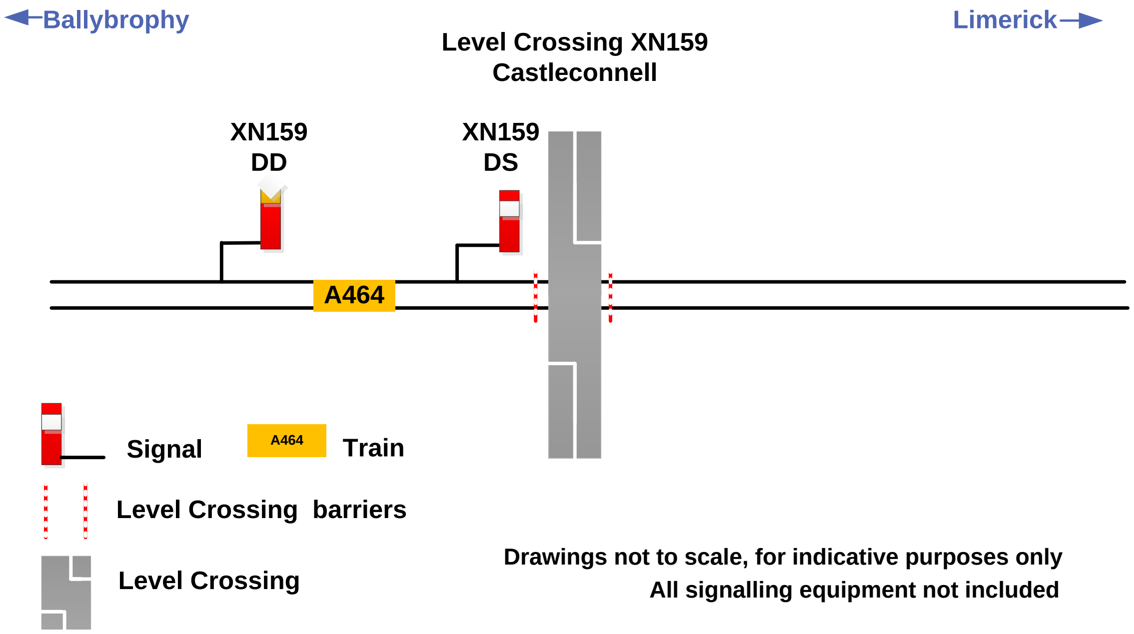

Figure 24 – Train A464 passing Signal XN159DD

99 At 21:16:35 Driver A464 applies a full service train brake, as the train is not slowing as expected.

100 At 21:16:40 Driver A464 put the train in emergency braking.

101 Gatekeeper XN159 has crossed the track to begin the gate opening process.

102 At 21:16:45 the horn begins to be sounded continuously by Driver A464.

103 Gatekeeper XN159 hears the train approaching and sees that it is almost upon Level Crossing XN159 Spa. Gatekeeper XN159 abandons opening the gates and steps out of the way.

104 At 21:17:43 the train passes through the Level Crossing XN159 Spa with gates closed against train, see Figure 23. The approximate speed that the train is travelling at is 16 km/h (10mph).

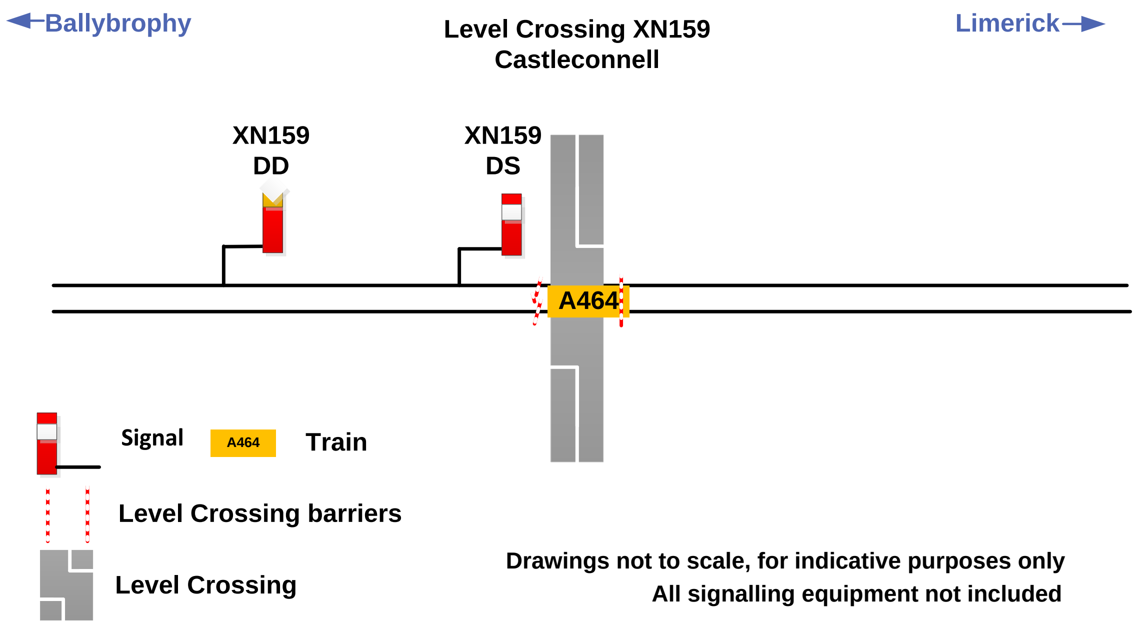

Figure 25 – Train A464 passing through Level Crossing XN159 Spa

105 At 21:18:03 the train comes to a stop 60 m beyond Level Crossing XN159 Spa having collided with the closed gates.

Events after the incident

106 After the train came to a complete stop the train driver advised the Birdhill Signalman of the occurrence.

107 The Birdhill Signalman reported the SPAD alert occurrence to the relevant IÉ Managers and the response was initiated.

108 Members of staff from the IM Operations and RU Operations, CCE, CME, and Safety Department attended at the scene.

109 Driver A464 was shaken by the events but was physically uninjured. Gatekeeper XN159 was in a shocked state and received medical attention from a doctor later that night. Arrangements were made for a relief driver to attend at the scene to work the train onwards to Limerick.

