Rail Accident Investigation Branch

Rail Accident Report

Collision and derailment at Neville Hill
13 November 2019

Report 13/2020
November 2020

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC
- the Railways and Transport Safety Act 2003
- the Railways (Accident Investigation and Reporting) Regulations 2005.

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Preface

The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability. Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

RAIB's findings are based on its own evaluation of the evidence that was available at the time of the investigation and are intended to explain what happened, and why, in a fair and unbiased manner.

Where RAIB has described a factor as being linked to cause and the term is unqualified, this means that RAIB has satisfied itself that the evidence supports both the presence of the factor and its direct relevance to the causation of the accident or incident that is being investigated. However, where RAIB is less confident about the existence of a factor, or its role in the causation of the accident or incident, RAIB will qualify its findings by use of words such as 'probable' or 'possible', as appropriate. Where there is more than one potential explanation RAIB may describe one factor as being 'more' or 'less' likely than the other.

In some cases factors are described as 'underlying'. Such factors are also relevant to the causation of the accident or incident but are associated with the underlying management arrangements or organisational issues (such as working culture). Where necessary, words such as 'probable' or 'possible' can also be used to qualify 'underlying factor'.

Use of the word 'probable' means that, although it is considered highly likely that the factor applied, some small element of uncertainty remains. Use of the word 'possible' means that, although there is some evidence that supports this factor, there remains a more significant degree of uncertainty.

An 'observation' is a safety issue discovered as part of the investigation that is not considered to be causal or underlying to the accident or incident being investigated, but does deserve scrutiny because of a perceived potential for safety learning.

The above terms are intended to assist readers' interpretation of the report, and to provide suitable explanations where uncertainty remains. The report should therefore be interpreted as the view of RAIB, expressed with the sole purpose of improving railway safety.

Any information about casualties is based on figures provided to RAIB from various sources. Considerations of personal privacy may mean that not all of the actual effects of the event are recorded in the report. RAIB recognises that sudden unexpected events can have both short- and long-term consequences for the physical and/or mental health of people who were involved, both directly and indirectly, in what happened.

RAIB's investigation (including its scope, methods, conclusions and recommendations) is independent of any inquest or fatal accident inquiry, and all other investigations, including those carried out by the safety authority, police or railway industry.

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Collision and derailment at Neville Hill 13 November 2019

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Summary

At 21:41 hrs on 13 November 2019, an empty LNER Intercity Express Train, approaching the maintenance depot at Neville Hill in Leeds, caught up and collided with the rear of a LNER High Speed Train moving into the depot. The leading train was travelling at around 5 mph (8 km/h) and the colliding train at around 15 mph (24 km/h). No one was injured in the accident, but the trailing bogie of the second and third vehicles and the trailing wheelset of the fourth vehicle of the Intercity Express Train derailed to the right, by up to 1.25 metres.

The collision occurred because the driver of the Intercity Express Train was focused on reinstating an on-board system which he had recently isolated, instead of focusing on the driving task. This was exacerbated by him unintentionally commanding too much acceleration due to his lack of familiarity with the train.

The driver had isolated the on-board system at Leeds station because he had been unable to correctly set up the train management system. He had been unable to do this because ambiguous documentation from Hitachi, the train manufacturer, had led to LNER misunderstanding the required process for setting up the train management system when developing the content of its driver training programme.

The driver's lack of adequate familiarity with the train probably arose because LNER had not recognised that his training needs were greater than for his peers.

The derailment occurred because the design of the Intercity Express Train is susceptible to derailment in low speed collisions. This susceptibility is related to the use of high-strength couplers with large freedoms of movement in pitch and yaw. These features were part of the train's design. However, the impact of these features on the train's resistance to derailment and lateral displacement in low speed collisions, was not considered by the train's designers.

The crashworthiness standard used to design the Intercity Express Train did not specifically require consideration of the likelihood of derailment during collisions at lower than the 22.5 mph (36 km/h) specified design speed, nor did it include specific criteria for assessing the derailment performance. As such, the assessment and validation of the design did not identify any issues with these design features.

RAIB has made five recommendations. Two recommendations are addressed to LNER and relate to correcting its understanding of the setup of the train management system and ensuring that the documentation provided by Hitachi has not led to any other safety issues. The other recommendations relate to:

- Hitachi to revisit the assessment of the design of the Intercity Express Train against the requirements of the crashworthiness standard
- LNER to assess the risk of a derailment of an Intercity Express Train involved in a low speed collision
- RSSB to consider whether it is appropriate for the crashworthiness standard to be modified.

Introduction

Definitions

1 Metric units are used in this report, except when it is normal railway practice to give speeds and locations in imperial units. Where appropriate the equivalent metric value is also given.

2 The report contains abbreviations and acronyms explained in Appendix A. Sources of evidence used in the investigation are listed in Appendix B.

Acknowledgements

3 RAIB would like to acknowledge Hitachi's contribution to this investigation.

The accident

Summary of the accident

4 At 21:41 hrs on Wednesday 13 November 2019, an empty passenger train, approaching the maintenance depot at Neville Hill in Leeds, caught up and collided with the rear of another empty passenger train moving into the depot on the same track. The leading train was travelling at around 5 mph (8 km/h) and the colliding train at around 15 mph (24 km/h). No one was injured in the accident.

5 The colliding train was a 9-coach class 800 set, part of the Intercity Express Programme, operated by London North Eastern Railway (LNER). Its leading end suffered significant damage during the collision (figure 2). The second train was a High Speed Train (HST) set comprising 9 coaches and a class 43 locomotive at each end. It was also operated by LNER. The trailing class 43 locomotive also suffered significant damage (figure 2).

6 As a result of the collision, the trailing bogie of the second and third vehicles and the trailing wheelset of the fourth vehicle on the class 800 train, derailed to the right in the direction of travel.

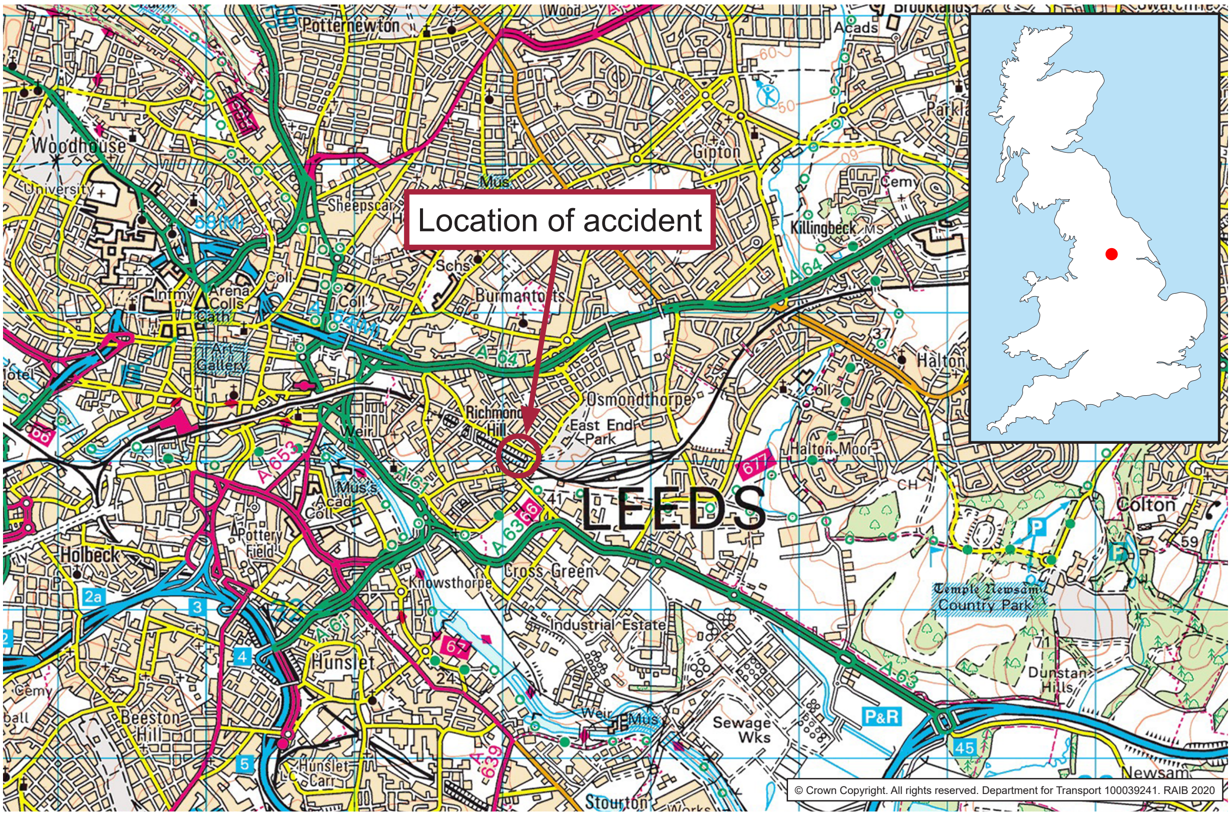

Figure 1: Extract from Ordnance Survey map showing location of accident

Figure 2: The class 800 train (top) and HST set (bottom) involved in the accident and the crash scene to the right (images courtesy of Network Rail)

Context

Location

7 The collision and derailment took place on the depot arrival line at the entrance to Neville Hill depot (figure 3). The maximum permitted speed for trains travelling along this line is 15 mph (24 km/h).

8 Trains leaving Leeds station heading towards Neville Hill depot, initially travel along the down Hull main line (figure 3) passing signal L3697 and a balise[1] that interacts with the class 800 trains' Automatic Power Changeover system (APCO balise). After passing signal L182 trains travel along the down Hull goods loop, passing signal L772 and onto the depot arrival line. Train movements along the down Hull main line and down Hull goods loop up to signal L772 are controlled from Network Rail's Railway Operations Centre (ROC) at York. Signal L772 is a 3-aspect, colour light, main signal with a position light signal and a route indicator. When the position light signal clears to two white lights a driver is authorised to pass the main signal at danger (red), in the knowledge that the section of track ahead is occupied by one or more trains (this is generally referred to as being 'called on').

[1] A data transmitter located close to the track or in the four-foot that provides information to passing trains.* This and other definitions marked with an asterisk have been taken from 'Ellis's British Railway Engineering Encyclopedia' © Iain Ellis http://ianellis.com.

9 The next signal on the depot arrival line is signal N18. It is controlled from Neville Hill depot. The maximum permitted speed for any train's movement within the depot is 5 mph (8 km/h).

10 The railway lines between Leeds station and Neville Hill depot are fitted with overhead power lines up to and including the depot. Beyond that location, the railway lines are not electrified. The purpose of the APCO balise is to initiate a power source changeover from overhead electric to on-board diesel engines on class 800 trains that are continuing their journey on the main line.[2]

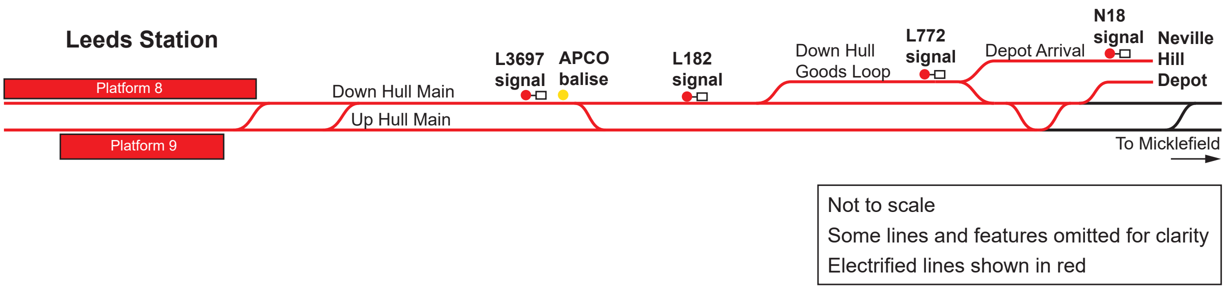

Figure 3: Track layout

Organisations involved

11 The Intercity Express Programme was an initiative of the Department for Transport (DfT) to replace the fleet of intercity trains operated on the East Coast and Great Western main lines. Under this initiative, DfT placed a contract with Agility Trains to finance, design, manufacture and maintain a fleet of new trains, known as the Intercity Express Trains (IET).

12 Agility Trains sourced private funding from banks and shareholders to finance the project and placed a contract with Hitachi for the design and manufacture of the IETs. A separate contract was placed with Hitachi for the maintenance of the trains.

13 LNER operated the trains involved in the accident and employed both drivers. LNER started operating IETs in passenger service on 15 May 2019.

14 Network Rail owns and maintains the infrastructure on which the collision took place.

15 DfT, Agility Trains, Hitachi, LNER and Network Rail freely co-operated with the investigation.

Trains involved

16 The IET involved in the collision was unit 800109. It weighed 430 tonnes at the time of the accident and had entered service on 8 July 2019. It had received its last 10-day exam at Doncaster two days before the accident and all maintenance activities on it were up to date. At the time of the accident, it had completed its passenger service for the day at Leeds station (paragraph 33) and was travelling as empty coaching stock to Neville Hill depot.

[2] APCO also controls diesel to electrical changeover where necessary.

17 The HST involved in the collision was set EC61. Power car 43308 was leading a rake of nine mark 3 coaches with power car 43300 at the trailing end. The HST weighed approximately 450 tonnes. It had completed its passenger service at Harrogate that day and was travelling as empty coaching stock to Neville Hill depot when the accident occurred.

Rail equipment/systems involved

18 IETs operate at speeds up to 125 mph (200 km/h) using the 25kV overhead electric power supply, or power generated from on-board generators driven by diesel engines. For these bi-mode trains, changing the power source from electric to diesel and vice-versa can be commanded manually by the driver or automatically by the train, using the APCO feature.

19 In common with most modern trains, the IETs are fitted with a computerised Train Management System (TMS) to assist the driver (figure 4). The TMS is a system that provides information and enables a driver to configure the train for the journey ahead. Control over whether APCO is operational or not is achieved using the TMS. The default setting is for APCO to be operational.

20 The operation of APCO is dependent on a train's route. This information is provided to the TMS by a driver entering the headcode of their train using the TMS touch screen at the start of the journey. The headcode is a four-digit alphanumeric reporting code allocated to each train operating on Network Rail infrastructure. The TMS uses the headcode to determine the starting location, final destination and the route planned for the journey. When passing over an APCO balise, the train will use the route information and knowledge of the location of electrified sections of line, to determine whether to initiate an APCO intervention. If the driver has not entered a headcode, or if the headcode is no longer valid (for example after the final destination has already been reached), passing over an APCO balise will initiate a power supply changeover to the diesel generators (if the train is not already being powered by them).

21 Unlike older stock operated by LNER, but in common with most modern stock, the IETs are fitted with a combined power brake controller (figure 4) which gives a driver access to the full range of tractive and braking efforts.

Figure 4: Class 800 cab layout showing TMS and power brake controller

Staff involved

22 The driver of the IET had 39 years' experience on the railway, with over 30 years as a driver of HSTs and class 91 (electric) locomotives. He was passed as competent to operate IETs in October 2019. This was his third unaccompanied drive of an IET; the previous time had been on Monday 11 November 2019. For health, personal and operational reasons, he had only driven trains for a period of two months in the two years prior to the accident.

23 The driver of the HST had 23 years' experience on the railway, 17 years as a driver of class 43 and class 91 locomotives. He drove his train into the depot within the 5 mph (8 km/h) limit. His actions on the night were not a factor in the accident.

External circumstances

24 The weather at the time of the accident was dry and cold. A temperature of 2°C and a light east-north-east wind were recorded at a nearby weather station. The weather did not play a part in this accident.

25 The railway along the depot arrival line is in a deep cutting with limited lighting. However, witness evidence indicated that the limited available light did not play a part in the accident.

26 There was no other train in the immediate vicinity at the time of the accident.

The sequence of events

Events preceding the accident

27 On Monday 11 November 2019, two days before the accident, the IET driver returned to work after two rest days. That day, he operated services between London King's Cross and Leeds. At 21:16 hrs, he arrived at Leeds, having operated train 1D29, the 19:03 hrs service from King's Cross. This had been his second unaccompanied passenger service journey driving an IET. His last duty of the day was to take the train as empty coaching stock into Neville Hill depot, a short drive from Leeds station. The train headcode associated with the trip from Leeds station to Neville Hill depot was 5D29.

28 In the past, on the older trains, the driver would have undertaken this short journey retaining the 1D29 headcode on the GSM-R[3] equipment. This was an unofficial practice, not endorsed by LNER corporately. As a result, the driver started the journey from Leeds station to Neville Hill depot as train 1D29. He did not realise he had to change the headcode to 5D29 on an IET to prevent an APCO intervention.

29 As the train passed over the APCO balise located between signals L3697 and L182 on the down Hull main line, the train automatically initiated a power supply changeover, starting the diesel engines. This was because APCO did not recognise the 1D29 headcode as valid (the journey for that headcode had ended at Leeds station).

30 The driver first became aware that APCO had intervened when he saw an indication on his control desk that the supply from the overhead power line had been lost, followed by a message on his TMS screen advising that the power changeover was complete. He finished his journey into Neville Hill depot, concerned that the unintended APCO intervention would be automatically flagged to Hitachi, because the engines had been started without any pre-heating.

31 The next day, the driver rang his manager to explain what had happened and, after seeking further clarification, they agreed that the right course of action was to enter the 5D29 empty coaching stock headcode into the TMS for the short journey to Neville Hill depot. This would prevent the unintended APCO intervention. The driver worked HSTs throughout the rest of that day.

32 On Wednesday 13 November 2019, the driver booked on at 14:48 hrs at Leeds train crew depot. His first journey was the 15:15 hrs Leeds to King's Cross service, arriving at 17:31 hrs. The train for this journey consisted of a class 91 locomotive and Mark 4 coaches, and the journey was uneventful. At King's Cross station, the driver was expecting to have his personal needs break before driving the 19:03 hrs King's Cross to Leeds service using unit 800109 travelling as train 1D29 (as he had done on the Monday night).

33 However, on arrival at King's Cross, the train manager advised him that unit 800109 had had door problems earlier that day and that the incoming service had been cancelled. The driver, train manager and the rest of the crew were instructed to catch a train to Peterborough to operate a curtailed service from Peterborough back to Leeds, using unit 800109.

[3] Global System for Mobile Communications – Railway.

34 Unit 800109 was moved as empty coaching stock from Leeds to Peterborough by another driver. It arrived at Peterborough at 19:45 hrs, with a due departure time of 19:52 hrs for its journey back to Leeds. The driver spoke to the driver who had brought the unit from Leeds to Peterborough, who explained that the door problem was still being reported on the TMS screen despite the door having been locked out of use. Unit 800109 formed train 1D29, which departed from Peterborough six minutes late at 19:58 hrs.

35 Throughout the journey from Peterborough to Leeds, the driver received several alerts on his TMS screen, advising him that a door was open in service when in fact the door had been locked out of use. In addition, the selective door operation system that detects automatically which doors to release when arriving at a station, was not working and the driver had to do a manual door selection at each station. Train 1D29 arrived at Leeds station platform 9 at 21:21 hrs, seven minutes late.

36 The HST involved in the accident was alongside in platform 8, having arrived from Harrogate at 21:17 hrs. The HST left Leeds station at 21:31 hrs, heading for Neville Hill depot.

Events during the accident

37 The last duty for the driver that day was to take unit 800109 to Neville Hill depot empty, as train 5D29. In line with what the driver had agreed with his manager the day before, he attempted to change the train's headcode from 1D29 to 5D29 using the TMS touch screen. However, he was unable to do so and the TMS continued to display that it was using headcode 1D29.

38 To avoid a repeat of what had happened on the Monday night, the driver decided to isolate APCO using the TMS touch screen. This was to prevent APCO from intervening when travelling over the balise between signals L3697 and L182. He completed this isolation at 21:27 hrs.

39 At 21:35 hrs, the train departed from Leeds station with APCO isolated. As the train passed over the APCO balise at 21:38 hrs, no power changeover took place which confirmed to the driver that the isolation had been successful. At 21:39 hrs, the train was approaching signal L772 at red when the driver noticed that the HST was stationary on the depot arrival line beyond the signal, waiting to enter the depot. The position light signal then cleared to two white lights while the train was still on the move, authorising the driver to proceed at caution past signal L772 towards the HST, a situation he had encountered many times before.

40 At 21:40:45 hrs, as the train was decelerating to come to a stop behind the HST, signal N18 ahead of the HST cleared and its driver started to move his train forward to enter the depot.

41 At 21:41:05 hrs, the IET came to a brief stop (just over one second) behind the HST, which by now was on the move. Knowing that his train had passed the APCO balise and keen to reinstate APCO as soon as possible, the driver turned his attention towards the TMS screen. At the same time, he realised that the HST was on the move and decided to follow it. He moved his power brake controller slightly to demand a low level of tractive effort, while continuing to focus his attention on the TMS.

42 At 21:41:28 hrs, unaware that his train had gained greater speed than he had intended, the driver completed reinstating APCO using the TMS touch screen. When he looked up from the screen, he realised that the HST was now only a few metres ahead of his own train and applied the emergency brake, but it was too late to avoid the collision.

43 At 21:41:32 hrs, the IET, travelling at 15 mph (24 km/h), collided with the HST which was travelling at 5 mph (8 km/h). During the collision, the trailing bogies of the second and third vehicle and the trailing wheelset of the fourth vehicle on the IET derailed to the right in the direction of travel.

44 The driver of the HST felt his train lurching forward and, despite being more than 250 metres away from the point of collision, thought that the engine on the rear power car had exploded because of the noise. In response, he quickly applied the emergency brake on the HST. By 21:41:40 hrs, both trains had come to a stop, 10 metres apart.

Events following the accident

45 Immediately after the accident, both drivers contacted the signaller in York ROC and LNER control to report the collision. Personnel from Neville Hill depot who had been contacted by LNER control were first on site and looked after the drivers' welfare until the arrival of representatives from LNER.

46 The HST was moved to Neville Hill depot at 04:15 hrs on Thursday 14 November. The IET was fully re-railed by 16:49 hrs on the same day and later moved to the depot. The depot arrival line was reopened for normal working at 21:00 hrs, following a track safety inspection undertaken by Network Rail.

Analysis

Identification of the immediate cause

47 When occupying a signal section that was already occupied by another train, the IET accelerated to too great a speed and caught up with the HST.

48 The IET forward-facing closed-circuit television (FFCCTV) shows how it came to a brief stop behind the HST, shortly before the accident (figure 5). Just before this brief stop, the on-train data recorder (OTDR) shows that the power brake controller was moved into a motoring position and the amount of demanded tractive effort remained unchanged until the last second before the collision, when the emergency brake was commanded. The footage of the FFCCTV shows how the IET gathered speed at a near constant rate and started closing in on the HST. Finally, the FFCCTV shows the collision and the trains moving in coalescence[4] by the end of the collision. The combined collision and coalescence phase lasted approximately 1.5 seconds.

Identification of causal factors

49 The accident occurred due to a combination of the following causal factors:

- The IET and HST were in the same section of track, at the same time (paragraph 50).
- The IET accelerated to too great a speed compared to the HST (paragraph 54).

Each of these factors is now considered in turn.

Permissive working

50 The IET and HST were in the same section of track, at the same time.

51 Normal railway operation is based on the principle that only one train can be in a signal section[5] at any time. The intent of this is to prevent the risk of collision between trains. However, there are certain circumstances where it is normal railway practice to authorise a train to enter a section already occupied by another train. This is called permissive working and it is covered by specific rules and requirements in the Rule Book. Permissive working is most commonly in place at stations to allow two or more trains to use the same platform, but is also often found on freight-only lines and the approach to yards and depots. Rules require that the driver should proceed at caution, ready to stop short of any obstruction.

52 Permissive working is allowed past signal L772 on the depot arrival line at Neville Hill to maximise the number of trains that can stand on the depot arrival line and down Hull goods loop without blocking the down Hull main line. The IET being called on at this signal to undertake a permissive move, and hence occupying the same section of track as the HST, is a normal event. The Rule Book also covers the situation where both trains are on the move during permissive working. The driver of the following train is to, again, proceed at caution and keep sufficient distance from the train in front.

[4] The joining of the two trains to form one mass, travelling at the same speed.

[5] The portion of line between two consecutive main signals.*

Figure 5: FFCCTV footage from unit 800109

53 The Railways and Other Guided Transport Systems (Safety) Regulations (ROGS) (as amended), place obligations on the industry to undertake risk assessments and to put in place measures necessary to ensure the transport system is run safely. This applies to the permissive working operations on the depot arrival line at Neville Hill. Railway Industry Standard RIS-0744-CCS[6] describes the requirements for such risk assessments to confirm that the risk of a train-to-train collision has been reduced to an acceptable level. Network Rail confirmed there was no risk assessment covering this location at the time of the accident. However, RAIB does not consider that the lack of risk assessment is causal to this accident, as, even if it had considered the increased acceleration of the IETs, it is unlikely that it would have resulted in any additional mitigation which would have averted this or similar accidents or anticipated a consequent derailment. The primary means of controlling the speed should have been visual feedback to the driver who had good visual cues, especially as to the location of the HST.

Handling of the IET

54 The IET accelerated to too great a speed compared to the HST.

55 The IET driver was an experienced driver who had undertaken this move into Neville Hill depot many times over his career. He knew that the speed on Neville Hill depot was limited to 5 mph (8 km/h) and hence he did not expect the HST to travel any faster than that. The IET driver has stated that he had no intention of travelling faster than 5 mph (8 km/h). Nevertheless, the OTDR shows that the IET reached a speed of 15 mph (24 km/h) at the time of the collision.

56 This causal factor arose due to a combination of the following:

- The driver's attention became focused on reinstating APCO using the TMS touch screen, instead of the driving task (paragraph 58).
- The driver unintentionally commanded too much acceleration, possibly because LNER had not adapted the driver's training to best match his needs (paragraph 77).

It is the combination of the higher than intended acceleration and the lack of visual feedback which led to the IET accelerating to too great a speed relative to the HST. Had the driver been monitoring the progress of his train, he would have been able to adapt the tractive effort demand to limit the acceleration. Each of these factors is now considered in turn.

[6] RIS-0744-CCS issue 1 dated December 2018 - 'Permissive Working Risk Assessment and Risk Controls'.

57 In common with other stock that LNER operates, the IET is fitted with Automatic Speed Limiting (ASL) equipment which, when activated, will prevent a train being accelerated to above the set speed. LNER's driver operating instructions and Professional Driving Policy[7] make reference to this equipment as something that drivers may use to assist them in the driving task. In March 2019, following a series of overspeed incidents, LNER changed its stance regarding the use of ASL and issued a Safety Bulletin asking drivers to ensure that, when operating any train with speed limiting equipment, they use it where practical. However, the driver's operating instructions were not updated. The professional driving policy was undergoing an update at the time the bulletin was published, but the updated policy did not capture the change in stance from LNER regarding ASL. RAIB has decided not to investigate this further as the wording of the Safety Bulletin allows a degree of judgement in the use of the ASL and LNER's revised expectations had not been captured in its policy or driving instructions.