110 Driver A464 and Gatekeeper XN159 were also screened for drugs and alcohol in accordance with the IÉ post incident policy. All tests returned negative for the presence of drugs or alcohol.

111 The railhead from the Level Crossing XN159 Spa back as far as the 46 MP was visually examined about two hours after the occurrence by a member of the SET, IM Operations and Safety Department and there was no visual evidence of railhead contamination. A sample swab was also obtained from the railhead for analysis.

112 After the train was examined by a member of the CME Department it was given permission to depart the scene with Relief Driver B at 23:42 hrs.

113 When the train arrived into Limerick it was then taken out of service for technical examination by the CME Department.

Similar occurrences

114 The similar occurrences are set out in paragraphs 66 and 67.

Part 4 – Evidence

Low Rail Adhesion

Introduction

115 LRA is the loss of adhesion (absence of friction) between a rail and a wheel, which reduces the ability for a train to change its velocity.

LRA Warning System

116 IÉ-IM operate warning system during the LRA season. The LRA season does not have defined dates but begins when the first leaves begin to fall from the trees. This IÉ-IM warning system summarises recent delays due to LRA. The CCE Department collates the data on low adhesion issues each day and compiles a report that is circulated to the management team across IÉ.

117 The report provides a weather forecast for the day, the following day and a general outlook. It also identifies the locations where LRA was experienced and any mitigating actions that took place such as railhead treatment using *sandite*. The report further identifies the severity of the LRA risk and leaf fall risk index by way of a colour coded matrix a copy of which is set out in Figure 26.

COLOUR KEY	LRA RISK	LEAF FALL RISK INDEX
Green	Low	<2
Yellow	Moderate	2 to 4
Red	High	4 to 8
Black	Severe	>8

Figure 26 – CCE LRA Rating Risk Matrix

Communication of LRA risks to drivers

118 A formal safety briefing (SB) “SB4 LRA” was given to drivers at the start of the LRA season. Daily LRA updates are posted on drivers’ notice board to be read as drivers “book on” for duty.

LRA conditions on the day of the incidents

Incident at Ardrahan on the 23rd October 2015

119 For the 23rd October, the LRA risk by IÉ’s internal forecast system was identified as ‘Red’, meaning there was a high risk.

Incident at Spa on the 28th November 2015

120 For the 28th November, the day of the occurrence, the LRA risk was identified by IÉ's internal forecast system as 'Yellow' for the network, meaning there was a moderate risk.

Operations

Standards related to driving during LRA conditions

121 Guidance on driving technique in LRA conditions are contained principally in two documents:

- The Professional Driving Handbook, Issue 4 published in November 2014;
- The Seasonal Low Adhesion Driving Booklet (LRA Booklet) reissued in each district normally during August/September.

The Professional Driving Handbook

122 Key Principle 5.2, Section 1 of the Professional Driving Handbook provides the following guidance:

- Carry out frequent running brake tests; this will give you the 'feel' of the rail conditions and enable you to adjust your braking technique accordingly;
- Take extra care with short formation trains as these normally have a much higher occurrence rate in terms of low adhesion incidents;
- In general, drivers should brake earlier, taking into account that under some circumstances braking distances will need to be significantly extended and in some cases doubled;
- According to the braking characteristics of the train select an appropriate braking position to achieve the desired level of retardation;
- In the event of wheel slide, keep the brakes applied and allow the WSP operate;
- Do not release the brake to counter the effect of the speedometer and brake gauge flicker;
- If there is any doubt that the train will stop safely at the intended point or there is a risk of the train over-speeding on a speed restriction, apply the emergency brake.

123 Section 3, of the Seasonal LRA Booklet, also provides the above guidance (paragraph 122).

Driver's competencies

Incident at Ardrahan on the 23rd October 2015

124 Driver A788 was a Galway based driver with all competency assessments up to date. Driver A788 had been assessed in various forms fifteen times in the preceding two years; including twice specifically on Class 2600s in the three months prior to the incident. All driver training and competency certificates were in date at the time of the incident due for renewal on 10/06/2016.

125 Driver A788 had been issued the seasonal LRA booklet in September 2015 by the RU, Galway District.

Incident at Spa on the 28th November 2015

126 Driver A464, was a Limerick based driver with competency assessments up to date. Driver A464 was formally assessed twenty-three days prior to the incident and was deemed competent.

127 Driver A464 had been issued the seasonal LRA booklet in September 2015 by the RU, Limerick District.

Actions of the drivers at the time of the incident

Incident at Ardrahan on the 23rd October 2015

128 Driver A788 had been carrying out a normal service, and braking had been as expected. When Driver A788 became aware that there were LRA conditions, he started to brake earlier, and when he realised that the train was not going to stop in the intended position he applied the emergency brake as per the standards associated with driving in LRA conditions

Incident at Spa on the 28th November 2015

129 Driver A464 had been carrying out a normal service, and braking had been as expected. When Driver A464 noticed XN159DD was indicating his next signal would be at danger, he started to brake, and when he realised that the train was not going to stop in the intended position he applied the emergency brake as per the standards associated with driving in LRA conditions

Actions of the Gatekeeper

130 Four out of the nine Gatekeepers did not answer the Birdhill Signalman's phone call. The Gatekeeper XN159 stated that they heard the call and knew what it meant. They did not ring back to confirm any potential message to open gates. Gatekeeper XN159 could not have known if this call was to inform of a further delay or that the train was approaching.

Infrastructure

Level Crossing Operation

Incident at Ardrahan on the 23rd October 2015

131 The level crossing performed as designed. Immediately after Train A788 passes through Level Crossing XE136 Kiltartan a four minute initiation sequence is triggered for Level crossing XE156 Ardrahan. The barriers did not lower and the LCCO was not given an opportunity to set the signal to green as the train passes signal XE156DS at danger. The four minute auto-initiation sequence for barriers was cancelled; this started flashing red lights on crossing to warn road traffic to stop immediately.

Incident at Spa on the 28th November 2015

132 This level crossing was a manual level crossing, operated by a gatekeeper, at the time of the incident, Gatekeeper XN159 had only begun the process of opening the gates.

Post incident inspection

Incident at Ardrahan on the 23rd October 2015

133 A visual inspection of track carried out by the CCE Department reported no visual or obvious signs of contamination.

134 There was no swabbing of the railhead or train wheels, immediately post incident. As a result evidence of contamination, that may or may not have been present, was not preserved, although it should be noted that this is not a requirement at the time of the incident.

Incident at Spa on the 28th November 2015

135 The railhead was visually examined two hours after the occurrence by a member of the SET, IM Operations and Safety Department. There was no visual evidence of railhead contamination. At this time a sample swab was also taken from the railhead.

136 The samples obtained underwent microscopic analysis and the results indicated that they did not contain organic residue. However, the analysis did indicate the presence of iron oxide (rust) from steel; the presence of iron oxide maybe due to the fact that the Birdhill to Limerick track is a low frequency route.

Braking System – Design & Maintenance

Braking system design – two-pipe air brake system

137 The 2600 Class DMU has a standard automatic two pipe air pressure brake system. Once the train is charged with air, the driver can request a brake application using the brake handle. This tells the system through a number of valves and distributor (three way valve) to adjust the brake cylinder pressure. A drop in brake pipe applied causes a rise in the brake cylinder pressure, this in turn causes a piston to extend that applies a clamping force between the brake pad and axle mounted brake disc using friction to slow the train.

138 The brake is graduated in steps from initial application to full service; as can be seen in Figure 27, the driver command is translated through a series of valves and pipe work. This can lead to a system delay also known as *hysteresis*. When the driver requests full service it can take a number of seconds for the clamping force to build and begin retarding the train.

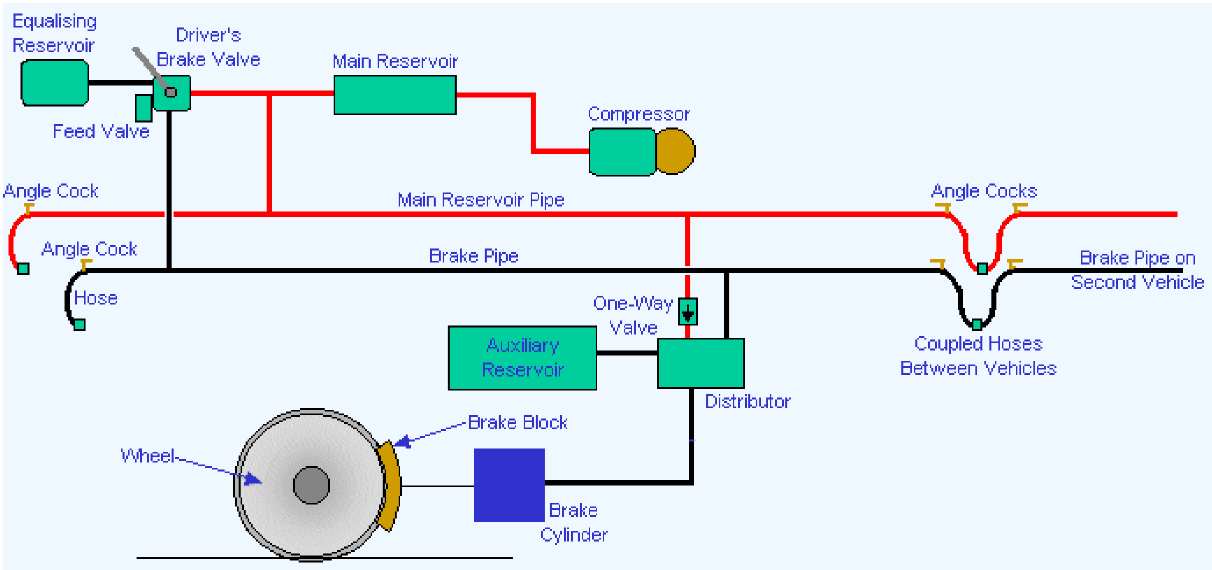

Figure 27 – Block diagram of two-pipe air brake system

139 Emergency braking is a step beyond full service but does not achieve a significantly higher braking force. It applies a similar brake cylinder pressure as full service but its advantage is that it does it quicker. It does this by bypassing a lot of the valves and pipe work that give finer increments of brake pressure that are required during normal operation.

Braking performance

140 As mentioned previously (paragraph 40) the maximum service braking rate is 0.88 metres per second (m/s^2). The emergency braking rate is $0.96m/s^2$. Figure 9 provides the other information in relation to train performance.

Variables that affect braking distances

141 The braking distance is the distance that a vehicle travels while slowing to a complete stop. The braking distance is a function of several variables:

- Gradient (slope) of the railway – A steep gradient would result in slower braking but was not considered as an important component to these investigations as this variable remains a constant for every train service braking in that area;
- Correct operation of the trains braking system to deliver the requested braking rates – the post incident inspection of the units identified that the braking operated as per specification, see paragraphs 140;
- Initial velocity of the train – The higher the initial speed the longer it will take the train to stop, given a constant deceleration. Driver A788 brakes early before the normal braking zone, 2052m. A Class 2600 unit normally takes 570m to stop at the Ardrahan incident speed. Driver A464 brakes early before the normal braking zone, 949 m. A Class 2600 unit normally takes 203 m to stop at the Spa incident speed (assuming correct operation of brakes, no impact of gradients and sufficient adhesion);
- Frictional resistance between the railhead and the train wheel face – this can influence the braking distance. This is the most variable figure and likely had the biggest influence on the elongated braking distance.

142 The frictional resistance between the railhead and the train wheel face is the most variable figure and will be discussed further in the 'Wheel/ Rail Interface' Section.

Maintenance

Vehicle Maintenance Instructions

143 Vehicle Maintenance Instructions (VMIs) are the procedures set out for the inspection and maintenance of rolling stock as per the Chief Mechanical Engineer's Technical Management Standard, entitled 'Maintenance Programs and Documentation', (Document No. CME-TMS-002) published on the 29th April 2015.