Distraction

58 The driver's attention became focused on reinstating APCO using the TMS touch screen, instead of the driving task.

59 The train left Leeds station with APCO isolated (paragraphs 38 and 39). Having passed the APCO balise, the driver knew that he needed to reinstate APCO. Although there was no need to do this immediately, he decided to reinstate APCO as he was bringing his train to a stop behind the HST (paragraph 41). Up to this time, the driver's attention had been fully focused on the driving task. But from then on, he began focusing some of his attention on the TMS screen, which he needed to use to reinstate APCO.

60 However, before he fully engaged with that task, he noticed that the HST was on the move and he decided that he would let his train follow it up to the next signal. He therefore moved his power brake controller to demand a low level of tractive effort with the expectation that his train would slowly follow the HST. His attention then became fully focused on the TMS screen, not on the driving task. Reinstating APCO took approximately 20 seconds, navigating through the menus on the TMS screen.

61 After the accident, the driver was unable to explain why he decided to reinstate APCO when he did. However, the task was only necessary because APCO had previously been isolated (see paragraph 62). The driver's decision to reinstate APCO immediately was possibly a result of his concern about forgetting that he had isolated APCO, and this not being obvious to other drivers taking over the train (see paragraph 72). Each of these factors is now considered in turn.

APCO isolation

62 APCO had previously been isolated by the driver as his training had not taught him to enter the train headcode correctly. This was because the Hitachi train operation manual was ambiguous in this regard.

63 The driver isolated APCO in Leeds station when he was unable to change the headcode using the TMS touch screen (paragraph 37). He was unable to do this because the method that he was trying to use, a method LNER also believed to be suitable, was incorrect.

[7] LNER Safety Management System, SMS19.5 – Professional Driving Policy, issue 3, May 2019.

64 When setting up a train for an upcoming journey in the TMS, a driver is presented with a series of screens. The driver enters their driver login ID on the first screen (figure 6) and then the train headcode on the second screen (figure 7). Upon pressing ENTER after typing the headcode, the TMS displays the journey's time, origin and destination stations for the driver to check.

65 When satisfied that the correct headcode has been entered, a driver has the choice between two buttons to take the TMS to the home screen, which is the default screen during a journey. The HOME button takes the TMS to the home screen but does not cause the TMS to accept the entered headcode. The CHECK STOPS button takes the TMS to a screen where the driver can check the stops for the intended journey, before reaching the home screen. It is the pressing of this CHECK STOPS button which causes the TMS to accept the entered headcode.

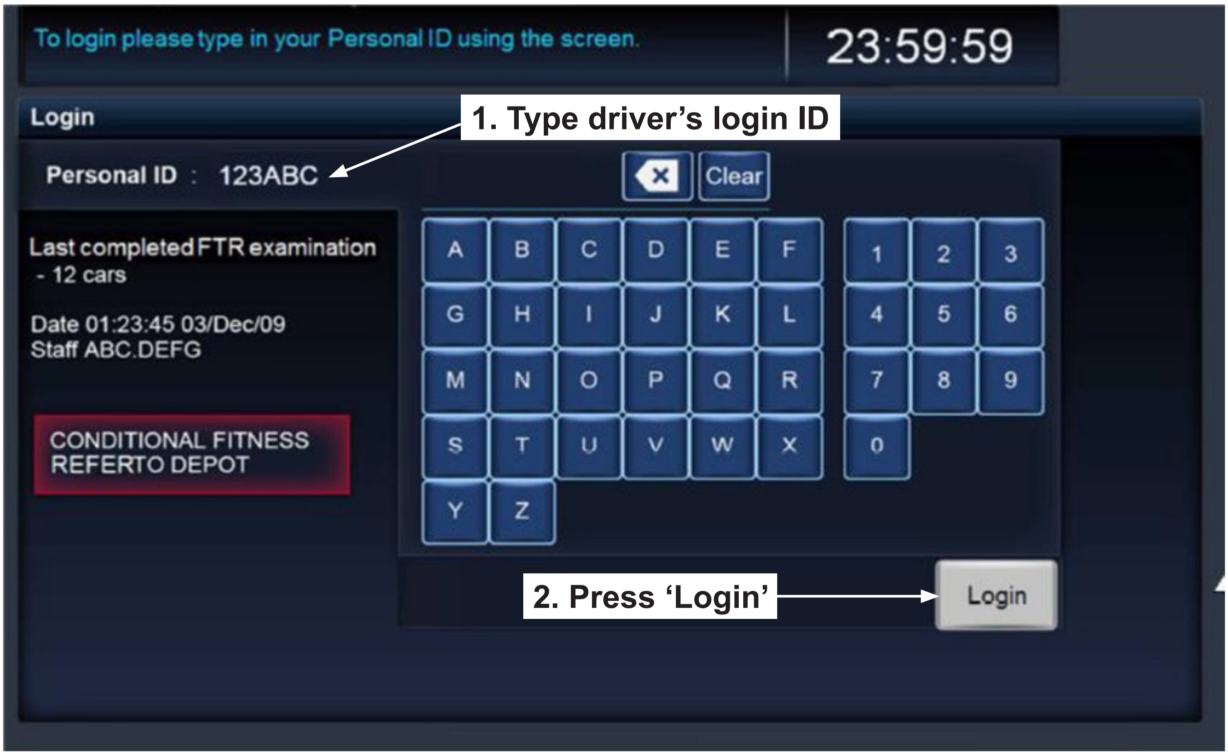

Figure 6: TMS login screen

Figure 7: TMS headcode screen

66 LNER trained its drivers that pressing CHECK STOPS would allow a driver to check the station stops for the journey ahead. The driver operating instructions identified this as a step in the cab setup process. LNER also trained its drivers that pressing HOME on the headcode screen would take the TMS to the home screen with the headcode having been accepted. This was the method used by the driver on the night at Leeds station. LNER did not understand that CHECK STOPS had to be pressed for the headcode to be accepted.

67 LNER's understanding of the working of the TMS came principally from documents supplied by Hitachi in late 2017 and early 2018, as well as a tablet app replicating the behaviour of a TMS. The main source document was the train operation manual.[8] LNER developed the training courses for its drivers on the basis of this document.

68 The train operation manual is the instruction manual for drivers on how to operate the trains. It is a large document and a third of its content is focused on the TMS. This part of the train operation manual replicates the content of another document, the TMS screen specification for train crew.[9] The TMS screen specification for train crew describes each TMS screen individually and explains the effects of pressing each button on each screen. RAIB reviewed both documents and concluded that neither clearly conveys the message that CHECK STOPS has to be pressed on the headcode screen for the TMS to accept the headcode. The Hitachi documentation was ambiguous in this regard.

[8] Train operation manual - OPE-300-VAR-TOM-00001 issue 5 dated 31 October 2017.

[9] TMS screen specification for train crew – 3E844460 issue 66 dated 25 September 2018.

69 These documents were not only used by LNER to develop its training course and its driver operating instructions, they were also used by a UK-based company, under contract to Hitachi, to develop the app replicating the behaviour of the TMS, and by a French company, under contract to LNER, to develop the IET full-cab driving simulator. The TMS app and the simulator both incorporate the mistaken understanding of the effect of pressing the HOME button on the headcode screen (paragraph 65). They both model the TMS accepting the headcode when the HOME button is pressed, which does not happen on an actual train.

70 Between 2014 and 2016, when the IET design was being developed, Hitachi commissioned a UK-based human factors specialist to review the IET design from a human factors and ergonomics perspective. The design of the TMS was extensively reviewed as part of this exercise and many comments were made on how the TMS screens could be improved to better match users' expectations. However, none of the comments related to any possible confusion or ambiguity associated with the process for entering a headcode.

71 Having been unable to enter the headcode, the driver could have contacted maintenance control to seek assistance, but concerns over the difficulty of getting through to control and time pressure meant that he did not. The driver stated that he had intended to contact maintenance control on arrival at the depot. LNER's driver training and driver operating instruction manual suggest that drivers should contact maintenance control when encountering irregularities while setting up a cab. This is to both facilitate assistance to the drivers and to help LNER better understand its new trains. However, given that LNER's training material was incorrect, it is unlikely that maintenance control would have been able to help the driver in this instance.

Dormant APCO isolation

72 The driver was possibly concerned about forgetting that he had isolated APCO, and this not being obvious to other drivers taking over the train.

73 The TMS is one of many systems on board an IET supporting a driver operating the train. LNER's Professional Driver Policy recognised that, while the provision of these systems enhances safety and efficiency, the use of these systems must be carefully managed to ensure that they do not become a distraction from the primary driving task. The policy provides guidance on how to manage this risk. The policy had been updated with the introduction of the IET in May 2019 and the update had been briefed to all drivers, including the driver involved in the accident.

74 After the accident, the driver could not remember why he reinstated APCO at the time he did. However, it is possible that his actions were influenced by the training he had recently received. LNER drivers were taught that *'it is imperative that APCO is reinstated once well clear of the affected area, otherwise it will remain inconspicuously isolated (even after the DDS and master switch is turned to OFF)'.* LNER was concerned that a dormant isolation would lead to the next driver having an incident, as an APCO isolation would not be immediately obvious on the TMS screen and a driver would need to work down through several sub-menu levels before being able to establish whether APCO was isolated.

75 However, at the start of November 2019, the TMS software was updated to provide an indication of an APCO isolation on the home screen (figure 8). As part of the update, a driver also received a warning that APCO was isolated when starting a train using the master switch.

Figure 8: APCO isolation on TMS home screen

76 The driver was unaware of this new feature because he had not been briefed by LNER on the introduction of the software update. LNER and Hitachi have an engineering change process for managing and briefing such changes, which normally results in briefing updates being provided to drivers. However, in this instance, it appears that the importance of this information was lost in the vast array of changes introduced in this particular software update. It is possible that, if a more thorough description of the change had been included in Hitachi's engineering change pack, its relevance would have been more easily identified.

Familiarity with IET

77 The driver unintentionally commanded too much acceleration, possibly because LNER had not adapted the driver's IET training to best match his needs.

78 The driver was very experienced, having driven trains since 1986. He stated after the accident that he had been caught out by the IET accelerating faster than he had been expecting.

79 The OTDR shows that the driver demanded about 20% of the available tractive effort on the train immediately after the brief stop. Despite the rising gradient towards Neville Hill depot, this was sufficient for his train to reach a speed of 15 mph (24 km/h) within 27 seconds.

80 In order to understand the driver's statement, RAIB estimated the effects of an equivalent tractive effort demand on an HST over 27 seconds. On an HST, the traction and brake controllers are separate, and it is normal driving practice to demand tractive effort with the brakes still applied, to prevent a rollback. This means that the time delay between the tractive effort demand and the train moving is partly dependent on the driving style of the driver. Based on a range of data available, RAIB estimated that a mean delay between the command and train movement is 8 seconds. By comparison an IET, with its increased performance and combined power brake controller, responds to the command in half that time. In addition, the data available to RAIB suggests that an IET will accelerate about twice as fast as an HST, with the equivalent tractive effort commanded.

81 As a result, an HST would have been likely to have reached approximately 7 mph (11 km/h) with equivalent driver inputs. At this rate of acceleration, it is probable that the gap between the two trains would have remained sufficient for the driver to realise that his train had started to catch up with the train ahead by the time he refocused on the driving task, and an accident would have been averted.

82 Although he was experienced, the driver's familiarity with driving IETs was limited. This was only his third unaccompanied turn driving an IET (a normal event in itself). Evidence indicates that he felt unfamiliar with the new technology, in particular, the TMS computer interface and the use of a combined power brake controller. The new technology made the IETs very different to the trains he had previously driven. He had also not driven any trains for a significant portion of the previous two years.

83 In June 2017, at his request, the driver was placed on compassionate leave, due to family issues. This continued until October 2017 when he was diagnosed with a condition requiring major surgery, which he received in March 2018, and he was put on sick leave. Having been declared fit to return to work, and following a period of retraining, the driver returned to driving HSTs and class 91s on 13 August 2018. Just over a month later, on 18 September 2018, the driver was involved in a signal passed at danger (SPAD) incident at Grantham following which he was suspended from driving duties. This was his second SPAD in two years, having been involved in one at York in November 2016.

84 The investigation into the SPAD at Grantham took a long time to complete and it was not until August 2019 that the driver was allowed to drive trains again, while being placed on a long-term competence development plan. LNER's safety management system mandates that a training needs analysis should be carried out following long periods of absence from train driving because of knowledge and skills fade. However, LNER could not provide documented evidence that this took place. On 22 August 2019, the driver restarted driving HSTs and class 91 locomotives. On 25 September he completed his last journey before going on annual leave. He had, by then, driven trains for just over 2 months over the previous 27 months and was, in his own view, only just getting used to driving HSTs again.