144 Scheduled maintenance requirements for Class 2600 are specified in the VMI examinations. The examinations relevant to these incidents are as follows:

- Fuel Point Exam (FPE Exam) – Is a low level visual exam that occurs every 84 hours and includes Brake Functional Test (VMI BX026J0001);
- B1 Exam to B13 Exam – These thirteen periodic B Exams have all the maintenance instructions that a vehicle is to undertake annually, all thirteen exams require a more extensive 'Brakes – Full Test' (VMI BX026J0002).

Maintenance of rolling stock related to the incident at Ardrahan on the 23rd October 2015

145 During the month prior to the incident the unit had the following examinations:

- 08/10/2015 – The unit received a B4 Exam, which contains a 'Brakes – Full Test'. The results were within specification and the units wheel condition was recorded as good. The unit was recorded as having no issues, concessions or deferred works;
- 20/10/2015 – The unit received its routine FPE Exam on which reported everything (including the Brake Functional Test) to be in order and within outlined specifications.

146 All the required documentation associated with these maintenance tasks were signed off with no work of relevance arising from the checks.

Maintenance of rolling stock related to the incident at Spa on the 28th November 2015

147 During the month prior to the incident the unit had the following examinations:

- 06/11/2015 –The unit received a B5 Exam which contains a 'Brakes – Full Test'. The results were within specification and the units wheel condition was recorded as good. The unit was recorded as having no issues, concessions or deferred works;

- 25/11/15 - The unit received its routine FPE Exam on which reported everything (including the Brake Functional Test) to be in order and within outlined specifications.

148 All the required documentation associated with these maintenance tasks were signed off with no work of relevance arising from the checks.

Post incident inspections

Incident at Ardrahan on the 23rd October 2015

149 After the incident, in accordance with standard CME-TMS-002, a post incident exam was completed on the 24th October including 'Brakes – Full Test' (VMI BX026J002).

150 The necessary brake pressures required, for the braking system to operate in accordance with the original equipment manufacturer (OEM) specification, were checked and were found to be within the required tolerances. Brake cylinder pressures were at the upper limit of tolerance which would have resulted in a crisper brake. The brake cylinder pressure readings were consistent with routine exams before incident.

151 Wheel size was recorded as 840 mm on the post incident download. The OTDR input had a size of 786 mm recorded instead of the correct 840 mm. This would have resulted in a speed variance of approximately 7%. Driver A788 would have been unaware that he was travelling 7% faster than the indicated speed[2].

152 One item of note recorded in the work arising section was related to the OTDR which read "Teloc changed out on 2601"; this means that the OTDR was changed and that this might be the reason for the difference in the wheel diameter.

Incident at Spa on the 28th November 2015

153 As the unit was the same unit involved in the Ardrahan incident five weeks earlier, a post incident exam was completed on the 5th December including "brake test instruction post heavy maintenance refit" (VMI BX26A1001). The exam checked the brake functionality values including the forces between the brake pads and brake discs which were measured with a load cell.

154 These measurements showed that the pad forces were approximately the same at all positions, indicating that all of the *actuators* were functioning.

[2] It should be noted that the correct wheel diameter was inputted into the WSP system, and as a result, operated as designed. This is a mechanical counter that is adjusted using push buttons.

155 Comparison tests were also conducted on two other railcar units, (Class 2600 and Class 2800 units). The results were found to be within specification. Interfleet Technology Limited were engaged by IÉ RU to carry out analysis and comparison, to be discussed in paragraph 172. All equipment was found to be performing well and as designed.

156 The brake cylinder pressure readings were consistent with routine exams before the incident. The necessary operating brake pressures required for the braking system to operate in accordance with the original equipment manufacturer (OEM) specification was checked and all found to be within the required tolerances. Brake cylinder pressures were at the high limit of tolerance which would have resulted in a crisper brake.

157 Additional dynamic brake test was carried out on the unit as part of its post incident examinations and is discussed in paragraph 160 to 162.

158 Wheel size was recorded as 827 mm on the post incident download. The OTDR input had a size of 840mm recorded instead of the correct 827mm. This would have resulted in a speed variance of approximately 1.5%. Driver A464 would have been unaware that he was travelling 1.5% slower than the indicated speed.

159 It was discovered during the dynamic testing post Spa operational incident that the OTDR wheel size defaulted back to the previous wheel size reading; this was due to an issue with the software, when the software kept updating the incorrect wheel size.

Stopping distance tests

160 IÉ-RU undertook a number of stopping distance tests on the vehicles. The tests were undertaken in damp conditions (these are '*Damp*' Conditions as opposed to '*Damp + Leaf Film'* Conditions as set out in 172 - 173), which were close to those of the two incidents (in practice it is difficult to replicate any given rail conditions and testing is normally undertaken under whatever conditions there are on the day).