85 On his return from annual leave on 7 October, he started a training course for existing LNER drivers converting from driving HSTs and class 91s to driving IETs. This was the penultimate course of a training programme which LNER had started running in May 2018 to convert all its existing drivers to the new trains. The course lasted two weeks and included classroom and simulator training. It was followed by 20 hours of practical handling of an IET under the supervision of a trainer. This included all aspects of driving, including passenger service, undertaking low speed moves within depots and empty coaching stock moves to and from other depots. Having completed this course and qualified to drive IETs, the driver returned to driving HSTs and class 91s at the start of November 2019. Because LNER had not explicitly considered the driver's training needs, it had not identified that he might need more training than his peers to become sufficiently familiar with all aspects of the new IETs. On Monday 11 November, the driver was undertaking his second unaccompanied turn on an IET when he experienced the APCO intervention between Leeds and Neville Hill depot (paragraph 27) which started the sequence of events which led to the accident.

86 As well as training its existing drivers to drive IETs, LNER was also running training courses for drivers from other train operating companies who had recently joined LNER to operate the new trains. These drivers were required to hold an EU train driving licence and to demonstrate that they had been regularly driving on the UK network for the previous two years. Their course lasted three weeks and was followed by 20 hours of practical handling of an IET. These hours could be increased based on a training needs analysis carried out at the start of their training. LNER was also running courses for trainee drivers with no previous experience of train driving. They would receive a minimum of four weeks classroom and simulator training, followed by a minimum of 270 accompanied driving hours.

87 RAIB concluded that if LNER had explicitly considered the driver's training needs following his extended break from driving, both with respect to returning to driving HSTs and class 91s and for conversion to the new IETs, it might have decided to provide the driver with more theoretical training and/or practical handling experience, or even delayed his training. The driver's recent safety incidents, and the fact that he was on a driver competence development plan, should have been an additional flag to LNER of the importance of undertaking such an assessment. Had he had additional training or experience, he might have been more familiar with, and conscious of, the different performance of the IETs.

Factors affecting the severity of consequences

The derailment

88 RAIB examined the trains at Neville Hill shortly after the accident. The leading end of the IET and the trailing end of the HST both suffered structural damage at the point of collision. The couplers of an IET are formed of two coupler halves. They are designed to collapse and absorb energy in the event of a collision which takes place at speeds high enough to generate sufficient forces between vehicles. The energy absorption is achieved on each half by the coupler shank and coupler pin being forced into a cylinder of smaller diameter and deforming it as a result (figure 16). The examination revealed that none of the IET couplers had started collapsing in this accident.

89 The trailing bogie of the second and third vehicles and the trailing wheelset of the fourth vehicle on the IET, derailed to the right in the direction of travel as a result of the collision. Figure 9 shows the lateral movement of the vehicles during the collision as witnessed by the marks left by the couplers on the vehicle structures. The extent of the derailment (up to 1.25 metre of lateral displacement on the second vehicle) would have been sufficient to significantly infringe the swept path of a vehicle travelling on an adjacent line, assuming a typical gap between adjacent running lines (known as the ‘six-foot’), as shown in figure 10.

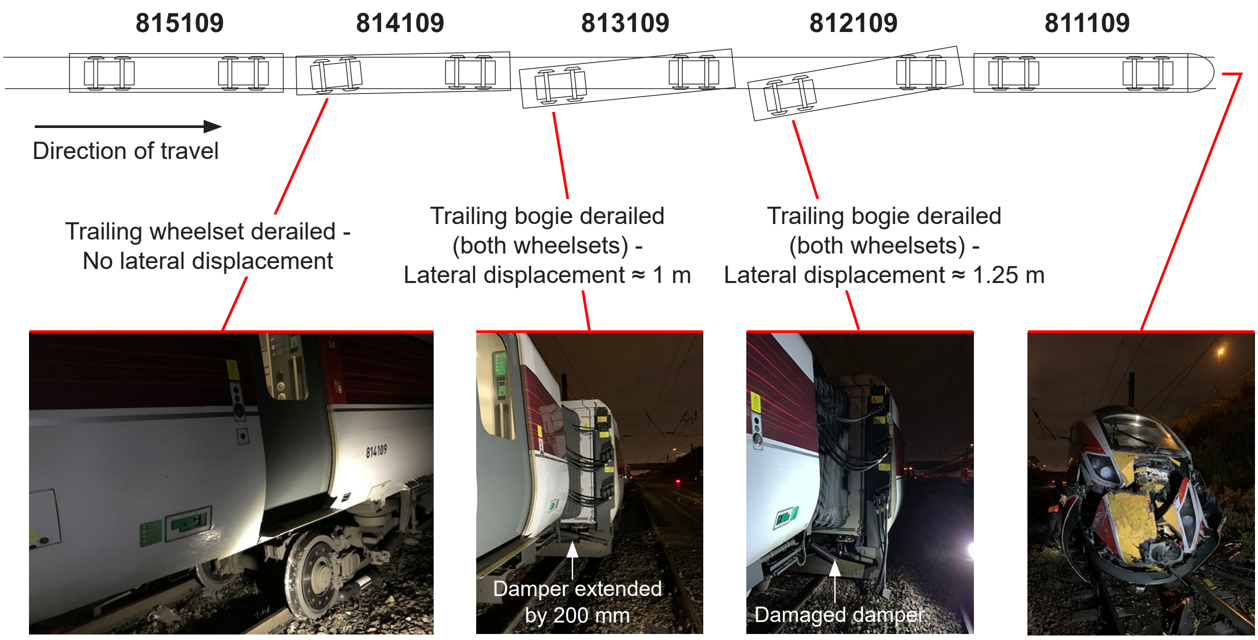

Figure 9: Schematic showing extent of derailment during collision (not to scale)

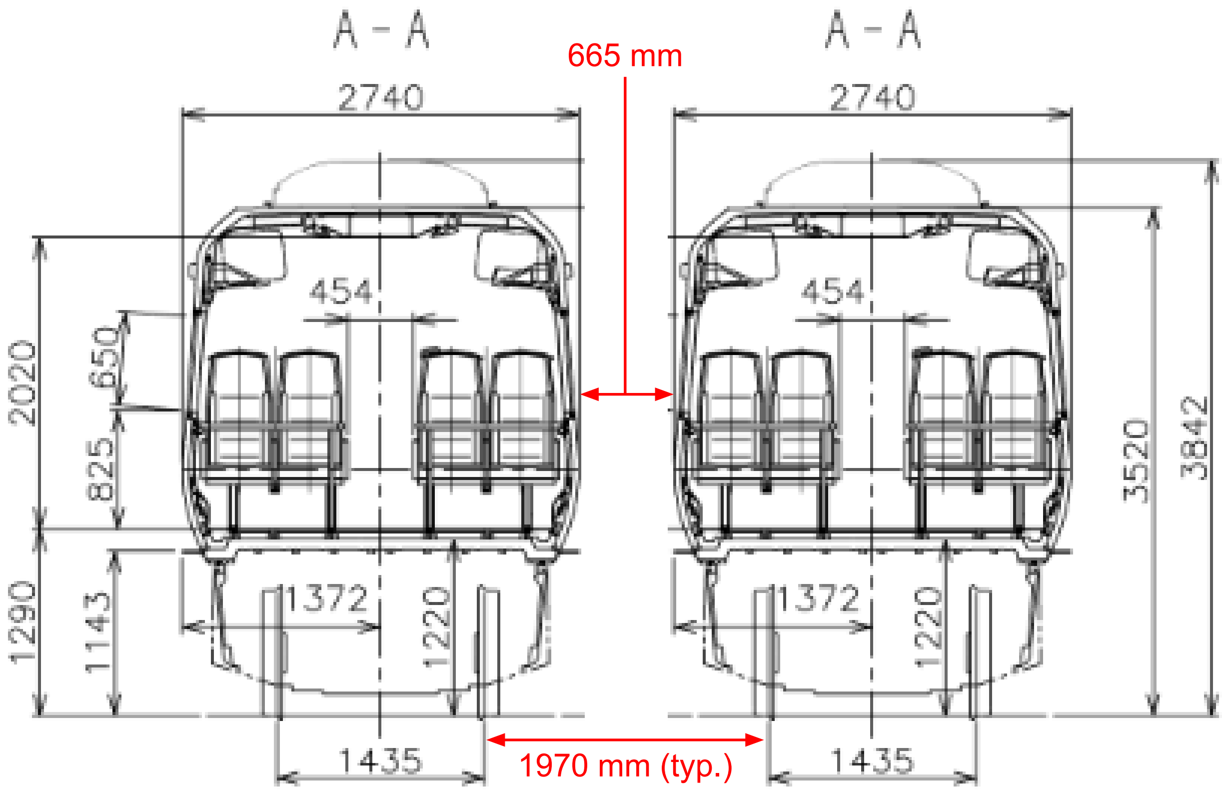

Figure 10: Typical passing clearance between two IETs on adjacent tracks

90 Post-accident testing of the IET revealed that there was no vehicle defect which would explain the derailment, such as wheel load imbalance, suspension lock-up, or body twist. RAIB also measured and analysed the track geometry following the accident and found no track feature which would explain the derailment, such as twist, gauge, or lateral track alignment faults.

91 A review undertaken by RAIB of similar accidents over the last 30 years (Appendix C) indicated that the character and degree of the derailment were atypical. None of the other accidents that RAIB considered resulted in derailment of vehicles remote from the point of collision, even in collisions with significantly greater energy. Therefore, RAIB investigated the elements of the train design and operation that could have influenced the outcome.

92 Hitachi designed the IET to comply with the crashworthiness requirements of standard EN 15227.[10] The objective of the standard is to limit the consequences of a collision as they affect the safety of people on-board a train. It defines general principles to provide protection to occupants in the event of a collision, namely: reducing the risk of overriding vehicles, absorbing collision energy in a controlled manner, maintaining survival space, limiting decelerations, reducing the risk of derailment and limiting the consequences of hitting a track obstruction. The standard specifies four design collision scenarios, involving a front-end impact:

- between two identical trains
- with a different type of railway vehicle
- with a large road vehicle
- with a low obstacle.

In particular, in accordance with the standard, the IET was designed to be able to withstand a collision with another IET at 22.5 mph (36 km/h).

The simulation models

93 In order to better understand the factors that influenced the derailment, two sets of computer models were developed:

- A three-dimensional (3D) model developed by Hitachi in Japan to predict the behaviour of the IET during the collision with the HST
- A set of three one-dimensional (1D) models commissioned from a consultancy by RAIB, to understand the sensitivity of the derailment performance to operational and design parameters.

[10] EN 15227:2008 + A1:2010 'Railway applications – Crashworthiness requirements for railway vehicle bodies'.

The 3D model

94 Hitachi, under the guidance of RAIB, prepared a computer simulation of the collision using a 3D finite element model.[11] The simulation was based on the train finite element model which had been developed during the original approval of the IET design against the requirements of EN 15227. The original model was modified to better represent the accident conditions. It incorporated:

- A 9-car IET weighing approximately 430 tonnes:
  - As the original model only included the first four vehicles modelled in detail, a refined representation of the fifth vehicle was created to enable the study of its likelihood of derailment.
  - The original model had taken advantage of the symmetry of the vehicle structure to model only one side of the vehicles. Symmetrical boundary conditions along the vehicle centreline had been created to represent the opposite side, but the effect of these was to prevent the model from moving laterally. This artificial mathematical limitation was removed by modelling both sides of the vehicle structure.
  - An inter-vehicle coupler on an IET can pitch unrestrained until either of the following occurs: the coupler shank contacts the vehicle structure (figure 11), or contact between parts of the coupler itself prevents further movement. However, when a coupler starts to collapse, internal contact reduces the freedom of movement in pitch (figure 16). The representation of the inter-vehicle couplers was improved to model this variable restraint (figure 12).
  - An inter-vehicle coupler on an IET can yaw unrestrained until it contacts the vehicle structure. Again, when a coupler starts to collapse, internal contact reduces the freedom of movement in yaw.
  - The modelling of the connection between the couplers and the carbodies was improved, and the inter-vehicle dampers which connect the carbody to the inter-vehicle couplers were also introduced in the model.
  - The modelling of the connections between the carbodies and bogies was improved to more accurately represent the transfer of longitudinal and lateral loads.
  - The original model had been set up with wheels that were not free to rotate, but able to slide on top of the rails. However, train 5D29 was unbraked at the start of the collision, and this was represented by setting the coefficient of friction at the wheel-rail interface in the model to zero. The IET driver applied the emergency brake shortly before the collision started (around 0.6 seconds) and braking would have become effective at some point during the collision. The model was rerun with the coefficient of friction at the wheel-rail interface set at 0.15, which represented the typical braking effort developed by the train under braking. The actual coefficient at the wheel-rail interface on the night was unknown, but it was likely to be greater as it was a dry night, therefore able to withstand the full emergency brake application without sliding.

[11] Finite element modelling (FEM) is a common method for solving problems of engineering by dividing a large system into smaller parts that are easier to study.

- A simplified representation of an 11-car HST weighing approximately 450 tonnes. This incorporated the structural components of the HST which had come into contact with the IET and deformed during the collision.
- A closing speed of 10 mph (16 km/h) was used to represent the IET travelling at 15 mph (24 km/h) colliding with the HST travelling in the same direction at 5 mph (8 km/h).

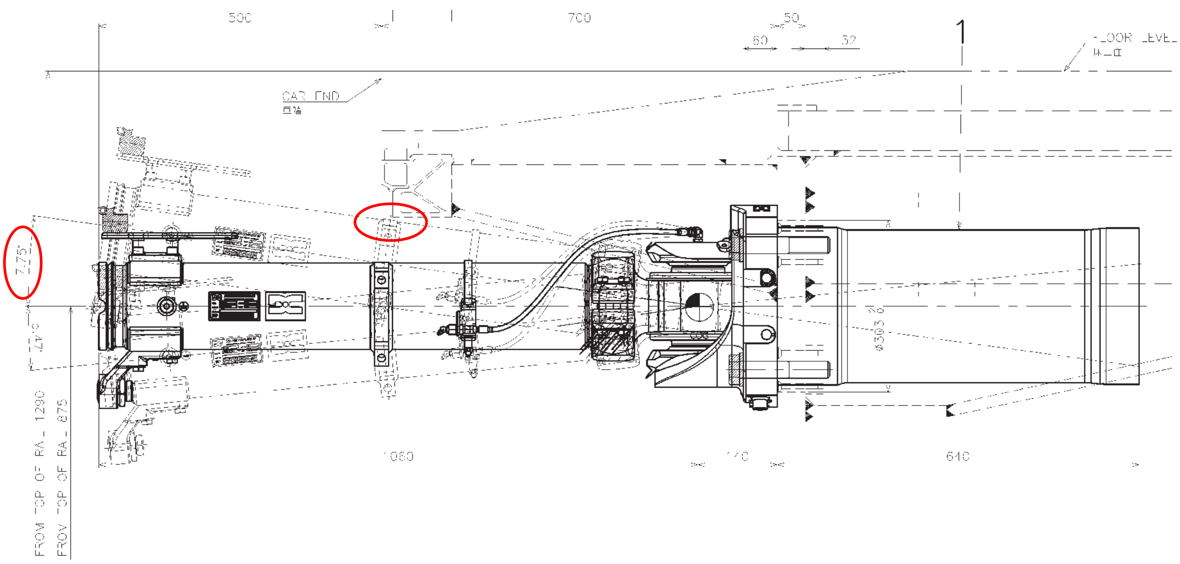

Figure 11: Coupler pitch up movement and limit due to coupler contacting the carbody (courtesy of Hitachi)

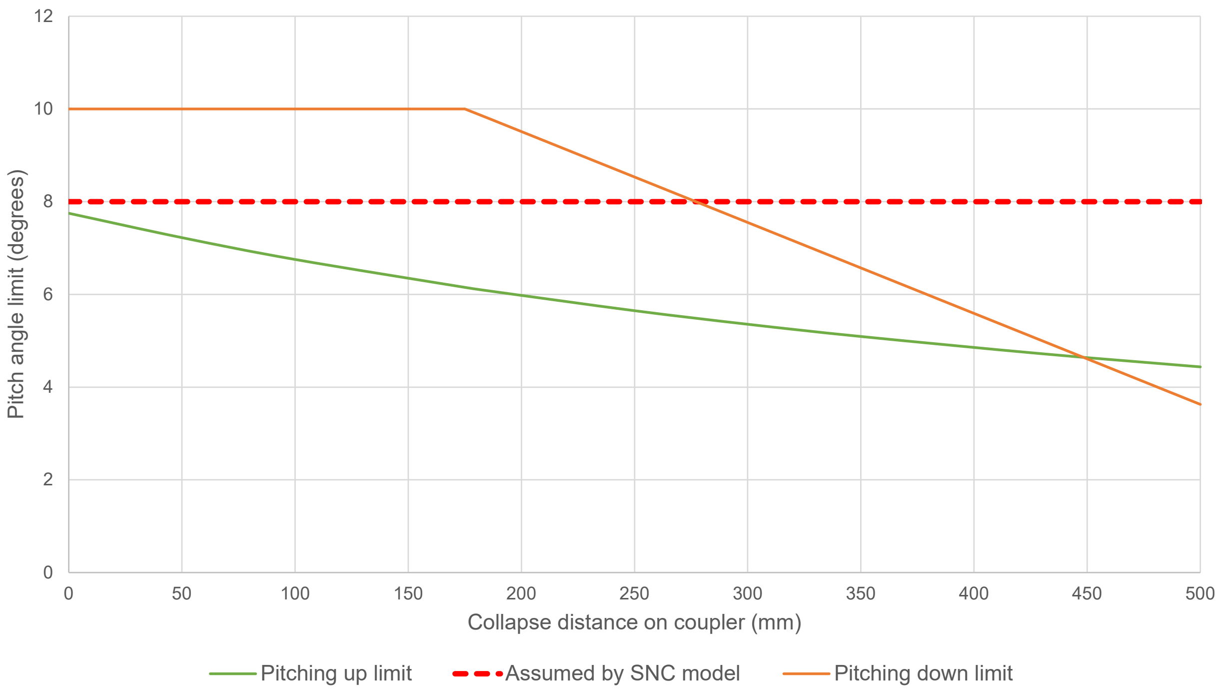

Figure 12: Graph showing how the pitch limits change as the inter-vehicle coupler collapses[12]

[12] Each coupler half can collapse by up to 500 mm. The inter-vehicle gap is 1000 mm.

The 1D models

95 To identify the factors that influence the predicted derailment, RAIB commissioned a separate sensitivity study using simplified 1D models. These 1D models studied the effects of the collision in all three directions: longitudinal, vertical and lateral. The longitudinal 1D model calculated the deceleration rate of each IET vehicle and the forces transmitted by the inter-vehicle couplers. This data was used as input to the vertical and lateral models. The vertical model represented the carbody's pitching behaviour under the deceleration and coupler forces and calculated the vertical lifting of the rear bogies (accounting for all stiffnesses and gaps in the bogie suspensions). The lateral model represented the carbody's yawing behaviour under the deceleration and coupler forces and calculated the lateral displacement of the rear bogies.

96 A number of simplifications were made in the 1D models which meant that they were likely to be less accurate than the 3D Finite Element model in absolute terms. For example, the 1D models were not able to represent the changing pitch and yaw freedom of the inter-vehicle couplers as they collapsed. The 1D models could only be run with a fixed pitch and yaw limit which was initially set, based on Hitachi's advice, at +/-8° and +/-24° respectively. Nevertheless, these 1D models were quicker to run and well suited to study the influence of input parameters in comparative terms.

97 The sensitivity study used a 9-car IET model in tare condition on straight track. A different train configuration (e.g. 5-car IET in laden condition on a curve) may lead to different results. The factors considered during the sensitivity study included:

- Speed (5 mph, 7.5 mph, 10 mph and 22.5 mph, respectively 8 km/h, 12 km/h, 16 km/h and 36 km/h) – 22.5 mph (36 km/h) is the design speed for the IET in a like-to-like collision
- Coupler characteristics (length, height, stiffness and collapsing strength, pitch and yaw restraints, inter-vehicle damping)
- Vehicle characteristics (vehicle mass, position of centre of gravity, bogie spacing, suspension stiffnesses and gaps)
- Impacted train (collision with another IET and with the 80-tonne wagon described in EN 15227).

The results

98 Figure 13 shows the results from the 3D simulation at the relative collision speed of 10 mph (16 km/h). The amount of deformation on the class 43 power car and at the leading end of the IET was checked to ensure that it was representative of what had been experienced during the accident. As shown on figure 13, the trailing bogies of vehicles 2, 3 and 4 on the IET were predicted in the simulation to lift up above the railhead during the collision.

99 Figure 14 shows the predicted lateral displacement on the first five vehicles. The trailing bogies of vehicles 2, 3 and 4 were predicted in the simulation to derail to the right during the collision. Vehicle 5 was predicted to remain guided by the rails.

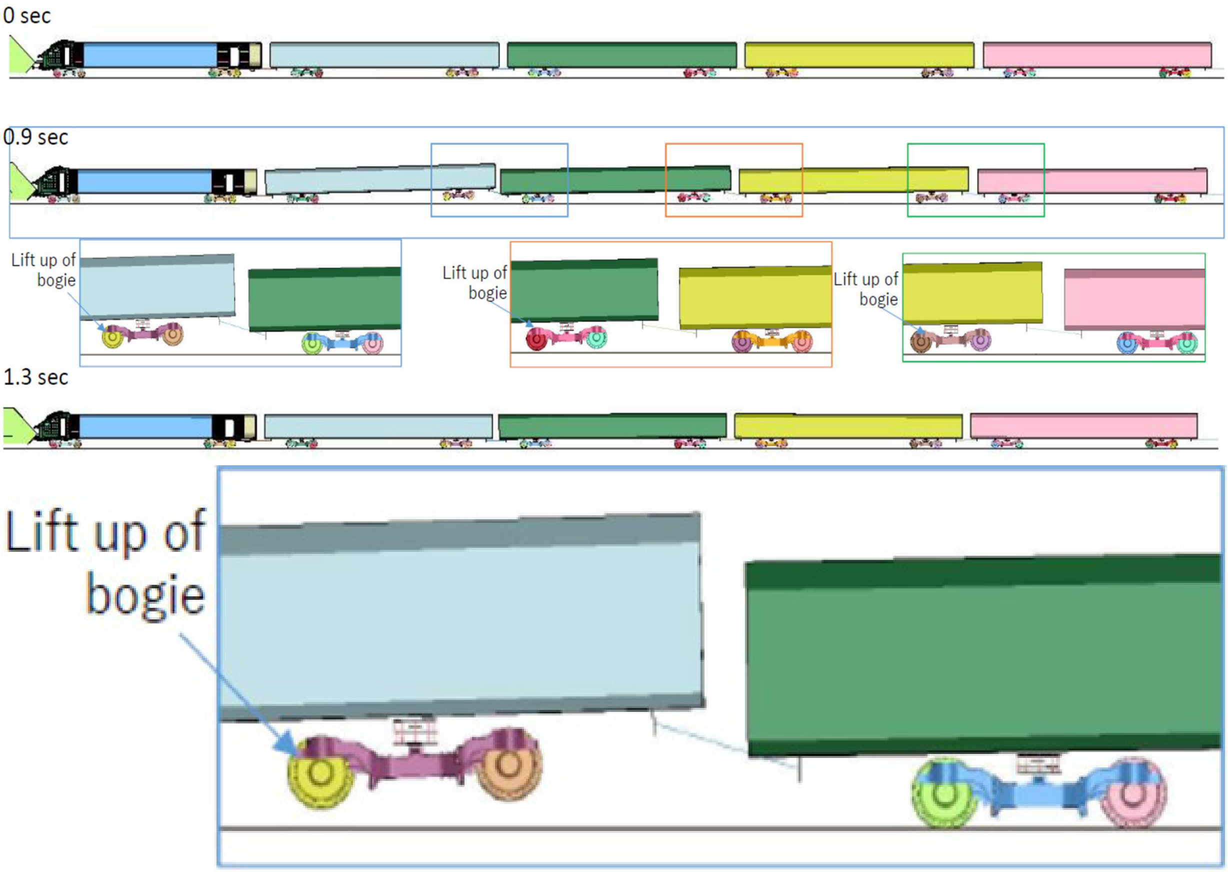

Figure 13: Output from collision and derailment simulation – sequence of events (courtesy of Hitachi)

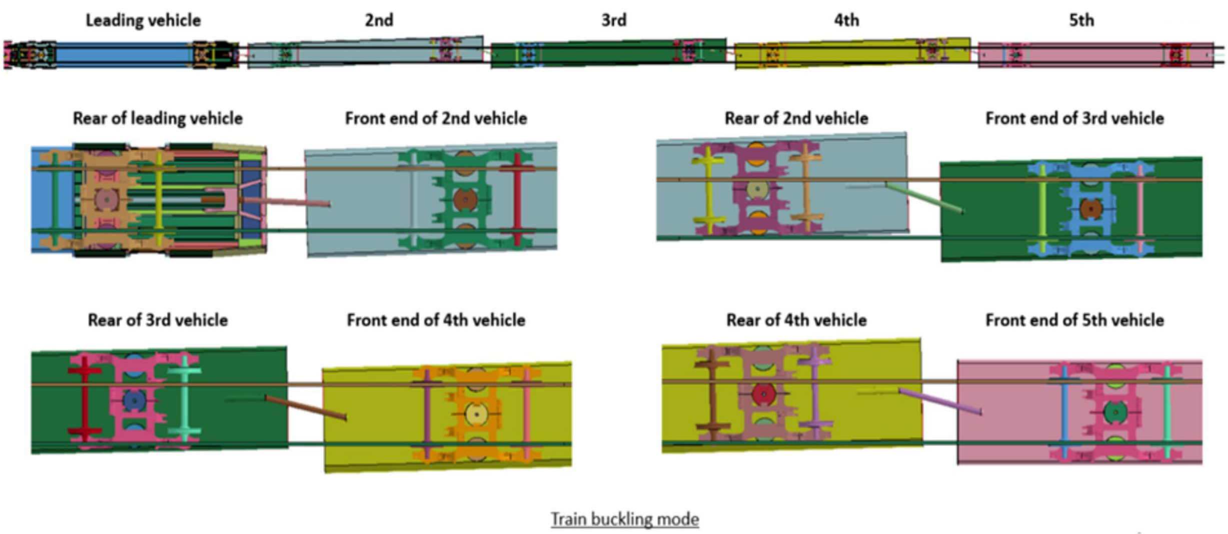

Figure 14: Output from collision and derailment simulation – bird's eye view (courtesy of Hitachi)

100 The Hitachi 3D model predicted that the leading couplers of the HST and IET would deflect each other sideways during the collision. This generated yaw movement on the leading vehicle which was then transferred to the other vehicles. Overall, the Hitachi 3D model predicted vertical and lateral displacements on all vehicles which were consistent in magnitude and direction with the observations on site.