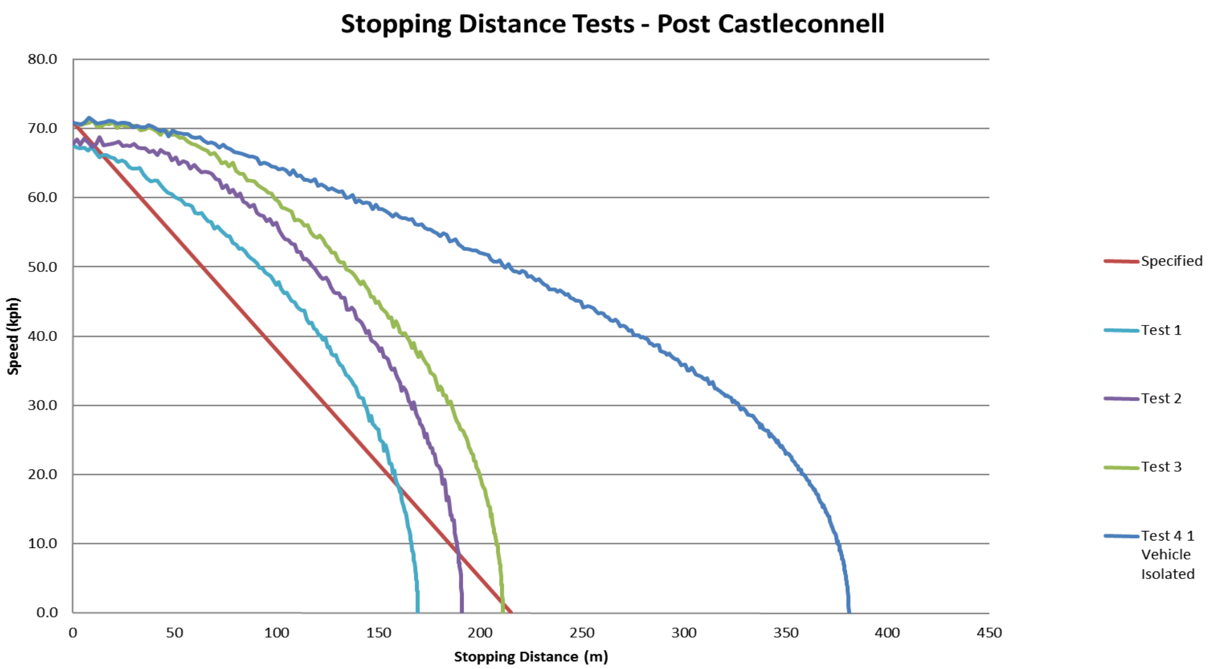

Figure 28 – Results of IÉ dynamic brake testing

161 The tests were carried at speeds of approximately 112 km/h (70 mph), which was line speed. The 'Specified' stopping distance, as per the design of the train, is illustrated as the red line, Figure 28, it is a distance of approximately 215 m. Test 1, Test 2 and Test 3 show similar stopping distances of approximately 170 m, 190 m and 210 m, respectively. This demonstrates a reasonable level of consistency of all tests meeting the requirements of the 'Specified' stopping distance. There was also no indication of WSP activity or poor performance during the testing, indicating the unit performed as designed.

162 Test 4 (1 Vehicle Isolated), meaning that the brakes in one vehicle were deliberately isolated, i.e. the two-car unit only had half its normal braking force. In this configuration it took approximately twice as long to stop i.e. a stopping distance of approximately 380 m versus an average of 190 m (average of Test 1, Test 2, and Test 3). Test 4 shows that even with half of the trains brakes isolated, the train still stops in a shorter distance than which was experienced during the LRA incidents at Ardrahan (2052 m) and Spa (1021 m).

Braking System – Wheel/Rail Interface

Introduction

163 Steel on steel is the best medium for heavy rail but has limitations. The contact patch between steel wheel and rail head is small and can be susceptible to localised changes in the co-efficient of friction. The wheel to rail contact patch is typically 1-1.5cm^2, for comparison the typical contact patch of a road vehicle tyre would be in the region of 80cm^2. Figure 29 illustrates the elliptical contact patch formed by the elastic deformation of the wheel and rail at the contact point. This region of contact is the only way an axle or thread braked train can impart force to the rail to change rate of deceleration. Thus the co-efficient of friction in the area is vital.

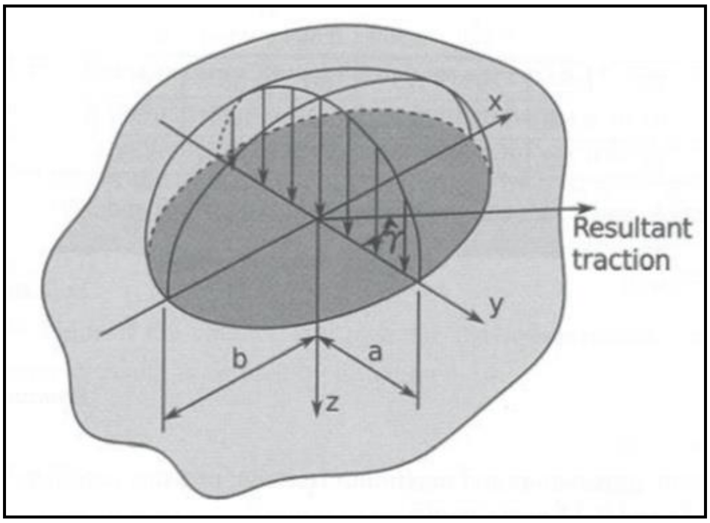

Figure 29 – Elliptical contact patch – circa 1 – 1.5 cm^2
(Source: Wheel Rail handbook)

Co-efficient of friction

164 Dry, clean rails allow a co-efficient of friction or *Mu* (µ) from 0.3**,** up to a theoretical ceiling of 0.8. Wet or slightly contaminated rails that still supply normal expected braking rates have a co-efficient of friction typically in the region of 0.3 to 0.15. Very slippery rails that allow LRA are normally classified as having a µ below 0.05. For a comparative illustration the average co-efficient of friction between rubber and ice is in the region of 0.15.

165 Contaminant such as crushed foliage, diesel fuel, leaking lubrication oil, moisture, ice, dust such as coal dust, defective rail mounted flange lubricators, can all reduce the co-efficient of friction on a section of rail below 0.3. Even tiny amounts of contaminant, often not visible to the naked eye can cause LRA conditions which can be present for a short period.

166 The significant factor in this is not only the contaminant itself, but also the presence of an amount of moisture in the environment. It should also be noted that a lot of moisture can restore grip levels by washing away contaminants. Hence, the highest risk of LRA is when there is a small amount of moisture present and why there is less risk during times of heavy rain.

167 The co-efficient of friction during a brake application is displayed as an average. In reality the co-efficient of friction would fluctuate between good adhesion (maybe >0.1) and levels near zero as a unit moves along a section of rail, a disproportionate amount for deceleration would be achieved when favourable adhesion levels were present.

Calculated co-efficient of friction

Incident at Ardrahan on the 23rd October 2015

168 Calculated co-efficient of friction for Ardrahan incident, using OTDR data, are presented in Figure 30; also calculated are the approximate co-efficient of friction that would have been required to stop at key locations.

Level Crossing XE156 Ardrahan Braking Rates	μ
Average Co-efficient of friction experienced	0.0214
Required Co-efficient of friction to have stopped at station	0.045
Required Co-efficient of friction to have stopped at signal XE156DS	0.037

Figure 30 – Co-efficient of friction for Ardrahan

169 With very slippery rails normally classified as having a μ below 0.05, and the calculated μ being 0.0214, the conditions on the day of the incident can be considered to be very slippery.

Incident at Spa on the 28th November 2015

170 The calculated co-efficient of friction for Spa incident, using OTDR data, are presented in Figure 31. Also calculated are the approximate co-efficient of friction that would have been required to stop at key points.

Level Crossing XN159 Spa Braking Rates	μ
Average Co-efficient of friction experienced	0.0178
Required Co-efficient of friction to have stopped at signal XN159	0.0202
Required Co-efficient of friction to have stopped before gate	0.0189

Figure 31 – Co-efficient of friction for Spa

171 Again, with very slippery rails normally classified as having a μ below 0.05, and the calculated μ being 0.0178, the conditions on the day of the incident can also be considered to be very slippery.

172 Consultants, Interfleet Technology Limited, in a report titled 'Independent Review of the Overruns at Ardrahan and Castleconnell' carried out an independent technical analysis on the train's performance. (In this report they have referred to XN159 Spa as the townland Castleconnell). The report calculated the theoretical brake distances for different track conditions, i.e. Dry, damp and 'damp + leaf' conditions (damp and leaf conditions allow for contaminants on the rail in addition to damp conditions). The actual stopping distances for the incidents at Ardrahan and Castleconnell are 2052 m and 1021 m, respectively (blue rectangle in Figure 32). The Dry, Damp and 'Damp + Leaf Film' calculations are also set out in Figure 32. The report notes at the 'Damp + Leaf Film' conditions are most comparable to the recorded stopping distances of those recorded at the incidents (red rectangle) e.g. Ardrahan's actual stopping distances was recorded as 2052 m as compared to the 'Damp + Leaf Film' of 2420.

		Dry			Damp			Damp + Leaf Film			
Incident	Initial speed	Coefficient of friction (μ)	Decel-eration m/s²	Stopping Distance (m)	Coefficient of friction (μ)	Decel-eration m/s²	Stopping Distance (m)	Coefficient of friction (μ)	Decel-eration m/s²	Stopping Distance (m)	Actual stopping Distance (m)
Ardrahan	70mph 112kph	0.17	1.7	285	0.08	1	484	0.02	0.2	2420	2052
Castleconnell	42mph 68kph	0.2	2	89	0.1	1	178	0.025	0.25	714	1021

Figure 32 – Brake rates at different co-efficients of friction

173 It is noted that the co-efficient of friction for the 'Dry' rail conditions is approximately a factor of ten higher than for the 'DAMP +Leaf Film' and the stopping distances have increase also by approximately a factor of ten between the two. There is an inverse relationship between stopping distances and the coefficient of friction. When the co-efficient of friction reduces the stopping distances increase.

Recognised methods to improve wheel/rail interface

174 The use of *sanders* is accepted within the rail industry to increase the co-efficient of friction, and thus improve braking performance. Braking systems with integrated sanding have been demonstrated to reduce stopping distances by up to forty-five percent in the UK.

175 The effectiveness of sanding depends on a number of design variables. The number of sanding units, how early sanding of the wheel rail interface commences, duration that sand is applied and the flow rate in kg/s of sand dispersed.

176 The Class 2600 brake system is not fitted with a rail head preconditioning system such as sanding, this has become standard on newly built rolling stock. On board sanding systems target the wheel/rail interface to improve adhesion levels.

177 The fact that the Class 2600 brake system was not fitted with a rail head preconditioning system such as sanding, was not included on the Fleet Risk Register.

Braking System – Wheel Slide

Wheel slide

178 Wheel slide is a product of the loss of wheel and rail adhesion during braking, when the available adhesion does not match the braking forces being exerted on the braked wheel sets. This results in the wheel set rotational speed being much lower than the vehicles forward speed, in extreme cases leadings to locked wheel sets. Wheel slide increases the trains stopping distance and has the potential to damage the wheel set by creating wheel flats (University of Birmingham, 2010).

Wheel slide protection

179 As a component of the brake system the Class 2600 fleet have a *wheel slide protection* (WSP) system fitted. The purpose of a WSP system is to optimise the braking distance achievable in lower adhesion conditions. The WSP system applies and releases the severity of the brake application to minimise wheel slide. This optimises the friction available to minimise braking distance whilst also preventing damage to wheels.

180 This is a microprocessor controlled, bogie mounted WSP system providing per axle slide correction for the pneumatic brakes. Speed sensors are mounted on the 2nd, 3rd, 4th axles of DC1 and DC2. The system compares the speeds of the three axle groups and when it detects an axle rotating too slowly, it releases the brake on that axle to allow it to stop skidding and return to rotating before reapplying the brake again.

181 A sliding vehicle takes longer to stop than one that has a controlled deceleration. The best rates of deceleration can be achieved in a region where the wheels are rotating as slow as possible but retain tractive contact. The ‘point of slip’ is noted as the region that achieves maximum transference of rates of retardation. Once tractive contact is lost, the ability to change speed is lost. The WSP system attempts to remain in this region.

182 WSP systems also protect the unit from extreme wheel damage whilst achieving reduced stopping distance.

Part 5 – Analysis

LRA

183 The CCE Department calculate (paragraphs 116 - 117) and communicate the LRA Risk Rating Matrix to RU and IM staff (paragraph 118).

Operations

184 There are two standards available to drivers related to guidelines for driving under LRA conditions (paragraph 121). Both drivers involved in the incidents, were briefed on these guidelines prior to the incidents, both drivers adhered to these guidelines. The drivers could not have undertaken any further actions to prevent these incidents.

185 Although in these instances, the drivers adhered to the guidelines, there is some ambiguity in the standards, in that the standards state that "according to the braking characteristics of the train select an appropriate braking position to achieve the desired level of retardation". The IÉ investigation report (published on the 27th April 2016) into the incident at Ardrahan on the 23rd October 2015 found that "A drivers' (and DTEs') interpretation of this guidance is open to argument and is an item in the guidance which may benefit from a review to attain continuous improvement on technique during LRA conditions". This finding has lead IÉ to make the following recommendation: "The RU Safety Manager should arrange to review the policy, in the Professional Drivers Handbook, in relation to braking technique during LRA conditions to provide clarity on what is 'appropriate braking'".