101 The coupler forces were input in the 1D vertical and lateral models along the vehicle centreline. As the centre of gravity of each vehicle was nearly laterally centred, the coupler forces and deceleration were initially generating very little yaw response on the vehicles. Therefore, the lateral model required a small initial yaw offset on each vehicle for the results to be consistent with the site observations. The required yaw offset was within what could easily be explained by possible relative positioning of wheelsets on the track, especially considering the turnout that the train had just passed through, and considering the yaw movement transferred by the leading vehicle to the others, which was not explicitly represented in the model.

102 The extent of the lateral displacement predicted in the 1D lateral model was dependent on the initial yaw offset, which is difficult to quantify. Therefore, the following discussion of the results focuses on the likelihood of derailment, as predicted by the vertical model, while still commenting on the results of the lateral model in relative terms.

103 The sensitivity study, using the 3D and 1D simulations, demonstrated that the occurrence of derailment was strongly influenced by the following factors:

- The train being under braking during, at least, part of the collision
- The low speed of impact
- The high collapsing strength of the inter-vehicle couplers
- The large freedom of movement of the inter-vehicle couplers
- The type of train the IET collided with.

104 The effect of each of these factors is now considered in turn.

The effects of braking on the derailment risk

105 Braking increased the likelihood of derailment following the collision.

106 Figure 15 shows the predicted amount of wheel lift for the leading and trailing wheelset of the trailing bogie of vehicles 2, 3 and 4 for different coefficients of friction at the wheel-rail interface. These results show that the amount of wheel lift predicted in the 3D model was dependent on the amount of friction at the wheel-rail interface in the model (representing the amount of braking). In the case of zero friction (representing an unbraked train), only the trailing bogie of vehicle 2 was predicted to lift vertically. As modelled friction was increased, so did the amount of wheel lift on vehicles 2, 3 and 4. This is due to the additional vehicle body pitching introduced by braking.

107 The effect of braking on the degree of lateral displacement was not investigated.

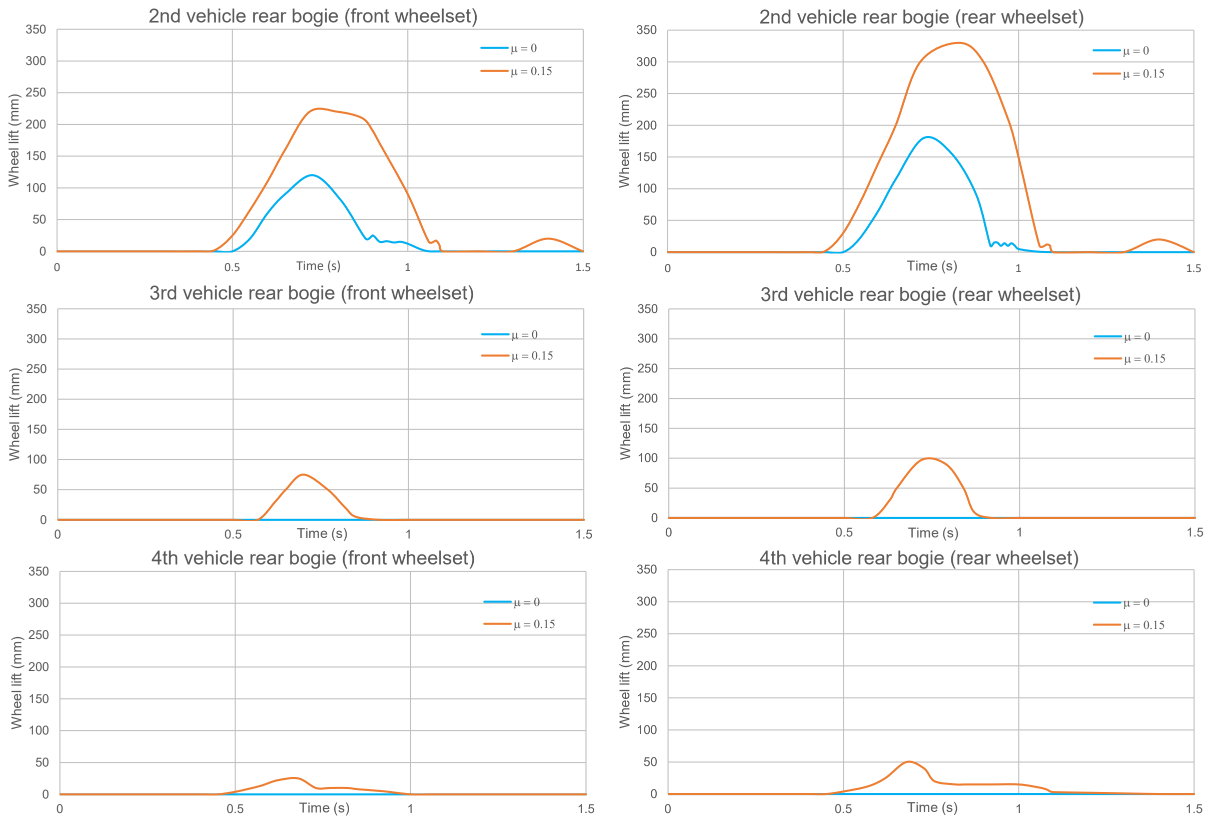

Figure 15: Output from collision and derailment simulation – wheelset vertical lift (courtesy of Hitachi)

The effects of speed on the derailment risk

108 The low speed of collision increased both the likelihood of derailment following the collision and the extent of lateral displacement.

109 Table 1 shows the results for the 1D simulations looking at the effects of speed, in a collision between an IET and an HST, on the amount of predicted wheel lift on the trailing bogies of vehicles 2 to 4. At 5 mph (8 km/h) the derailment of any vehicle was unlikely, as none of the wheels were predicted to lift. At 7.5 mph (12 km/h), the wheels of the trailing bogie of vehicles 2, 3 and 4 were predicted to be fully unloaded and lifted off the railhead; they would therefore be at risk of derailment. The critical speed at which the wheels started lifting off the rail was therefore likely to be between 5 and 7.5 mph (8 and 12 km/h).

Speed (km/h)	Vehicle 2 trailing bogie wheel lift (mm)	Vehicle 3 trailing bogie wheel lift (mm)	Vehicle 4 trailing bogie wheel lift (mm)
5 mph (8 km/h)	0	0	0
7.5 mph (12 km/h)	25	15	15
10 mph (16 km/h) (Accident case)	60	40	55
22.5 mph (36 km/h)	25	10	30

Table 1: Effects of speed on trailing bogie lift prediction

110 At 22.5 mph (36 km/h), the inter-vehicle couplers were predicted to collapse significantly, which reduced the angle that the couplers can freely pitch and yaw (figure 16). The original 1D models had been set with a constant +/-8º pitch limit (and +/-24º yaw limit) which was only accurate for the cases where the couplers did not collapse. The model with the 22.5 mph (36 km/h) collision speed was rerun initially with a constant pitch limit of +/-6º (and +/-6º yaw limit) and then with a constant pitch limit of +/-5º (and +/-5º yaw limit) representing increasing levels of coupler collapse.

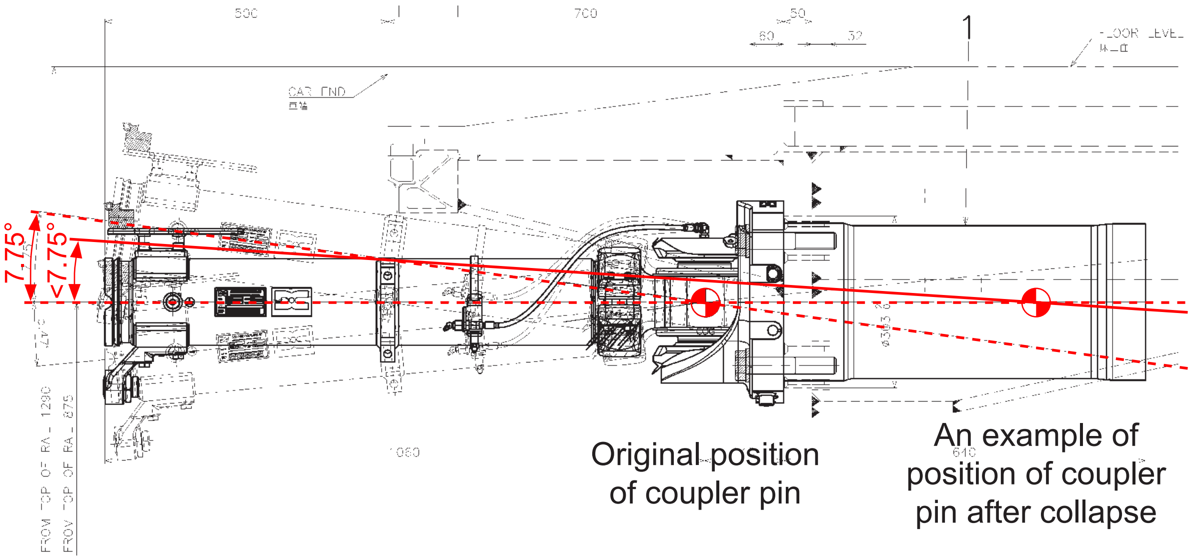

Figure 16: Effect of coupler collapse on pitch freedom

111 Prior to the coupler starting to collapse, as the speed of collision increased the degree of lateral displacement of a derailment increased.

112 However, as the coupler started to collapse, and the pitch limit decreased, the predicted amount of wheel lift decreased. Similarly, as the yaw limit decreased, the predicted amount of lateral displacement also decreased. RAIB concluded that it was therefore probable that the risk of derailment decreased as the speed of collision increased (because the inter-vehicle couplers collapse and limit the pitch and yaw movement of the couplers). Overall, the risk of derailment appeared to be greatest at low speeds: very low speeds do not generate enough energy to lead to a derailment and high speeds create enough energy to collapse the inter-vehicle couplers which appear to reduce the risk of derailment.

The effects of the coupler collapsing strength on the derailment

113 The high collapsing strength of the inter-vehicle couplers increased both the likelihood of derailment following the collision, and the extent of lateral displacement.

114 The couplers fitted to an IET are all designed to collapse in the event of a collision. However, the load at which they will collapse is not the same throughout the train. Figure 17 shows the distribution of coupler collapsing strength along the train.

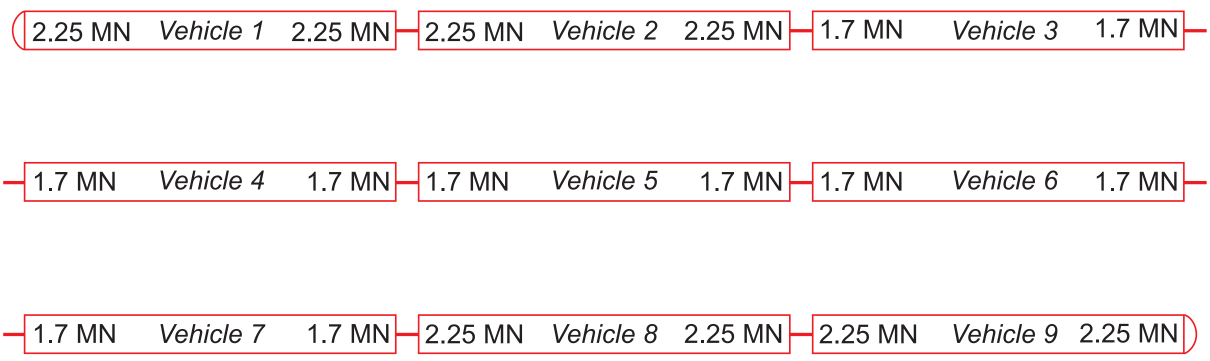

Figure 17: Distribution of coupler collapsing strength along the IET rake

115 The IET coupler collapsing strengths of 2.25 MN and 1.7 MN are high compared to those of other trains on the UK network. The requirement in EN 12663[13] is to design the carbody of trains to withstand a compressive 1.5 MN load at the coupler attachment. The coupler collapsing strength tends to be designed to be the same or less than 1.5 MN to ensure that the coupler will collapse before the carbody starts deforming permanently.

116 In 2008, RSSB[14] commissioned a project looking at determining the factors which influence the dynamic stability of long trains during collisions.[15] One of the main findings of this project was that the load at which the couplers collapse plays a significant role in the stability of a train in an end-on collision. During a collision, a high longitudinal collapse load in the couplers can generate a large pitching moment on the carbody which can be sufficient to lift wheelsets off the rails. Any lateral offsets generated during the impact, or due to the track curvature or asymmetric vehicle strength, then create a risk of derailment. This research project concluded that no specific change to the crashworthiness design requirements mandated in EN 15227 was needed. The findings regarding the significant role played by the strength of couplers in the stability of a train in an end-on collision was never converted into formal guidance for vehicle manufacturers.

117 Table 2 shows the results of a simulation carried out by RAIB as part of this investigation, where the collapsing strength of the IET couplers had been reduced to 1.0 MN throughout to align with the value used in the RSSB project.[16] The results showed that the wheel lift was reduced for vehicles 2, 3 and 4, with vehicles 2 and 4 reduced most significantly. Similarly, where derailment was predicted, the amount of lateral displacement was significantly reduced for all vehicles. RAIB concluded that the high collapsing strength of the couplers on the IET was a factor which contributed to the derailment.

[13] EN 12663-1:2010 'Railway applications – Structural requirements of railway vehicle bodies'.

[14] A not-for-profit company owned and funded by major stakeholders in the railway industry, which provides support and facilitation for a wide range of cross-industry initiatives. The company is registered as ‘Rail Safety and Standards Board’ but trades as ‘RSSB’.