Braking

186 Marginally incorrect speed readings (+7% Ardrahan, -1.5% Spa) would have been displayed to the drivers due to the incorrect wheel size input to the OTDR. Nothing else of note was defective on the train set and was in date for its maintenance exams. The braking system performed as designed in routine maintenance tests as well as during post incident testing.

187 Extensive testing undertaken (paragraph 162) indicates that even with half of the trains brakes isolated, the train still stops in a shorter distance than which was experienced during the LRA incidents. This indicates that degraded braking or marginal over-speeds would not have resulted in such elongated braking distance as experienced at either incident.

188 The current Class 2600 braking system does not have the ability to condition the railhead during braking.

Wheel/Rail interface

189 Environmental issues are likely to have contributed significantly to conditions required for an elongated braking incident as change is speed depends on adhesion levels between the wheel/rail interface. Nearby weather stations recorded levels of very light rain at the time of the both incidents.

190 There was no swabbing of the railhead or train wheels, immediately post incident at Level Crossing XE156 Ardrahan. As a result evidence of contamination, that may or may not have been present, was not preserved. Although it should be noted that this is not a requirement at the time of the incident.

191 Swabbing was undertaken on the later incident at Level Crossing XN159 Spa on 28th November. This swab showed the presence of iron oxide, a substance that could reduce available friction. The Birdhill to Limerick track is a low frequency route; and lightly used track contributed to the presence of iron oxide and was a factor in the low rail adhesion of that section of track. A higher frequency of use, or longer train sets would reduce this problem, however that may be impractical.

192 The combination of the iron oxide on the rails from the infrequent line use, and the damp conditions pertaining at the time of the occurrence, would have been sufficient to reduce the adhesion levels significantly.

193 Although no swab was taken in Ardrahan post incident, it is almost certain that microscopic contaminants combined with moisture led to an insufficient rate of adhesion.

194 The distances calculated by Interfleet Technology Limited, see Figure 32 show that the train stopping distances were similar to those of ‘Damp + Leaf Film’ conditions, meaning that the train was experiencing LRA conditions and as such could not meet the train’s typical (specified) stopping distances. The actual stopping distances show that the co-efficient of friction at the time of the incidents was therefore low and to shorten stopping distances the co-efficient of friction between the steel wheel and steel railhead would have to be improved.

195 An improvement such as providing sand at the wheel rail interface has been shown to condition the interface area and improve adhesion levels. Removal of possible railhead contaminants through regular cleaning and treatment would also improve the adhesion levels.

Infrastructure

196 The position of the Ardrahan Level crossing after the station stop is 430 m to the centre of the crossing. This allows an overrun of 420 m before conflict with the crossing. This is a significant length of overrun as a train braking in sight of the platform (150m) would be able to come to a stop from maximum speed in normal conditions.

197 If the auto initiation sequence had reached its time out, the barriers would have begun to lower (taking approximately twenty–two seconds), which may have reduced the risk of a collision at the Level Crossing. However, this would not have prevented the SPAD, as the LCCO would have to check the level crossing was clear before setting the green signal. The crossing performed as designed see paragraph 131.

Operations

198 Four out of the nine gatekeepers did not answer the Birdhill Signalman's phone call. Gatekeeper XN159 stated that they heard the call and knew what it meant, however, they did not ring back to confirm any potential message to open gates. Gatekeeper XN159 could not have known if this call was to inform of a further delay or that the train was approaching.

199 Driver A788 and Driver A464 both took appropriate actions and could not have taken any other actions to prevent the incident.

Part 6 - Conclusions

200 The drivers of both incidents used the correct procedures, as they were trained to do, and applied emergency braking early, see paragraph 122 to 129.

201 The investigation found no deficiencies in the physical infrastructure or signalling design and layout see paragraph 131.

202 The train brakes performed as designed and had received all relevant maintenance inspections prior to and post each incident, see paragraph 145 to 159.

203 The wheel rail interface contained evidence of contaminants combined with moisture in the Spa incident and contaminants more than likely would have been present in Ardrahan. These conditions would have led to poor adhesion and was a factor see paragraph 189 to 195.

Immediate cause, contributory factors and underlying causes

Immediate cause of the operational incidents

204 The immediate cause of both operational incidents was an insufficient level of adhesion, between the rail and the train wheel, to bring the vehicle to a stop before the relevant signals.

Contributory factors

205 Contributory factors associated with the incidents are as follows:

- CF-01 – The incident locations experienced light rain prior to the train services operating, resulting in LRA conditions;
- CF-02 – There was no on-board sanders to improve adhesion, between the rail and the train wheel.

206 Additional contributory factors associated with the incident in Spa

- CF-03 – Gatekeeper XN159 had not opened the gate as in a timely fashion prior to Train A464 expected arrival.

207 Additional contributory factors associated with the incident in Ardrahan

- CF-04 – Incorrect OTDR input resulted in the speed displayed to driver varying by up to 5mph (8 km/h) at 70mph (112km/h).

Underlying & root causes

208 No underlying or root causes associated with the incidents were identified.

Additional observations

209 There is some ambiguity in the standards related to driving in LRA conditions (the Professional Driving Standard and the Seasonal LRA Booklet) in that the standards request that drivers select an appropriate braking position based on the braking characteristics of the train to achieve the desired level of retardation; as a result this can lead to some variance in interpretation.

Relevant actions taken or in progress

Actions taken by IÉ

210 The CCE imposed an Emergency Speed Restriction (ESR) of 40km/h (25mph) on the Down approach to Ardrahan Station. Sandite was also hand applied on the line at the site and a traction gel applicator was installed at the location in the days following the occurrence while further investigation was carried out.

211 The CME VMI has been updated to include the requirement that wheel diameters are checked/ updated during wheel changes on a vehicle as well as routine exams (CF-04).

212 All gatekeepers at the nine crossings in the Birdhill/Killonan section received an individual written instruction from the Operations Control Manager reminding them of the requirements of Rule Book, Section A and General Appendix, Section G regarding their attendance for duty at level crossings (CF-03).