[15] RSSB project T118 ‘Whole train dynamic behaviour in collisions and improving crashworthiness’.

[16] To enable a direct comparison with the accident case, no benefit was assumed for the increased pitch and yaw restraints as the couplers collapse.

Coupler collapsing strength	Vehicle 2 trailing bogie wheel lift (mm)	Vehicle 3 trailing bogie wheel lift (mm)	Vehicle 4 trailing bogie wheel lift (mm)
2.25 MN / 1.7MN (Accident case)	60	40	55
1.0 MN	25	30	15

Table 2: Effects of the coupler collapsing strength on trailing bogie lift prediction

The effects of the coupler pitch and yaw restraints on the derailment

118 The large freedom of movement of the inter-vehicle couplers increased both the likelihood of derailment following the collision, and the extent of lateral displacement.

119 The IET inter-vehicle couplers were free to pitch and yaw until they contacted the vehicle structure or until the coupler itself restricted the movement because of internal contact at interference points. The technical file prepared during the validation of the IET design showed that this freedom of movement was needed to negotiate all possible track features described in the Train Technical Specification (TTS).[17]

120 The 1D models representing the accident case initially included a pitch restraint of +/-8º and a yaw restraint of +/-24º. Table 3 shows the results of the simulation where the pitch and yaw restraints have been arbitrarily halved. The results showed that the wheel lift was significantly reduced for all vehicles. Similarly, where derailment was predicted, the amount of lateral displacement was also reduced. A closer inspection of the results showed that it was the reduction in pitch restraint which provided the improvement. RAIB concluded that the large freedom of movement of the couplers, particularly in pitch, was a factor which contributed to the derailment behaviour. However, the large freedom of movement of the couplers was needed to meet the requirements of the TTS, for the overall design solution chosen by Hitachi.

Pitch and yaw restraint angles	Vehicle 2 trailing bogie wheel lift (mm)	Vehicle 3 trailing bogie wheel lift (mm)	Vehicle 4 trailing bogie wheel lift (mm)
8º / 24º (Accident case)	60	40	55
4º / 12º	20	10	15

Table 3: Effects of the pitch and yaw restraint angles on trailing bogie lift prediction

[17] Intercity Express Programme – Schedule 1 – Appendix A – Train Technical Specification – Document No: IEP-TECH-REQ-35 issue 5.

The effects of the impacted train on the derailment

121 The collision with a relatively heavy train, such as an HST, increased both the likelihood of derailment following the collision, and the extent of lateral displacement.

122 The 1D models representing the accident case were modified to represent a collision with another IET. Table 4 shows the results of the simulations. The results showed that in a collision with another IET, the amount of wheel lift was increased for vehicles 2 and 4. Similarly, the predicted lateral displacements were increased for vehicles 2 and 4. The amount of wheel lift for vehicle 3 reduced as the inter-vehicle coupler connecting it to vehicle 2 was predicted to collapse, which reduced the ability of the coupler to pitch and yaw.

Impacted train	Vehicle 2 trailing bogie wheel lift (mm)	Vehicle 3 trailing bogie wheel lift (mm)	Vehicle 4 trailing bogie wheel lift (mm)
IET with HST (Accident case)	60	40	55
IET with IET	175	10	70
IET with 80t wagon	0	0	0

Table 4: Effects of the impacted train on trailing bogie lift prediction

123 RAIB concluded that the risk of derailment also existed when an IET collides with another IET at 10 mph (16 km/h). The sensitivity study looked at the collision at 10 mph (16 km/h) between an IET and the 80-tonne wagon defined in EN 15227. The simulation suggested that the risk of derailment was low, almost certainly because the IET is significantly heavier than the wagon.

124 RAIB concluded that in low speed collisions with trains of significant mass, the IET was likely to be prone to derailment.

125 Using the refined 3D finite element model, the design scenario of EN 15227 was rerun with an IET colliding with another IET at 22.5 mph (36 km/h). The simulations predicted that the trailing bogie of the leading vehicle would lift by 60 mm at the start of the collision but not derail. No other vehicle was predicted to lift. This reinforces the conclusion that the derailment risk for an IET involved in a collision with another IET is likely to be greater at low speeds.

Underlying factor

The crashworthiness standard EN 15227

126 EN 15227 does not require an assessment of the derailment performance of a train in a low speed collision.

127 Of the factors that had been found to have contributed to the derailment, only the high collapsing strength of the couplers and the large freedom of movement of the couplers were factors that are within the train designer's control. Speed, the train impacted with and the application of brakes during the collision are not. Both the high collapsing strength of the couplers and the large freedom of movement of the couplers are directly related to the design of the IET.

128 Hitachi stated that, when it was originally designing the IET to the requirements of EN 15227, it carried out a study to determine whether it could prevent damage to the vehicle structures at the intermediate ends by absorbing all the collision energy at the specified design case of 22.5 mph (36 km/h), in the couplers. Hitachi concluded that it was possible to do so, therefore ostensibly making the design safer for passengers at that speed, as the vehicle structures at the intermediate ends did not need to collapse to absorb energy. The technical solution was to use high-strength couplers. This appears to be a reasonable decision if the effect on 'derailment-worthiness' during low speed collisions is not appreciated.

129 The large freedom of movement of the couplers was partly driven by the TTS requirements which defined the track geometry that had to be safely negotiated by the train, and partly driven by the design solution chosen by Hitachi. For example, the vehicle length, the distance between bogies and the distance between the coupler pivot point and the vehicle end, have a direct effect on the freedom of movement needed for the couplers to meet the TTS requirements. Again, these design choices appear reasonable if the effect on derailment-worthiness during low speed collisions is not appreciated.

130 Hitachi might have become aware of the potential weakness with both solutions if EN 15227 had required consideration of the derailment risk of trains involved in a collision at speeds up to 22.5 mph (36 km/h). However:

- Although EN 15227 includes the principle that the risk of derailment should be reduced, it does not provide any specific requirement against which to assess this risk.
- EN 15227 does not require demonstration of acceptable performance at a speed below the design speed of 22.5 mph (36 km/h).

131 In addition, the EN 15227 design scenario also assumes that the train is not braking. This is a reasonable assumption for collisions at 22.5 mph (36 km/h) as the contribution to retardation from any braking is relatively small compared to the collision itself, but this may not be the case for collisions at lower speeds.

132 Unrelated to this accident, EN 15227 was revised in April 2020. None of the changes introduced by this revision addressed the issues in the standard identified by this investigation.

Observations

Compliance with EN 15227

133 The original Hitachi 3D model used to demonstrate compliance with EN 15227 had to be developed for its prediction to match the actual collision's consequences.

134 During this investigation, the original 3D finite element model used to validate the performance of the IET design against the requirements of EN 15227 was modified extensively to better represent the design, and to match the actual collision's consequences in terms of the derailment that consequently occurred (paragraph 94).

135 The results of the simulation for the design case from EN 15227 using the refined model are now different from what was reported to the Notified Body and Safety Authority during the original validation of the IET design.

Risk assessment

136 The permissive working arrangements at the entrance to Neville Hill depot had not been risk assessed.

137 Immediately after the accident, Network Rail was unable to provide RAIB with evidence that a risk assessment had been carried out to manage the risk associated with permissive working at the entrance to Neville Hill depot (paragraph 53). RAIB observes that Network Rail had also been unable to provide risk assessments covering permissive working during the investigations into the accidents at Norwich in 2013 (see paragraph 138) and Plymouth in 2016 (see paragraph 139).

Previous occurrences of a similar character

138 A passenger train operated by Greater Anglia, carrying 35 passengers, collided at 8 mph (13 km/h) with a stationary train in platform 6 at Norwich station on 21 July 2013. As a result of the collision, eight injured passengers were taken to hospital. RAIB investigated the accident (RAIB report 09/2014) and concluded that it occurred because, during the last 20 seconds of the driver's approach to the station, he either had a lapse in concentration or a microsleep. Network Rail was unable to provide a risk assessment covering permissive working at this location.

139 At 15:34 hrs on Sunday 3 April 2016, the 13:39 hrs passenger train service from Penzance to Exeter collided with an empty train which was standing in platform 6 at Plymouth station (RAIB report 02/2017). The collision occurred at a speed of about 15 mph (24 km/h) and resulted in injuries to 48 people and damage to both trains. Network Rail was unable to provide a risk assessment covering permissive working at this location.

Summary of conclusions

Immediate cause

140 When occupying a signal section that was already occupied by another train, the IET accelerated to too great a speed and caught up with the HST (paragraph 47).

Causal factors

141 The causal factors were:

1. The IET and HST were in the same section of track, at the same time. This is a normal factor (paragraph 50).
2. The IET accelerated to too great a speed compared to the HST (paragraph 54). This causal factor arose due to a combination of the following:
   a) The driver's attention became focused on reinstating APCO using the TMS touch screen, instead of the driving task (paragraph 58, **Learning point 3**). This happened because:
      i. APCO had previously been isolated by the driver as his training had not taught him to enter the train headcode correctly. This was because the Hitachi train operation manual was ambiguous in this regard (paragraph 62, **Recommendations 1 and 2**, **Learning point 6**).
      ii. The driver was possibly concerned about forgetting that he had isolated APCO, and this not being obvious to other drivers taking over the train (paragraph 72, **Learning point 4**).
   b) The IET driver unintentionally commanded too much acceleration, possibly because LNER had not adapted the driver's IET training to best match his needs (paragraph 77, **Learning point 2**).

Factors affecting the severity of consequences

142 The fact that the train was being braked at the time of the collision increased the likelihood of derailment following the collision (paragraph 105, **Recommendation 5**).

143 The following factors increased both the likelihood of derailment following the collision, and the extent of lateral displacement:

- The low speed of impact (paragraph 108, **Recommendations 4 and 5**).
- The high collapsing strength of the inter-vehicle couplers (paragraph 113, **Recommendation 3**, **Learning point 5**).
- The large freedom of movement of the inter-vehicle couplers (paragraph 118, **Recommendation 3**).
- The type of train the IET collided with (paragraph 121, no recommendation).

Underlying factor

144 The following factor was underlying to the factors that contributed to the derailment:

- EN 15227 does not require an assessment of the derailment performance of a train in a low speed collision (paragraph 126, **Recommendations 4 and 5**).

Additional observations

145 Although not directly linked to the cause of the accident on 13 November 2019, RAIB observes that:

- The original Hitachi 3D model used to demonstrate compliance with EN 15227 had to be developed for its prediction to match the accident consequences (paragraph 133, **Recommendation 3**).
- There was no risk assessment covering permissive working on the depot arrival line leading to Neville Hill depot (paragraph 53).

Actions reported as already taken or in progress relevant to this report

146 On 21 November 2019, LNER issued a Safety Information brief to all its drivers about managing in-cab distractions. The brief bolstered the advice already provided to drivers in LNER's Professional Driving Policy regarding managing distractions.

147 On 5 December 2019, LNER issued a Traction Information brief to all its drivers, which included a reminder to contact maintenance control if the TMS refuses to accept a headcode.

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

148 On 17 July 2020, LNER issued a Traction Information brief to all its drivers advising them that the only acceptable method to enter a headcode in the TMS was to use the CHECK STOPS button.

149 On 8 October 2020, Network Rail, with support from the relevant train operating companies, assessed the risk associated with permissive moves at the entrance to Neville Hill depot in accordance with RIS-0744-CCS, taking into consideration the May 2020 working timetable.

Recommendations and learning points

Recommendations

150 The following recommendations are made:[18]

1 *The intent of this recommendation is to ensure that LNER's procedures and training material are based on a correct interpretation of the documentation provided by Hitachi.*

LNER, with support from Hitachi, should review the Train Operation Manual and Train Management System documentation that Hitachi has provided, to confirm that it has correctly interpreted it in all areas which could impact the safe operation of its IETs (paragraph 141.2.a).i).

This recommendation may be applicable to other Train Operating Companies with IETs.

2 *The intent of this recommendation is to make sure that LNER drivers can correctly interact with the TMS on the IETs.*

LNER should review, and make any necessary changes to, its procedures, training, and associated materials and aids (including the TMS app and simulator) to confirm that they prepare drivers to correctly interact with the TMS on its IETs. It should also review the TMS touch screen displays to make sure that they clearly reinforce the correct processes. In particular, these activities should include consideration of the method of entering a headcode and any issues raised by Recommendation 1 (paragraph 141.2.a).i).

[18] Those identified in the recommendations have a general and ongoing obligation to comply with health and safety legislation, and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail and Road to enable it to carry out its duties under regulation 12(2) to:

(a) ensure that recommendations are duly considered and where appropriate acted upon; and

(b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 200 to 203) can be found on RAIB's website www.gov.uk/raib.

3 *The intent of this recommendation is to confirm compliance of the IET design with the requirements of EN 15227.*

Hitachi should revisit its assessment of the performance of the IET against the requirements of EN 15227 using a refined 3D model. This model should include, as a minimum, the modelling changes demonstrated by this investigation to be necessary to predict the train behaviour with sufficient accuracy. The assessment should be subject to a review by an independent third-party, as defined in RIS-2700 (paragraphs 143 and 145). If applicable, Hitachi should inform LNER, any other operators of IETs and ORR of any area of non-compliance with EN 15227 identified during the re-assessment.

4 *The intent of this recommendation is for LNER to ensure that the risks resulting from a low speed collision of an IET are acceptable.*

LNER, with support from Hitachi, should assess the risk associated with derailment of an IET following collision at low speeds, and take any necessary actions to demonstrate an acceptable risk. It should take into account the likelihood of occurrence of a derailment and the possible consequences, including the potential to foul an adjacent running line (paragraph 144).