213 A system has been put in place by the Operations Control Manager whereby a log is being maintained by Signalmen to identify any trends in Gatekeepers not responding to calls advising of an approaching train to any given crossing (CF-03).

214 The investigation noted that prior to both occurrences the CME Department had initiated a project to install an adhesion improving sanding system on the 2600 Class fleet. This project was completed by October 2016.

Safety recommendations

General description

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

216 As a result of the RAIU investigation one new safety recommendations is made.

New safety recommendations related to the occurrence

217 It can be hard to defend against the sudden onset of LRA conditions caused by changing weather conditions (CF-01). Therefore it is important that the train has an ability to counteract this. Sanding systems are shown to improve stopping distances by conditioning the wheel/rail interface and improving the co-efficient of friction available.(CF-02)

IÉ-RU should review all traction fleets that do not have sanding capabilities, and fit suitable systems to minimise the risk of low adhesion incidents.

218 Actions reported that address factors which otherwise would have resulted in a RAIU recommendation:

- OTDR exams, which includes the input of the correct wheel size, are now included in maintenance exams as per standard CME-TMS-002 and are monitored under relevant compliance standards;
- The communication between Signalman and Gatekeepers has been reviewed; and all Gatekeepers on the line have been written to reminding them of the requirements of Rule Book, Section A and General Appendix, Section G regarding their attendance for duty at level crossings. This action, by IÉ addresses contributory factor CF-03, and as such no recommendation is required;
- Testing of rail head for evidence of contaminants by means of swabbing the rail head has now been included as part of post incident investigation processes;
- The time out for Level Crossing XE156 has been reviewed and a speed restriction introduced to increase the time it takes for the train to reach the level crossing. This is an interim speed restriction, until all trains have been fitted with sanders;
- The Class 2600 is now fitted with sanders, the sanding performance is to be monitored in the coming LRA season.

Additional information

List of abbreviations

°C	Degrees Celsius
µ	Co-efficient of friction
ABS	Anti-lock Braking System
CCE	Chief Civil Engineer
CCTV	Closed-Circuit Television
CME	Chief Mechanical Engineer
CF	Contributory factor
CRR	Commission for Railway Regulation
DART	Dublin Area Rapid Transport
DMU	Diesel Multiple Unit
DTE	District Traffic Executive
DTTAS	Department of Transport, Tourism and Sport
ETS	Electronic Token System
ESR	Emergency Speed Restriction
FTS	Fleet Technical Support
IÉ	Iarnród Éireann
IM	Infrastructure Manager
Kg	Kilogram
km/h	Kilometres per hour
LCCO	Level Crossing Control Operator
LED	Light Emitting Diode
LRA	Low Rail Adhesion
M	Metre
MLCCC	Mallow Level Crossing Control Operator
MP	Mile Post
Mu	Co-efficient of friction
No.	Number
OEM	Original Equipment Manufacturer
OTDR	On Train Data Recorder
RAIU	Railway Accident Investigation Unit
RSC	Railway Safety Commission
RSD	Railway Safety Directive
RU	Railway Undertaking
SB	Safety Briefing
SET	Signal Electrical and Telecoms

SI Units	International System of Units
SMS	Safety Management System
SPAD	Signal Passed At Danger
TSI	Technical Specifications for Interoperability
UC	Underlying cause
UN	United Nations
VMI	Vehicle Maintenance Instruction
WSP	Wheel Slide protection

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.
Actuators	A component of brake system they are electrically controlled and apply a blast of air to activate brake rigging.
Auto-initiation	Automatic countdown sequence triggered by a train passing a defined point.
Bi-directional	Line can have rail traffic operating in either direction.
Colour light signals	Signals that convey movement authority to train drivers by means of coloured lights.
Continuous welded rail	Sections of rail that are welded together.
Contributory factor	Factors relating to actions taken by persons involved or the condition of rolling stock or technical installations.
Controlling signalman	The signalman designated to control a specific section of track.
Damp	Conditions that yield wet rails that have a lower mu than dry rails.
Damp + Leaf Film	Conditions that yield wet rails and a contaminant that have a lower mu than damp rails.
Distant Signal	Signal that indicates to driver the current colour of the next signal.
Dynamic Brake Test	Practical brake test on the line measuring actual brake effectiveness in action.
Electrical Multiple Unit	A multiple unit train whose source of power is an electrical powered engine.
Electric Token System (ETS)	Token system that allows only the train with the token to entre a section of track.
Extensive damage	Damage that can be immediately assessed by the RAIU to cost at least €2,000,000 in total.

Failsafe	A design principle that requires a failed system to preserve the safety of the railway line.
Hysteresis	Delay or lag in a system.
Immediate cause	Direct and immediate causes of the occurrence including contributory factors relating to actions taken by persons involved or the condition of rolling stock or technical installations.
Incident	Any occurrence, other than an accident or serious accident, associated with the operation of trains and affecting the safety of operation.
Infrastructure Manager	Organisation that is responsible for the establishment and maintenance of railway infrastructure, including the management of infrastructure control and safety systems.
National safety authority	The national body entrusted with the tasks regarding railway safety in accordance with European directive 2004/49/EC.
Rail adhesion	Describing the friction produced between a rail and a rail wheel.
Railway Undertaking	Organisation that operates trains.
Rolling stock	Railway vehicles.
Root cause	Causes related to framework conditions and application of the SMS.
Sanders	A means of delivering small amounts of sand onto the rail head near the driving wheels of a traction unit in order to improve adhesion in areas of very poor rail head conditions.
Sandite	Gritty gel containing fine particles of sand that is applied to rail head to improve adhesion. Usually lasts for approximately 150 passes of an axle.
Section Token	Physical piece that allows only the train with the token to entre a section of track.
Semaphore	A system of visual signals to direct traffic
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.
Slip/Slide Light	Light that illuminates when the WSP system is active.
Track circuit block	A signalling system that uses track circuits to confirm the absence of trains in order to control the movement of trains.
Underlying cause	Causes related to skills, procedures and maintenance.
Wheel Flat	Flat spot on wheel usually caused by sliding on a single point of wheel.
Wheel Turning	Machining of wheel surface to remove imperfections such as wheel flats.

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