LNER should share the findings of its assessment with other operators of IETs.

5 *The intent of this recommendation is to ensure that the designers of future trains adequately consider the risk from low speed collisions*.

RSSB should consider whether the findings of this investigation indicate that there is merit in proposing revisions to standard EN 15227 and associated guidance, in the following respects:

- To make it clear that the intention of the standard is for the safety performance to be demonstrated to be acceptable up to and including the design speed
- To include specific requirements against which to assess the derailment performance in a collision
- To include the effects of braking, where appropriate.

If it considers there is merit in any of the above, RSSB should actively lobby the relevant national and international bodies to raise the issues for consideration in future updates of EN 15227 (paragraphs 142 and 144).

Learning points

151 RAIB has identified the following important learning points:[19]

1 Train operating companies are reminded that changes in policy regarding the use of on-board safety equipment should be reflected in their professional driving policy and/or driver operating instructions (paragraph 57).

2 Train operating companies are reminded of the importance of undertaking a thorough and documented training needs analysis when employees return to work after a long absence (particularly those that are linked to illness or safety incidents), and to adapt their training accordingly.

3 Train drivers are reminded that there are times when it is particularly unsafe to engage with tasks other than the primary driving task (such as when undertaking permissive moves).

4 Train operating companies are reminded of the importance of briefing their drivers about engineering changes made to the trains that they operate.

5 Train manufacturers are reminded that, according to RSSB project T118, the risk of derailment on long trains involved in an end-on collision can be mitigated by limiting the level of energy absorption and axial load capacity designed into coupler units.

6 Authors of technical documentation to support the operation and maintenance of traction and rolling stock are reminded that it is essential to ensure that the documentation provides a clear and unambiguous message to the recipients.

[19] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when the RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where the RAIB has not identified management issues that justify a recommendation) and the consequences of failing to do so. They also record good practice and actions already taken by industry bodies that may have a wider application.

Appendices

Appendix A - Glossary of abbreviations and acronyms

1D / 3D	One dimensional / Three dimensional
ASL	Automatic Speed Limiter
APCO	Automatic Power Changeover
CCTV	Closed-circuit television
DfT	Department for Transport
EN	European Norm
FFCCTV	Forward-facing closed-circuit television
HST	High Speed Train
IET	Intercity Express Train
LNER	London North Eastern Railway
ORR	Office of Rail and Road
OTDR	On-train data recorder
RAIB	Rail Accident Investigation Branch
ROC	Rail operations centre
RSSB	Rail Safety and Standards Board
SPAD	Signal passed at danger
TMS	Train management system
TTS	Train technical specification

Appendix B - Investigation details

The RAIB used the following sources of evidence in this investigation:

- information provided by witnesses
- information taken from the train's on-train data recorder (OTDR)
- closed circuit television (CCTV) recordings taken from unit 800109
- site photographs and measurements
- weather reports and observations at the site
- IET drawings and documentation
- IET Train Technical Specification
- Hitachi Japan 3D simulation model results
- Neville Hill IET derailment modelling parametric study
- a review of previous RAIB investigations that had relevance to this accident.

Appendix C - Derailment outcome

C1 The degree of derailment as a result of this relatively low speed collision prompted RAIB to review the consequences of other comparable train collisions in the last 30 years. The review considered both train-to-train collisions and train-to-large object collisions (such as with buffer stops or other obstacles, such as a lorry at a level crossing) likely to have generated comparable collision energies. The sources of information included previous RAIB reports, Network Rail logs, industry reports and the Railways Archive website.[20]

C2 The collision energy in each accident was estimated from the speed of impact and the mass of the trains/objects involved, and the accidents were ranked in severity order, on the basis of this. The review also included a description of the damage sustained by the trains, whether or not the train(s) had derailed (focusing particularly on vehicles remote from the point of impact), and a short description of the derailment and its likely cause. Table C1 presents the outcome of this review, with the accidents in order of estimated collision energy.

C3 The data gathered by RAIB indicates that the outcome at Neville Hill was unusual. No other low speed collisions had resulted in derailment of vehicles remote from the point of collision. This remained the case even considering collisions with significantly higher energy.

Date of event	Location	Train accident type	Closing speed	Source	Unit type	Damage	Derailment?	Derailment description/cause	Collision energy est.
23/06/1999	Winsford	Train to train collision	50 mph	Archive	10-car class 87+Mkiii vs 4-car class 142	Significant damage to both trains	Yes	Class 87 derailed but all Mkiii coaches in line and not derailed	15-20 MJ
18/10/1999	Lewes	Train to train collision	30 mph	Archive	12-car class 421 vs 8-car class 421	Damage to both units	Yes	Leading bogie of leading vehicle on 12-car train	15-20 MJ
11/07/1995	Largs	Buffer stop collision	20 mph	Archive	6-car class 318 vs buffer stops	Significant damage to unit and stops (demolished)	Yes	Leading vehicle ran out of track and hence derailed. The other 5 vehicles stayed in line with the track.	5-10 MJ
08/01/1991	Cannon Street	Buffer stop collision	10 mph	Archive	10-car class 415/416 vs buffer stops	Significant damage to several vehicles in the rake	Yes	Vehicle 6 overrode vehicle 5 (old Mk 1 design), not sure about the bogies	2.5-5 MJ
04/08/1990	Stafford	Train to train collision	< 20 mph	Archive	4-car class 310 vs 8-car Mk2+class 47	Significant damage to both trains	Yes	Leading bogie of leading vehicle on class 310 only	2.5-5 MJ
07/12/1991	Severn Tunnel	Train to train collision	20 mph	Archive	2-car class 155 vs 10-car HST	Significant damage to both trains	No	-	2.5-5 MJ
17/08/2010	Sewage Works Lane	Train vs lorry at LC	41 mph	RAIB report	2-car class 156 vs lorry	Significant damage to unit	Yes	Leading coach fully derailed. Second vehicle remained on the track.	2.5-5 MJ

[20] http://www.railwaysarchive.co.uk/.

Date of event	Location	Train accident type	Closing speed	Source	Unit type	Damage	Derailment?	Derailment description/cause	Collision energy est.
13/11/2019	Neville Hill West Jcn	Train to train collision	10 mph	RAIB report	9-car IET vs 11-car HST	Damage to both units	Yes	3 trailing bogies on IET	2-2.5 MJ
03/04/2016	Plymouth	Train to train collision	15 mph	RAIB report	4-car class 150 vs 10-car HST	Damage to both units	No	-	2-2.5 MJ
19/12/2011	Llanboidy	Train to lorry at LC	38 mph	RAIB report	2-car class 175 vs lorry	Significant damage to unit	No	-	2-2.5 MJ
01/02/2008	Barrow	Train vs object (bridge)	65 mph	RAIB report	2-car class 158 vs bridge	Significant damage to unit	Yes	Debris under wheelsets of leading bogie	1.5-2 MJ
10/03/2000	Waterloo	Train to train collision	15 mph	-	4-car class 455 vs 4-car class 455	-	-	-	1.5-2 MJ
27/11/2019	Wembley Depot	Buffer stop collision	7-10 mph	Log	4-car class 168 vs buffer stops	Damage to unit and buffer demolished	Yes	Train ran out of track	0.75-1.5 MJ
08/05/2019	London Victoria Stn	Buffer stop collision	7.6 mph	NR log	4-car class 377 vs buffer stops	Minor damage to unit and buffer stops pushed back by 3-4 metres	No	-	0.5-1 MJ
17/09/2015	King's Cross	Buffer stop collision	7.5 mph	RAIB report	4-car class 317 vs buffer stops	Minimal to unit, buffer stops absorbed energy by deformation (by design)	No	-	0.5-1 MJ
20/11/2013	Chester	Buffer stop collision	5-6 mph	RAIB report	5-car class 221 vs buffer stops	Significant damage to unit and buffers	Yes	Leading bogie lifted by impact	0.5-1 MJ
6/11/2018	North Pole depot	Train to train collision	7 mph	Hitachi	5-car IET vs 5-car IET	Damage to the autocoupler and its supporting structure	No	-	0.5-1 MJ
12/03/2018	Larkhall	Buffer stop collision	8 mph	NR log	2-car class 318 vs buffer stops	Minor damage to unit and buffer stops	No	-	0.25-0.5 MJ
15/08/2017	King's Cross	Buffer stop collision	4 mph	RAIB report	4-car class 387 vs buffer stops	Minor damage to unit, buffer stops pushed back by one metre	No	-	0.25-0.5 MJ
01/04/2017	Preston (Lancs)	Buffer stop collision	6 mph	RAIB report	3-car class 158 vs buffer stops	Minor damage to unit, buffer stops bent back	No	-	0.25-0.5 MJ
21/07/2013	Norwich	Train to train collision	8 mph	RAIB report	2-car class 156 vs 2-car class 158	Minor damage to both units	No	-	0.25-0.5 MJ
04/01/2010	Exeter	Train to train collision	11 mph	RAIB report	2-car class 142 vs 6-car class 159	-	No	-	0.25-0.5 MJ
27/01/2020	Paddington	Buffer stop collision	-	Log	5-car IET vs buffers	Nose cone damage + buffer moved a foot	No	-	0-0.25 MJ

Date of event	Location	Train accident type	Closing speed	Source	Unit type	Damage	Derailment?	Derailment description/cause	Collision energy est.
25/10/2019	Penzance	Buffer stop collision	2.5 mph	Hitachi	5-car class 802 vs buffer stops	Nose cone damage to unit	No	-	0-0.25 MJ
25/06/2019	Paddington	Train to train collision	< 2 mph	-	5-car IET vs 5-car IET	Nose cone damage	No	-	0-0.25 MJ
10/08/2018	Stoke on Trent	Buffer stop collision	4 mph	Log	3-car class 323 vs buffer stops	Coupler damage on unit	No	-	0-0.25 MJ
15/06/2018	Manchester Piccadilly	Train to train collision	4.4 mph	Log	3-car class 323 vs 4-car class 142+150	Minor damage to both units	No	-	0-0.25 MJ
09/01/2017	Bradford Interchange	Buffer stop collision	6 mph	NR log	2-car class 155 vs buffer stops	Minor damage to unit and buffer stops pushed back by 2 metres	No	-	0-0.25 MJ
21/06/2016	Shrewsbury	Buffer stop collision	3.9 mph	NR log	2-car class 170 vs buffer stops	Minor damage to unit, buffer stops bent back	No	-	0-0.25 MJ
23/11/2015	Streatham Hill Traincare Depot	Buffer stop collision	< 6 mph	NR log	4-car class 377 vs buffer stops	Minor damage to unit, buffer stops bent back	No	-	0-0.25 MJ
10/11/2015	Colchester Town (St Botolphs)	Buffer stop collision	4 mph	Log	4-car class 321 vs buffer stops	Minor damage to unit and buffer stops	No	-	0-0.25 MJ
25/09/2015	Ashford International	Train to train collision	4.5 mph	NR log	4-car class 375 vs 12-car class 395	Electrical coupling box damage on 375 + nose cone damage on 395	No	-	0-0.25 MJ
30/05/2015	Cambridge	Train to train collision	6 mph	Log	4-car class 365 vs 4-car class 365	Minor damage to both units	No	-	0-0.25 MJ
11/03/2020	Aberdeen Clay	Buffer stop collision	0.81 mph	Log	9-car IET vs buffer stops	Minor damage to nose cone	No	-	0-0.25 MJ

Table C1 - Previous train collisions of potential relevance

C4 RAIB also reviewed the outcome from each of the known collisions involving an IET, in its short history of operating in the UK. The results are presented in Table C2.

C5 RAIB identified five other collisions involving an IET, since they started operating on the UK network; three of them were buffer stop collisions and one was a low speed collision (< 2 mph (3 km/h)) between two 5-car IETs. The energies generated in these collisions were much lower than in the Neville Hill collision and there is therefore little that can be learned from them. The collision at North Pole depot on 6 November 2018 between two 5-car IETs at 7 mph (11 km/h) would have generated a collision energy similar to a collision between an 9-car IET and HST at 5 mph (8 km/h) (paragraph 109). The lack of derailment at North Pole depot is consistent with the prediction in the sensitivity study.

Date of event	Location	Train accident type	Closing speed	Source	Unit type	Damage	Derailment?	Derailment description/ cause	Collision energy est.
13/11/2019	Neville Hill West Jcn	Train to train collision	10 mph	RAIB	9-car IET vs 11-car HST	Damage to both units	Yes	3 trailing bogies on IET	2-2.5 MJ
6/11/2018	North Pole depot	Train to train collision	7 mph	Hitachi	5-car IET vs 5-car IET	Damage to the autocoupler and its supporting structure	No	-	0.5-1 MJ
27/01/2020	Paddington	Buffer stop collision	-	Log	5-car IET vs buffers	Nose cone damage + buffer moved a foot	No	-	0-0.25 MJ
25/10/2019	Penzance	Buffer stop collision	2.5 mph	Hitachi	5-car class 802 vs buffer stops	Nose cone damage to unit	No	-	0-0.25 MJ
25/06/2019	Paddington	Train to train collision	< 2 mph		5-car IET vs 5-car IET	Nose cone damage	No	-	0-0.25 MJ
11/03/2020	Aberdeen Clay	Buffer stop collision	0.81 mph	Log	9-car IET vs buffer stops	Minor damage to nose cone	No	-	0-0.25 MJ

Table C2: Previous collisions involving IETs

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